Shoulder Joint Protection Program

DEVELOPMENT OF SHOULDER JOINT PROTECTION PROGRAM FOR PEOPLE WITH SHOULDER ARTHRITIS: A SYNTHESIS OF EVIDENCE AND DEVELOPING JOINT PROTECTION PROGRAM FOR DAILY ACTIVITIES

By

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ABSTRACT

This dissertation aimed to develop a joint protection program for people with shoulder arthritis. The program was developed throughout a two-phase process.

The first stage in developing the Shoulder Joint Protection Program for patients with different stages of arthritis focused on comprehending existing research and understanding the factors that influence shoulder joint protection. We considered the priorities and preferences of both patients and therapists, integrating different types of evidence like systematic reviews, narrative and scoping reviews, and analysis of shoulder movement. This evidence guided the creation of a preliminary joint protection program.

The second stage assessed the content validity of this program, using cognitive interviews with patients and therapists. The findings from each phase were then presented in separate chapters, providing a complete view of the Shoulder Joint Protection Program (SJPP) for individuals with shoulder arthritis.

The evidence presented in Chapters 2 and 3 suggests that no single optimal program has been defined for patients undergoing total shoulder joint replacement surgery, including both anatomical and reversed types. Further high-quality RCTs are needed to provide more conclusive results. To assess outcomes, various patient-reported outcomes have been developed and validated. However, our study, as presented in Chapter 4, reveals inconsistencies and a lack of clarity in the conceptual frameworks of the identified PROMs. Our scoping review in Chapter 5 offers comprehensive research on shoulder biomechanics during various activities, and spotlights potential injury prevention strategies. These identified strategies can guide the creation of training programs, coaching practices, and rehabilitation strategies aimed at minimizing the risk of shoulder injuries and bolstering overall shoulder health. Results from Chapter 6 suggest that participants have the capacity to modify their movement patterns to implement joint protection strategies, potentially beneficial in post-surgery rehabilitation and enhancing shoulder function. The application of motion analysis software tools, such as MediaPipe, has yielded reliable results, indicating their potential for future kinematic studies.

The developed SJPP comprises two sections: general joint protection principles and specific protective strategies for daily activities. Both digital resources and a printed version were

developed to increase the accessibility of the program. The study (Chapter 7) presents a substantial contribution to the resources for patients with shoulder arthritis. It was designed to enhance their quality of life and enable them to navigate everyday activities with greater ease and less discomfort. Further enhancements, such as the inclusion of content on sports and recreational activities, could make the program even more comprehensive and beneficial.

Overall, the study underscores the importance of evidence-based, user-friendly resources for patients with shoulder arthritis and provides potential directions for future research and enhancements, such as including content on sports and recreational activities. The SJPP's ultimate goal is to enhance patients' quality of life, allowing them to perform everyday activities with less discomfort.

Keywords: Shoulder joint protection program, total shoulder arthroplasty, shoulder arthritis, physiotherapy, video-based analysis, machine learning, movement analysis, shoulder biomechanics, joint protection behavior.

Summary for Lay Audience

This Ph.D. research project set out to create a program to help people with shoulder arthritis protect their joints. The development process was broken down into two main stages.

In the first step, we looked at what we already know from research and figured out the main things that affect how well someone can protect their shoulder joint. We thought about what patients and therapists want and need. We looked at many different kinds of studies and even how people move their shoulders. All this helped us make a first version of our plan.

In the second step, we checked how good our plan was. We did this by talking with patients and therapists. We wrote about everything we found out in different chapters. This gave us a full picture of our Shoulder Joint Protection Program (SJPP) for people with shoulder arthritis.

Our final SJPP has two main parts: general rules to protect the joint and special tips for everyday activities. We made it available online and on paper so it's easy to get. Our study is a big help for patients with shoulder arthritis. It's meant to make their lives better and help them do everyday things with less pain. In the future, we might add more tips about sports and fun activities, which could make it even more helpful.

In conclusion, our research shows how important it is to have easy-to-use, research-based tools for patients with shoulder arthritis. We've also given some ideas for future research. The main goal of the SJPP is to make patients' lives better, helping them do everyday things with less pain.

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Co-Authorship Statement

The fundamental concept of the research question and the structure of the studies were crafted by Ze(Steve) Lu, along with his supervisor, Dr. Joy C MacDermid. Subsequently, the committee members offered their insights on the central concept, the specifics of each milestone, and shared their expectations. Additional co-authors were sought when further assistance or expertise was necessary. The individual contributions of each co-author are detailed as follows:

Chapter 1: Introduction

Ze(Steve) Lu: Sole Author

Chapter 2: A Narrative Review and Content Analysis of Functional and Quality of Life Measures Used to Evaluate the Outcome After TSA: An ICF Linking Application.

Ze(Steve) Lu: Primary author, study design, running search strategy, study selection, data extraction, quality appraisal, data analysis, writing manuscript, preparing the manuscript for submission.

Joy C. MacDermid: Co-author, conception of study idea and study design, revising the manuscript for important intellectual content, final approval of the manuscript before submission.

Peter Rosenbaum: Co-author, manuscript reviewer

Chapter 3: The Clinical Outcome of Physiotherapy After Anatomical Total Shoulder Arthroplasty: A Systematic Review

Ze(Steve) Lu: Primary author, study design, running search strategy, study selection, data extraction, quality appraisal, data analysis, writing manuscript, preparing the manuscript for submission.

Goris Nazari: Co-author, data extraction, quality appraisal, data analysis.

Pedro H. Almeida: Co-author, data extraction, quality appraisal, data analysis.

Tatiana Pontese: Co-author, data extraction, quality appraisal, data analysis.

Kenneth Faber: Co-author, manuscript reviewer

Tara Packham: Co-author, manuscript reviewer

Dianne Bryant: Co-author, manuscript reviewer

Joy C. MacDermid: Co-author, conception of study idea and study design, revising the manuscript for important intellectual content, final approval of the manuscript before submission.

Chapter 4: The Clinical Outcome of Physiotherapy After Reversed Shoulder Arthroplasty: A Systematic Review.

Ze(Steve) Lu: Primary author, study design, running search strategy, study selection, data extraction, quality appraisal, data analysis, writing manuscript, preparing the manuscript for submission.

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Tatiana Pontese: Co-author, data extraction, quality appraisal, data analysis.

Joy C. MacDermid: Co-author, conception of study idea and study design, revising the manuscript for important intellectual content, final approval of the manuscript before submission.

Chapter 5: Understanding and preventing Shoulder Injuries: A Scoping Review of Shoulder Joint Biomechanics in Daily Activities and Sports

Ze(Steve) Lu: Primary author, study design, running search strategy, study selection, data extraction, data analysis, writing manuscript, preparing the manuscript for submission.

Erfan Shafiee: Co-author, study selection, data extraction, data analysis

Joy C. MacDermid: Co-author, conception of study idea and study design, revising the manuscript for important intellectual content, final approval of the manuscript before submission.

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Tara Packham: Co-author, manuscript reviewer

Dianne Bryant: Co-author, manuscript reviewer

Chapter 6: Assessment of Shoulder Range of Motion Using Video-Based Movement Analysis Software - A Kinematic Analysis and Measurement Validation Study.

Ze(Steve) Lu: Primary author, conception of study idea and study design, study design, data collection, data analysis, writing manuscript, preparing the manuscript for submission.

James Frase: Co-author, data collection, data analysis

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Tara Packham: Co-author, manuscript reviewer

Dianne Bryant: Co-author, manuscript reviewer

Chapter 7: Developing Digital Resources for Shoulder Joint Protection Program for People with Shoulder Arthritis

Ze(Steve) Lu: Primary author, study design, running search strategy, study selection, data extraction, quality appraisal, data analysis, writing manuscript, preparing the manuscript for submission.

Erfan Shafiee: Co-author, data collection.

Joy C. MacDermid: Co-author, conception of study idea and study design, revising the manuscript for important intellectual content, final approval of the manuscript before submission.

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Chapter 8: General Discussion and Future Direction

Ze(Steve) Lu: Sole Author

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1. Introduction

1.1 Shoulder Osteoarthritis Arthritis

Glenohumeral osteoarthritis (OA), a widespread joint disorder, is the third most common after knee and hip OA.[1] Precise prevalence is elusive, but data suggest 16.1%-20.1% of adults over 65 exhibit radiographic signs of this condition. Primary glenohumeral OA is more prevalent among females and those aged 60 and older.[1]

Several risk factors are associated with glenohumeral OA. Age is the most significant, but sex, obesity, Caucasian ethnicity, previous shoulder trauma, rotator cuff injuries, glenohumeral instability, crystalline arthropathy (e.g., gout), and sickle cell disease also contribute.[2] The condition's progression involves a gradual, degenerative process affecting articular cartilage, bone, and the joint capsule. As the articular surface erodes, intra-joint friction intensifies, leading to functional disability and pain. [2]

Patients typically present with gradually worsening activity-related pain.[3] Night pain can become a common complaint as OA advances. [3] In many patients, pain persists even at rest, disrupting sleep. In advanced stages, stiffness can impose significant functional limitations. [2,3] Symptoms may also include crepitus or joint effusion. It's noteworthy that younger patients may develop OA as a result of trauma, dislocation, or prior surgeries addressing shoulder instability. [2,3]

Treatment for shoulder arthritis is multi-faceted, comprising medications, physical therapy, and lifestyle modifications. In extreme cases, surgical intervention may be necessary, involving the replacement of the damaged joint with an artificial one.[4–9] Early diagnosis and prompt treatment are key to effectively managing the condition and preserving joint function. [1–3]

1.2 Total Shoulder Arthroplasty

Total Shoulder Arthroplasty (TSA) has firmly established itself as the preeminent surgical intervention for primary or secondary osteoarthritis (OA) stemming from diverse etiologies such as shoulder instability, osteonecrosis, inflammatory arthropathies, and proximal humeral fractures.[7,10,11] Epidemiological trajectories underscore its burgeoning acceptance; for instance, the

U.S. witnessed a paradigmatic shift with a 12% escalation in TSA procedures over a mere nine-year span. [12] Similarly, demographic assessments from Australia illuminate that a significant proportion of TSA beneficiaries are septuagenarians or older. [12,13]

This increased proclivity towards TSA isn't merely a reflection of the rising incidence of OA. It can also be attributed to seminal breakthroughs in orthopedic technology. Advancements in this domain are palpably evident in the biomechanical sophistication of implant designs, the meticulous precision of surgical techniques, and the evolution of postoperative care paradigms.[14] To assess the efficacy and patient-centric outcomes of these orthopedic interventions, the medical community has increasingly turned to robust patient-reported outcome measures (PROMs). Tools such as the Simple Shoulder Test (SST), American Shoulder and Elbow Surgeon (ASES) score, Shoulder Pain and Disability Index (SPADI), and pain visual analog score (VAS) are employed to quantify functional outcomes and gauge postoperative therapeutic success. [15–17]

However, like any advanced surgical intervention, TSA is not without its challenges. Despite rigorous procedural standards and postoperative care, there are inherent risks associated with the procedure, ranging from potential joint instability to microbial infections.[5,7,18] Moreover, the pivotal role of postoperative rehabilitative regimens in determining the success of TSA cannot be overstated.[19] There exists a broad spectrum of rehabilitative protocols, each with its unique emphasis—be it on passive kinematics, active range of motion, or progressive musculoskeletal strengthening. Such diversity in therapeutic strategies underscores the ongoing endeavor in the orthopedic community to delineate and establish an optimal rehabilitative gold standard for TSA. Level of activity is usually restricted for a specific postoperative period to safeguard against potential compromise of implant stability and soft tissue repairs. Among published studies, however, there is a lack of consensus regarding the PT program needed to optimize postoperative outcomes, including ROM, pain, or function.

1.3 Shoulder Biomechanics

The shoulder is a unique structure with remarkable mobility that permits positioning of the hand within a large spatial volume. The mobility comes at a cost: stability. The shoulder joint involved in diverse activities and sports: understanding the biomechanics is essential for identifying injury risks, informing effective treatments, managing shoulder conditions, and devising rehabilitation strategies, particularly in light of the high prevalence of shoulder injuries and arthritis.[20] The term shoulder biomechanics refers to studying the mechanical properties and movements of the shoulder joint complex - inclusive of the glenohumeral joint, acromioclavicular joint, scapulothoracic joint, and sternoclavicular joint. [20] It involves analyzing forces, torques, muscle activations, and joint kinematics that contribute to the functioning of the shoulder joint during different activities and movements. [20] However, quantifying shoulder joint forces in living subjects without invasive procedures poses significant challenges.[20,21] Hence, our grasp of shoulder biomechanics relies heavily on experimental studies involving cadaveric specimens or computational modeling. [20]

A common method for quantifying shoulder joint force is the application of a motion analysis system coupled with inverse dynamics, a well-established technique used for calculating net joint torques within a rigid body linked segment model.[22–25] This approach bases its calculations on measured kinematics and, in some instances, external forces to determine the forces acting on the shoulder. [20] Alternate methodologies for assessing shoulder joint force include task simulation [26], implantable sensor technology[27], electromyography (EMG)[28,29], and a variety of other techniques[30].

A thorough understanding of shoulder biomechanics, particularly as they are altered in common shoulder pathologies, is fundamentally important. Such insights serve as valuable tools for diagnosing, treating, and managing shoulder conditions and can guide the creation of effective rehabilitation strategies. Repetitive overhead activities, such as pitching, swimming, and badminton, intensify the stress on the shoulder joint, potentially leading to injury.[31,32] Faulty shoulder biomechanics can also lead to the development of OA shoulder joint arthritis, a degenerative joint disease marked by pain, stiffness, and restricted range of motion.[33,34] The impact of shoulder injuries and arthritis on daily activities can be significant, imposing limitations on performing routine tasks like dressing, grooming, and overhead reaching. Despite the high prevalence of shoulder injuries and arthritis, there is a gap in current literature regarding the ideal biomechanics of the shoulder in daily activities and sports, and effective injury prevention.

1.4 Shoulder Dynamics

Studying shoulder dynamics of daily activities should enable the identification and modification of movements that could reduce pain from arthritis. Certain movements, such as overhead shoulder motion, unsupported reaching, and repetitive shoulder movements, can exert additional stress on the already compromised joint, leading to increased pain and potential further damage.[35] By understanding and analyzing these kinematics, healthcare professionals can design personalized shoulder joint protection programs to alleviate stress on the affected joint, minimize discomfort, and prevent any additional harm.[36] Such tailored approaches empower individuals with shoulder arthritis to engage in activities that are less likely to aggravate their condition, improving their overall well-being and joint health.[36]

1.5 Shoulder Joint Protection Program (SJPP)

Adopting a joint protection program for shoulder arthritis can integrate principles of adaptation intended to lessen stress on the compromised joint and enhance overall function. The importance of such a program, complementing exercise regimes and daily activity modifications, can't be overstated. Measures such as avoiding repetitive overhead movements and heavy lifting, utilizing adaptive tools, and offering the shoulder support while seated or reclining can effectively decrease pressure on the impacted joint. [36–38]

Although healthcare professionals widely recommend these general principles to alleviate load on the affected joint, scientific evidence backing specific modifications for shoulder arthritis daily activities remains somewhat sparse. When tailoring a SJPP, one must account for multiple factors, including the underlying cause of the shoulder issue, the patient's lifestyle and day-to-day activities, functional capability, patient education, and patient compliance.[36–38] The program should aim to mitigate the burden of daily activities on the shoulder joint while still facilitating the execution of essential tasks. It should also incorporate exercises and activities commensurate with the patient's strength and physical capacity.[36–38] Patients must be educated on the importance of safeguarding their shoulder joint and properly executing activities.

Ultimately, a tailored SJPP is crucial to enhance overall shoulder joint function and minimize further joint deterioration. Involvement of both patients and clinicians is a critical facet in the development of joint protection programs. Their insights can aid in identifying knowledge gaps and ensuring the program caters to specific patient needs while also avoiding overuse of protective measures that may not be valued by patients.

1.6 Knowledge Gap

While joint protection programs are increasingly recognized in arthritis care, there is an evident lack of focus on shoulder joint concerns. Current programs, though effective in steering patients away from detrimental activities and towards beneficial approaches, do not incorporate evidence-based practices specifically tailored for shoulder joint recovery. The value of clear, readily available scientific information in enabling patients to manage their conditions independently underscores the pressing need for a program dedicated to shoulder joint protection. Establishing such a program could bridge this existing gap, enhance patient results, and promote autonomy for those grappling with shoulder joint complications.

1.7 Objectives of the dissertation

This dissertation is devoted to addressing the identified gap in arthritis care by scrutinizing various aspects of the treatment of patients with shoulder OA, assessing the effectiveness of physiotherapy post-TSA, and suggesting methods for an all-encompassing SJPP. The ultimate objective is to augment patient outcomes and bolster self-reliance for those facing shoulder joint challenges. The dissertation comprises six papers, which include two systematic reviews with meta-analyses delving into the effectiveness of post-TSA physiotherapy, one narrative review incorporating the International Classification of Functioning, Disability and Health (ICF) linkage process to explore the content of patient-reported outcomes for shoulder conditions, one scoping review focused on shoulder biomechanics, one movement analysis for capturing shoulder kinematics and validating a novel video-based machine learning software, and one cognitive interviewing study to assess the face and content validity of the developed SJPP. The findings of this dissertation contribute to the body of evidence-based joint protection programs that can boost independence in daily activities. The SJPP developed in this study, is grounded on comprehensive evidence and is designed to be adaptable to the needs and preferences of both patients and clinicians.

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Chapter 2

2. A narrative review and content analysis of functional and quality of life measures used to evaluate the outcome after TSA: An ICF linking application

Abstract

Background: Total shoulder arthroplasty (TSA) is considered as the standard reconstructive surgery for patients suffering from severe shoulder pain and dysfunction caused by arthrosis. Multiple patient-reported outcome measures (PROMs) have been developed and validated that can be used to evaluate TSA outcomes. When selecting an outcome measure both content and psychometric properties must be considered. Most research to date has focused on psychometric properties. Therefore, the current study aims to summarize the PROMs that are being used to assess TSA outcomes, to classify the type of measure (International society for quality of life (ISOQOL) using definitions of functioning, disability, and health (FDH), quality of life (QoL) and health-related quality of life (HRQoL)) and to compare the content of these measures by linking them to the International Classification of Functioning, Disability and Health (ICF) framework.

Methods: A literature review was performed in three databases including MEDLINE, EMBASE, and CINAHL to identify PROMs that were used in TSA studies. Meaningful concepts of the identified measures were extracted and linked to the relevant second-level ICF codes using standard linking rules. Outcome measures were classified as being FDH, HRQoL or QoL measures.

Result: Thirty-five measures were identified across 400 retrieved studies. The most frequently used PROM was the American Shoulder and Elbow Society score accounting for 21% (246) of the total citations, followed by the single item pain-related scale like visual analog scale (17%) and Simple Shoulder Test (12%). Twelve PROMs with 190 individual items fit inclusion criteria for conceptual analysis. Most codes (65%) fell under activity and participation categories. The top 3 most predominant codes were: sensation of pain (b280; 13%), hand and arm use (d445; 13%), recreational activity (d920; 8%). Ten PROMs included in this study were categorized as FDH measures, one as HRQoL measure, and one could not be classified.

Conclusions: Our study demonstrated that there is an inconsistency and lack of clarity in conceptual frameworks of identified PROMs. Despite this, common core constructs are evaluated. Decision-making about individual studies or core sets for outcome measurement for TSA would be advanced by considering our results, patient priorities and measurement properties.

Keyword: *Patient-reported outcome measures, Total shoulder arthroplasty, ICF, Health-related quality of life, Quality of life.*

2.1 Background

The high prevalence of shoulder pain (7%-21%) in the general population results in high, and increasing, levels of disability and health-care costs(1,2). Glenohumeral arthritis is the primary cause of shoulder pain and dysfunction in an aging population(1). Psychological issues such as depression, anxiety, and decreased quality of life (QoL) are associated with chronic musculoskeletal pain(1–4). The combined physical and psychosocial impacts of shoulder pain are complex and contribute to lower quality of life(2).

Total shoulder arthroplasty (TSA) is a reconstructive surgical procedure that can provide pain relief and restore function in severely damaged arthritic shoulders(5–8). Such treatments have a predictable outcome for patients with joint destruction arising from pathologies such as osteoarthritis, rheumatoid arthritis and proximal humeral head fracture(8–10). Previous studies indicated significant improvement of both psychological status and health-related quality of life (HRQoL) by 3-months after surgery(2,11). However, implant issues, such as loosened glenoid components can lead to poorer outcomes over the longer-term(3,7). While improvement can be expected, normal function cannot be restored and the outcome achieved is variable and dependent on many factors including different surgical indications, soft tissue recovery, subscapularis integrity, and post-operative rehabilitation (5,12).

To evaluate surgery outcomes, many clinicians and researchers are aware of the importance of measuring pain, functional outcomes, biopsychological health, QoL, and HRQoL (13). Since the 1990s, numerous patient-reported outcome measures (PROMs) have been developed and validated to assess outcomes in shoulder conditions(14–16). Researchers have established acceptable levels of reliability, validity, and responsiveness of PROMs such as the American Shoulder and Elbow Society score (ASES) and the Simple Shoulder Test (SST), and synthesized the evidence of psychometric properties in a systematic way(7,13,17,18).

Content validity is a fundamental property of PROM, but relatively overlooked in the literature. Although standard definitions exist for functioning, disability, and health (FDH), rather than HRQoL or QoL(19–21), there is overlap in these concepts and insufficient precision by developers and users with respect to these terms (20). The absence of a theoretical framework or conceptual definition leads to difficulty of interpreting study results using different outcome measures, since it can be unclear which domains of health are affected by the intervention, and whether differences in outcomes relate to the intervention or the measure (5). Since few developers provide clear definitions of their latent constructs or how items were mapped to these constructs it is important to do a retrospective evaluation to inform content validation and understand differences in constructs evaluated by commonly used measures.

The World Health Organization (WHO) definitions provided in the International Classification of Functioning, Disability and Health (ICF) and the manual of the WHO-Quality of Life brief version (WHOQOL-BREF)(21–24) provided internationally used frameworks, definitions and coding language to describe the impact of health conditions on function, disability and health(21). With the ICF framework, the concept of FDH refers to the biopsychosocial components and interactions among body structures and function, and activities and participation in the context of the environment and personal factors(25–28). The QoL is defined by the WHO as " a person's perception of their position in life affected by the culture and value system in which they live and in relation to goals, expectations, standards, and concerns(21,23)."

However, the terminology HRQoL, remains variably defined by different sources(20). In HRQoL is specific focus on how QoL is influenced by a health condition(20,23). While culture, politics and economic context also affect QoL, those influences are generally not addressed in HRQoL measures or health-related PROM(20).. See Table 1 for orgnizations of the concepts for FDH, QoL, and HRQoL.

Insert Table 1 here

Using the ICF framework, researchers can evaluate individual content items with a standardized coding, or "linking" procedure(29,30). According to the ICF linking rules, a second level codes start with the letters b, s, d and representing the classification of body function and structure, activity, participation, environmental factors and personal factors followed by a numeric code for the chapter number (one digit) and another two digits as the second level(29). The linking process is a universal language that can be used to define the content of items and describe their meaningful contructs (26). A systematic review conducted in 2013 evaluated the content of 475 shoulder related outcome measures by linking invidual items to ICF codes(18). This work provided some evidence on content validity of shoulder PROM. We are building on this work by focusing on shoulder arthroplasty to understand the use of PROM in this area of practice, providing an updated assessment of PROM usage, and classifying the conceptual framework according to standard definitions from the International Society for Quality of Life Research.

The objective of the current study was to analyze the classification and content of functional and quality of life measures used to evaluate the outcome after TSA using the ICF framework by (1) identifying the PROMs used for patients after TSA; (2) mapping the content of the individual items using second level ICF codes; (3) summarizing the focus of these PROMs based on ICF domains; and (4) providing an updated assessment of PROM usage and summarizing the predominant application of included PROMs based on ICF linking and pre-defined concepts of FDH, HRQoL, and QoL.

2.2 Methods

2.2.1 *Design*

A structured literature review was carried out following the PRISMA guideline(31). The PRISMA flow diagram containing all steps of the screening and extraction measures are displayed in Figure 1. The content analysis of PROMs used for patients post TSA surgery was performed based on the existing ICF linking rules(29,30).

Insert Figure 1 here

2.2.2 *Information sources*

A literature search was performed in three databases including MEDLINE, EMBASE, and CINAHL to capture PROMs used for patients with TSA in both clinical and research settings.

Search: MeSH terms used for PROMs, including questionnaire, score, index, tool, survey, outcome measure, and patient-report, were connected by the Boolean operator ‘OR.’ The same operator was applied for other MeSH terms that specified TSA management by total shoulder arthroplasty and total shoulder replacement. PROMs and TSA terms were then combined with the operator ‘AND’ for final search. We limited searching to the last five years and three months, from January 2014 to December 2019, to reflect recent practice. Details of search keywords are listed in Appendix 1.

2.2.3 *Eligibility Criteria*

The inclusion criteria were any articles published in peer-reviewed journals on studies of TSA surgery using named PROMs to measure FDH, QoL or HRQoL. Outcome measures, such as the Constant Score, that include any physical assessment that requires administration by health care providers or researchers, were excluded since our focus was PROM. We also excluded studies using unnamed instruments without prior validation.

Study selection: All identified articles were imported into Mendeley reference management software (version 1.19., 2008 Glyph & Cog, LLC) for duplicate, author and journal information checking. After removal of the duplication, the first author [ZL] performed the title, abstract and full-text review. At full-text review stage, the second author [JMacD] randomly reviewed 50% of the articles and discussed the disagreement with the first author through regular meetings.

2.2.4 *Data collection process*

Data extraction was initially performed by the first author [ZL]. The original intention of using the instrument (e.g., to measure pain, function, QoL, HRQoL, surgery outcome, patient satisfaction, etc.) was recorded. Ambiguous or difficult cases were presented through online-based discussion for the final decision. We calibrated the details of PROMs, such as different versions of the questionnaires, according to a previous systematic review and a guideline of shoulder outcomes measures(18). To avoid detailed analysis of rarely used PROM, we excluded PROMS that had not been cited at least 10 times from the overall data pool of 1175 citations thereby excluding those that represent less than 1%The tracking sheet of excluded questionnaires is available upon request.

Data items

According to the predetermined definitions of FDH, QoL, and HRQoL, the original intention of applying the PROMs was recorded and analyzed through the data extraction (23). The first author

(ZL) documented text in the articles where they referred to researchers' purpose of using PROMs and then coded the outcome measures for different conceptual applications. Direct clarifications in terms of function, disability or health, QoL or HRQoL were categorized onto terms FDH, QoL, or HRQoL. Ambiguous statements were coded with the consideration of the context of studies. For example, patients' satisfaction level with their shoulder condition was coded as HRQoL.

2.2.5 Summary measures (Content analysis)

The content of included PROMs was evaluated item by item based on existing ICF linking rules (23,29,30). One of the authors [ZL] finished the entire linking work independently and then presented the result to an external expert with experience in ICF. Any discrepancies were marked as addressed if agreement was achieved. Meaningful concepts were linked to the specific second level of the ICF codes. An individual item can map onto several codes if needed. For example, *pain pushing with the involved arm* contains meaningful concepts as *pain* and *pushing with involved arm,* which was coded separately as *sensation of pain* (b280) and *hand and arm use* (d445). General concepts that cannot be assigned with a code but are still within the classification system were linked as *non-definable (nd)* (18,23,29). For example, the general evaluation of the health condition was coded as *nd* due to the coverage of all aspects of health without specific definitions. *Not covered (nc)* was used for the concepts beyond the ICF conceptual framework, such as the satisfaction level about the quality of health care Personal factor was labeled as *pf,* and consistent with ICF were acknowledged, but not coded.

We used summary indices to decide the extent to which content of a measure can be captured with ICF codes(32,33). The formula was listed as follows: The number of items linked to at least one ICF code/total number of items on the measure × 100%.

Synthesis of results (from the content analysis)

Individual item codes were then categorized into the five ICF domains, including *body function and structure, activity, participation, environmental factors and personal factors* according to the linking result.

As the final step, included PROMs were summarized into FDH, HRQoL and QoL measures with the recommended use based on the previous analysis. Measures focusing on pain, shoulder function, capacity, performance, difficulty, barriers, or facilitators of contextual factors were categorized as FDH measures. The dominant perspectives of measures were provided based on content analysis using ICF. Other questionnaires that mainly assess expectations, evaluation, and person judgment about health or health-related domain were coded as HRQoL. QoL measures were also classified based on the WHO definition. FDH measures with HRQoL/QoL features were given when at least one item from FDH scales was not covered by ICF component but within the HRQoL/QoL. For example, if one item from a given measure was categorized onto HRQoL related content, while other questions were all identified as FDH, this specific PROM was considered as a FDH measure with HRQoL features.

Previous evidence from the literature review was cross-referenced at this stage. Consensus was required from all three authors to finalize the result(25,33).

2.3 Results

2.3.1 *Study selection*

Overall, 1036 studies were screened through the title and abstract review, and 400 of these articles were included. We identified thirty-five measures that have been cited 1175 times from all retrieved studies. Among them, five were single item questionnaires, and 30 were multi-item measures. Please see Appendix 2 for all 35 outcome measures. The Constant and three other non-PROMs, including the Constant-Murley and Charlson Morbidity Index, were not involved in further content analysis. Numeric rating scales (NRS) and visual analog scales (VAS) for pain were considered as the same measure due to similar meaning of the content of the question. The same strategy was applied for the Single Assessment Numeric Evaluation (SANE) and Subjective Shoulder Value (SSV). All studies used an English version of the PROMs. In total, 12 PROMs for our inclusion and exclusion criteria and underwent detailed ICF linking and conceptual analysis.

2.3.2 *Results of individual studies (Second level of ICF linking)*

A total of 36 second level ICF codes were linked to individual items (Table 2). There were 23 different codes under the *activities and participation* category (*d* codes) and 10 under the *body structure (s* codes*) and body function (b* codes*)*. *Personal factors* were identified within three included PROMs: The Disabilities of the Arm, Shoulder, and Hand (DASH), Western Ontario Osteoarthritis Score (WOOS), and PENN shoulder score (PSS). Only two codes under environment factors were identified *as products or substances for personal consumption* (e110) and *climate* (e225). Eleven of the total linked codes were found with a frequency above 5% as *sensation of pain* (b280), *hand and arm use* (d445), *recreation and leisure* (d920), *remunerative employment* (d850), *lifting and carrying objects* (d430), *doing housework* (d640), *muscle power functions* (b730), *dressing* (d540), *washing oneself* (d510), *carrying out daily routine* (d230), and *sleep functions* (b134). The occasions of using these codes to link individual items in each PROMs were listed in rank order in Table 2.

Of all the measures, one item proposed as "Since beginning therapy for your shoulder, would you say that your shoulder has" from PSS could not be linked by specific categories but was considered still within the ICF framework (nd). Six PROMs including SANE, SSV, SF-12, DASH, WOOS, and PSS had a question that was not covered by the ICF but was within HRQoL. One item of WOOS, asking how much of a burden do you feel you are on others, was categorized as QoL-related content. A summary of the distribution of items from each PROM under the ICF chapter level is listed by frequency order in Table 3.

Insert Table 2 here

Insert Table 3 here

2.3.3 *Synthesis of Results (Summarization of predominant application)*

An overview of the summarized information for each PROM is presented in Table 4. The most frequently used PROM was the American Shoulder and Elbow Society score (ASES) accounting for 21% (246 times) of the total citations, followed by the NRS or VAS for 17% and SST for 12%. Most of the analyzed measures were used as functional outcome instruments. Through the review, we found that the SF-12 was often used as a tool to evaluate QoL, although it was designed as a health status measure. Patient satisfaction scales were used to quantify the personal expectation of the surgery, care or shoulder conditions.

The high percentage of the measure to ICF linkage indicated that most of the items from included PROMs can be linked with second level ICF, except for SANE/SSV and patient satisfaction, which are not linkable constructs. Ten of the PROMs included in this study were categorized as FDH measures, with specific focus of quantifying symptoms and functional limitations for people with shoulder problems.

Insert Table 4 here

2.4 Discussion

This study found variation among commonly used PROMs used to assess the outcomes of TSA in terms of their overall latent construct and the item level content, although most were more focused on activity and participation rather than on patient's perceptions of body structure and function. Overall, the content covered by the PROMs included 10 second level ICF codes under the domain of *body functions and structures*, and 23 codes under the domain of *activities and participation*. This is consistent with the fact that PROMs focus on the patient being experienced and uniquely able to assess how a person functions in their own life; whereas impairments in body structure and function can be better measured with clinical tests. Only two categories under *Environmental factors* were mentioned. Another content analysis of PROMs also noted a similar lack of attention to the environment(18). Even where the environment is not explicitly addressed, we expect it to be an important factor in disability that may partially explain why patients with similar impairments experience different disabilities.

Pain is a primary concern for patients undergoing TSA surgery(6). This is consistent with the category s*ensation of pain (b280),* being the most frequently linked code. Although pain is considered an impairment in ICF, it also a subjective experience that is typically captured by PROMs. The second most frequently linked code under *body function* domain was *muscle power function* (b730), which belongs to the impairment domain under the ICF framework. Strength can be assessed by clinicians using dynamometers or other devices; or can be self-reported by patients. Typically, we expect that PROM would focus on functional items and that pain, motion and strength might all interfere with functional performance. However, some PROMs do ask questions that specifically target muscle strength. Generally, these questions must be generic rather than targeted to specific muscle groups as might be assessed by dynamometers. For example, questions from the SST that ask participants to rate the difficulty of three pre-defined lifting tasks with weight levels ranging from one lb to 20 lbs., assess strength, but do not identify particular muscle groups or adaptations.

*Activit*y was the predominant ICF domain, accounting for 41% of the items (21,28). *Hand and arm use* and *lifting and carrying objects* were the most commonly linked ICF codes under the *activity* domain. This suggests a consistent recognition of the importance of these tasks in patients with shoulder arthritis, requiring TSA. However, on the other hand, the ICF categories related to mental function such as *sleep function, emotional function, and energy and drive* were infrequently linked suggesting less agreement that these are central to TSA outcomes. The importance of psychological health (18,34) in post-surgical patients may be underrepresented especially if the instrument is intended to measure QoL. However, outcome instrument developers often try to focus on a clear construct, and it would be the responsibility of researchers to include measures of physical health and psychologic health within their studies, since summing different constructs together may not always be appropriate. Further, developers may consider psychological factors as mediators of outcomes rather than the outcomes themselves. Ideally, developers should explicitly define these conceptual assumptions.

Recreation and leisure (d920) and *Remunerative employment* (d850) were ranked as third and fourth order among all the linked items. This high ranking is consistent with a previous systematic review focusing PROMs of shoulder pain and functioning(18). Most PROMs such as ASES, DASH, and Oxford Shoulder Scale (OSS) imply these concepts by formulating questions as leisure activities and usual work. Overall, these items and others that fit within participation comprise 24% of the total items. The concept of *participation* defined by the ICF framework is subject to qualifiers that describe what a person does in their usual life. That means subjects' response to such questions might be modified by the usual roles or environmental factors, but these are not directly measured.

According to the WHO, different PROMs used for patients after TSA share areas of content and purposes of application. The single item measure SANE, and SSV, that investigate to what extent a patient would rate their shoulder as being normal, was classified as HRQoL perspective since it address a global evaluation, whereas researchers and clinicians commonly use it as a functional outcome since it assumed to be rating physical function on a scale of 0-100%(36). A previous study found that patients have a lot of confusion about what is being calibrated when responding to this questions, which reflect the ambiguity in its definition(37). It is important to have a conceptual distinction between measures designed to assess HRQoL which is intended to be comprehensive, versus those designed to measure physical functioning which is a smaller construct that might affect QoL. The confusion we found in conceptual clarity and content of items across many of these measures emphasizes the importance for instrument developers to define their conceptual framework so that users of outcome measures can match the measurement purpose is to a specific conceptual framework.

Patient satisfaction is important, but often variably measured in health research. Satisfaction with care is a process measure, whereas satisfaction with health/shoulder status can be considered as an HRQoL measure. However, by asking about the satisfaction with surgery and care, this scale mixes evaluation of the process of care or Quality of Care(38), with outcome evaluation. Researchers and clinicians should be more explicit about whether they are measuring process or outcome satisfaction; and ensuring their selected measure reflects that choice.

A key issue in the literature was the vague and imprecise terminology used to for different outcome measures and the definition of the FDH, QoL, and HRQoL. For researchers, clearly defined concepts within PROMs help them detect the most appropriate and precise latent construct. For clinicians, in both research and daily practice work, appropriate selection of the outcomes measures is not only dependent upon the psychometric properties and intention of the application, but also on the precise understanding of the content informed by a unified conceptual framework(25). Developers rarely provide a strong conceptual framework, and users rarely state their measurement rationale or the content validity of the tools they selected for the constructs of interest. Rather justification of PROMs within studies tend to focus on psychometric properties like reliability, which do not reflect content validity. Some measures mix different constructs. For example, The DASH provides a comprehensive set of items and is defined an as FDH instrument but contains items that fall within a HRQoL construct. Terms are often used incorrectly, for example health status measures and functional measures are often referred to as QoL measures. The use of terms like clinical outcome measures or functional outcomes happens without clear distinction about what these terms mean(11,39).The conceptual analysis performed in the current study may help resolve the issue by precisely categorizing the retrieved PROMs into three types as: (1) FDH (the capacity, performance, presence ⁄ absence, frequency, severity, or other biopsychosocial domains), (2) HRQoL (the expectations, standards, or concerns about individual health), and (3) QoL (the patient's personal assessment of their position in life). Mapping the ICF domains within PROM can help researchers and clinicians to select the most appropriate PROMs for their context (and research question). That is considering the impacts of shoulder joint destruction (or indications for TSA) and expected impacts of TSA (outcomes) should drive the PROM that have the best conceptual match. Further, this can identify when important constructs are missing, and supplemental measures might be needed. This would complement, not replace, considering important psychometric properties like reliability and responsiveness.

TSA outcomes measures should be developed using a clear conceptual framework. Many of the investigator panels that attempt to achieve consensus on outcome measurement start with defining the core constructs that should be measured for a given health problem, and then choose the best measure within those constructs(25,33,40). Our findings could support such a process. A better understanding of the latent construct evaluated within PROMs should enable clinicians and researchers to make valid conclusions. For those validated PROMs, clinicians should also be cautious to use them in different conditions such as other language versions. The cross-cultural adaptation might not have satisfactory content validity when considering the effect of translation, the various culture backgrounds and healthcare systems.

Limitation

The current review does have limitations. Our search strategy may not have identified all studies using PROMs. However, the large number of studies we reviewed created robust findings. Our exclusion of rarely used PROMs may have missed some emerging but higher quality PROMs that have different or more robust content validity. Extraction of data was complicated by a lack of clear reporting in some papers. Even with the updated version of ICF linking rules, personal factors are still not classified F(29). ICF coding is one approach to assess content validity and should be supplemented by other methods including cognitive interviews and quantitative patient/expert ratings of relevance.

2.5 Conclusion

We found confusion in conceptual definitions on PROMs, and wide variation in PROM content and use. Despite the variability there were some common constructs evident in measurement of pain, hand and arm use, recreational activities work and employment, lifting and carrying. Mental function components such as emotional function, energy and drive were rarely covered reflecting the focus on physical recovery following TSA. Investigators evaluating these constructs may require supplemental PROMs. Efforts to achieve consensus on the key constructs that should be measured following TSA are needed.

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2.7 List of Tables

Table 2-1 The organization of concepts of functioning, disability, and health (FDH), quality of life (QoL), and health-related quality of life (HRQoL)

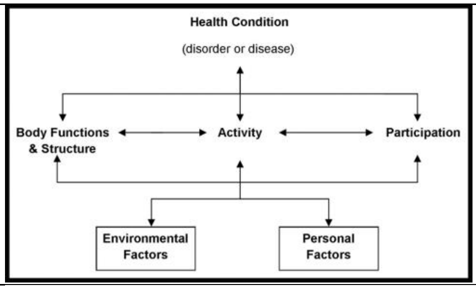
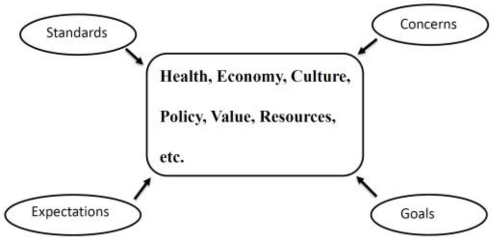
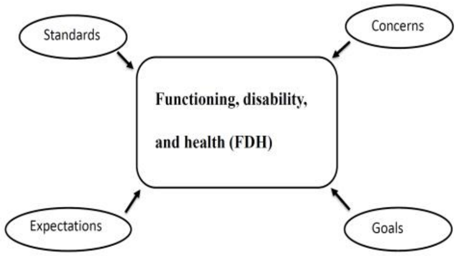
Concept	Definition adopted	Visual explanation	Item example (name of measurement)
Functioning, disability, and health (FDH)	Biopsychosocial components and interactions among body structures and function, and activities and participation in the context of the environment and personal factors		Is it difficult for you to manage toileting? (American Shoulder and Elbow Society Score)
Quality of life(QoL)	A person's perception of their positions in life affected by the culture and value system in which they live and in relation to goals, expectations, standards, and concerns		How much of a burden do you feel you are on others? (Western Ontario Osteoarthritis Score)
Health-related quality of life (HRQoL)	The subjective assessment of the impact of disease and treatment across the physical, psychological, social and somatic domains of functioning and well-being		How satisfied are you with the current level of function of your shoulder? (PENN shoulder score)

Table 2-2 Second level ICF categories linked to the individual items from included PROMs in ranked order

Identified PROMs (Number of items) \ ICF code linked to items	*b280 Sensation of pain*	*d445 Hand and arm use*	*d920 Recreation and leisure*	*d850 Remunerative employment*	*d430 Lifting and carrying objects*	*d640 Doing housework*	*b730 Muscle power functions*	*d540 Dressing*	*d510 Washing oneself*	*d230 Carrying out daily routine*	*b134 Sleep functions*
ASES (17)	4	2	2	2	1		1	1	1		1
VAS&NRS-pain	1										
SST (12)	1	5		1	3		1	1	1		1
SANE & SSV (1)	***None***										
Sf-12 (12)	1		2	4		2				4	
SPADI (13)	5	3			2		1	3	2		
DASH (38)	4	7	7	5	1	5	2	1	2	1	1
WOOS (19)	4	3	1		1	1	1	2		1	1
Quick-DASH (19)	4	2	5	5	1	4	1		1	1	1
OSS (12)	4	1		1	1	2		1	1		
PSS (26)	3	5	2	1	7	1	4	3	3		1
Patient satisfaction (1)	***Not covered***										

In a total, 36 second level ICF codes were used to link individual items.
Eleven of the total linked codes were found with a frequency above 5%

ASES: American Shoulder and Elbow Society
SST: Simple Shoulder Test
DASH: Disabilities of the Arm, Shoulder, and Hand
WOOS: Western Ontario Osteoarthritis Score
PSS: PENN shoulder score
NRS: Numerous Numeric rating scales

VAS: Visual analog pain scales SANE: Single Assessment Numeric Evaluation SSV: Subjective Shoulder Value SPADI: Shoulder Pain and Disability Index OSS: Oxford Shoulder Scale

Table 2-3 Categorization of items under ICF domains with corresponding percentage

	Body function and structure (25%)	Activity (41%)	Participation (24%)	Environment (2%)	Personal factors (2%)	Not defined but within ICF (1%)	QOL/HRQOL (5%)
ASES	2	8	4	3			
VAS&NRSpain	1						
SST	5	9	1				
SANE & SSV							1
Patient satisfaction							
SF-12	3	1	7				3
SPADI	6	12					
DASH	10	17	16		1		1
WOOS	7	7	2	1	2		3
Quick-DASH	6	4	12				
OSS	4	7	2				
PSS	7	18	5		1	1	2

ASES: American Shoulder and Elbow Society
SST: Simple Shoulder Test
DASH: Disabilities of the Arm, Shoulder, and Hand
WOOS: Western Ontario Osteoarthritis Score
PSS: PENN shoulder score
NRS: Numerous Numeric rating scales
VAS: Visual analog pain scales
SANE: Single Assessment Numeric Evaluation
SSV: Subjective Shoulder Value
SPADI: Shoulder Pain and Disability Index
OSS: Oxford Shoulder Scale

Table 2-4 Description of the FDH, HRQoL, and QoL perspective based on ICF linking.

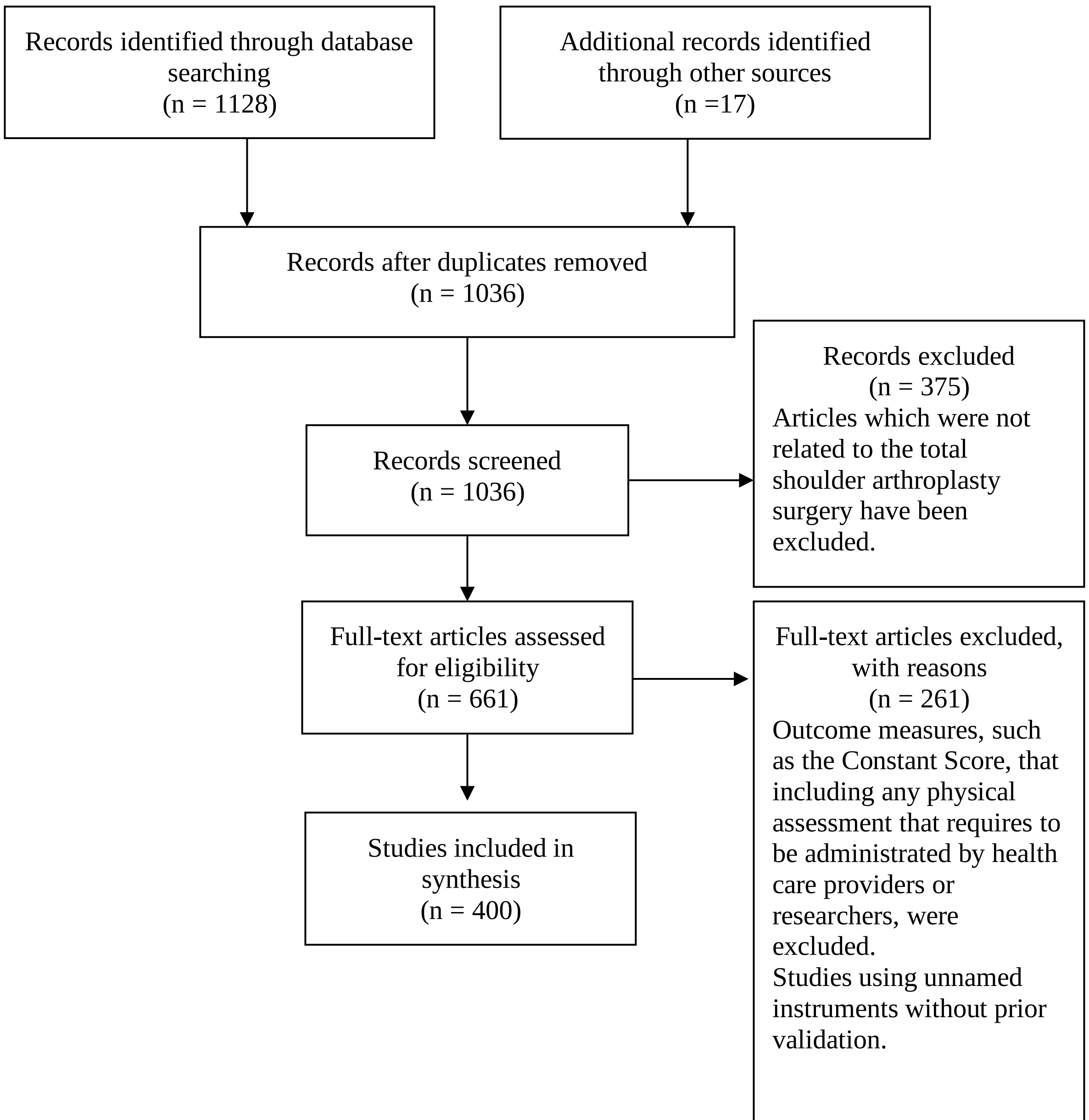
	Percentage of total citations	Measure to ICF linkage	Dominant ICF Component	Dominant intention	Instrument recommendations
ASES	21%	100%	Activity	Functional outcome	FDH instrument focusing on activity concerns
VAS-pain	17%	100%	Body function	Pain evaluation	FDH instrument for pain
SST	12%	100%	Activity Body function	Functional outcome	FDH instrument focusing on activity and body function
SANE & SSV	8%	0	none	Functional outcome	HRQoL
Patient satisfaction	5%	0	none	Patient satisfaction	Unknown
SF-12	3%	92%	Participation	QoL	FDH instrument focusing participation with HRQoL feature
SPADI	3%	100%	Activity Body function	Functional outcome	FDH instrument focusing on activity and body function
DASH	3%	100%	Activity Participation Body function	Functional outcome	FDH instrument with HRQoL
WOOS	2%	95%	Activity Body function	Functional outcome	FDH instrument focusing on activity and body function with HRQoL and QoL feature
Quick-DASH	2%	100%	Participation	Functional outcome	FDH instrument focusing on participation

OSS	2%	100%	Activity	Functional outcome	FDH instrument focusing on activity concerns
PENN	1%	92%	Activity	Functional outcome	FDH instrument focusing on activity with HRQoL feature

FDH: Functioning, disability and health
HRQoL: Health-related quality of life
QoL: Quality of life
ASES: American Shoulder and Elbow Society
SST: Simple Shoulder Test
DASH: Disabilities of the Arm, Shoulder, and Hand
WOOS: Western Ontario Osteoarthritis Score
PSS: PENN shoulder score
NRS: Numerous Numeric rating scales
VAS: Visual analog pain scales
SANE: Single Assessment Numeric Evaluation
SSV: Subjective Shoulder Value
SPADI: Shoulder Pain and Disability Index
OSS: Oxford Shoulder Scale

2.8 List of Figures

Figure 4-1 PRISMA flow diagram of the literature search with the total number of identified measures and their number of citations



2.9 List of Appendices

Appendix 1 Search Keywords

Ovid search

1. Total shoulder arthroplasty.mp. or total shoulder arthroplasty/
2. total shoulder replacement.mp. or total shoulder arthroplasty/
3. Questionnaire.mp. or questionnaire/
4. score.mp.
5. index.mp.
6. tool.mp.
7. survey.mp.
8. patient-reported outcome/ or outcome measure.mp.
9. 1 or 2
10. 3 or 4 or 5 or 6 or 7 or 8
11. 9 and 10
12. limit 11 to yr="2014 -Current"

PubMed Search

(("arthroplasty, replacement, shoulder"[MeSH Terms] OR ("arthroplasty"[All Fields] AND "replacement"[All Fields] AND "shoulder"[All Fields]) OR "shoulder replacement arthroplasty"[All Fields] OR ("total"[All Fields] AND "shoulder"[All Fields] AND "replacement"[All Fields]) OR "total shoulder replacement"[All Fields]) OR ("arthroplasty, replacement, shoulder"[MeSH Terms] OR ("arthroplasty"[All Fields] AND "replacement"[All Fields] AND "shoulder"[All Fields]) OR "shoulder replacement arthroplasty"[All Fields] OR ("total"[All Fields] AND "shoulder"[All Fields] AND "arthroplasty"[All Fields]) OR "total shoulder arthroplasty"[All Fields])) AND (((((("surveys and questionnaires"[MeSH Terms] OR ("surveys"[All Fields] AND "questionnaires"[All Fields]) OR "surveys and questionnaires"[All Fields] OR "questionnaire"[All Fields]) OR score[All Fields]) OR ("abstracting and indexing"[MeSH Terms] OR ("abstracting"[All Fields] AND "indexing"[All Fields]) OR "abstracting and indexing"[All Fields] OR "index"[All Fields])) OR tool[All Fields]) OR survery[All Fields]) OR ("patient reported outcome measures"[MeSH Terms] OR ("patient"[All Fields] AND "reported"[All Fields] AND "outcome"[All Fields] AND "measures"[All Fields]) OR "patient reported outcome measures"[All Fields] OR ("patient"[All Fields] AND "reported"[All Fields] AND "outcome"[All Fields]) OR "patient reported outcome"[All Fields])) AND ("2014/01/01"[PDAT] : "2019/12/31"[PDAT])

Appendix 2 The list of all 35 outcome measures.

1. ASES: American Shoulder and Elbow Society
2. VAS: Visual analog pain scales
3. SST: Simple Shoulder Test
4. Constant
5. Patient satisfaction
6. SANE: Single Assessment Numeric Evaluation
7. SSV: Subjective Shoulder Value
8. UCLA Shoulder Score
9. 12-Item Short Form Survey (SF-12)
10. SPADI: Shoulder Pain and Disability Index
11. DASH: Disabilities of the Arm, Shoulder, and Hand

12. Constant-murley
13. WOOS: Western Ontario Osteoarthritis Score
14. Quick DASH
15. OSS: Oxford Shoulder Scale
16. Pain
17. 36-Item Short Form Survey
18. PSS: PENN shoulder score
19. NRS: Numeric rating scale
20. EQ-5D
21. shoulder activity level
22. Charlson Comorbidity Index
23. HADS: Hospital Anxiety and Depression Scale
24. BRS: Brief Resilience Scale
25. VR-12: Veterans RAND 12 Item Health Survey
26. Patient-Reported Outcomes Measurement Information System
27. WHOQOL-BREF
28. 15D The health-related quality of life (HRQoL)
29. The Pain Catastrophizing Scale
30. 11-item DASH
31. Korean shoulder scoring
32. ADLER score: Activities of Daily Living [ADL] which require active External Rotation [ER])
33. MAC SHOULDER ACTIVITY
34. Rowe Score
35. WORC: Western Ontario Rotator Cuff Index

Chapter 3

3. The Clinical Outcome of Physiotherapy After Anatomical Total Shoulder Arthroplasty: A Systematic Review

ABSTRACT

Objective: The purpose of this systematic review was to analyze the current literature on the pain relief and functional restoration of a physiotherapy (PT) program after total shoulder arthroplasty (TSA).

Design: Systematic review of interventions

Literature Search: A search was performed in 4 databases (MEDLINE, EMBASE, PUBMED, GOOGLE SCHOLAR) until June 2020.

Study Selection Criteria: Eligible studies (randomized / cohort studies / case-controls and case-series) reported outcomes including range of motion (ROM), function and pain of patient who received PT after TSA surgery were synthesized. Data was extracted to describe study designs and rehab programs. The quality of evidence was assessed as high, moderate, and low-level according to the Evaluation of Quality of an Intervention Study critical appraisal criteria.

Results: There were 15 eligible studies (total sample size was 1442) including 1 randomized control trial, 1 prospective cohort, 6 retrospective cohort, 3 case-control, and 4 case-series studies. Eight studies were rated as moderate to high quality. We identified significant variation in the post-operative PT protocols in terms of the initiation time of the passive ROM and AAROM exercise, the amount of the shoulder motion, and long-term precautions. Included studies demonstrate substantial improvement of pain and function in patients after TSA who completed PT rehabilitation.

Conclusion: The literature on TSA rehabilitation is primarily observational. There is no single optimal program defined, although progressive mobilization and addition of strength training at 5 or more weeks are consistent elements. All programs reported provide positive outcomes. High-quality RCTs are required to provide more conclusive results.

Keywords: total shoulder arthroplasty, systematic review, physical therapy, clinical outcome.

3.1 Introduction

Anatomic total shoulder arthroplasty surgery (TSA) is indicated in persons experiencing primary osteoarthritis (OA) or secondary OA resulting from shoulder instability, osteonecrosis, inflammatory joint diseases, and proximal humeral fractures. [1–3] TSA has been increasingly utilized around the world, with a 12 % increase in rates of TSA in the United States alone (from 18,621 to 46,951 over a 9-year period). [4–9] Within 40,130 total shoulder replacements reported to the Australian Orthopaedic Association National Joint Replacement Registry, most surgical candidates were aged over 65 years old. [10] Time and demand has led to evolution in implant design, surgical techniques, and post-operative rehabilitation. [11] post-surgical outcomes can be evaluated through patient-reported outcome measures (PROM) such as the Simple Shoulder Test (SST), American Shoulder and Elbow Surgeon (ASES), Shoulder Pain and Disability Index (SPADI), and pain visual analog score (VAS). [12–14]

Optimizing outcomes after TSA extends beyond surgical management to include patient selection, pre-operative rehabilitation, patient education, and post-operative physiotherapy/physical therapy (PT) programs. [15,16] Most existing PT programs are collaborative approaches consisting of time-efficient initiation of progressive gentle, passive mobilization, followed by active motion exercises, and finally muscle strength training. [17,18] Most rehabilitation protocols restrict the level of activity for a specific time period after surgery to avoid compromising implant stability and soft tissue repairs. [19,20]

Patients undergoing TSA have often had a prolonged period of pain, disuse, and disability prior to surgery, and there is a need to restore joint motion and neuromuscular function following surgery. A graded rehabilitation program should maximize functional capability, while teaching patients how to avoid overuse that might contribute to implant failure.

Therefore, the aim of this review was to synthesize the current literature on the clinical outcomes associated with PT programs after TSA, to determine the content of programs, expected outcomes and quality of the supporting evidence.

3.2 Materials and Methods

3.2.1 *Patient and Public Involvement*

There was no patient or public involvement in the design or planning of this study.

3.2.2 *Study Design*

This systematic review was executed using the guidelines established by the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) statement. [21] The protocol for this systematic review was registered on PROSPERO (CRD42020183150).

3.2.3 *Eligibility Criteria*

We included studies in this systematic review if the following criteria were met:

- Design: randomized / cohort studies / case-controls and case-series
- Participants: study's patient population receive the PT after the TSA (anatomical type) surgery
- Intervention/Comparison: clinic-based, home-based or other formats of PT program

- Outcomes: studies that reported patient-reported or clinician-reported outcome including range of motion (ROM), function and pain.
- Studies were published in English.

The current study excluded studies with no information of PT program details; studies with no data on the ROM, pain, and function outcomes; and conference abstract/posters.

3.2.4 *Information Sources*

To identify studies on the clinical outcomes (ROM, pain, and function) we searched the Medline, Embase, PubMed and Google Scholar databases from inception till June 2020, using a combination of keywords. Furthermore, we identified additional studies by examining the reference list of each of the selected studies. The full list with keyword strategy is presented in APPENDIX 1.

3.2.5 *Study Selection*

Two investigators (ZL and GN) conducted systematic electronic searches independently in each database. The same investigators then proceeded to identify and remove the duplicate studies. In the next stage, we independently screened the titles and abstracts and obtained all full-text articles marked as “include” or “uncertain”. In the final stage, the same two reviewers independently performed full text reviews to assess final article eligibility. In case of disagreement, a third reviewer (JM), facilitated a consensus through discussion.

3.2.6 *Data Extraction*

The third author (PA) performed the data extraction that included the author, year, location, age at surgery, surgical implants, surgical type, sample size, lengthen of follow up, study design, PT protocol, and clinical outcome (ROM, pain, and function). The extracted data were then cross-checked by another author (ZL).

3.2.7 *Assessing the quality of individual studies*

The Evaluation Guidelines for Rating the Quality of an Intervention Study, a 25 item quality appraisal tool that can be used across different study designs, was used to rate the eligible studies.[22] The tool included the rating of the quality of evidence such as randomization, allocation concealment, and imprecision. The quality score was calculated based on the sum of 25 items (2, 1, 0 for each item). We considered a score of 38 and above as a high-quality study, a score of 28 to 37 as a moderate-quality study, and a score below 28 as a low- quality study. The individual studies included in this review were appraised by two independent authors (PA and TP) to summarize the quality of available evidence. To address the disagreement, differences of 2 points for any item was adjudicated to 1 point or less. Differences of 1 point were discussed and an attempt was made for reviewers to assign a score by consensus; if a consensus could not be reached, then the lower score was assigned.

3.2.8 *Synthesis of Results*

A qualitative synthesis was conducted to report findings of the included articles based on study design (randomized controlled trials, prospective/ retrospective cohorts, case-controls, and case-series) and clinical outcomes. We reported descriptive statistics (means and standard deviations) pertaining to each study to provide the magnitude of intervention effects. Improvement was defined as the change from preoperative scores to the most recent post-operative follow-up score. Effect size of each outcome was calculated using mean treatment change over time divided by the pooled standard deviation.

3.3 Results

3.3.1 *Study Selection*

The initial search yielded 1271 publications and after title screening, abstract review and duplicate publication removal, 273 studies were selected for full text review. The agreement between reviewers was 90% for both the review of the abstract and the full text. The flowchart of studies through the selection process is displayed in **FIGURE 1**.

3.3.2 *Study Characteristics*

The 15 eligible studies were conducted between 1987 and 2019. Study size ranged from 10 to 374 patients with a total of 1067 participants. Studies were conducted in USA, France, Brazil, Germany, Italy, Belgium. Of these, 15 studies including 1 randomized controlled trial, [23] 1 prospective cohort, [24] 6 retrospective study, [25–30] 4 case-series, [31–34] and 3 case-control studies [35–37] were eligible. A description of all the included studies is presented in **TABLE 1**.

3.3.3 *Quality appraisal*

Two studies were assessed as high-quality of evidence. [38,39] Six studies were rated as moderate-level quality with scores ranged from 29 to 33.[30,32,34,40–42] We graded another 6 articles as low quality. [29] Due to the lack of sufficient information in the methodology section, we were unable to appraise Nijs et al.[43] The quality items with the highest number of 0's was item 6 for rating the allocation concealment. The item that scored the best (2) was item 3, "Was patient status at more than 1 time point considered?"[22] A summary of the quality appraisal ratings is provided in **TABLE 2**.

3.3.4 *Program Characteristics*

TSA PT Programs

From 15 TSA studies, five papers evaluated a standardized clinic or hospital- based PT program, [39,40,44–46] five studies evaluated a home-based PT program, [29,30,41,47,48], one study compared both clinic and home based programs,[42] and the remaining 4 articles did not state the type of PT program.[34,38,43,49] Thirteen studies reported details of the PT program [29,30,32,34,39–45,48,49] with 12 describing a rehabilitation strategy that was based on 2 to 4 recovery phases. [29,30,34,39–46,48] Only 2 studies described a 4-phase rehabilitation program (from day 1 to week 14 or 16), [39,42] five papers included 3 rehabilitation phases ranging from 5 to 12 weeks,[29,34,40,44,48] and 3 articles reported 2 phases within a 6 to 12-week time frame. Various types of immobilization including an abduction pillow, [41,46] sling, [29,30,34,39,43,49] and shoulder immobilizer [29,40,42,48] were recommended in 12 studies. However, only one study provided details of limb positioning with the shoulder in internal rotation to abdomen.[46] The sling was used for pain relief in 1 study, [43] and for comfortable use in 1 study: [49] reasons were not stated in the remaining studies.

The duration of immobilization ranged from within 4 to 9 weeks post-surgery. Five studies reported that passive or active-assisted range of motion (AAROM) exercise was initiated on the 1st day after surgery.[39,43–45,49] One study suggested the active forward elevation should start in the second week post-surgery,[45] while two other studies recommended this motion be initiated between 4 to 6 weeks.[39,44]

The initiation of strengthening varied across 7 studies from 5 weeks to 12 weeks post-surgery.[29,30,39,40,42,44,48] In 1 of 12 studies, patients were allowed to start lifting weights at the 12-week post-surgery with a restriction of less than 25 pounds.[39] A summary description of all PT protocols are presented in **TABLE 3**.

3.3.5 *Outcomes*

Due to significant heterogeneity during pooled analysis, relevant statistical analysis including meta- analysis was not performed.

TSA ROM

RCTs

A single RCT comparing an immediate passive range of motion program (IM) versus delayed motion (DM) program reported the average of pre-post improvements of 39 (26) degrees in forward flexion, 39 (15) degrees in external rotation, consistent across both IM and DM cohorts, including 55 patients at 1 year follow up. A summary description of all ROM outcomes is presented in **TABLE 4**.

Prospective Studies

One study with 10 patients reported the average of improvements of 51 (29) degrees in forward flexion ROM, and 26 (19) degrees in external rotation at 1 year follow up.[38]

Retrospective Studies

Three studies involving 155 patients reported improvements in forward flexion ROM that ranged from 38 – 71 (29) degrees, and improvements in external rotation ROM that ranged from 23 – 32 (19) degrees comparing preoperative scores to follow-up scores at up to 4.1 years following surgery.[29,44,45]

Case-control Studies

Three studies involving 214 patients reported improvements in forward flexion ROM that ranged from 42 (26) – 55 (33) degrees at up to 4.2 years follow up.[40–42] One study reported improvements of 28 (16) degrees in external rotation ROM, and nearly 4 degrees in internal rotation at 4.2 years follow up.[40] Two studies with 94 patients reported improvements in abduction ROM that ranged from 19 (30) – 55 (35) degrees, at up to 3.8 years follow up.[41,42]

We combined the mean and standard deviation (SD) of case and control groups for two studies as the first one compared patients with more or less than 20 degrees of preoperative glenoid retroversion , and the second study compared two PT programs (standard and home-base).[40,42]

Case-series Studies

Three studies with 39 patients displayed improvements in forward flexion ROM that ranged from 29 (25) – 77 (29) degrees, at up to 3 years follow up.[31,32,34] One study with 10 patients reported improvements of 65 (26) degrees in external rotation ROM, and 51 (14) degrees in internal rotation at 3 years follow up.[32] Two studies with 22 patients indicated improvements in abduction ROM that ranged from 35 (30) – 54 (27) degrees, at up to 3 years follow up.[32,34]

TSA Function (PROM)

RCTs

In a single RCT, the presented improvements was 52 (14) points in ASES, 52 (21) points in SANE and 7 (2) in SST scores, at 1 year follow up. [39] A summary description of the functional outcomes is presented in **TABLE 5**. For diverse shoulder pathologies, the Minimal Clinically Important Differences (MCID) for ASES stood at 6.4, while it registered at 3 points for SST, and 15% in total score for SANE.[50–52]

Prospective Studies

One study with 10 patients assessed function and reported improvements in ASES scores of 29 (SD not reported) at 1 year follow up.[38]

Retrospective Studies

Two studies involving 404 patients assessed function and indicated improvements, in ASES scores ranging from 32 (17) – 43 (17) points, and in SST ranging from 5 (3) – 6 (3) points at up to 2.1 years follow up.[30,44] One study with 374 patients examined function and reported improvements in SPADI scores of 47 (17) at 2 years follow up.[30]

Case-control Studies

Two studies involving 200 patients assessed function and indicated improvements, in ASES scores that ranged from 44 (18)– 49 (18) points, and in SST ranging from 5 (3) – 6 (3) points at follow-up of up to 4.2 years.[40,42] One study with 120 patients examined function and reported improvements in SANE scores of 43 (25) at 4.2 years follow up.[40]

Case-series Studies

One study with 17 patients examined function and reported improvements in SST scores of 7 (SD not reported) at 2.4 years follow up.[31]

TSA Function (Clinician - rated ROM)

Case-control Studies

One study including 13 patients examined function and reported improvements of 42 (11) points in Constant scores, at 6-month follow up.[41] A summary description of the functional outcomes is presented in **TABLE 5**.

Case-series Studies

Two studies involving 29 patients assessed function and indicated improvements, in Constant scores ranging from 34 (11) – 43 (11) points, at up to 2.4 years follow up.[31,34]

TSA Pain

RCTs

In the only RCT identified, the average of decrease in pain level measured by VAS was reported as 6 (2) points at 1 year follow up in a sample size of 55 participants for both IM and DM groups.[39]. A summary description of all the pain outcomes is presented in **TABLE 6**.

Prospective Studies

One study of 10 patients displayed improvements of 4 (SD not reported) points in pain levels at 1 year follow up.[38]

Case-control Studies

A single including 120 patients indicated improvements of 5 (2) points in VAS pain levels at 4.2 years follow up.[40]

Case-series Studies

One study with 17 patients reported improvements of 6 (SD not reported) points in pain levels measured by VAS at 2.4 years follow up.[31]

3.4 Discussion

Summary of evidence

This study synthesizes the current evidence from 15 studies reporting the clinical outcomes of TSA surgery that included PT during the immediate postoperative period. Overall, clinically significant improvements were noted in the clinical outcomes of pain, function, and range of motion in persons who were administered PT rehabilitation programs after TSA. [53] However, since only one RCT was located, most of the evidence is useful for reporting expected outcomes and improvement trajectories with different programs but cannot distinguish whether any specific approach is better than another. Furthermore, no evidence was identified that compared outcomes following TSA in patients receiving post-op physiotherapy with patients who received no physiotherapy treatment.

We identified significant variation in the post-operative PT protocols in terms of the initiation time of the passive ROM and AAROM exercise, the amount of the shoulder motion permitted, and long-term precautions. The description of the strengthening program was only stated in 1 out of 15 studies for TSA.[39] Due to the lack of RCTs, we used a quality appraisal tool that would allow us to calculate a score on the same metric across cohort, case-control, and case-series studies. This approach allowed a more descriptive approach to synthesizing the nature of different PT programs by including a range of studies. However, we were unable to quantitatively summarize the effectiveness of meta-analysis due to the methodological heterogeneity present in the identified studies. We reported the mean and standard deviations (if reported) with corresponding effect sizes pertaining to each functional outcome across studies. For studies where a measure of dispersion was not reported, we adopted the guideline recommendations put forward by the Cochrane Handbook for Systematic Reviews of Interventions 2019 of imputing the standard deviations by providing an average score of standard deviation based on previous studies.[54] The effect sizes for treatment change over time were calculated from 1.7 to 3.8 in the PROM, 3.1

to 3.9 in C-ROM, and 1.9 to 3.7 for pain relief indicating a large variation existing in the literature across different study designs. The largest effect size was 3.9 as the improvement of Constant score reported by Lafosse et al.[31,32] The single RCT suggests that an immediate PT program could facilitate a more rapid functional recovery versus a delayed PT program, and that both of the programs achieved same ultimate ROM or functional outcome in the longer term.[39] Since it is unlikely that PT would be withheld given documented benefits, future trials are needed to examine differences in adjunct interventions, dosages, or modes of delivery. Most notably, given the recent pandemic, there is a need for trials evaluating remote delivery of rehabilitation programs.

Based on the present study and on the existing literature, TSA with a standardized clinic-based or home-based PT program can provide substantial improvements of clinical and functional outcomes. However, there are some potential factors not controlled in this analysis that may have an impact on the summary of clinical outcomes including but not limited to : a) surgeon experience, b) rehabilitation protocols (given variation identified in the PT programs from this study), c) diverse surgical indications, operational complications, d) different surgical techniques such as the choice of prostheses, and e) the lengthen of follow up period.[55]

Our study identified little consistency in rehabilitation strategies for TSA which is similar with previous findings.[56,57] Immobilization was a common management strategy following TSA for pain relief and to protect soft tissue repairs. However, the positioning of stabilization was only provided in 1 study.[46] A previous rehabilitation guideline following TSA separated the post recovery into four phases and emphasized joint protection with the use of a sling for 3 to 4 weeks, followed by deltoid and scapular isometric exercises, and the gradually passive ROM by week 6.[58] The AAROM and AROM was the final phase of the rehabilitation progress.[59] The effect of rehabilitation program remains ambiguous at specific time points during post-surgical management and there is a need to investigate the required dose and duration of the treatment program to achieve optimal treatment effect. Based on the available evidence, our study refines the protocol into a 12-week program segmented into three phases. These phases are tailored to individual factors, such as soft tissue healing, range of motion (ROM), and strengthening, rather than adhering strictly to a fixed timeline.

Phase 1: Rest the shoulder but mobilize within defined limits. The program begins with immobilization combined with restricted PROM in therapy until post -op week 4, whereas longer duration is not supported by superior evidence. Pendulum exercises are highly recommended within this stage.

Phase 2: Mobilize with variable sequencing of AAROM, AROM and PROM (until post-op week 6) is considered as a transitional period preparing patient to obtain appropriate ROM by AAROM and AROM for further strengthening exercise.

Phase 3: Strengthening exercises can be gradually introduced either in the later stages of phase 2 or at the onset of phase 3, which corresponds to post-operative weeks 8-12.

Implications for practice

Clinical outcomes of pain, function and shoulder range of motion displayed substantial improvements in patients after TSA surgery who completed PT rehabilitation programs. However, due to a lack of control groups it is impossible to determine how much improvement results from the natural course of recovery and how much is due to rehabilitation. Further, the evidence does not provide the high-quality comparative studies needed to differentiate the best approaches to rehabilitation.

Limitations

This systematic review only examined studies published in the English language, which may affect generalizability and result in publication bias. Most included publications were non-randomized observational studies. We were not able to isolate potential factors including age, initial diagnosis, type of surgeries, surgeon experience, pre-op anatomic conditions, health literacy of the patient, and incidence of complications which might influence the clinical outcome of the post-op physiotherapy in the analysis.

Conclusions

Due to the lack of the data, the effectiveness of post-op physiotherapy improving the pain, function, and range of motion remains ambiguous. High-quality RCTs comparing physiotherapy with the natural course of recovery following TSA should be conducted.

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3.6 List of tables

TABLE 3-1 Summary of study information.

Author	**Year**	**Location**	**Age at surgery** *Mean (range) Years old*	**Sample size** *N (Shoulders) sex*	**Lengthen of follow up** *Mean -years (range –years)*	**Study design**
Armstrong	2016	USA	64 (45-81)	30 (30); 15 females	Mean, 2.1 years (range, 1-4.9 years).	Retrospective review including one cohort. Improvement defined as Pre-post difference
Arnold	2011	USA	70 (49-89)	29 (35); 15 females	Mean, 3.6 (2.0-5.5)	Retrospective review including one cohort. Improvement defined as Pre-post difference
Barrett	1987	USA	59 (24-82)	48 (50); 19 females	3.5 (2-7.5)	Retrospective review including one cohort. Improvement defined as Pre-post difference
Boardman	2001	USA	65 (31-85)	77 (81)	Mean, 4.1 years Range, 2–7.1 years	Retrospective review including one cohort. Improvement defined as Pre-post difference
Chapman	2019	USA	TSA group:70 (62-78) Control: 69 (49-89)	10 (10); 4 Females	1.02	Prospective nonrandomized cohort Intervention: TSA patients Control: Healthy patients Improvement defined as Pre-post difference Group comparisons were performed
Denard	2016	USA	67.9 (42-85)	55 (NA); 26 females	1 year	Randomized Controlled Trial Intervention: Immediate passive range of motion group Control: Delayed motion group Improvement defined as Pre-post difference Group comparisons were performed
DeVito	2019	USA	71	120 (NA)	4.2 years	Case-Control study Case: more than 20 degrees of preoperative glenoid retroversion Control: less than 20 degrees of preoperative glenoid retroversion

						Improvement defined as Pre-post difference Group comparisons were performed
Kasten	2010	Germany	69.8 (7.2)	13 (13 shoulders) 8 females Another 10 healthy as control group	0.5 year	Case-Control Study Case: TSA patients Control: healthy patients Improvement defined as Pre-post difference
Lafosse	2009	France	66.47	17 (NA) 10 females	2.4 years	Case series study including one cohort Improvement defined as Pre-post
Maier I (BMC)	2014	Germany	65	10 (10) 7 females	3 years	Case series study including one cohort Improvement defined as Pre-post
Merolla	2019	Italy	TSA:62 (55-69) RSA:76 (68-84)	25 (25) TSA:2 females RSA: 10 females	1 year	Case series study Two cohorts including both TSA and RSA Improvement defined as Pre-post Results of RSA was not the focus of current study
Michael	2019	USA	67.9 (SD=9, 35-93)	754 (848) 359 Females **TSA:** 374 **RSA:** 474	2 years	Retrospective review Two cohorts including both TSA and RSA Improvement defined as Pre-post Results of RSA was not the focus of current study
Mulieri	2010	USA	65.41 (SD=11.6, 38-87)	81 (81) 46 females Standard PT: 43 Home-based: 38	3.8 years	Case-control study Case: Home -based PT Control: Standard PT Improvement defined as Pre-post difference Group comparisons were performed
Nijs	2001	Belgium	73 (47-87)	36 32 females	1 year	Case Series study including one cohort Improvement defined as Pre-post
Triplet	2015	USA	TSA: 70 (32-89) RSA: 76 (52-88)	**TSA** 132;69 females **RSA** 91 (91);58 females	TSA: 3.1 years RSA: 2.9 years	Retrospective review Two cohorts including both TSA and RSA Improvement defined as Pre-post Results of RSA was not the focus of current study

TABLE 3-2. Summary of quality appraisal.

Study	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	Total	Level
Armstrong 2016	1	0	1	1	0	0	0	1	2	0	2	2	0	2	2	0	1	1	1	1	2	0	0	1	1	22	L
Arnold, 2011	2	0	0	0	0	0	0	1	2	0	1	0	1	2	1	0	1	1	1	1	0	0	1	1	1	17	L
Barrett, 1987	0	0	2	2	0	0	0	1	0	1	0	0	1	2	1	0	1	1	1	0	0	0	1	1	1	16	L
Boardman, 2001	0	0	2	2	0	0	0	1	0	0	0	0	0	1	0	0	1	0	1	0	0	0	2	1	1	12	L
Chapman, 2019	2	2	2	2	0	0	1	1	1	1	2	2	2	2	2	1	2	2	2	2	2	1	2	2	2	40	H
Denard, 2016	2	2	2	2	1	0	1	1	2	2	2	2	2	1	1	2	1	1	2	2	2	1	2	0	2	38	H
DeVito,2019	2	2	2	2	1	0	1	1	0	2	2	0	2	1	1	2	1	1	2	2	0	1	2	1	2	33	M
Kasten, 2010	2	2	2	2	0	0	1	1	0	1	1	0	2	1	1	1	2	1	1	2	1	0	2	2	2	30	M
Lafosse, 2009	2	0	2	2	0	0	1	1	0	1	1	0	1	2	1	0	1	1	2	2	0	0	2	2	1	25	L
Maier, 2014	2	2	2	2	0	0	1	1	0	1	2	0	1	2	1	1	2	2	2	2	0	0	2	1	1	30	M
Merolla, 2019	2	1	2	2	0	0	1	1	1	1	1	0	2	1	1	2	2	1	2	1	0	0	2	1	2	29	M
Michael, 2019	1	0	2	1	0	0	0	1	1	2	2	1	2	1	1	0	2	2	2	2	1	1	2	1	2	30	M
Mulieri, 2010	2	1	2	1	0	0	1	1	1	1	1	2	2	2	1	2	1	1	2	1	2	0	2	2	2	33	M
Nijs, 2001*													N/A														
Triplet, 2015	2	1	0	0	0	0	1	1	2	1	1	0	2	1	1	2	1	1	1	1	0	0	2	1	2	24	L

Total quality score was calculated based on the sum of 25 items (2, 1, 0 for each).
We considered a score of 38 and above as a high-quality study, a score of 28 to 37 as a moderate-level study, and a score below 28 as a low-level study.
L: Low M: Moderate H: High
* Article was not evaluated due to the lack of methodology information.

TABLE 3-3. Summary of rehabilitation protocols.

TSA Study	Type of rehab	Timeline	Rehab details	
Armstrong, 2016	Standardized Clinic-based	Post-op day 1	Start passive and active assisted motion E.g. pendulum exercises, supine lateral rotation using a cane or stick to 30°, and shoulder flexion in the scapular plane up to 130°	
		Post-op week 6	Start tolerated full active ROM into forward elevation and 30° of external rotation from the side with careful progression of isometric strengthening of scapular muscles.	
		Post-op week 12	Start Strengthening Start to reach behind the back.	
Arnold, 2011	Standardized Home-based	12 weeks	PT intervention details have neither been reported nor are study protocol details available".	
Barrett, 1987	Clinic-based	Post-op day 2	**Intact or securely repaired rotator cuff**	**Tenuous repair of the rotator cuff**
			Start pendulum exercises	NA
		Post-op day 3 and 4	Start assisted stretching with forward elevation and external rotation.	NA
		Post-op week 1	Start active forward elevation	NA
		Post-op 10 to 14 days	Hospitalization All patients remained in hospital until obtain 140º of active assisted forward elevation and 40º external rotation.	
		Post-op 6 weeks	NA	No active movement or assisted internal rotation
Boardman, 2001	Standardized Home-based	Post-op 1 week Post-op 1 month at night	Start shoulder immobilizer, then sling for 4 weeks.	
		Post-op week 3	Start Assisted pulley exercises for elevation.	
		Post-op week 5	Start active assisted ROM Start stretching with a wand for flexion-extension, elevation-adduction, external rotation and internal rotation at the side, and external rotation and internal rotation at 90° of abduction. Light strengthening with isometric exercise	

Chapman, 2019	NA	Post-op	Outpatient, in-home, and self-guided exercises that require frequent humeral elevation above 90º	
Denard, 2016	Standardized Clinic-based	Post-op 4 weeks	**Immediate ROM group (IM)**	**Delayed ROM group (DM)**
			Immobilization in sling	Immobilization in sling Active hand, wrist, and elbow exercises, and active scapular retraction exercises
		Post-op day 1	Start tolerated passive forward flexion with an overhead rope and pulley Start passive external rotation to 30º with a stick. Start active hand, wrist, and elbow exercises and active scapular retraction	NA
		Post-op week 4	Stop sling Start tolerated passive external rotation Start tolerated forward flexion from active assist to active ROM	Stop sling Start tolerated passive forward elevation with a rope and pulley and passive external rotation with a stick
		Post-op week 8	Start strengthening	Start tolerated active assisted to active ROM Start strengthening
		Post-op week 12	Start tolerated activities with recommendation for no repetitive lifting over 25 lbs. (11.3 kg).	NA
		Post-op week 16	NA	Start tolerated activities with recommendation for no repetitive lifting over 25 lbs. (11.3 kg).
DeVito,2019	Standardized Clinic-based	Post-op 6 weeks	Immobilization by shoulder immobilizer Self-administered exercise program such as pendulums	
		Post-op 6 to 12 weeks	Active-assisted stretching	
		Post-op week 12	Strengthening and lifting	

Kasten, 2010	Standardized Home based	Post-op 4 weeks	Passive ROM exercises, limitation of external rotation to 0 and abduction to 90, and use of an abduction pillow
		Post-op week 4 to 6	Start progressive active assistive ROM
		Post-op week 10 or 12	No limitations
Lafosse, 2009	Immediately post-op procedures	Post-op day 1	Start abduction sling for comfortable use Start full active and passive ROM with a therapist
Maier I, 2014	Standardized Clinic-based	Post-op 4 weeks	Immobilization in a shoulder abduction pillow
		Post-op 6 weeks	Passive ROM to 60° of flexion and abduction and 0° of external rotation with the supervision under physiotherapist
		Post-op week 6	Start free ROM
Michael, 2019	Standardized Home-based	Post-op 6 weeks	Immobilization in a sling External rotation was limited to neutral in RSA patients and to 30 in TSA Internal rotation was limited to the abdomen.
		Post-op week 12	Start strengthening
Nijs, 2011	Not described	Post-op day 1	Start mobilization if replacement component is stable Start rehabilitation exercises to avoid adhesion Start tolerated passive mobilization Start active assisted mobilization if conditions apply
		Post-op 6 weeks	No stretching, especially in rotation Immobilization in sling, except for analgesic reasons
Merolla, 2019	Standardized Protocol, not mentioned if home or clinic-based	Post-op 3 weeks	Immobilization in a sling
		Post-op week 4	Start active mobilization
		Post-op week 6	Start active exercises
Mulieri, 2010		Post-op 3 weeks	**Standard PT program** **Physician's directed, Home program**

	Group A – Standardized clinic-based Group B – Standardized, home-based		Immobilization Elbow, wrist and hand AROM Supine passive ROM (PROM) to a maximum of 20º of external rotation (ER) 120º of elevation in the scapular plane	NA
		Post-op 4 to 6 weeks	Continue immobilization Resisted elbow, wrist, and hand exercises Supine active-assisted ROM (AAROM) of the shoulder with a wand, isometric shoulder exercises, and closed chain kinetic shoulder exercises	**NA**
		Post-op 6 to 8 weeks	NA	Immobilization
		Post-op week 6 to 8	NA	Stop immobilization Start to wear sling when leave the house. Supine, active-assisted forward flexion exercises Start ADL
		Post-op 7 to 9 weeks	Stop immobilizer AAROM of the shoulder, isometrics, and closed chain kinetics	NA
		Post-op week 7 to 9	Start Supine and prone AROM of the shoulder Start AROM in the standing position, resistive strengthening exercises, and activities of daily living (ADLs)	NA
		Post-op week 14	NA	Activities with confidence and pain-free

Triplet, 2015	Standardized home-based	Post-op 6 weeks	Immobilization by shoulder immobilizer Pendulum exercises 3 times daily.
		Post-op week 6	Start self-directed supine active-assisted exercises

		Start to use the extremity for light ADLs with a 2-pound weight restriction. (recommend)
	Post-op week 12	Start self-directed stretching and tolerated full activity

TSA: total shoulder arthroplasty
RSA: reversed total shoulder arthroplasty
Post-op: post-operational
ROM: range of motion
AAROM: active-assisted range of motion
AROM: active range of motion
ADL: activity of daily living

TABLE 3-4. Summary of the range of motion outcomes.

Design (Outcome)	Study	Sample Size	Mean difference	Pooled Standard Deviation	Follow up
Retrospective: (Forward Flexion)	Armstrong 2016	30	38	29*	2.1 years
	Barrett 1987	48	71	29*	3.5 years
	Boardman 2001	77	52	29*	4.1 years
Retrospective: (External Rotation)	Armstrong 2016	30	32	19*	2.1 years
	Barrett 1987	48	23	19*	3.5 years
	Boardman 2001	77	27	19*	4.1 years
Case-series: (Forward Flexion)	Lafosse 2009	17	77	29*	2.4 years
	Maier I (BMC) 2014	10	39.4	35	3 years
	Merolla 2019	12	29	25	1 year
Case-series: (External Rotation)	Maier I (BMC) 2014	10	65	26	3 years
Case-series: (Internal Rotation)	Maier I (BMC) 2014	10	50.6	13.7	3 years
Case-series: (Abduction)	Maier I (BMC) 2014	10	54	26.5	3 years
	Merolla 2019	12	35	30	1 year
Case-controls: (Forward Flexion)	DeVito 2019	120	42	26	4.2 years
	Kasten 2010	13	55.4	33.4	0.5 years
	Mulieri 2010	81	43.3	29*	3.8 years
Case-controls: (External Rotation)	DeVito 2019	120	28.3	15.5	4.2 years
Case-control: (Internal Rotation)	DeVito 2019	120	3.5	2.1	4.2 years

Case-control: (Abduction)	Kasten 2010	13	55.2	34.5	0.5 years
	Mulieri 2010	81	18.6	30*	3.8 years
Prospective: (Forward Flexion)	Chapman 2019	10	51	29*	1 year
Prospective: (External Rotation)	Chapman 2019	10	26	19*	1 year
RCT: (Forward Flexion)	Denard 2016	55	39	26	1 year
RCT: (External Rotation)	Denard 2016	55	39	15.2	1 year

RCT: Randomized controlled trial
*SD imputed based on previous studies

TABLE 3-5. Summary of functional outcomes.

Design	Study	Sample Size	Mean difference	Pooled Standard Deviation	Effect size	Follow up
Retrospective: (PROM)	Armstrong 2016 (ASES)	30	31.5	17*	1.9	2.1 years
	Michael 2019 (ASES)	374	42.8	17	2.5	2 years
	Michael 2019 (SPADI)	374	46.6	17.3	2.7	2 years
	Armstrong 2016 (SST)	30	5.1	2.6*	2.0	2.1 years
	Michael 2019 (SST)	374	5.8	2.6	2.2	2 years
Case-series: (PROM)	Lafosse 2009 (SST)	17	7.07	NR	NA	2.4 years
Case-controls: (PROM)	DeVito 2019 (ASES)	120	49.6	18.25	2.7	4.2 years
	Mulieri 2010 (ASES)	81	44.2	18.25*	2.4	3.8 years
	DeVito 2019 (SST)	120	5.8	2.73	2.1	4.2 years
	Mulieri 2010 (SST)	81	4.7	2.73*	1.7	3.8 years
	DeVito 2019 (SANE)	120	43.4	24.65	1.8	4.2 years
Prospective: (PROM)	Chapman 2019 (ASES)	10	29	NR	NA	1 year
RCT: (PROM)	Denard 2016 (ASES)	55	52.3	13.7	3.8	1 year
	Denard 2016 (SANE)	55	51.6	20.7	2.5	1 year
	Denard 2016 (SST)	55	6.46	2.435	2.7	1 year
Case-series: (C-ROM)	Lafosse 2009 (Constant)	17	43.4	11*	3.9	2.4 years
	Merolla 2019 (Constant)	12	34.2	11	3.1	1 year
Case-control: (C-ROM)	Kasten 2010 (Constant)	13	42.2	11*	3.8	0.5 years

NR: not reported
NA: not available
PROM: Patient-reported outcome
C-ROM: Clinician-rated outcome
ASES: American Shoulder and Elbow Surgeon score
SPADI: Shoulder Pain and Disability Index
SST: Simple Shoulder Test
SANE: Single assessment numeric evaluation
RCT: Randomized controlled trial
*SD imputed based on previous studies

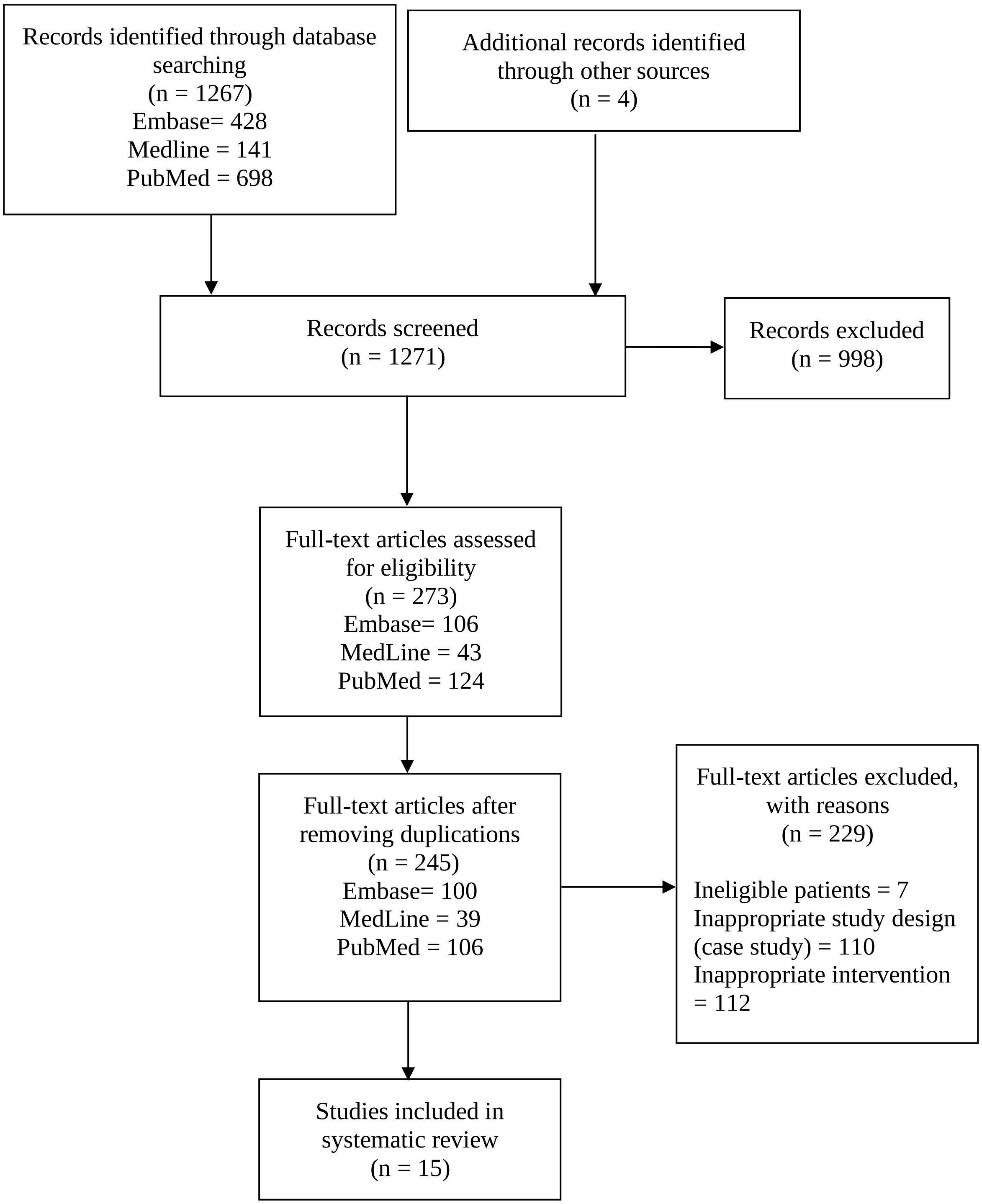
TABLE 3-6. Summary of pain outcomes.

Design	Study	Sample Size	Mean difference	Pooled Standard Deviation	Effect size	Follow up
Case-series	Lafosse 2009	17	5.7	NR	NA	2.4 years
Case-controls	DeVito 2019	120	4.8	2.53	1.9	4.2 years
Prospective	Chapman 2019	10	3.5	NR	NA	1 year
RCT	Denard 2016	55	5.6	1.53	3.7	1 year

NR: not reported
RCT: Randomized controlled trial
Pain level was measured by visual analog score (VAS).

3.8 List of Figures

FIGURE 3-1. PRISMA flow diagram of study selection.



3.9 Appendix

Embase and Medline search keywords

1. total shoulder arthroplasty.mp. or total shoulder arthroplasty/ or shoulder arthroplasty/
2. reverse total shoulder arthroplasty.mp. or reverse shoulder arthroplasty/
3. total shoulder replacement.mp. or total shoulder arthroplasty/
4. reverse total shoulder replacement.mp. or reverse shoulder arthroplasty/
5. physiotherapy.mp. or physiotherapy/ or home physiotherapy/
6. physical therapy.mp. or physiotherapy/
7. rehabilitation.mp. or rehabilitation/ or home rehabilitation/
8. telerehabilitation
9. 1 or 2 or 3 or 4
10. 5 or 6 or 7 or 8
11. 9 and 10

PubMed search keywords

((((((home[All Fields] AND ("rehabilitation"[Subheading] OR "rehabilitation"[All Fields] OR "rehabilitation"[MeSH Terms])) OR ("rehabilitation"[Subheading] OR "rehabilitation"[All Fields] OR "rehabilitation"[MeSH Terms])) OR ("physical therapy modalities"[MeSH Terms] OR ("physical"[All Fields] AND "therapy"[All Fields] AND "modalities"[All Fields]) OR "physical therapy modalities"[All Fields] OR "physiotherapy"[All Fields])) OR ("physical therapy modalities"[MeSH Terms] OR ("physical"[All Fields] AND "therapy"[All Fields] AND "modalities"[All Fields]) OR "physical therapy modalities"[All Fields] OR ("physical"[All Fields] AND "therapy"[All Fields]) OR "physical therapy"[All Fields])) OR (home[All Fields] AND ("physical therapy modalities"[MeSH Terms] OR ("physical"[All Fields] AND "therapy"[All Fields] AND "modalities"[All Fields]) OR "physical therapy modalities"[All Fields] OR "physiotherapy"[All Fields]))) OR ("telerehabilitation"[MeSH Terms] OR "telerehabilitation"[All Fields])) AND ((((("arthroplasty, replacement, shoulder"[MeSH Terms] OR ("arthroplasty"[All Fields] AND "replacement"[All Fields] AND "shoulder"[All Fields]) OR "shoulder replacement arthroplasty"[All Fields] OR ("total"[All Fields] AND "shoulder"[All Fields] AND "arthroplasty"[All Fields]) OR "total shoulder arthroplasty"[All Fields]) OR (reverse[All Fields] AND ("arthroplasty, replacement, shoulder"[MeSH Terms] OR ("arthroplasty"[All Fields] AND "replacement"[All Fields] AND "shoulder"[All Fields]) OR "shoulder replacement arthroplasty"[All Fields] OR ("total"[All Fields] AND "shoulder"[All Fields] AND "arthroplasty"[All Fields]) OR "total shoulder arthroplasty"[All Fields]))) OR (reverse[All Fields] AND ("shoulder"[MeSH Terms] OR "shoulder"[All Fields]) AND ("arthroplasty"[MeSH Terms] OR "arthroplasty"[All Fields]))) OR ("arthroplasty, replacement, shoulder"[MeSH Terms] OR ("arthroplasty"[All Fields] AND "replacement"[All Fields] AND "shoulder"[All Fields]) OR "shoulder replacement arthroplasty"[All Fields] OR ("total"[All Fields] AND "shoulder"[All Fields] AND "replacement"[All Fields]) OR "total shoulder replacement"[All Fields])) OR (reverse[All Fields] AND ("arthroplasty, replacement, shoulder"[MeSH Terms] OR ("arthroplasty"[All Fields] AND "replacement"[All Fields] AND "shoulder"[All Fields]) OR "shoulder replacement arthroplasty"[All Fields] OR ("total"[All Fields] AND "shoulder"[All Fields] AND "replacement"[All Fields]) OR "total shoulder replacement"[All Fields]))) OR (reverse[All Fields] AND ("shoulder"[MeSH Terms] OR "shoulder"[All Fields]) AND ("arthroplasty"[MeSH Terms] OR "arthroplasty"[All Fields])))

Chapter 4

4. The Clinical Outcome of Physiotherapy After Reversed Shoulder Arthroplasty: A Systematic Review.

ABSTRACT

Purpose: The purpose of this systematic review was to analyze the current literature on the clinical outcomes of physiotherapy (PT) programs after reversed total shoulder arthroplasty (rTSA) and to summarize the improvements in this population.

Methods: A search was performed in 4 databases (MEDLINE, Embase, PubMed, Google Scholar) from its inception to April 30th, 2020. Data were extracted to describe study design and rehab programs. The quality of evidence was assessed as high, moderate, and low-level according to the Evaluation of Quality of an Intervention Study critical appraisal criteria.

Results There were 22 eligible studies including 2 randomized controlled trials, 4 prospective cohort studies, 10 retrospective reviews, 5 case-series, and 1 case-control study, with the sample sizes ranging from 9 to 474 patients followed for 1 to 10 years. All studies indicated substantial improvement in patients after PT program in terms of functional outcomes and forward flexion.

Conclusions: High-quality RCTs are required to provide more conclusive results. We identified substantial variation in the post-operative PT programs except for the progressive mobilization strategy and the common management following surgery to increase the soft issue healing within 4 to 6 weeks.

Keywords: functional outcome, quality appraisal, range of motion, shoulder arthroplasty, systematic review

4.1 Introduction

In the 1970s, the reverse shoulder arthroplasty (rTSA) was originally developed specifically for patients with Rotator Cuff arthropathy and the indications were expanded for treatment of OA with glenoid bone defects and for proximal humerus fractures.[1–4].[3–10] Biomechanically, the rTSA provides a stable and fixed fulcrum for rotation while increasing the moment arm and resting tone of the deltoid muscle. As a result, the rTSA can often improve arm elevation and abduction despite a non-functional rotator cuff. Since 2003, when the United States Food and Drug Administration (FDA) officially approved the rTSA, there has been a significant increase in use, [5] with 51% of the TSA performed now being the reversed type. [11–13] Patients receiving rTSA tend to be older than those with traditional TSA. [5] Previous studies reported complications for rTSA ranging from 19% to 68% including instability and dislocation, infection, and neurologic compromise, scapular notching, glenoid baseplate loosening, and periprosthetic and acromial fractures. [14,15] However, the revision rates were 10 % and 22% at 5- and at 10-year follow up, respectively. [16,17]

A successful outcome following rTSA is dependent on the surgical management and the physiotherapy (PT) program. [18–22] The postoperative PT protocols vary among different studies. For example, the application of a sling was recommended for comfort use only while other studies proposed it as a requirement of immobilization for 6 weeks. Types of post-operative shoulder exercises include passive range of motion (ROM), active -assisted ROM, active ROM, resisted activity, and progressive strengthening.[4] Despite this, a consensus was made on initiating deltoid isometric exercises in the early post-op period. [4,23]

The outcomes of rTSA are evaluated with a variety of psychometrically validated clinical outcomes through patient-reported outcome (PROM), such as American Shoulder and Elbow Surgeon (ASES), Simple Shoulder Test (SST), Shoulder Pain and Disability Index (SPADI), University of California, Los Angeles score (UCLA), and The Disabilities of the Arm, Shoulder and Hand (DASH) questionnaire. [24–28] The clinician-reported outcome measure (CROM) like the Constant score which was developed by The European Society for Surgery of the Shoulder and the Elbow as an official tool for assessment of the shoulder, and is a validated measure of shoulder function. [28]

However, there is no consensus on the most appropriate PT program following rTSA among the many published studies that report the post-operative outcomes including ROM, pain or function. Therefore, the aim of this systematic review was to map out and analyze the current literature on the clinical outcomes of various physical therapy protocols after rTSA and to summarize the improvements of ROM, pain, and shoulder function in this population.

4.2 Methods

4.2.1 *Study Design*

This systematic review was executed using the guidelines established by the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) statement. [29] The protocol for this systematic review was registered on PROSPERO (CRD42020183120).

4.2.2 *Eligibility Criteria*

We included studies in this systematic review if the following criteria were met:

- Design: randomized / cohort studies / case-control and case-series.
- Participants: patients who received rTSA
- Intervention/Comparison: pre-rehab or post-operative rehabilitation including clinic-based, home-based, web, telemedicine or other formats of PT programs.
- Outcomes: patient-reported or clinician-reported outcome including ROM, function and pain, or quality of life.
- Studies were published in English.

The current study excluded studies that lacked description of the PT program or data on the ROM, pain, and function outcomes, conference abstract/posters,

4.2.3 *Information Sources*

To identify studies on the clinical outcome (ROM, pain, and function) we searched the MEDLINE, Embase, PubMed and Google Scholar databases from inception until April 30th, 2020, using a combination of keywords covering reverse total shoulder arthroplasty, physiotherapy, and outcomes. Furthermore, we identified additional studies by examining the reference list of each of the selected studies. The full list with search strategy is presented in **APPENDIX 1**.

4.2.4 *Study Selection*

Two investigators (ZL and GN) performed the systematic electronic searches independently in each database. The same investigators then identified and removed the duplicate studies and performed an independent screening of the titles and abstracts and any full-text articles marked as include or uncertain were obtained. In the final stage, the same two independent authors performed the full text reviews independently to assess final article eligibility. In case of disagreement, a third reviewer; the most experienced member (JM), facilitated a consensus through discussion.

4.2.5 *Data Extraction*

The third author (PA) performed the data extractions. The extracted data were then cross-checked by another author (ZL). Data extraction included the author, year, location, age at surgery, surgical implants, surgical type, sample size, length of follow up, study design, PT program components including specific timelines of each program stage, exercise parameters and dosage, and clinical outcomes (ROM, pain, and function).

4.2.6 *Quality appraisal*

Given we expected a variety of study designs (not RCTs), we used The Evaluation Guidelines for Rating the Quality of an Intervention Study, a 25-item quality appraisal tool that can be used across different study designs. [30,31] The quality appraisal approach included the rating of the quality of evidence such as study limitations, risk of bias, publication bias, and imprecision. This assessment tool was designed to assess quality across different studies and was ideally suited for this review where we expected different study designs including case series. [30,31] The individual studies included in this review were appraised by two independent authors (PA and TP) to summarize the quality of available evidence. We calculated the total score based on the sum of scores for 25 items (2, 1, 0 for each) out of 50. A ranking of quality based on total score was set as (0-28) being low quality, (29-37) were rated as moderate quality, and (38-50) as high quality.

4.2.7 *Synthesis of Results*

A qualitative synthesis was conducted to report study results of shoulder ROM, functional outcomes, and pain based on study designs (case-series, case-control, retrospective/prospective cohorts and randomized controlled trials (RCTs)). We reported descriptive statistics (means and standard deviations) to allow comparability of effects. Improvement was defined as the change in pre- and post-operative (last follow-up) differences in active and passive shoulder ROM (forward flexion, abduction, external rotation, and internal rotation), pain VAS, and functional outcomes including ASES, SST, UCLA, SPADI, DASH, and Constant score.

4.3 Results

4.3.1 *Study Selection*

Initially, our search yielded 1295 publications from the search in the database [Embase (n = 435), MEDLINE (n = 144), PubMed (n = 712) and Google Scholar (n = 4)], of which 252 studies were relevant. In total, 22 studies met our inclusion/exclusion criteria. The flow of studies through the selection process is displayed in figure 1.

figure 1 to be inserted here.

4.3.2 *Study Characteristics*

The 22 eligible studies were conducted in Australia, Brazil, Canada, France, Germany, Italy, Republic of Korea, Spain, Switzerland, and USA between 2012 and 2020. The sample size ranged from 9 to 474 patients. The study designs included: 2 randomized controlled trials, [24,28] 4 prospective cohort studies, [25,32–34] 10 retrospective studies, [26,27,35–42] 5 case-series, [23,43–46] and 1 case-control study. [47] The average age of the populations ranged from 67.9 to 85 years old with more female recipients. Eleven of 22 publications reported standardized clinical or hospital- based PT programs for post-surgery, [24,27,28,32,33,40,43–46,48] 3 studies specified their program following home-based protocol, [34,36,39] 6 studies had no information on the type of their PT programs, [23,35,37,38,42,47] and other 2 studies provided a home-based program under the direction of the registered therapist. [26,41] A summary description of all the included studies is presented in table 1.

table 1 to be inserted here.

4.3.3 *Quality appraisal*

The quality of the studies ranged from 14 to 37 with 14 studies rated as low quality, [27,34–36,39,41–43,45–47,49–51] 8 studies were moderate quality with scores ranging from 28 to 37 [23,24,26,28,32,33,40,48] and none were rated as high quality. A summary of quality appraisal is provided in table 2.

table 2 to be inserted here.

4.3.4 *PT ROM*

One RCT including 65 patients that compared delayed-rehabilitation group (no ROM exercise for the first 6 weeks after surgery) with early-rehabilitation group reported between-group differences in passive (1.6 degrees) and active (3 degrees) forward flexion ROM, favoring the early-rehabilitation group at 1 – 2 years follow up. [24] Another case-control study involving 13 patients reported a group difference in active flexion ROM of 30 degrees, favoring the non-operative group versus operative group, at 2 years follow up. [47] The within-group improvements in shoulder forward flexion ROM of 37 – 80 degrees involving 418 patients were reported in 9 studies including 2 prospective cohort, 4 retrospective, and 3 case-series studies, at up to 5.9 years follow up. [23,27,32,36,37,41,43,44,48]

Hagen et al 2020 [24] reported group differences of passive and active abduction (4 and 6.2 degrees), respectively, favoring the early-rehabilitation group at 1 – 2 years follow up in a cohort of 65 patients. Rienmüller et al 2020 [47] reported a difference of 30 degrees in active abduction favoring the non-operative group versus operative group, at 2 years follow up in a cohort of 13 patiets. Another 6 studies involving 230 patients reported within-group improvements ranging from 37 – 80 degrees in abduction ROM, at up to 3.5 years follow up. [23,32,36,37,41,44]

One RCT with 65 patients reported between-group differences in passive and active external rotation ROM (8.7 and 10.4 degrees) respectively, favoring the early-rehabilitation group, at 1 – 2 years follow up.[24] A difference of 20 degrees in external rotation ROM, favoring the non-operative group versus operative group was reported by a case-control study involving 13 patients, at 2 years follow up.[47] Eight studies with 405 patients reported within-group improvements in external rotation ROM that ranged from 2 – 29 degrees, at up to 5.9 years follow up.[27,32,36,37,41,43,44,48]

Collin et al 2017 [48] and 2 retrospective cohort studies [27,41] with 253 patients reported within-group improvements in internal rotation ranging from 1 – 2.3 spinal levels, at up to 5.9 years follow up. Other 2 studies involving 27 patients reported pre-post improvements in internal rotation of 10 – 30 degrees, at up to 2.3 years follow up.[37,44] The between-group difference in internal rotation ROM of 20 degrees, favoring the non-operative group over the operative group was reported in a case-control study with 13 patients, at 2 years follow up.[47]

A summary description of all ROM outcomes is presented in table 3.

table 3 to be inserted here.

4.3.5 *PT Function (PROM)*

One RCT involving 65 patients reported between-group differences in ASES (5.3 points on function sub-scale; 5.7 points total ASES), favoring the immediate rehabilitation group vs delayed rehabilitation group, at 1 – 2 years follow up.[29] Seven studies including 1 prospective cohort, 4 retrospective studies, and 2 case-series studies with 705 patients assessed function and indicated the pre-post improvements in ASES scores that ranged from 23.5 – 47 points, at up to 3.5 years follow up. [26,32,35,36,41,43,44]

Five studies including 740 patients examined function and reported improvements, in SST scores that ranged from 1.3 – 6.0 points, at 2 – 3.5 years follow up. [26,32,36,41,43]

Four studies with 639 patients indicated improvements of 50.3 – 59.9 points in function measured by SPADI at 2 – 3.5 years follow up. [26,36,41,43]

The functional improvements that ranged from 15.8 - 17 points assessed by UCLA were reported in 2 retrospective studies [27,41] and 1 case-series study [43] involving 162 patients, at up to 5.9 years follow up.

One RCT involving 59 patients reported the between-group difference of 8.1 points in DASH, favoring the non-operative group vs operative group, at 1 year follow up. [28] One case-control study including 13 patients examined function and reported difference in Quick-DASH scores of 34 points favoring the non-operative group vs the operative group, at up to 2 years follow up. [47]

Another 2 studies with 44 patients assessed function and reported improvements in DASH scores that ranged from 38.5 – 45 points, at 1 – 2 years follow up. [32,44]

4.3.6 ***PT Function (CROM)***

One RCT involving 59 patients reported a between-group difference of 1.6 points in Constant, favoring the operative group vs non-operative group, at 1 year follow up. [28] One case-control study including 13 patients examined function and reported a difference in Constant scores of 37 points favoring the non-operative group vs the operative group, at up to 2 years follow up. [47] Eight studies including 400 patients examined function and reported improvements in Constant scores that ranged from 14.6 – 52 points, at up to 5.9 years follow up. [23,25,27,32,36,41,43,44] A summary description of all functional CROM is presented in table 4.

table 4 to be inserted here.

4.3.7 ***PT Pain***

Pain was measured by visual analog scale in included studies. One RCT of 59 patients reported a group difference in pain levels of 0.7 points that favored non-operative group vs operative group at 1-year follow up. [28] Five studies with 208 patients reported improvements in pain levels that ranged between 2 – 6 points at up 1 – 5.9 years follow up. [27,32,35,42,43] A summary description of all pain outcomes is presented in table 5.

table 5 to be inserted here.

4.3.8 *PT Program*

Eleven studies described a three phase PT program, [23,24,52,28,34,36,39,41,44,47,51] while five studies suggested initiating a two phase PT program with immobilization and passive ROM exercises in the first 4 to 6 weeks post-surgery. [25–27,37,53] Three studies provided details of a four stage rehabilitation program within a 12 weeks' time frame. [40,42,45] Kemp et al 2016 [43] included the pre-operational education as one component of a five stage protocol. The use of a sling was recommended in 13 studies for the immobilization with duration ranging from 4 to 6 weeks. [24,25,51,53,54,28,32,36,39–43] The abduction pillow was recommended in 2 studies for the stabilizing shoulder. [24,44]

Eight studies initiated the passive ROM immediately (post-op day 1 or 2) after the operation with the duration ranging from 4 to 12 weeks, [24,25,27,32,40,45,51,52] while another five studies did not allow it until the second or third week post-surgery. [28,34,42–44] Resisted activity or strengthening was permitted after 12 weeks post- surgery in 8 studies without any requirements on the weight. [24,26,36,40,42,43,45,51] Only one study recommended that active ROM should start by week 3, [36] while another 8 studies initiated active ROM or active assisted ROM at week six following surgery. [28,39–43,45,51] Details such as the limitation of weight lifting during strengthening exercises was not available for all rTSA studies. A summary description of all PT protocols is presented in table 6.

table 6 to be inserted here.

4.4 Discussion

4.4.1 Summary of evidence

This study synthesized 22 moderate- and low-quality studies as assessed by Evaluation Guidelines for Rating the Quality of an Intervention Study examining the PT program after rTSA. Overall, within-group improvements in shoulder forward flexion ROM of 37 – 80 degrees, abduction ROM of 37 – 80 degrees, external rotation ROM of 2 – 29 degrees, internal rotation of 1 – 2.3 spinal levels, VAS pain of 2 – 6 points, and in all functional outcome measures were observed in patients after rTSA who were administered PT programs. Methodological heterogeneity and lack of reporting of measure of dispersions in the included studies prevented us from conducting of meta-analyses.

We identified notable variation in the post-operative PT programs in terms of the initiation time of the passive and active assisted ROM, the amount of the shoulder motion, and long-term precautions.

4.4.2 Agreements / disagreements with other reviews

To our best knowledge, this is the first systematic review that investigated the clinical and functional outcomes of PT programs following rTSA depending on the type of different study designs. Bullock et al 2019 [4] summarized the evidence of published PT protocols for both TSA and rTSA and described the lack of consistency for progression of therapy and exercise loading. However, the authors only included the studies up to 2020 with the information of PT protocols without their clinical and functional outcomes. The present study synthesized relevant outcomes including shoulder ROM, functional outcome, and pain as well as content details of the PT programs. In addition, we identified more references in the last 2 years. Mata-Fink and colleagues published a systematic review summarizing functional outcomes of elders receiving rTSA for proximal humeral fractures and concluded the improved forward flexion and functional outcomes, which is consistent with the results of this review. [55] Despite the investigation on PT programs, our study included more surgical indications such as rotator cuff arthropathy and massive rotator cuff tears. [27]

Based on the present study and on the existing literature, rTSA with a standardized clinical- or home-based PT programs can provide clinical and functional outcome improvements. However, a challenge with the lack of comparative trials is uncertainty how much of the recovery was due to surgery and how much was dependent on the physical therapy since no trials compared no or minimal therapy with comprehensive therapy. While the cohort, case-control and case-series studies provide sufficient evidence of the size of the improvements to be expected in different outcomes, they cannot distinguish best practices. It should be recognized that there are some potential factors not controlled in this analysis that may have an impact on the summary of clinical outcomes including different surgeon's experience, [56] different rehabilitation protocols (given variation identified in the PT programs from this study), different surgical techniques such as the choice of surgical approach, prosthesis, and orientation of the glenosphere and humeral components. [57]

The current study identified little consistency in rehabilitation strategies for rTSA which is similar with previous findings. [4,58,59] Included PT programs vary on the time frame to intitiate motion progression presumably due to concerns for maintaining joint stability and incision integrity. [60,61]

Immobilization was identified as a common management strategy following rTSA to increase the instability within the first 4 to 6 weeks following surgery. However, 3 studies did not mention the use of sling or any other immobilization instruments post-operatively. [27,37,45] The rehabilitation progression including immobilization, PROM, AAROM, AROM, resisted activity, and strength training in most included studies was granted based on tolerated pain and no instability signs. The 12-week PT program was recommended in the majority of included studies. However, Kim et al 2020 [27] proposed a less restrictive program and initiated passive ROM exercise on post-op day 1.

Pre-operational education has been shown to be positively correlated with favourable outcomes following surgery. [62,63] During the informative sessions, the expectations following surgery and rehabilitation should be clearly explained and linked to the successful outcomes. [4] A similar relationship was found in the mental health domains. For example, better interactions with others increases the post-surgical SF-36 social functional score. [64] However, our study revealed a lack of the attention to this important consideration as the pre-operational education was only found in 1 study given the pre-surgical expectation shows the significantly positive correlation with post-surgery outcomes including pain relief, improved ROM, and weight lifting. [43]

The current body of evidence suggests similar effectiveness of the home-based PT program when compared to traditional clinic-based therapy when evaluated by the clinical outcome measures including ASES, SST, pain measured by VAS, SF-36, Constant, standardized Shoulder Rating Questionnaire (SRQ-S), and ROM. [65,66] Most studies included in this review contain a short follow up periods (<5 years), which may not allow researchers to investigate the clinical outcome in a long-term consideration.

Clinic-based PT program may not be accessible to all patients following rTSA due to the limited resources, remote locales, and economic burden. More recently, many rehabilitation clinics across world were closed in response to COVID -19 pandemic.[67] To bridge the gap, several studies have investigated the therapeutic usefulness of telerehabilitation systems within general populations to examine whether the telerehabilitation system can be used an alternative strategy to provide physiotherapy services.[68,69] Although the use of telemedicine/remote program for rTSA are not yet evaluated, the promising outcome has been reported elsewhere in other body region such as total knee arthroplasty.[70] Given the older population and the recent pandemic, thoughtful design and evaluation of accessible remote programs and strategied to optimize adherence/outcomes in these platforms are needed, followed by rigorous RCTs that compare delivery formats. Meanwhile, the current system for rTSA needs to be updated by incorporating a unified platform facilitating teleconference, measurement of AROM, online-based outcome measurement, exercise education, and real time feedback. [71]

4.4.3 Implications for research

High quality randomized controlled trials to investigate the effectiveness of clinical outcomes and PT strategy after rTSA to determine best practices in patients with shoulder pathologies are warranted. Future studies should focus on the development of alternative programs such as pre-operative education and web or telemedicine platform.

4.4.4 Implications for practice

A 12-week PT program starting with immobilization for 4 to 6 weeks, followed by 3 to 4 phases PT exercises including PROM, AAROM, AROM, and strength training was recommended as a common management plan for patients following rTSA. However, due to variations in the included studies, the evidence of PT protocols in our study was not sufficient to summarize the best clinical rehabilitation practice after rTSA.

4.4.5 Strengths & limitations

This systematic review only examined articles/manuscripts/papers published in the English language, which may result in publication bias. Most included publications were non-randomized observational studies; therefore, quality appraisal was rated from low to moderate level. Another limitation of this systematic review is that only published data were included. The potential source of imprecision may be due to the small sample size for majority of included studies. Included studies comprise primarily women aged around 75 years old who are representative of rTSA candidates. Finally, several studies did not report standard deviation, making it difficult to assess the significance between the calculated weighted averages by study size.

4.5 Conclusion

Within-group improvements in shoulder forward flexion ROM of 37 – 80 degrees, abduction ROM of 37 – 80 degrees, external rotation ROM of 2 – 29 degrees, internal rotation of 1 – 2.3 spinal levels, VAS pain of 2 – 6 points, and all function outcome measures were observed in patients after rTSA who were administered PT programs. Based on the existing literature, it remains inconclusive whether rehabilitation is the pivotal factor in optimizing clinical outcomes and attaining best clinical practices.

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4.7 List of Tables

Table 4-1. Study characteristics information

Author	Year	Location	Age at surgery *Mean (range)*	Sample size *N (Shoulders) sex*	Lengthen of follow up *Mean -years (range –years)*	Study design
Collin	2017	France	75.1 (58-90)	101 (NA) 74 females	2 years	• Prospective cohort • Improvement was defined as pre-post differences in shoulder ROM and functional outcomes (SST, Constant)
Franca	2018	Brazil	75.5 (65-86)	22 (NA) 18 females	1 year	• Retrospective review • Improvement was defined as pre-post differences in shoulder functional outcomes (ASES) and pain.
Jiménez	2017	Spain	74.9 ± 6.3	30 (NA) 26 females	2.9 years	• Prospective cohort • Only post-op data provided in shoulder functional outcomes (Constant, Quick-DASH, UCLA Scale) and ROM.
Kemp	2016	USA	71.9 (59-84)	10 (12 shoulders) 8 females	3.3 years	• Case series • Improvement was defined as pre-post differences in shoulder functional outcomes (SPADI, SST, ASES, UCLA,), QoL outcome (SF-12), pain (VAS), and ROM.
King	2015	USA	72 (55-93)	80 (83) 48 females	3.5 years	• Retrospective review • Improvement was defined as pre-post differences in shoulder functional outcomes (ASES, SST-12, SPADI-130, Constant), QoL outcomes (SF-12), ROM and strengthen. • Comparisons were made between cemented and uncemented humeral stem groups.
Maier II (AOTS)	2014	Germany	73.4 (4.5)	9 (9) 7 females	1 year	• Case series • Improvement was defined as pre-post differences in shoulder functional outcomes (Constant, ASES, DASH), ROM, pain, and ROM.
Martinez	2012	Spain	78.8 (75-84)	18 (18) 12 females	2.3 years	• Retrospective review • Improvement was defined as pre-post differences in shoulder functional outcomes (Constant, SSV), ROM., and satisfaction.
Merolla	2019	Italy	76 (68-84)	13 (NA) 10 females	1 year	• Case series • Improvement was defined as pre-post differences in shoulder functional outcomes (CMS) and ROM.

Michael	2019	USA	67.9 (SD = 9, 35-93)	474 (NA) 359 Females	2 years	• Retrospective review • Improvement was defined as pre-post differences in shoulder functional outcomes (ASES, SPADI, SST).
Ross	2015	Australia	79 (67-90)	20 (21)	4.5 years	• Case Series • Improvement was defined as pre-post differences in shoulder functional outcomes (ASES, Quick-DASH, Constant), pain (VAS), and ROM.
Roy	2010	Canada	72.6 (9.3)	44 (NA) 30 females	2.2 years	• Prospective cohort • Improvement was defined as pre-post differences in shoulder functional outcomes (SST, SF-12, Constant), ROM, strength, and patient satisfaction.
Russo	2015	Italy	75 (62-95)	50 (NA) 44 females	1 year	• Case Series • Improvement was defined as pre-post differences in shoulder functional outcomes (Constant, SST) and ROM.
Saier	2015	Germany	72 (58-89)	35 (35) 22 females	2 years	• Prospective cohort • Improvement was defined as pre-post differences in pain (VAS), shoulder functional outcomes (Constant, ASES, DASH), and ROM.
Simovitch	2019	USA	77 (65-87)	55 (55) 38 females	3.1	• Retrospective review • Improvement was defined as pre-post differences in shoulder functional outcomes (Constant, ASES, UCLA, SSL) and pain (VAS) and ROM.
Triplet	2015	USA	76 (52-88)	91 (91) 58 females	2.9 years	• Retrospective review • Improvement measured as changes in function (ASES, SST) and ROM, pre- and post-surgery.
Walters	2016	USA	68.5 (22-85)	46 (46) 29 females	2.2 years (1-3.7)	• Retrospective review • Improvement was defined as differences in pain (VAS), shoulder ROM, strengthen, participation/performance of self-care and productivity activities.
Hagen	2020	USA	Delayed group 69.4 ± 7.5 Immediate group 68.3 ± 10.5	65 (86) 35 females	1 to 2 years	• Randomized controlled trial • Improvement was defined as pre-post differences in shoulder functional outcomes (ASES), pain, and ROM. However, full data of post-operative outcomes was not available. • Comparisons were between two groups were early and delayed rehabilitation groups.

Kim	2020	Republic of Korea	70.4 ± 7.0 (54 - 87)	77; 49 females	70.6 months (36.1-120.3 months)	• Retrospective review • Improvement was defined as pre-post differences in shoulder functional outcomes (Constant, UCLA, ADL scores), pain (VAS), and ROM.
Lopiz	2019	Spain	rTSA 82 ± 3.4 Non-operative 85 ± 4.8	rTSA 29;25 females Non-operative 30;26 females	Minimum 1 year follow up	• Randomized controlled trial • Only post-op data provided in shoulder functional outcomes (Constant, DASH), QoL outcomes (SF-12, EQ-5D), pain (VAS), and ROM. • Comparisons were operative treatment versus non-operative management.
Patel	2020	USA	70.0 (53 - 85)	75; 42 females	3.3 (2 - 8) years	• Retrospective review • Improvement was defined as pre-post differences in shoulder functional outcomes (ASES, SPADI-130, SST, UCLA, Constant), QoL outcome (SF-12), and ROM.
Rienmüller	2020	Switzerland	73 ± 12 (48 - 87)	13; 7 females	24 ± 1 (23 - 26) months	• Case-control • Improvement was defined as pre-post differences in shoulder functional outcomes (Constant, Quick-DASH). • Only post-op data was provided for active ROM. • Comparisons were between operative and non-operative arms for active ROM.
Schmalzl	2020	Germany	76 ± 6	64; 55 females	22 ± 8 months	• Retrospective review • Only post-op data was provided for shoulder functional outcomes (Constant, ASES, SSV), QoL (VR-12), pain (VAS), and ROM.

Table 4-2. Summary of quality appraisal

Study	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	Total	Level
Collin, 2017	1	2	2	2	0	1	1	1	2	1	2	0	1	2	0	2	1	1	2	2	0	0	2	1	1	30	M
Franca, 2018	2	2	2	0	0	0	1	1	0	1	2	0	2	1	0	2	1	1	1	2	0	0	2	1	1	25	L
Jiménez, 2017	1	0	2	0	0	0	1	1	0	1	2	0	2	1	0	0	1	1	1	2	0	0	2	2	2	22	L
Kemp, 2016	1	0	2	1	0	0	0	0	0	1	1	0	1	2	0	0	1	1	2	0	0	0	2	2	1	18	L
King, 2015	1	1	2	2	0	1	1	1	0	1	2	0	0	1	0	2	1	1	2	2	2	0	1	1	2	27	L
Maier II (AOTS), 2014	1	0	2	2	0	0	0	1	1	1	2	0	2	1	0	0	2	1	1	2	0	1	2	1	2	25	L
Martinez, 2012	2	0	1	1	0	0	0	1	0	0	1	0	2	0	0	0	1	1	1	0	0	0	2	1	1	15	L
Merolla, 2019	2	1	2	2	0	0	1	1	1	1	1	0	2	1	1	2	2	1	2	1	0	0	2	1	2	29	M
Michael, 2019	1	0	2	1	0	0	0	1	1	2	2	1	2	1	1	0	2	2	2	2	1	1	2	1	2	30	M
Ross, 2015	2	0	0	1	0	0	0	1	2	1	2	0	2	1	1	0	1	1	1	0	0	0	2	2	1	21	L
Roy, 2010	1	0	2	2	0	0	1	1	1	1	2	0	1	1	2	0	2	2	2	2	0	0	2	2	2	29	M
Russo, 2015	1	0	1	1	0	0	0	1	1	1	1	0	1	1	0	0	1	1	1	0	0	0	0	1	1	14	L
Saier, 2015	2	0	2	2	0	0	1	1	0	1	2	0	1	2	1	0	1	1	2	2	0	1	2	2	2	28	M
Simovitch, 2019	2	0	1	2	0	0	1	1	0	1	2	0	2	1	1	0	1	1	2	1	0	0	1	1	1	22	L
Triplet, 2015	2	1	0	0	0	0	1	1	2	1	1	0	2	1	1	2	1	1	1	1	0	0	2	1	2	24	L
Walters, 2016	1	2	0	1	0	0	1	1	2	1	2	0	1	1	0	2	2	2	1	2	0	0	2	2	2	28	M
Hagen, 2020	1	2	2	2	2	1	1	1	2	1	1	2	1	2	1	2	2	1	2	2	2	0	1	1	2	37	M
Kim, 2020	2	0	2	1	0	0	0	1	0	1	2	0	2	1	0	0	1	1	2	2	0	0	2	1	2	23	L
Lopiz, 2019	2	2	2	2	2	1	1	1	2	2	2	2	2	0	0	2	2	2	2	2	0	0	0	2	2	37	M
Patel, 2020	2	2	1	1	0	0	1	0	0	0	1	1	1	1	0	2	2	2	0	1	2	0	2	2	2	26	L
Rienmüller, 2020	1	1	1	0	0	0	0	0	0	0	2	0	0	1	0	1	1	1	1	2	0	1	1	0	1	16	L
Schmalzl, 2020	1	0	0	0	0	0	0	0	0	1	2	2	0	1	0	0	1	1	1	2	0	0	1	2	2	17	L

Total quality score was calculated based on the sum of 25 items (2, 1, 0 for each).
We considered a score of 38 and above as a high-quality study, a score of 28 to 37 as a moderate-level study, and a score below 28 as a low-level study.
L: Low M: Moderate H: High

Table 4-3. Range of Motion Outcomes.

Outcome	Author and year	Design	Sample Size	Mean difference degrees	Pooled Standard Deviation	Follow up
Forward Flexion	Hagen 2020 (active flexion)	RCT	65	3º (favors immediate over delayed group)	40.35	1 – 2 years
	Hagen 2020 (passive flexion)	RCT	65	1.6º (favors immediate over delayed group)	45	1 – 2 years
	Collin 2017	Prospective	101	60.8	NR	2 years
	Saier 2015	Prospective	35	80	NR	2 years
	King 2015	Retrospective	80	42	NR	3.5 years
	Martinez 2012	Retrospective	18	55	NR	2.3 years
	Kim 2020	Retrospective	77	50.9	45.55	5.9 years
	Patel 2020	Retrospective	75	50	NR	3.3 years
	Rienmüller 2020	Case-control	13	30 º (favors non-operative over operative)	9	2 years
	Kemp 2016	Case-series	10	37	16.5*	3.3 years
	Maier II (AOTS) 2014	Case-series	9	43	16.5*	1 year
	Merolla 2019	Case-series	13	39	16.5	1 year
Abduction	Hagen 2020 (active abduction)	RCT	65	6.2º (favors immediate over delayed group)	38.9	1 – 2 years
	Hagen 2020 (passive abduction)	RCT	65	4º (favors immediate over delayed group)	43.5	1 – 2 years
	Saier 2015	Prospective	35	80	NR	2 years
	King 2015	Retrospective	80	42	NR	3.5 years
	Martinez 2012	Retrospective	18	50	NR	2.3 years
	Patel 2020	Retrospective	75	46	NR	3.3 years
	Rienmüller 2020 (active abduction)	Case-control	13	30 º (favors non-operative over operative)	14.5	2 years
	Maier II (AOTS) 2014	Case-series	9	37	25.5*	1 year
	Merolla 2019	Case-series	13	47	25.5	1 year
External Rotation	Hagen 2020 (active external rotation)	RCT	65	10.4º (favors immediate over delayed group)	21.45	1 – 2 years
	Hagen 2020 (passive external rotation)	RCT	65	8.7º (favors immediate over delayed group)	24.25	1 – 2 years
	Collin 2017	Prospective	101	6.5	NR	2 years
	Saier 2015	Prospective	35	20	NR	2 years

	King 2015	Retrospective	80	2	NR	3.5 years
	Martinez 2012	Retrospective	18	15	NR	2.3 years
	Kim 2020	Retrospective	77	3.6	20	5.9 years
	Patel 2020	Retrospective	75	13	NR	3.3 years
	Rienmüller 2020	Case-control	13	20 º (favors non-operative over operative)	11.5	2 years
	Kemp 2016	Case-series	10	29	NR	3.3 years
	Maier II (AOTS) 2014	Case-series	9	5	NR	1 year
Internal Rotation	Collin 2017	Prospective	101	1.4§	NR	2 years
	Martinez 2012	Retrospective	18	30	NR	2.3 years
	Kim 2020	Retrospective	77	1§	3.6§	5.9 years
	Patel 2020	Retrospective	75	2.3§	NR	3.3 years
	Rienmüller 2020	Case-control	13	20 º (favors non-operative over operative)	10	2 years
	Maier II (AOTS) 2014	Case-series	9	10	NR	1 year

* SD imputed based on previous studies
§ The internal rotation was referred to spinal levels.
RCT: randomized controlled trial
NR: not reported

Table 4-4. Functional outcomes.

Outcome measures	Author and year	Design	Sample Size	Mean difference	Pooled Standard Deviation	Mean Follow up
ASES	Hagen 2020 (function subscale)	RCT	65	5.3 (favors immediate over delayed)	9.25	1-2 years
	Hagen 2020	RCT	65	5.7 (favors immediate over delayed)	18.15	1-2 years
	Saier 2015	Prospective	35	47	23.25*	2 years
	King 2015	Retrospective	80	43.3	23.25*	3.5 years
	Franca 2018	Retrospective	22	43.1	23.25	1 year
	Michael 2019	Retrospective	474	40	17.4	2 years
	Patel 2020	Retrospective	75	42.3	NR	3.3 years
	Kemp 2016	Case-series	10	42	21.55*	3.3 years
	Maier II (AOTS) 2014	Case-series	9	23.5	21.55	1 year
SST	Collin 2017	Prospective	101	1.3	NR	2 years
	King 2015	Retrospective	80	5.8	NR	3.5 years
	Michael 2019	Retrospective	474	5.6	2.65	2 years
	Patel 2020	Retrospective	75	6.0	NR	3.3 years
	Kemp 2016	Case-series	10	5	NR	3.3 years
SPADI	King 2015	Retrospective	80	55.5	NR	3.5 years
	Michael 2019	Retrospective	474	50.3	18	2 years
	Patel 2020	Retrospective	75	59.9	NR	3.3 years
	Kemp 2016	Case-series	10	55	NR	3.3 years
UCLA	Kim 2020	Retrospective	77	15.8	NR	5.9 years
	Patel 2020	Retrospective	75	16.3	NR	3.3 years
	Kemp 2016	Case-series	10	17	NR	3.3 years
DASH	Lopiz 2019	RCT	59	8.1 (favors non-operative over operative)	16.75	1-year
	Saier 2015	Prospective	35	45	NR	2 years
	Rienmüller 2020 (Quick-DASH)	Case-control	13	34	16.5	2-years
	Maier II (AOTS) 2014	Case-series	9	38.5	17.3	1 year

Constant	Lopiz 2019	RCT	59	1.6 (favors operative over non-operative)	NR	1-year
	Collin 2017	Prospective	101	40	NR	2 years
	Saier 2015	Prospective	35	52	NR	2 years
	King 2015	Retrospective	80	37	NR	3.5 years
	Kim 2020	Retrospective	77	22.8	NR	5.9 years
	Patel 2020	Retrospective	75	38.7	NR	3.3 years
	Rienmüller 2020	Case-control	13	37	10	2-years
	Kemp 2016	Case-series	10	40	8.4*	3.3 years
	Maier II (AOTS) 2014	Case-series	9	14.6	7.35	1 year
	Merolla 2019	Case-series	13	38	9.4	1 year

*SD imputed based on previous studies
NR: not reported
PROM: Patient-reported outcome
ASES: American Shoulder and Elbow Surgeon score
SST: Simple Shoulder Test
SPADI: Shoulder Pain and Disability Index
UCLA: University of California, Los Angeles score
DASH: The Disabilities of the Arm, Shoulder and Hand questionnaire
RCT: Randomized controlled trial

Table 4-5. Pain Outcomes.

Author and year	Design	Sample Size	Mean difference	Pooled Standard Deviation	Follow up
Lopiz 2019	RCT	59	0.7 (favors non-operative over operative)	1.55	1 year
Saier 2015	Prospective	35	6	2*	2 years
Franca 2018	Retrospective	22	5.55	2	1 year
Kim 2020	Retrospective	77	2.2 (at rest) 4.5 (at motion)	NR	5.9 years
Schmalzl 2020	Retrospective	64	2	2	1.8 years
Kemp 2016	Case-series	10	5	NR	3.3 years

*SD imputed based on previous studies
Pain was measured by visual analog scale.
RCT: Randomized controlled trial
NR: not reported

Table 4-6. Details of included Physical Therapy (PT) programs.

Study	Immobilization	PROM	AAROM	AROM	Resisted Exercise	Others	Type of PT
Collin, 2017	0 – 4wk: sling	0-4wk: elevation and ER	4wk+: start AAROM			4wk+: based on deltoid reactivation and strengthening in zero position Neuromuscular techniques to pass from active elevation to functional movement. No Strength training	Standardized clinic-based
Franca, 2018	0 – 6wk					6wk+: start PT	
Jiménez, 2017	0 – 3wk	3wk+: abduction and antepulsion to 90°	3wk+: pendulums			6wk+: start delayed PT	Standardized home-based
Kemp, 2016	0 – 6wk: sling	3 wk+: start PROM	6wk+: start AAROM	6wk+: start AROM	12wk+: strength training and weight bearing through the prosthesis during transfers	Pre-op: patient education	Standardized clinic-based
King, 2015	0 – 6wk: sling		3wk+: start AAROM		12wk+: start strength training		Standardized home-based
Maier II (AOTS), 2014	0 – 4wk: in 45° abduction pillow	0 – 6wk: combined elevation and abduction of 60° and 0° of ER	0 – 6wk		0 – 6wk: strength training	6wk+: start 21-day PT program	Standardized clinic-based
Martinez, 2012			1d+: start AAROM			3wk+: start passive mobilization and active mobilization	Standardized
Ross, 2015		1wk+: tolerated passive flexion to 90° and ER to 20°		6wk+: avoid axial loading in adduction and extensions	12wk+: start strength training	3wk+: start passive mobilization and active mobilization	Standardized clinic-based
Roy, 2010	0 – 4 or 6wk: sling					0 – 4 or 6wk: standard PT	Standardized clinic-based

Russo, 2015	0 – 23 d	2d – 8wk: reach the highest anterior elevation, and then improvement of ER.				4wk+: Hydrokinesitherapy	Standardized clinic-based
Saier, 2015	1d+: start sling	1d+: assist passive exercises	1d+: start AAROM				Standardized clinic-based
Simovitch, 2019	0 – 4 or 6wk: sling	0 – 4 or 6wk: flexion and abduction limited to 120°, ER limited to 45°, and IR limited to anterior superior iliac spine	6wk+: start AAROM		6wk+: start isometrics 12wk+: start graduated strength training		Standardized
Walters, 2016	0 – 6wk: sling	0 – 6wk: 90° of forward elevation and ER to neutral 6 -12wk: full forward elevation and ER to 30°	6 -12wk: full forward elevation and external rotation to 30°	12 wk+: start AROM	10wk+: start isometric for flexion, extension, ER, and abduction in a neutral position 12 wk+: start progressive strength training	12 wk+: transition to home-based program.	Standardized clinic-based
Hagen, 2020*	0 – 12wk: sling with abduction pillow.	6 -12wk (7 – 10d+): forward elevation, ER, and abduction with a comfortable range in supine position	6 -12wk: pendulums and forward elevation, ER, and abduction in supine position assisted by the other arm (or cane or stick) and progresses to 45 °upright and completely upright when able.	6 -12wk: AROM should be initiated patients are comfortable with AAROM	6 -12wk: isometric when comfortable with AROM 12wk+: strength training with resisted exercise using an elastic band or hand weights. 12wk+: start introduce scapula muscle strength training	0 -12wk: scapular exercises include shrugs, depression, retraction and protraction done in a sling for first 6 (1) weeks and out of sling after 6 (1) weeks. 0 -12wk: hand, wrist, and elbow motion should be done in a sling. Full- and Empty - Can exercises are not allowed.	Standardized clinic-based with home exercise instruction

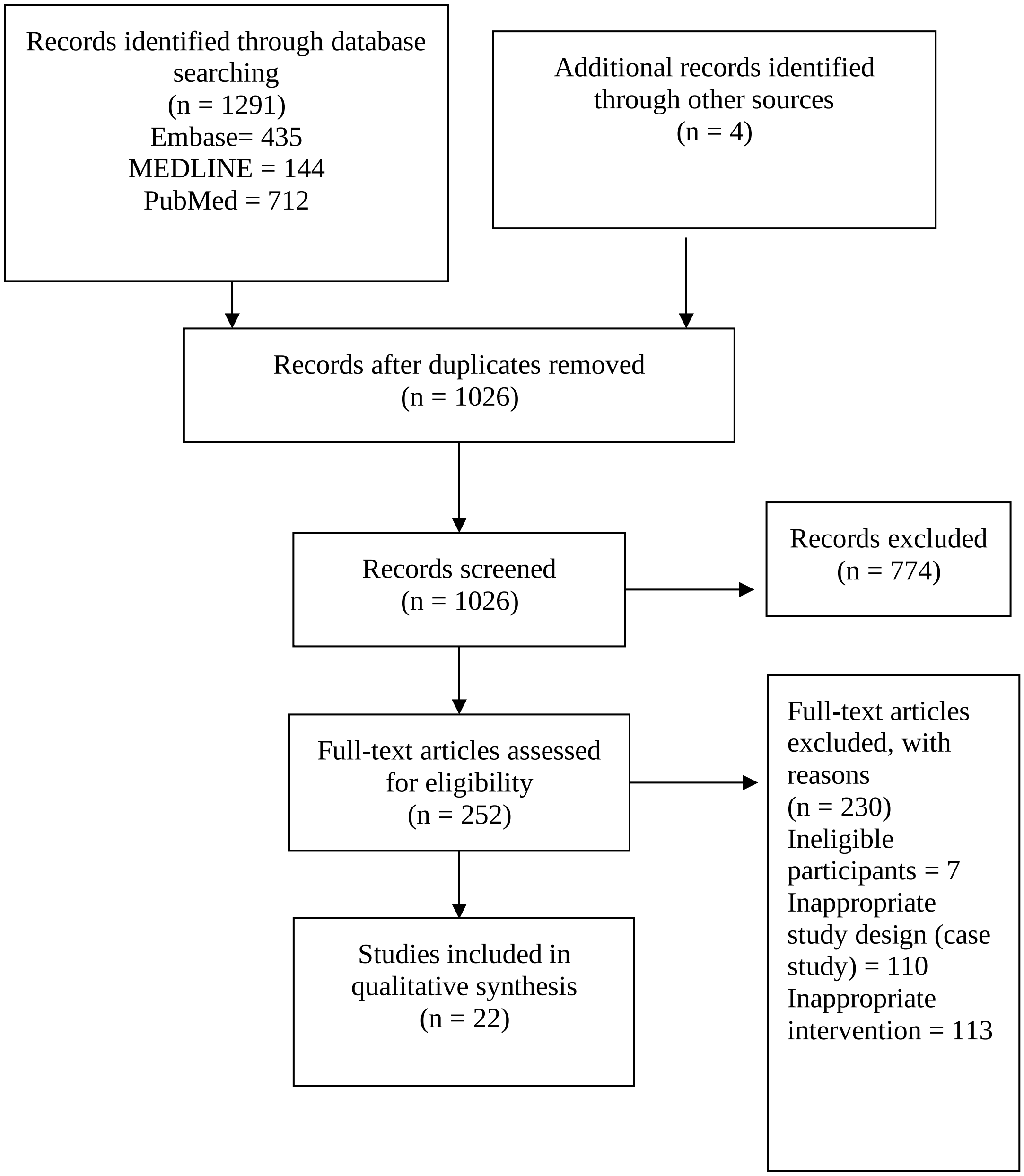
Kim, 2020		1d+: start forward flexion, and ER in a tolerable range.	1d+: start pendulums 4wk+: start AAROM		4wk+: start graduate strength training	PROM and pendulums: 10 repetitions, 3 times per day.	Standardized clinic-based
Lopiz, 2019	0 -3wk: sling	2wk+: start passive assisted Codman movements with neutral rotation and less than 90 degrees of anteversion.	0 -3wk: pendulums	6wk+: start AROM until strength training		0 -3wk: elbow, wrist, hand movement 6 wk+: no further improvements between 2 visits discontinue the formal rehabilitation.	Standardized clinic-based
Patel, 2020	0 – 6wks: sling			6wk+: start AROM		0 – 3m: weight restriction	Standardized home-based under physical therapist supervision.
Rienmüller, 2020	3 - 5 wk+: start active-dynamic stabilization				3 -5 wk+: start active resisted movements 6 – 12 wk: strength or corrdination in relation with ADLs.	0 -2 wk: active and active-assisted mobilization limited to pain and visual field was allowed.	Standardized
Schmalzl, 2020	0 – 6wk: sling	3wk+: start PROM		6wk+: start AROM	12wk+: start strength training		Standardized
Merolla, 2019	0 – 3wk: sling			6wk+: start AROM		4wk+: start active mobilization	Standardized
Michael, 2019	0 – 6wk: sling				12wk+: start strength training	0 – 6wk: ER limited to neutral and IR limited to the abdomen.	Standardized home-based under the direction of an occupational therapist
Triplet, 2015	0 – 6wk: sling		0 – 6wk: pendulums 6wk+: start self-directed supine active-			Pendulums: 3 times per day. 6wk+: start light ADLs with a 2-pound weight restriction	Standardized home-based

	assisted exercises	12wk+: start self-directed stretching and tolerated full activity

***: The information for immediate therapy is displayed in bracket.**
PROM: passive range of motion
AAROM: active -assisted range of motion
AROM: active range of motion
PT: physiotherapy
ER: external rotation
IR: internal rotation
ADL: activity of daily living

4.8 List of figure legends

Figure 1. The systematic review evidence flowchart



4.9 Appendix

Embase and MEDLINE search strategy

1. total shoulder arthroplasty.mp. or total shoulder arthroplasty/ or shoulder arthroplasty/
2. reverse total shoulder arthroplasty.mp. or reverse shoulder arthroplasty/
3. total shoulder replacement.mp. or total shoulder arthroplasty/
4. reverse total shoulder replacement.mp. or reverse shoulder arthroplasty/
5. physiotherapy.mp. or physiotherapy/ or home physiotherapy/
6. physical therapy.mp. or physiotherapy/
7. rehabilitation.mp. or rehabilitation/ or home rehabilitation/
8. telerehabilitation
9. 1 or 2 or 3 or 4
10. 5 or 6 or 7 or 8
11. 9 and 10

PubMed search strategy

((((((home[All Fields] AND ("rehabilitation"[Subheading] OR "rehabilitation"[All Fields] OR "rehabilitation"[MeSH Terms])) OR ("rehabilitation"[Subheading] OR "rehabilitation"[All Fields] OR "rehabilitation"[MeSH Terms])) OR ("physical therapy modalities"[MeSH Terms] OR ("physical"[All Fields] AND "therapy"[All Fields] AND "modalities"[All Fields]) OR "physical therapy modalities"[All Fields] OR "physiotherapy"[All Fields])) OR ("physical therapy modalities"[MeSH Terms] OR ("physical"[All Fields] AND "therapy"[All Fields] AND "modalities"[All Fields]) OR "physical therapy modalities"[All Fields] OR ("physical"[All Fields] AND "therapy"[All Fields]) OR "physical therapy"[All Fields])) OR (home[All Fields] AND ("physical therapy modalities"[MeSH Terms] OR ("physical"[All Fields] AND "therapy"[All Fields] AND "modalities"[All Fields]) OR "physical therapy modalities"[All Fields] OR "physiotherapy"[All Fields]))) OR ("telerehabilitation"[MeSH Terms] OR "telerehabilitation"[All Fields])) AND (((((("arthroplasty, replacement, shoulder"[MeSH Terms] OR ("arthroplasty"[All Fields] AND "replacement"[All Fields] AND "shoulder"[All Fields]) OR "shoulder replacement arthroplasty"[All Fields] OR ("total"[All Fields] AND "shoulder"[All Fields] AND "arthroplasty"[All Fields]) OR "total shoulder arthroplasty"[All Fields]) OR (reverse[All Fields] AND ("arthroplasty, replacement, shoulder"[MeSH Terms] OR ("arthroplasty"[All Fields] AND "replacement"[All Fields] AND "shoulder"[All Fields]) OR "shoulder replacement arthroplasty"[All Fields] OR ("total"[All Fields] AND "shoulder"[All Fields] AND "arthroplasty"[All Fields]) OR "total shoulder arthroplasty"[All Fields]))) OR (reverse[All Fields] AND ("shoulder"[MeSH Terms] OR "shoulder"[All Fields]) AND ("arthroplasty"[MeSH Terms] OR "arthroplasty"[All Fields]))) OR ("arthroplasty, replacement, shoulder"[MeSH Terms] OR ("arthroplasty"[All Fields] AND "replacement"[All Fields] AND "shoulder"[All Fields]) OR "shoulder replacement arthroplasty"[All Fields] OR ("total"[All Fields] AND "shoulder"[All Fields] AND "replacement"[All Fields]) OR "total shoulder replacement"[All Fields])) OR (reverse[All Fields] AND ("arthroplasty, replacement, shoulder"[MeSH Terms] OR ("arthroplasty"[All Fields] AND "replacement"[All Fields] AND "shoulder"[All Fields]) OR "shoulder replacement arthroplasty"[All Fields] OR ("total"[All Fields] AND "shoulder"[All Fields] AND "replacement"[All Fields]) OR "total shoulder replacement"[All Fields]))) OR (reverse[All Fields] AND ("shoulder"[MeSH Terms] OR "shoulder"[All Fields]) AND ("arthroplasty"[MeSH Terms] OR "arthroplasty"[All Fields])))

Chapter 5

5. Understanding and preventing Shoulder Injuries: A Scoping Review of Shoulder Joint Biomechanics in Daily Activities and Sports

Abstract

Background: Understanding shoulder joint biomechanics is crucial in identifying potential injury risks and creating effective prevention strategies. Shoulder biomechanics - defined as the study of the forces, torques, muscle activations, and joint kinematics - are key to diagnosing, treating, and managing shoulder conditions and informing rehabilitation strategies. Repetitive overhead motions and poor shoulder biomechanics can lead to injuries or arthritis, significantly impacting daily activities. Due to the high prevalence of such conditions, the review aims to examine available literature on shoulder biomechanics in different contexts, like daily activities and sports, aiming to understand injury correlation and explore joint loading reduction strategies based on appropriate shoulder biomechanics, particularly for those at higher risk.

Objective: To examine the last decade of literature from across disciplines on shoulder biomechanics in various conditions, such as daily activities and playing sports, to gain a better understanding of the relationship between shoulder biomechanics and injury. The secondary objective was to explore potential joint load reduction strategies based on proper shoulder biomechanics that could be beneficial for individuals at a higher risk of shoulder injury.

Methods: This study utilized a scoping review methodology as per Arksey and O'Malley's (2005) framework to identify and summarize all existing evidence on shoulder biomechanics and injury prevention. A comprehensive search was conducted across three databases (MEDLINE, Embase, and PubMed), along with manual searches, to locate articles on shoulder biomechanics in both healthy individuals and people with shoulder arthritis. The review included all relevant literature published or translated into English since 2012. Demographic information, aim of the study, a brief overview of methods including how the biomechanics data were collected, movement of interest, results, and recommendations for joint load reduction and injury prevention were recorded and synthesized qualitatively.

Results: This review analyzed 24 shoulder biomechanics studies that reported on 705 participants. The studies varied in focus, with eight centered on baseball pitching, one on softball, one on badminton, and one on bench press mechanics. Others explored specific activities such as cellphone use, violin playing, and driving. Three studies evaluated manual handling tasks, and five examined the shoulder joint's reaction force. Various tools were used to assess shoulder joint load, including motion capture systems, inverse dynamic algorithms, instrumented sensors, electromyography (EMG), task simulations, and isometric dynamometers.

Conclusions: This scoping review provides a comprehensive overview of the current state of research on shoulder biomechanics during various activities and highlights joint loading reduction. The findings have implications for athletes, manual laborers, and individuals engaged in daily activities involving repetitive shoulder movements. The identified strategies can inform the development of training programs, coaching practices, and rehabilitation strategies aimed at reducing the risk of shoulder injuries and improving overall shoulder health.

Keywords: Shoulder joint biomechanics, Shoulder joint's reaction force, Prevention strategies, Shoulder arthritis, Daily activities, Inverse dynamic algorithms, Task simulations

5.1 Introduction

The shoulder joint plays a vital role in a wide range of activities, including simple movements, daily activities, and sports.[1] Understanding the biomechanics of the shoulder joint during these activities is essential for identifying potential injury risks and developing effective strategies for injury prevention. The shoulder joint is complex and allows for a wide range of motions, including flexion, extension, abduction, adduction, internal rotation, and external rotation. It consists of the humerus, scapula, and clavicle. The shoulder joint is supported and stabilized by numerous muscles and soft tissues, including the rotator cuff muscles, which play a crucial role in maintaining stability and controlling shoulder movements.[1]

Shoulder biomechanics refers to the study of the mechanical principles and movements of the shoulder joint complex, which includes the glenohumeral joint, acromioclavicular joint, sternoclavicular joint, and scapulothoracic joint.[1,2] It encompasses the analysis of the forces, torques, muscle activations, and joint kinematics involved in the functioning of the shoulder joint during different activities and movements.[2] The measurement of joint reaction forces in live subjects without invasive procedures is challenging, thus our understanding of shoulder biomechanics relies heavily on experimental studies using cadaveric specimens or computational modeling.[2–4] The prevailing approach for quantifying shoulder joint force involves the application of motion analysis system with inverse dynamics. [2] Inverse dynamics is a well-established scientific technique used to calculate net joint torques within a rigid body linked segment model. [2] This approach relies on measured kinematics and, in some cases, external forces to determine the forces acting on the shoulder joint. [2] Alternative methodologies for assessing shoulder joint force encompass task simulation[5], implantable sensor technology[6], electromyography (EMG)[7,8], and various other techniques.[9] Gaining a comprehensive understanding of the principles of shoulder biomechanics and how they are altered in common shoulder pathologies is important. Such knowledge provides valuable insights for diagnosing, treating, and managing shoulder conditions and can inform the development of effective rehabilitation strategies. Activities that involve repetitive overhead motions, such as pitching, swimming, and badminton, increase load on the shoulder joint and can lead to shoulder injury.[10–12] Poor shoulder biomechanics can also contribute to the development of shoulder joint arthritis, a degenerative joint disease characterized by pain, stiffness, and limited range of motion.[13,14] The consequences of shoulder injury and arthritis on daily activities can be significant, leading to limitations in performing routine tasks such as dressing, grooming, and reaching overhead.[15] Despite the high incidence of shoulder injuries and arthritis, the current literature lacks evidence on proper shoulder biomechanics and injury prevention during daily activities and sports.

This scoping review aims to examine the last decade of literature on shoulder biomechanics in various activities, such as daily activities and playing sports, to gain a better understanding of the relationship between shoulder biomechanics and injury. It also explores potential injury prevention strategies based on proper shoulder biomechanics that could be beneficial for individuals at a higher risk of shoulder injury, such as athletes and manual laborers.

5.2 Method

As the quantity of literature on shoulder biomechanics and injury prevention was uncertain, a scoping review was conducted to identify and summarize all current evidence, following the methodological framework outlined by Arksey and O'Malley (2005)[16] to ensure rigor and transparency. This framework involves five stages, including identifying the research question, identifying relevant studies, selecting studies, charting data, and collating, summarizing, and reporting the results.

5.2.1 Research question

1. What is the current nature of research exploring shoulder joint biomechanics during simple movements, daily activities, and sports?

2. What is the suggestion derived from the literature for reductions in shoulder joint loading?

5.2.2 Literature search

The objective of the search strategy was to locate articles related to the shoulder joint biomechanics during simple movements, daily activities, and sports on healthy individuals or patients with shoulder arthritis. This was achieved through a comprehensive search of 5 databases: MEDLINE, Embase, CINAHL, Web of Science, and PubMed, as well as a manual search of relevant articles' reference lists and Google Scholar. The search terms included various keywords related to shoulder biomechanics, such as "biomechanics," "shoulder," "shoulder joint," "glenohumeral," "acromioclavicular," "sternoclavicular joint," "joint loading," and "joint force." The search terms were combined using Boolean operators "OR" and "AND", and all terms were "exploded" to obtain the maximum number of relevant articles. Abbreviations, synonyms, and alternate spellings were also used in the search. The latest search was conducted on Sept 3, 2023. Additionally, the search aimed to include unpublished materials known as "grey" literature, such as conference proceedings, theses, and industry documents.

5.2.3 Inclusion and exclusion criteria

This scoping review aimed to gather all relevant literature on shoulder joint force, including peer-reviewed studies, academic dissertations, conference presentations, and joint protection programs produced by patient-focused organizations (i.e., arthritis societies). The articles included in this review focused on evaluating shoulder joint force on healthy participants or individuals with shoulder arthritis such as shoulder rheumatoid arthritis (RA) and osteoarthritis (OA), posttraumatic arthritis, and rotator cuff tear arthropathy, and cadaver studies were also accepted. However, articles that focused on participants with other shoulder pathologies, exoskeletons, prosthetics, or animal models were excluded, as were articles investigating treatment effects such as surgery, physiotherapy, or manual therapy. In addition, articles that only included kinematic analysis were not considered. The measurement of shoulder biomechanics has remained consistent over the past decade. In an effort to maintain up-to-date with the most recent findings on the subject, this study has exclusively included articles that were published or translated into English since 2012. There were no restrictions concerning the country of publication, widening the scope and maximizing the number of articles taken into consideration.

5.2.4 Document screening

Two reviewers evaluated all articles retrieved from the databases. After removing duplicates, the reviewers screened the remaining articles by assessing the relevance of their titles and abstracts. Articles deemed irrelevant by both reviewers were excluded from the review. In cases of disagreement between the two reviewers, a third reviewer was consulted. Subsequently, both reviewers read the full text of each article and assessed whether it met the inclusion criteria.

Articles that met the criteria were included in the review. The same screening process was applied to articles found through hand-searching. Both reviewers verified the final list of articles for relevance, and any disputes were resolved by re-reading the full text and discussion until an agreement could be made. A third reviewer was consulted if necessary.

5.2.4 Data extraction and synthesis of information

Two reviewers used Microsoft Excel to organize information from the included articles into charts. The charts included the author, title, publication date, study design, country of publication, sample size or total number of shoulders examined, demographic characteristics such as age, gender, height, weight, and pathologies if relevant, aim of the study, a brief overview of methods including how the biomechanics data were collected, movement of interest, and results. Strategies related to joint loading reduction were subsequently summarized by the first and second authors (ZL and ES) based on the selected studies. This process of charting is akin to that of a narrative review, as it involved charting information related to methodology and specific findings. [16]

5.3 Results

The initial search yielded 15775 articles from electronic databases and 9 articles from hand-searching. After removing duplicates and screening by title and abstract, 39 articles were identified for full-text screening. Of these, 15 articles met the eligibility criteria and were included in the review. In total, this scoping review analyzed 24 articles (see Fig. 1).[17]

In the collective sample comprising 21 studies, a total of 705 participants were included, of which three studies were conducted as literature reviews (Weber et al 2014, Thompson et al., 2017, and Chalmers et al., 2017).[18–20] Among 9 studies reporting sex information, the participant composition consisted of 150 males and 66 females.[21–29] Please refer to Table 2.

Out of the total of 24 studies examined, eight were focussed on baseball pitching (Dutton et al 2022, Kenzie et al 2022, Lin et al., 2022, Manzi et al., 2022(1), Manzi et al., 2022 (2), Solomito et al., 2013, Thompson et al., 2017, Chalmers et al., 2017),[19,20,22,26,29–32] while one study focused on softball (Friesen et al., 2021).[21] One study was dedicated to the analysis of the overhead forehand smash (OFS) technique in badminton (Barnamehei et al., 2020).[23]

Additionally, one study delved into the mechanics of the bench press exercise (Mausehund et al 2021).[33] In relation to specific daily activities, we identified one study exploring the effects of daily cellphone use (Gorce et al 2021),[34] another refining proficiency in violin performance (Saffert et al 2021),[35] and a third study examining shoulder joint load during driving (Pandis et al 2015).[36] Furthermore, three studies were conducted on manual handling tasks, such as lifting boxes and stocking groceries (Potash et al 2021, Skovlund et al., 2022, Goubault, et al., 2020). [24,28,37] Lastly, five studies analyzed the reaction force within the shoulder joint, employing various shoulder movements studies in laboratory settings. (V. Brito et al 2022, Cross et al., 2022, O'Sullivan et al., 2022, Brown et al 2020, Faity et al 2021.)[9,25,38–40]

To assess the load on the shoulder joint, numerous studies have employed motion capture systems and inverse dynamic algorithm (Dutton et al 2022, Solomito et al., 2013, Brown et al 2020, Manzi et al., 2022 (1), Manzi et al., 2022 (2), Pandis et al 2015, Barnamehei et al., 2020, Faity et al 2021, Gorce et al 2021, Saffert et al 2021, Lin et al., 2022) [23,26,27,29–31,34–36,39,40] Additionally, two studies have utilized instrumented sensors to collect external force, as reported by Mausehund et al (2021) and Pandis et al (2015).[33,36] Muscle Electromyography (EMG) collected from Electromyographic electrodes was employed in five studies (Skovlund et al., 2022, Goubault, et al., 2020, Barnamehei et al., 2020, Kenzie et al 2022, Friesen et al 2021). [21–24,28] Furthermore, one study performed a task simulation based on kinematic information collected from 3D movement analysis, conducted by Potash et al (2021).[37] Moreover, the isometric dynamometer, specifically the Biodex system, was utilized in laboratory settings to measure simple shoulder movements, as observed in the studies by Cross et al. (2022), Brito et al (2022), and O'Sullivan et al. (2022).[25,38,41]

5.4 Joint loading reduction

From the studies selected through our search, we inferred a variety of strategies for reducing joint loading, drawing insights from the chosen studies. These strategies were then categorized based on the associated types of activities.

5.4.1 Joint loading reduction for overhead throwing in cricketers:

Using a run-up approach during throwing can result in quicker arm acceleration and follow-through, which can reduce the risk of injury. This involves taking a few steps before throwing the ball, which allows the cricketer to generate momentum and use their body more efficiently.[30,42]

Focus on hip and lumbo-pelvic flexion: This means bending at the hips and pelvis during the throwing motion, which helps to transfer the force generated by the legs and core to the arm, reducing the stress on the shoulder and elbow. [42]

Optimizing load distribution between shoulder and elbow muscles: Different approaches to throwing can result in different load distribution patterns in the shoulder and elbow muscles. Coaches and trainers should work with cricketers to optimize their technique and ensure that they are using the correct muscle groups during overhead throwing. [30,42]

Proper technique and biomechanics during throwing are important for preventing injury. This involves correct positioning of the feet, hands, and shoulders, as well as proper arm motion, follow-through, and landing. [30,42]

5.4.2 Joint loading reduction for softball pitchers:

Examining the sequencing of segment motion between the relative forearm and upper arm segments can potentially minimize the joint loading. This involves analyzing the timing and coordination of different body parts during the pitching motion. Considering the role of the biceps tendon in assisting with shoulder and elbow flexion during the acceleration phase of the pitch. This means ensuring that the biceps muscle is properly conditioned and strengthened to handle the demands of the pitching motion. [21]

Increasing elbow flexion velocity may decrease movement of the upper arm segment and subsequently decrease throwing shoulder distraction force, which could help reduce the risk of injury. This involves optimizing the timing and coordination of different body parts to reduce the stress on the shoulder joint. [21]

5.4.3 Joint loading reduction for bench press exercise:

Varying the lifting technique to use a more vertical bar path may help prevent shoulder injuries during bench press. This involves adjusting the angle of the barbell during the lift to reduce the stress on the shoulder joint.[33] Optimizing load distribution between shoulder and elbow muscles can improve bench press performance and reduce the risk of shoulder injury. [33] This means ensuring that the weight is evenly distributed across different muscle groups during the lift. Choosing the right grip width may help prevent shoulder injuries during bench press. [33] This involves experimenting with different grip widths to find the one that is most comfortable and effective for each individual. Avoiding powerlifting style bench press may be better for reducing the risk of shoulder injuries. [33] This means avoiding certain techniques or styles of lifting that may be more stressful or demanding on the shoulder joint.

5.4.4 Joint loading reduction for baseball pitchers:

Monitoring body composition to prevent joint damage. This involves tracking and managing the body fat mass of baseball pitchers, as higher levels of body fat mass were associated with increased shoulder joint forces during the pitching motion. The act of throwing represents an interconnected sequence, originating from the lower extremities, coursing through the core, and culminating at the upper limb.[19,31,43,44]

A foundational tenet of this kinetic chain is the core muscles balance, which ensures efficient power transfer and movement coordination. Discrepancies in core strength disrupt this seamless energy transfer, potentially leading to biomechanical misalignments. Furthermore, the core's pivotal role in providing spinal stability becomes evident when such imbalances precipitate unwarranted torsional forces, subsequently exerted on the shoulder or elbow. These imbalances not only compromise rotational efficacy during sport-specific actions but also induce surrounding musculature to adopt compensatory mechanisms, escalating the potential for strain. Additionally, the core's intrinsic role in maintaining optimal postural alignment is underscored when imbalances inadvertently modify throwing dynamics, subjecting specific joints and tissues to non-physiological stressors. Given these insights, the emphasis on holistic training, dedicated core conditioning, and periodic biomechanical assessments becomes paramount, providing a proactive approach in preventing injuries and ensuring optimal athletic performance. [42]

5.4.5 Joint loading reduction for tennis players:

Correcting body asymmetries through exercises and training programs that promote symmetrical development. This involves identifying any imbalances between the two sides of the body and addressing them through targeted exercises and training.[38]

Ensuring that players have adequate rest periods and avoiding overloading the shoulder joint with too many repetitions.[38] This means developing training programs that balance the number of repetitions with adequate rest periods to prevent fatigue and reduce the risk of injury.

Emphasizing proper technique and form to prevent unnecessary strain on the shoulder joint. [38] This involves working on the player's range of motion, grip, and follow-through to ensure that the shoulder joint is properly aligned.

5.4.6 Joint loading reduction for daily activities and instrument play

The included articles provide various measures for preventing shoulder injuries in different scenarios such as reaching, smartphone use, wheelchair propulsion, violin playing, box lifting, medicine cart operations, driving, and inappropriate techniques. To prevent shoulder injuries during reaching, trunk stabilization exercises can be included in rehabilitation programs, and gradual increases in weight or resistance can be used. Ergonomic interventions, such as using a lightweight smartphone and switching hands frequently, can reduce the risk of shoulder injury during smartphone use.[34]

For violinists, proper scapular upward rotation and external rotation of the humerus should be maintained, shoulder strengthening, and mobility exercises should be included in rehabilitation programs.[35]

To prevent shoulder injuries during driving, both hands should be on the wheel, and the hands should be below the "3 o'clock" and "9 o'clock" positions. The same side of the shoulder will experience the highest joint force when turning in one direction, so individuals can use the opposite hand to turn. Strengthening exercises for specific muscles can also be beneficial.

Novices should avoid inappropriate lifting techniques, such as holding it in an elevated position for too long, holding it too far from the body, or keeping it too close to the body during deposit phase while lifting weight. [36]

5.5 Discussion

The current review included a total of 24 studies, examining shoulder biomechanics in different contexts such as daily activities and sports. The studies utilized various methodologies, including motion capture systems, instrumented sensors, electromyography (EMG), task simulation, and isometric dynamometers, to measure shoulder joint forces and muscle activations.

This review revealed that most of the studies focused on specific sports activities such as baseball pitching, badminton, softball, and bench press exercise. These activities involve repetitive and demanding movements of the shoulder joint, increasing the risk of injury. The findings emphasized the importance of proper technique and biomechanics during these activities to prevent shoulder injuries. For example, in cricket, using a run-up approach, focusing on hip and lumbo-pelvic flexion, and optimizing load distribution between shoulder and elbow muscles were identified as potential injury prevention strategies.

Furthermore, the review highlighted the significance of analyzing motion segment sequencing and muscle coordination during specific movements. Understanding the timing and coordination of different body parts, such as the relative forearm and upper arm segments in softball pitching, can minimize the risk of shoulder injuries. Additionally, optimizing elbow flexion velocity and reducing upper arm movement can decrease throwing shoulder distraction force, reducing the risk of injury.

Similarly, in the context of activities like tennis, the review suggested injury prevention strategies specific to daily activities. It emphasized the importance of correcting body asymmetries, as these can contribute to imbalances and increased stress on the shoulder joint. Furthermore, ensuring adequate rest periods between activities can help prevent overuse injuries and promote proper recovery of the shoulder muscles. By implementing these strategies, individuals participating in daily activities like tennis can reduce the likelihood of shoulder injuries and promote long-term shoulder health.

This study explored joint loading reduction strategies not only in sports but also in daily activities like driving and smartphone use. For driving, maintaining proper posture, adjusting seat position, and ensuring lumbar support were identified as techniques to minimize back and neck injuries. Taking breaks and doing stretching exercises during long drives can reduce muscle tension and fatigue-related injuries. Regarding smartphone use, adopting ergonomic practices is crucial to prevent repetitive strain injuries. This includes maintaining a neutral wrist position, taking breaks to rest and stretch the hands and fingers, and utilizing voice commands or dictation features when possible. These practices help reduce the risk of conditions like carpal tunnel syndrome and musculoskeletal issues related to smartphone use.

Classical inverse dynamics in the field of biomechanics relies on simplified assumptions, such as the presence of idealized pin joints and rigid body segments. Such assumptions, however, don't reflect the viscoelastic characteristics inherent to musculoskeletal structures, and thus, can deviate from true-to-life scenarios.[1,2] Moreover, the accuracy of kinematic data is compromised by measurement errors stemming from factors like noise, skin artifacts, and assumptions to simplify the joint force calculation. These errors introduce inaccuracies in determining joint center locations, velocities, and accelerations, consequently affecting the calculation of net joint torques. Additionally, anthropometric parameters specific to individuals, including segment masses and inertias, are often estimated based on limited anthropometric characteristics and data from cadaver studies. As a result, deviations from actual values occur, further contributing to errors in net joint torques.

To enhance the accuracy of inverse dynamics analysis, researchers often incorporate. measured external forces as an additional input. However, integrating both measured kinematics and external forces presents a new challenge due to their inherent inconsistencies arising from the previously mentioned limitations.[2] Consequently, variations in net joint torques arise depending on whether the analysis commences from the unconstrained end (e.g., hands) or from the feet, when conducted sequentially along a chain of segments. [2]

Therefore, enhancing biomechanical models to more authentically encapsulate the nuanced properties of human tissues is paramount. Additionally, the pursuit of techniques to attenuate measurement errors, whether through advanced sensor technologies or sophisticated data processing paradigms, warrants attention. The generalization inherent in using broad-spectrum anthropometric data necessitates a shift towards methodologies that can capture and integrate individual-specific metrics, potentially leveraging contemporary imaging modalities enriched with machine learning algorithms. The reconciliation of inconsistencies, especially when measured kinematics with external forces, might benefit from data fusion techniques, ensuring congruous data integration. Furthermore, given the observed torque variations contingent on the initial point of biomechanical analysis, there's an impetus to optimize segmental analysis protocols. This might entail algorithmic innovations to establish the most representative starting points, or the synthesis of data sets initiated from varying points. With the advent of wearable technologies, the potential incorporation of real-time feedback into biomechanical evaluations is another frontier, offering avenues for instantaneous rectifications, be it in research contexts or therapeutic interventions. Collectively, these proposed directions advocate for a more holistic, precise, and patient-tailored approach to biomechanical investigations, beckoning a new epoch in the realm of biomechanics research.

Overall, the scoping review provides valuable insights into shoulder biomechanics during various activities and their implications for injury prevention. The findings underscore the importance of proper technique, load distribution, muscle coordination, and rest periods in minimizing the risk of shoulder injuries. The identified strategies can be incorporated into training programs and coaching practices for athletes and individuals engaged in manual labor. However, it is worth noting that the literature in this field is still limited, and further research is needed to enhance our understanding of shoulder biomechanics and develop more targeted injury prevention strategies.

The scoping review is subject to several limitations that warrant acknowledgment. First, our search was confined to specific databases and solely incorporated articles published or translated into English post-2012, possibly omitting pertinent studies in other languages or from different time frames. Second, despite endeavors to encompass grey literature, including conference proceedings and theses, there remains a likelihood of overlooking relevant unpublished works. Third, the studies we selected did not comprehensively report on the effects of sex and gender. This gap limits a conclusive understanding of how joint loading varies across different sex and gender groups, underscoring the need for prioritizing these considerations in subsequent research. Fourth, a constraint arises from extrapolating joint protection strategies, which might introduce bias from either the review authors or potentially reflect the biases of the original study authors. Additionally, not all facets of daily activities and sports were addressed in our review. Furthermore, the analysis did not scrutinize joint loading parameters and corresponding strategies across various age ranges, which could have provided more nuanced insights.

In conclusion, this scoping review provides a comprehensive overview of the current state of research on shoulder biomechanics during various activities and highlights potential injury prevention strategies. The findings have implications for athletes, manual laborers, and individuals engaged in daily activities involving repetitive shoulder movements. The identified strategies can inform the development of training programs, coaching practices, and rehabilitation strategies aimed at reducing the risk of shoulder injuries and improving overall shoulder health. Future research should continue to explore shoulder biomechanics in different contexts and expand our knowledge to further enhance injury prevention efforts.

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5.7 List of tables

Table 5-1 Demographic information of included studies

Study	study location	Study populations	Demographic characteristics
Megan Dutton et al 2022	South Africa	15	healthy male cricketers. two were left- and 13 righthanded, with a group mean age of 22.0 (3.4) years, mass of 76.9 (10.5) kg and height of 1.9 (0.8) m.
Germain Faity et al 2021	US	26	healthy participants, 12 males, age 21 ± 3 years, 3 left-handed, height 1.73 ± 0.09 m, weight 66.92 ± 9.29 kg, maximum voluntary force (MVF) of shoulder flexion 65.32 ± 19.50 N m)
Philippe Gorce et al 2021	France	10	healthy participants (mean height: 1.76 ± 0.14 m; height range: 1.60–1.91 m; mean weight: 80.33 ± 29.95 kg; range weight: 50–109; BMI range: 18.6–35)
Kenzie et al 2022	US	37	high school softball pitchers (mean ± SD; height, 1.71±0.06 m; weight, 75.53 ± 16.12 kg; age, 16 ± 2 years)
Lasse Mausehund et al 2021	Norway	34 (19 males and 15 females)	healthy adults, 12 powerlifters (6 women and 6 men) and 22 recreational strength-trained individuals (9 women and 13 men) participated in this study
Colin Brown et al 2020	Canada	1 female	Canadian Sports Institute Ontario Experimental Data. One subject (WCB003) severe, nonspinal lower body knee injury (28 yr, 170 cm, 67 kg, class 4–4.5),
Anne-Sophie Saffert et al 2021	Germany	4 (2 males and 2 females)	Ranging from 22 to 59 years of age (mean 44 years)
Zohar Potash et al 2021	Israel	18 (9 males and 9 females)	The participants mean age was 26.8 (range: 24–28). Females had an average height of 1.65 m (SD 0.061 m), and males had an average height of 1.79 m (SD 0.05 m). Females had an average weight of 63.4 kg (SD 12.2 kg), and males had an average weight of 73 kg (SD 6.8 kg).
Kenzie b. Friesen et al 2021	US	38	high school pitchers. 1.69 ± 0.07 m, 74.71 ± 16.36 kg, 15.2 ± 1.1 yr
Xu Xu et al 2013	US	20 females	without musculoskeletal problems. Two groups. The first group consisted of 10 professional nurses (age: 47.1 ± 8.8 years, height: 1.63 ± 0.06 m, weight: 76.1 ± 19.9 kg) who had had at least 6 months of work experience and used medicine carts in nursing homes as part of their jobs in the past 12 months. The second group consisted of 10 nursing students (age: 21.7±1.4 years, height: 1.69 ± 0.07 m, weight: 60.2 ± 9.0 kg) who did not have prior work experience with medicine carts but had basic knowledge of health care service delivery.
André V. Brito et al 2022	Portugal	20 (15 males and 5 females)	healthy competitive tennis players. No previous injuries, competed at national and international levels, and were positioned in the best national rankings of their age groups Age 18.7 (5.3)

Alexander E. Weber et al 2014		literature review	including 6 articles published data Fleisig et al 26 Dillman et al 29 Werner et al 7 Feltner and Dapena 8 Pappas et al 15
Petros Pandis et al 2015	UK	8 males	healthy Right-hand male subjects with no history of shoulder pathology participated in the study (age: 25 SD 4 years, height: 178 SD 10 cm, body mass: 71 SD 12 kg)
Hamidreza Barnamehei et al 2020	Iran	20	healthy professional and amateur badminton players free from any upper or lower limb injuries or pain five years before the experiments. In addition, they did not any surgical operation before ten years of experiments. Professional (elite) Amateur (non-elite) Number of subjects 9 11 Age (years) 24 ± 2.5 26 ± 3.2 Height (cm) 173 ± 6.1 175 ± 4.4 Weight (kg) 62 ± 5.5 68 ± 7.2 Experience (years) 13 ± 2 2 ± 1
Lin et al., 2022	Taiwan	57 males	Right shoulder- dominant elite throwers of professional and collegiate champion team, who were free of pain at the time of testing and had no history of surgeries due to injuries sustained while throwing.
Manzi et al., 2022 (1)	US	112	Professional baseball pitchers with a history of core injury Professional baseball pitchers from Major League Baseball teams as well as from Minor League Baseball teams from all levels of play. Professional pitchers were included in the following subgroupings: Core Musculature/Soft Tissue subgroup (CM/ST), n=10; No Prior Injury (NPI), n=76; General Core/Groin injury group (GCG); n=19; Spine or Back, n = 8.
Cross et al., 2022	US	13 males	Uninjured college pitchers
Skovlund et al., 2022	Denmark	64	supermarket workers
O'Sullivan et al., 2022	Ireland	19	without injuries (self-reported) and in good physical condition
Manzi et al., 2022 (2)	US	121	professional baseball pitchers. Pitchers were divided into high-accuracy (n = 33), moderate-accuracy (n = 52), and low-accuracy (n = 36) groups
Solomito et al., 2013	US	36	collegiate pitchers
Goubault, et al., 2020	Canada	32	16 experts in manual handling and 16 novices
Thompson et al., 2017	US	Literature review	10 biomechanical studies describing youth pitching mechanics
Chalmers et al., 2017	US	A Review of Current Concepts.	No. of studies not reported

Table 5-2 Summary of Information Including Methodology, Movement of Interest, Results, and Study Summary

Author and year of publication	methodology like how the biomechanics were recorded	movement of interest	Important results	Summary
Megan Dutton et al 2022	An eight-camera Vicon MX motion analysis system with 2 force platforms (900 × 600 mm). 73-12 markers used allover the body. A Newton-Euler inverse dynamics approach was used to calculate 3D joint angles and net resultant joint forces. Shoulder force was determined as the force applied by the trunk to the upper arm;	1. six overhead throws from a stationary position. 2. perform another six overhead throws by running forward over 15–20 m and fielding a stationary ball with their dominant hand as quickly as possible. All throws were directed towards a set of stumps, surrounded by a one square metre target, positioned 20 m away. The overhead throw was analysed from neutral shoulder rotation to maximum external rotation (MER) as the preparation/cocking phase; MER to ball release (BR) as the acceleration phase; BR to maximum shoulder internal rotation (MIR) representing dominant arm deceleration; and the reversal of shoulder rotation (MIR to neutral rotation) achieved when the forward motion of the entire body ceases, as the follow-through phase.	Kinetic data for the shoulder and elbow were determined at critical points in the overhead throwing cycle, including MER, point of BR and MIR. three good-quality trials averaged. Maximum external rotation stationary vs dynamic p value Distraction (+)/Compression (−) −102.2 (30.8)* vs −129.3 (31.4)* 0.02 Superior (+)/Inferior (−) 156.4 (77.3) vs 207.9 (94.7) 0.11 Anterior (+)/Posterior(−) −7.2 (14.1)* vs −21.8 (14.5)* 0.009 Ball release Distraction (+)/Compression (−) −22.3 (26.4) vs −4.4 (20.2) 0.06 Superior (+)/Inferior (−) 119.8 (64.5)* vs 53.1 (48.8)* 0.005 Anterior (+)/Posterior(−) 7.1 [−60.6–25.4] vs 6.6 [−29.2–31.3] 0.83 Maximum internal rotation Distraction (+)/Compression (−) 61.4 (24.1) vs 68.6 (24.5) 0.42 Superior (+)/Inferior (−) 119.7 (35.4) vs 145.9 (37.7) 0.06 Anterior (+)/Posterior(−) −62.2 (35.8) vs −74.7 (30.6) 0.31	The study examined the biomechanics of overhead throwing in cricketers using a run-up approach versus a stationary approach. The 15 cricketers had a mean age of 22.0 years and a mean mass and height of 76.9 kg and 1.9 m, respectively. The time taken to complete the throwing cycle was not significantly different between the two approaches, but a run-up approach resulted in quicker arm acceleration and follow-through. Kinematic waveform analysis showed differences in hip and lumbo-pelvic flexion between the two approaches. Shoulder joint kinetics showed compression and posterior force at maximum external rotation and superior force at ball release with a run-up approach, while the stationary approach resulted in greater compression and medial force at elbow maximum flexion. No differences were found in the shoulder, elbow, and thoraco-lumbar joints.
Germain Faity et al 2021	Movements were recorded at 100 Hz with 8 infrared optical cameras from the Vicon Motion Capture System antigravity shoulder torque was computed as the Euclidean norm of the 3D static torque against gravity at the final posture (torques applied to the shoulder by the upper arm (shoulder to elbow link), the forearm and hand (elbow to hand link) and the dumbbell,)	In the loaded conditions (upper row), participants held a dumbbell which mass corresponded to 75% of their maximal voluntary shoulder force (MVF). In the unloaded conditions (lower row), participants had to reach the target without the dumbbell. In the spontaneous conditions, participants had to reach the target in a natural way. In the trunk restraint conditions, participants had to reach the target while minimising trunk movement. Participants had to reach a target with the side of their thumb nail. participants performed 5 unloaded trials and 5 loaded trials, i.e., carrying a dumbbell. hold a 2 kg dumbbell in front of them with the arm extended and pull up as much as possible for 3 s.	Increasing the weight of the arm raises trunk recruitment. Reaching in the spontaneous unloaded condition induced a trunk recruitment of 11% of reach length. Trunk recruitment increased to 27.5% when loaded (W = 0, p < 0.001, r = 0.87). In the trunk restraint conditions, trunk recruitment could be reduced to 8% when unloaded (W = 22, p < 0.001, r = 0.72), and to 12% when loaded (W = 0, p < 0.001, r = 0.87) Trunk recruitment reduces antigravity shoulder torque. Trunk restraint increased shoulder antigravity torque in the final posture from 11.7 to 12.7% of maximum when the hand is unloaded (W = 351, p < 0.001, r = 0.87) and from 60.4 to 74.1% of maximum in the loaded condition (W = 349, p < 0.001, r = 0.86). In other words, trunk restraint increased the mechanical cost that is needed at the shoulder to maintain the final posture.	The study investigated the effect of arm weight and trunk restraint on shoulder biomechanics during reaching. The results show that increasing the weight of the arm during reaching increases trunk recruitment, indicating that handling a heavy dumbbell during reaching requires more trunk involvement. Trunk restraint reduced antigravity shoulder torque, indicating that the trunk plays a role in stabilizing the shoulder during reaching. The increase in trunk recruitment and the reduction in shoulder torque were not affected by the dominant side of the subject. Participants were able to reduce trunk recruitment in the loaded condition, suggesting that they were able to adapt to the increased mechanical demands of handling a heavy weight. Overall, the results suggest that trunk recruitment and shoulder torque are important factors in shoulder biomechanics during reaching and should be taken into consideration when designing rehabilitation or training programs.
Philippe Gorce et al 2021	79 markers were captured using an optoelectronic system with 10 infra-red cameras(Miqus M5), force plate, The proposed model enables the postures, joint torques and reaction forces to be estimated from subject's body mass index and environmental configuration without resorting to experimentation, which is relevant in industry. torque force was calculated based on the algorithm (equation not provided)	a phone call and a texting task in a static standing posture support for the upper limbs allowing the subject to lean back (with a variable height comprised between 90 and 115 cm), as well as a support for one of the two feet (with a variable height comprised between 0z and 60 cm), materialising the presence of a footrest for example. Range of estimated values by the model for a calling and a texting task for a load between 10 g and 1 kg, a barrier height between 1 and 1.25 m, and a lower limb support height between 20 and 55 cm.	Dominant Shoulder torque (N.m) calling task min: 0.1 max: 13.7 texting task: min 0.1 max 18.2	The study developed a predictive model to quantify joint torques and support reaction forces when using a smartphone while standing with support. The model was based on motion capture data and ground reaction force measurements collected from 10 participants. The study found that the model was able to accurately estimate joint torques and support reaction forces during smartphone use while standing with support. The results showed that shoulder abduction and elbow flexion were the most significant predictors of shoulder joint torque, while trunk flexion was the most significant predictor of support reaction force. The study also found that increasing the weight of the smartphone and using a non-dominant hand increased shoulder joint torque and support reaction force. The study suggests that the predictive model can be used to evaluate the biomechanical risks associated with smartphone use and to inform the design of ergonomic interventions to reduce the risk of musculoskeletal disorders.
Kenzie et al 2022	14 electromagnetic sensors, force plate, MotionMonitor (Innovative Sports Training). Moments were expressed as a percentage of body weight * body height (Nm). Kinetic data were measured using the motion analysis software using inverse dynamics. Shoulder distraction (+) and compression (–) force was measured in the y direction relative to the throwing shoulder axis.	Pitchers were instructed to throw fastballs for strikes to a catcher located at regulation distance (43 ft [13.1 m]). 10 strikes were captured	Peak throwing shoulder distraction force: mean (SD) 85.18 % BW (14.41) BW, body weight; BWH, body weight * body height	This study aimed to examine the biomechanics involved in shoulder distraction force within a group of high school softball pitchers. The study found that peak throwing shoulder distraction force was influenced by peak elbow distraction force, extension moment, flexion velocity, and trunk flexion at FC. Strong relationships were found between elbow variables and shoulder distraction force, likely due to the nature of the windmill pitch and the common motion of the entire upper extremity. Future research should examine how sequencing of segment motion between the relative forearm and upper arm segments may influence force distribution through the kinetic chain to potentially minimize the risk of injury at the shoulder joint. The study also suggested that the increased elbow extension moment might further point to the biceps tendon as a location of injury and anterior shoulder pain among softball pitchers. Additionally, the study highlighted the importance of the biceps tendon in assisting with shoulder and elbow flexion during the acceleration phase of the pitch. Greater elbow flexion velocity may have the potential to decrease movement of the upper arm segment and may subsequently decrease throwing shoulder distraction force.
Lasse Mausehund et al 2021	Kinetic data were collected at 1500 Hz by means of a custom-made instrumented barbell capable of measuring horizontal forces acting along the bar, as well as by 2 force plates (AMTI LG6-4-1) The external NJMs about the shoulder and elbow joints were calculated as the products of the resultant force vector (FR) and the respective moment arms (dS and dE). The moment arms and NJMs were normalized to the subjects' arm length and estimated 6RM load, respectively.	warm up then bench press 7 repetition maximum (RM) load with a medium grip width. A 75° inner angle between the extended armand the barbell (AB-angle) was chosen, which corresponded to163 6 4% of biacromial distance.	Shoulder NJM, mean (Nm·kg-1) male: 0.84 +/- 0.10 female: 0.74 +/- 0.12, p=0.005. recreational:0.80 +/- 0.11 Powerlifter 0.78 +/- 0.13 p=0.696 Shoulder NJM, peak (Nm·kg-1) male: 1.45 +/- 0.18 female: 1.47 +/- 0.22 p=0.976 recreational: 1.49 +/- 0.19 Powerlifter: 1.41 +/- 0.21 p=0.208	This study investigates how training expertise and sex affect bench press biomechanics, lifting technique, and net joint moments. The researchers analyzed data from 34 participants, both male and female, with varying levels of bench press training experience. They found that experienced lifters tended to use a more vertical bar path, while less experienced lifters tended to use a more horizontal bar path. Male lifters tended to generate higher net joint moments than female lifters. The study provides insights into how different factors can affect bench press biomechanics, which may have implications for training programs and injury prevention. The study compared the normalized joint moments (NJMs) in bench press exercises between powerlifters and recreational lifters and between men and women. Powerlifters used a different bar path, resulting in lower normalized peak elbow NJMs and shorter joint ROMs than recreational lifters. However, no differences in normalized shoulder NJMs and muscle activity were observed between powerlifters and recreational lifters. Women showed higher normalized peak elbow NJMs and mean elbow to shoulder NJM ratios than men. The findings suggest that optimizing the load distribution between the shoulder and elbow muscles could improve bench press performance, and the choice of grip width could be a technical factor affecting performance. Finally, performing a powerlifting style bench press might be suboptimal for strength adaptations and hypertrophy compared with a standard bench press.
Colin Brown et al 2020	Three-dimensional motion capture technology was used to collect kinematic data of the upper body segments, which included data for the upper arms, forearms, hand,	The subject completed isometric testing by exerting a 5 s maximal flexor activation and extensor activation. This was completed for eight different angles of the shoulder (40 deg, 20 deg, 0 deg, 20 deg, 40 deg, 60 deg, 80 deg, and 100 deg) with an elbow angle of 0 deg, and 9 deg for the elbow (0	Push times for vertical (Y) and horizontal (X) seat changes, with optimum values bolded	The study aimed to develop a validated, predictive computer simulation of wheelchair propulsion by generating forward dynamic simulations that could provide similar profiles and magnitudes of kinematic and kinetic data between fixed final time simulations and experimental data of a submaximal first push. The results showed that an anterior seat placement to the neutral experimental position produced the quickest push time with the least amount of shoulder torque required. However,

	and wheel. Net torque of each joint produced by equation	deg, 15 deg, 30 deg, 45 deg, 60 deg, 75 deg, 90 deg, 105 deg, 120 deg) with a shoulder angle of 45 deg. Following this, the subject exerted a maximal effort for two repetitions of a full concentric/eccentric cycle for each joint and velocity tested (30 deg/s, 75 deg/s, 120 deg/s, 180 deg/s, 240 deg/s, 300 deg/s, and 360 deg/s) for both the flexor and extensor muscle groups. The maximal torque isometric and isokinetic data sets were obtained using the regression method proposed by Yeadon et al	Seat position (cm) Push time (s) Peak shoulder torque(Nm) Neutral 0.346 88.4 Y: -5 0.338 77.6 Y: -10 0.331 77.5 X: +10 0.334 74.0 X: -10 0.356 97.0	the wrist torque results remain to be further validated as the optimizer tended to maximize wrist torque. Future work should improve upon this study by continuing the validation of this method through testing more subjects and increasing the complexity of the model.
Anne-Sophie Saffert et al 2021	infrared-camera system Vicon (Vicon Motion Systems Ltd, Oxford, UK) within a setup including 12 Vero cameras with a sampling frequency of 250 Hz was used. To record the kinematic data, the subjects were equipped with 29 markers,) and then further processed with a musculoskeletal simulation software (AnyBody Modeling SystemTM) to calculate the required joint angles and reaction forces via inverse dynamics. To provide a more realistic representation of shoulder forces, Hill-type muscles were used as muscle models in the simulation	only the 'legato'-technique playing, i.e., playing with the bow on the strings (as opposed to pizzicato: plucking the strings), is analyzed. To be able to use the expression 'high shoulder', the right shoulder of each subject must be elevated at least 5 degrees more than the average elevation angle in the sternoclavicular (SC) joint of all trials of each subject in a normal position. Each subject played the first 12 bars from the 4th movement (Presto) of Bach's G minor solo sonata (BWV 1001) [17] three times in normal posture and three times with elevated shoulder	Force increase of median resulting force in GH joint from shoulder position low to a high shoulder Subject Median force (N) of all trials of Force increase (%) from 'DOWN' to 'UP' 'UP' 'DOWN' s1 381.34 259.67 147 s2 883.50 494.64 179 s3 959.82 318.64 301 s4 779.76 330.61 236	The study aimed to analyze the shoulder biomechanics of violinists during legato-playing, focusing on the right elevated glenohumeral joint. The researchers used motion capture and electromyography (EMG) to measure shoulder kinematics and muscle activity in 12 professional violinists. The results showed that during legato-playing, the violinists exhibited increased scapular upward rotation and posterior tilt, which could lead to increased muscle activity in the upper trapezius and serratus anterior muscles. Additionally, the violinists showed a decrease in external rotation of the humerus, which may increase the risk of impingement syndrome. Overall, the study suggests that legato-playing in violinists may put increased demands on the shoulder, specifically the right elevated glenohumeral joint. These findings may have implications for injury prevention and rehabilitation in violinists.
Zohar Potash et al 2021	motion was recorded using a motion capture system and then using Jack simulation (Siemens), the low back compression force and shoulder sagittal torque (flexion/extension) motion prediction with Jack using Task Simulation Builder (TSB) that creates trajectories (a sequence of postures that the virtual worker performs) and trajectories based on motion capture data from the experiments Jack TSB software to simulate the motion performed during the experimental tasks using the GET function (for removing) and the PUT function (for depositing)	The participants performed the following tasks. They: 1) removed a box from a shelf; 2) turned 180◦ and carried the box in front of the body for 2.7 m; and 3) deposited the box on a shelf. The dimensions of the box were 0.20 × 0.55 × 0.36 m (height × width × depth), and it had handles on both sides at a height of 0.15 m from the bottom. The mass of the box was distributed evenly along its width and depth, concentrating at its bottom. Box masses [kg] 2, 5, 8, 12* (*Only males) Removing/Depositing heights [m] 0.5, 0.8, 1.1,1.4, 1.7	Shoulder torque removing 2 - 12 kg, median, experiment group vs simulation 7 -17 vs 6-16 nm. Carrying: 2-12 kg, median, experiment group vs simulation 7 -15 vs 4 -14 nm. Depositing: 2-12 kg, median, experiment group vs simulation 8-20 vs 7-20nm. Removing 0.5 - 1.7 m lift height, median, experiment group vs simulation 6 -20 vs 4-16 nm. Depositing: 0.5 - 1.7 m lower height, median, experiment group vs simulation 7-21vs 6-16 nm.	This study investigated the effect of motion type on low back compression force and shoulder flexion torque in the context of removing, carrying, and depositing boxes of varying masses from shelves of varying heights. The study found that experimental motion resulted in higher compression forces and torque levels compared to predicted motion. The differences in distance between the lower back/shoulder joint and the box were highly correlated with differences in compression force and torque levels. The study also found that the range of back compression forces was larger using experimental motion compared to predicted motion, which could be explained by motion variability between participants. Finally, the study noted that the risk of injury may be even higher for individuals with lifting techniques resulting in higher compression force and that the quasi-static model used by DHM software may underestimate back torque.
Kenzie B. Friesen et al 2021	Throwing shoulder distraction force was identified along the long axis of the throwing upper arm and defined relative to the TA shoulder. Anterior shoulder force was determined along the x-axis (anteriorly directed axis) of the local coordinate system placed at the throwing shoulder and defined relative to the thorax. Both forces were nonnormalized to body weight motion capture system, 15 wired electromagnetic sensors electromagnetic tracking system (trakStar; Ascension Technologies Inc.; sampled at 240 Hz) and force plate (Bertec 4060 NC; Bertec Corp., Columbus, OH; sampled at 1200 Hz) synced with motion analysis software, The MotionMonitor (Innovative Sports Training, Chicago,IL).	Softball pitch, no specific protocol of the movement	Peak distraction force (N) 597.75 ± 160.21 Peak anterior force (N) 236.87 ± 74.72	The study by Friesen and Oliver aimed to investigate the relationship between body composition and shoulder biomechanics in baseball pitchers. The researchers collected data on the body composition of 38 high school baseball pitchers and used motion capture and force plate technology to analyze their pitching mechanics. They found that higher levels of body fat mass were associated with increased shoulder joint forces during the pitching motion, which could increase the risk of injury. The study suggests that monitoring body composition could be an important aspect of injury prevention in baseball pitchers.
Xu Xu et al 2013	The raw 3-D coordinate data and the external hand forces collected by the motion tracking system and the load cells were	For the surface transition task, participants pushed the medicine cart on the two long tracks from end to end, passing the transition strips. Because each transition strip was located at approximately one-third of the length of the long track, the	Among all medicine cart tasks for the initial, transition, and turning phases, the peak shoulder joint moments were 25.1 (9.2) Nm, 20.3 (7.7) Nm, and 26.8 (11.1) Nm The study investigated the effects of environmental and user-related factors on the peak shoulder joint moment and shoulder elevation angle during medicine cart	The study found that lane congestion, cart load stability, distance from the starting position to the transition strip, shoulder tendency, floor surface friction, and handedness influenced the shoulder joint moment and shoulder elevation angle while pushing a medicine cart.

	filtered with a fourth order Butterworth zero-lag low pass filter at 8 Hz. Three distinctive task phases were extracted for analysis: the initial phase, transition phase of surface transition tasks, and turning phase of turning tasks. Combined with a biomechanical model(31) and the external force measured by the load cells, the left and right net shoulder moments were calculated	direction of the pushing tasks determined the location of the strip relative to the starting position (TS in Table I). Also, the opposing pushing direction resulted in two different starting surface friction levels (IS in Table I). For the turning task, participants pushed the cart from the long track to the short track over a right-angle corner without surface transition. There were two levels of shoulder tendency, which was determined by the direction of the turn (ST in Table I) (e.g., right shoulder is the outer one when making left turn). Due to the configuration of the rectangular track, the surface transition task and turning task were performed alternately For the surface transition task there were 48 pushing trials for each participant (2 congestion levels×2 cart load stability levels×2 transition strip locations × 2 starting surface frictions × 3 repetitions). For the turning task there were also 48 pushing trials for each participant (2 congestion levels × 2 cart load stability levels × 2 shoulder tendencies × 2 surface frictions × 3 repetitions). For each task, the conditions of congestion and cart load stability were randomized first, and all other conditions were balanced among participants.	operations. The average peak shoulder joint moments ranged from 20.3 to 26.8 Nm across various tasks	The high congestion task resulted in greater peak shoulder moments in the turning phase, while the congestion level did not affect straight-line surface transition tasks. The peak shoulder joint moment and the average shoulder elevation angle were both lower when the cart load stability level was high. The longer the distance from the starting position to the transition strip, the less the shoulder joint moment. During the turning phase, the outer shoulder carried a greater joint moment than the inner counterpart. The study suggests that environmental and user-related factors have significant effects on the shoulder joint moment and shoulder elevation angle during medicine cart operations, which may affect the risk of shoulder injuries among healthcare workers. In the present study, a greater shoulder joint loading was in general accompanied by a greater shoulder elevation angle. One possible explanation is that during the initial phase, the participants tended to lean into the cart and used their body weight to drive the cart. This posture required greater shoulder abductions that increased the shoulder elevation angle. The larger the trunk inclination angle, the larger the shoulder joint loading and the larger the shoulder elevation angle.
André V. Brito et al 2022	isokinetic dynamometer (Biodex System 4, Biodex Medical Systems, NY, USA)	first moment includes ten shoulder external and internal rotations of the dominant and non-dominant upper limbs were performed at angular velocities 90 and 180 degree/s. In the second and third moments (48 h apart), players performed, in a randomized order, five and ten forehands on the court, simulating a short and long point, respectively. Before and after the court test, players executed ten shoulder external and internal rotations of the dominant and non-dominant upper limbs only at 180 degree/s (the nearest angular velocity to the forehand made on the court).	angular velocities 90 degree/s IR and ER Nm * for significant difference between dominant and non-dominant side 90 dominant non-dominant Peak torque ER 21.9 (6.6) 20.2 (6.3) * Peak torque IR 40.0 (14.9) 29.1 (10.1)* Peak torque/body weight (%) ER 34.9 (6.1) 32.1 (5.9)* Peak torque/body weight (%) IR 63.1 (15.6) 45.9 (9.8)* Average peak torque ER 19.1 (5.9) 18.0 (6.3) Average peak torque IR 35.3 (14.5) 25.8 (9.7)* 180 Peak torque ER 21.4 (7.9) 19.1 (6.8)* Peak torque IR 39.9 (16.4) 28.1 (11.5)* Peak torque/body weight (%) 33.7 (7.8) 29.9 (6.0)* Peak torque/body weight (%) 62.5 (17.3) 44.0 (12.6)* Average peak torque ER 19.0 (7.0) 16.6 (6.4)* Average peak torque IR 36.2 (15.7) 25.1 (10.4)*	The study investigated the effect of repeated forehand actions on shoulder torque, power, ball speed, and accuracy in tennis players. The authors hypothesized that dominant limb torque and power would be higher, torque and power production would decrease after five and ten forehands, fatigue would cause a decrease in internal rotation torque and power, and ball speed and accuracy would decrease from five to ten forehands. The study found that dominant upper limb internal rotations were more proficient, and dominant external rotation showed higher peak torque and power. After ten forehands, total work, maximal repetition total work, average power, average peak torque, and range of motion decreased. Moreover, the study found that long-term accumulated loads in different sports can lead to body asymmetries and upper-dominant limb dominance. Peripheral fatigue caused by unilateral and repeated tennis movements can cause disturbances in the player's performance. The study suggests that the findings could be useful for coaches in providing information about the overload in the shoulder function.
Alexander E. Weber et al 2014	literature review including 6 articles published data	The well-described phases of baseball pitching are: wind-up, stride, arm cocking, arm acceleration, arm deceleration, and follow-through.	NA	The well-described phases are: wind-up, stride, arm cocking, arm acceleration, arm deceleration, and follow-through. During the wind-up phase, the shoulders and elbows are held in a flexed position. The shoulders are maintained in an abducted and flexed position by activation of the anterior and medial deltoids, supraspinatus, and clavicular head of the pectoralis major.29,30 The elbows are maintained in a flexed position by isometric contractions of the major elbow flexors (brachialis, biceps brachii, brachioradialis). Stride: The deltoid and supraspinatus initiate throwing shoulder external rotation and horizontal abduction.4 The upper trapezius and serratus anterior muscles contract to bring the scapula into internal rotation (scapular protraction), anterior tilt (scapular forward tilt), and upward rotation (scapular lateral rotation), the position necessary to initiate the upcoming phases of the throwing motion. Arm cocking: Illustration of the forces and torques at the shoulder and elbow during the arm-cocking phase immediately before maximum external rotation of the shoulder. The arm is externally rotated 165 degrees, whereas the elbow is flexed 95 degrees. There is a 310N anterior force and a 67Nm internal rotation torque at the shoulder. The elbow experiences 64Nm of varus torque. Arm acceleration: transition of the throwing shoulder from maximal external rotation toward internal rotation. The positions of shoulder and elbow during arm acceleration and subsequent ball release are important for velocity of the throw and injury prevention. Dillman et al23,73 have shown that 90 degrees of coronal arm abduction can optimize strength and minimize shoulder impingement. The horizontal arm abduction at MER is 18±6 and 9±7 degrees at ball release. This change of position is a result of the elbow being slightly in front of the trunk at the end of arm cocking (MER), and as the hand moves forward during arm acceleration. Arm

				deceleration: After ball release, the throwing arm is extended at the elbow, abducted at the shoulder, and moving toward the target. This arm position causes GH distraction, which is counteracted by contraction of the rotator cuff musculature. 24 The net joint force necessary to decelerate the throwing arm, as calculated by kinematics, at the shoulder can be as great as the body weight (1000 to 1200 N).3,24 To resist horizontal adduction and decelerate the arm, a posteriorly directed shoulder force of 400±90N is generated. The shoulder passive restraints also create a horizontal abduction torque of up to 97±25Nm to resist anterior translation of the humerus in relation to the glenoid. Follow through: continuous phase od the deceleration.
Petros Pandis et al 2015	The forces at the hands are measured by a calibrated, strain-gauge-instrumented attachment on the driving rig Specifically, the system consists of four TML (FLA-5-23) strain gauges (Tokyo Sokki Kenkyujo Co. LTD, Tokyo) at each handle, using a full Wheatstone bridge configuration with a bending strain gauge arrangement. Torque resistance on the wheel is set at 4 Nmin order to simulate a standard driving torque (Li and Xian, 2013). The model is an inverse dynamics musculoskeletal model of the upper limb including 91 muscle elements crossing five joints (sternoclavicular, acromioclavicular, scapulothoracic, glenohumeral and elbow). Motion of the subject and simulator wheel is tracked using optical motion tracking (VICON Motion Tracking System, VICON, Oxford, UK) acquiring data at 100 Hz (Fig. 1). A micro analogue 2 (FE-366-TA) amplifier (Flyde Electronic Laboratories LTD, Preston) was used for the communication between the strange gauges and the VICON capture system	A driving simulator was designed and built with a user interface that instructs the subject to suddenly turn right or left in a random order; simulating an avoidance task. The simulator was set up to assess right upper limb function during turning to the left or right. The task is completed when the wheel has been turned 65°. Six left and six right turn recordings were taken. Each subject repeated the measures for the following conditions I Comfortable seated position, both hands on wheel. II Comfortable seated position, single hand on wheel. III Distant seated position, both hands on wheel. IV Close seated position, both hands on wheel.	Turning direction: When subjects were turning right, the mean maximum glenohumeral joint force was 61.1% body weight (BW) (SD 7.8%, ≈425 N) as compared to 39.4% BW (SD 6.0%) when turning left. Turning right showcased higher muscle forces and activations, making it of greater clinical importance. Driving positions: Condition III (distant to the wheel): This position resulted in the highest individual muscle activation, notably a 71% (SD 3%) activation in the medial deltoid head. It generally also led to higher activations in other muscles. Condition IV (close to the wheel): This position significantly reduced muscle forces ($p < 0.05$) and decreased the glenohumeral joint force to 35.3% BW (SD 3.1%, $p < 0.05$) from 61.1% BW (SD 7.8%). The largest difference between these two positions was seen in the medial deltoid head. One hand vs two hands driving: The maximum muscle activation was found to be similar in comfortable positions whether driving with one or two hands, although there were significant differences in some cases. Muscle analysis during right steering: The study highlighted the roles of the six most active muscles during right steering across four different driving positions. These muscles are the trapezius medial head, triceps medial head, deltoid medial head, supraspinatus, infraspinatus, and long head of biceps.	The study found that using right shoulder, turning right while sitting in a comfortable position resulted in higher glenohumeral joint force compared to turning left. Muscle forces and activations were also higher when turning right. The longer 'distant to the wheel' driving position led to the highest individual muscle activation, while driving close to the wheel significantly reduced muscle forces (7.8%BW to 3.1%) and joint force. The study also identified the six most active muscles during right steering in different driving positions. The six most active muscles: trapezius medial head, triceps medial head, deltoid medial head, supraspinatus, infraspinatus, and long head of biceps are presented during right steering in the four different driving positions
Lin et al., 2022	outdoor motion analysis; For each pitching task, reflective markers were attached to the participants and tracked by a motion capture system (Motion Analysis Corporation, Santa Rosa, CA, USA) that comprised 8 charge-coupled device cameras with a sampling frequency of 300 Hz. The ball velocity in each pitch was measured using a radar gun (Jugs Sports International Distributors, Tualatin, OR, USA). The position of the tracked markers was then used for the estimation of joint centers, 3-dimensional body-segment locations, kinematics, and kinetics during each pitching task.	The kinematic parameters included stride knee flexion angle, pelvic axial rotation angle, trunk axial rotation angle, throwing shoulder horizontal abduction/adduction angle, vertical abduction/adduction angle, and external/internal rotation angle.	The shoulders of throwers in the early trunk rotation (ETR) group showed pathokinematics of ''horizontal adduction lag'' and ''dropped elbow.'' The increases in maximal posterior force, inferior force, horizontal abduction moment, and vertical adduction moment were 9.2%, 13.6%, 21.3%, and 24.3%, respectively, in the shoulders of throwers in the ETR group. These results indicate that ETR may be hazardous for the throwing shoulder. With lower ball velocity and higher shoulder joint loading, ETR is not a proper pitching pattern for kinetic energy transfer. Conclusion: Improper pitching mechanics among baseball throwers, such as ETR, may result in higher shoulder joint loading and increased risk of shoulder injuries. When treating throwers with shoulder injuries, it is important not only to address shoulder anatomy and pathology but also to understand the possible pathomechanics and pathogenesis of the shoulder caused by ETR. ball velocity was faster in the non-ETR group (127 km/h) than it was in the ETR group (120 km/h).	The study found that improper pitching mechanics, specifically "Early Trunk Rotation" (ETR), may increase the risk of shoulder injuries among baseball throwers. The ETR group showed pathokinematics of "horizontal adduction lag" and "dropped elbow," which resulted in lower ball velocity and higher shoulder joint loading. The ETR group also exhibited a greater shoulder horizontal abduction angle and a more elevated shoulder vertical abduction angle initially, followed by a drop. The ETR group had significantly increased values of maximal posterior force, inferior force, horizontal abduction moment, and vertical adduction moment compared to the non-ETR group, indicating that ETR may be hazardous for the throwing shoulder. Therefore, when treating throwers with shoulder injuries, it is important to understand the possible pathomechanics and pathogenesis of the shoulder caused by ETR.
Manzi et al., 2022 (1)	The 8-camera Raptor-E motion analysis system (Motion Analysis Corp, Santa Rosa, CA, USA) was collected at 480 Hz. Non-normalized kinetics were collected while all forces were also normalized by individual pitcher's weight (BW) (kilograms x meters per second squared); torque values were normalized by each player's weight x body height (BH) (kilograms x meters per second squared x meters).	shoulder abduction, shoulder horizontal adduction, shoulder external rotation, During the arm cocking phase, the following peak kinetic values were compared between subgroups: shoulder internal rotation torque, shoulder horizontal adduction torque, shoulder superior force, shoulder anterior force, elbow varus torque, and elbow medial force. Peak elbow anterior force and elbow flexion torque were compared during the arm acceleration phase. Peak shoulder adduction torque, shoulder distractive force, and elbow distractive force were compared during the arm deceleration phase.	The CM/ST subgroup had significantly less shoulder abduction than the NPI cohort (88 ± 8 vs. 94 ± 8◦ respectfully, $p = 0.037$). Shoulder external rotation at ball release did not differ between groups (NPI: 85 ± 13◦; GCG: 84 ± 13◦, $p= 0.704$; CM/ST: 85 ± 10◦, $p = 0.775$; Spine or Back: 87 ± 16◦, $p =0.700$), nor did ball velocity (NPI: 38.9 ± 1.6 m/s, GCG: 38.3 ± 2.0 m/s, CM/ST: 38.4 ± 2.1 m/s, Spine or Back: 38.8 ± 1.2 m/s; $p \geq 0.316$). The CM/ST subgroup had significantly greater normalized elbow anterior force (44.5 ± 4.3 vs. 40.0 ± 5.2 %BW, $p = 0.031$), elbow flexion torque (4.4 ± 0.4 vs. 3.8 ± 0.5 %BWxBH, $p = 0.002$) and normalized (9.5 ± 1.4 vs. 7.9 ± 1.9 %BWxBH, $p = 0.007$) as well as non-normalized (170.1 ± 34.8 vs. 141.6 ± 38.3 N•m, $p = 0.019$) shoulder adduction torque than the NPI pitchers. Core Musculature/Soft Tissue subgroup (CM/ST); No Prior Injury (NPI); General Core/Groin injury group (GCG); BodyWeight (BW); Body Height (BH); Non-Normalized (N or N•m)	The study found that pitchers with a CM/ST pitching style had significantly greater normalized elbow anterior force, elbow flexion torque, and shoulder adduction torque than NPI pitchers. However, the CM/ST subgroup had significantly less shoulder abduction than the NPI cohort. Shoulder external rotation at ball release did not differ between groups, nor did ball velocity. The CM/ST subgroup also had greater non-normalized shoulder adduction torque than the NPI group.

Cross et al., 2022	long-armed clinical goniometer (Jamar) + Biodex 3	shoulder internal and external rotation range of motion peak isokinetic internal and external rotator strength peak isometric internal and external rotator strength. normalized peak shoulder compressive force (nSCF) normalized peak shoulder IR torque (nSIRT), Clinical measures included ROM (ER, IR, and total), isokinetic measures (ERcon, ERecc, IRcon, IRecc, ERcon/IRcon, ERecc/IRecc, and ERecc/IRcon), and isometric measures (ERi, IRi, and ERi/IRi).	Five significantly strong correlations were found between nSCF and strength, including IRi, ERi/IRi, and ERcon at 90°/s, ERcon at 180°/s, and IRcon at 180°/s Four significantly strong correlations were found between pitching velocity and strength, including ERi, IRi, and ERcon at 90°/s and ERcon at 180°/s No significant correlations were found between nSIRT and clinical measures.	The study found significant correlations between peak shoulder compressive force and pitching velocity with shoulder rotational strength. No significant correlations were found between range of motion and pitching kinetics or velocity. The study suggests that knowledge of these relationships may allow for improved strength training routines with the goal of increasing velocity without increasing injury risk. The study involved 13 healthy male college pitchers with an average pitching velocity of 34.5 m/s, and correlations were investigated between clinical measures of arm strength and range of motion and biomechanics of the pitching motion. Five significant correlations were found between peak shoulder compressive force and strength, and four significant correlations were found between pitching velocity and strength.
Skovlund et al., 2022	surface electromyography (sEMG) and video recordings during the workday to determine the influence of lifting height and load mass on muscular workload of the low-back and neck/shoulder muscles during un-restricted manual material handling (grocery stocking)	neck/shoulder muscles lifting task in supermarket	Significant effect of load mass and start and end position of the lifts for both the low-back and neck/shoulder muscles ($p < 0.001$). Thus, increments in load mass were generally associated with higher muscular workload of the low-back and neck/shoulders. All load mass intervals differed significantly in terms of neck/shoulder muscular workload, expect for the 5–10 kg and 10–15 kg intervals. Albeit the differences were generally minor compared with the differences between the load mass intervals, there were significant differences in low-back and neck/shoulder muscular workload between all lifting start and end positions. A 'High' start and/or end position demonstrated the highest muscular workload of the neck/shoulders, whereas differences between lifting heights were less pronounced and generally more modest for the low-back muscles. Lifts performed at 'High' start or end positions generally associated with higher neck/shoulder muscular workloads compared to lifts that did not involve 'High' start or end positions.	This study found a significant effect of load mass, i.e., higher loads associated with higher muscular workload in the low-back and neck/shoulder muscles. It demonstrated a significant interaction between start and end position, i.e., lifts performed from 'Low' start positions to 'High' end positions demonstrated the highest low-back muscular workload, whereas 'High' positions were associated with increased neck/shoulder workload. In conclusion, lifting higher loads and lifting goods from low to high positions (low-back) and at high positions (neck/shoulder) are associated with higher muscular workload. These results can be used to guide highly warranted preventive initiatives to reduce the physical workload during supermarket work.
O'Sullivan et al., 2022	Maximum shoulder and elbow joint torques using a dynamometer. OMRON BF511 Body composition Monitor was used to measure the body's composition parameters.	Two seated testing positions were selected. The maximum force produced at the shoulder joint was tested with the arm outstretched straight ahead in supination with the shoulder, wrist and elbow joints in alignment. The maximum force produced at the elbow joint was tested with the elbow joint flexed 90° relative to the upper arm on the coronal plane, and the palm in supination. shoulder and elbow maximum at 2 different seated positions. The participants were asked to perform a maximal voluntary contraction as they pressed against the dynamometer in the shoulder testing position One-minute rest between recordings and the average value was used in the analysis. T is torque [Nm], F is the force [N] detected by the dynamometer and d is the length [m] from the acromion to mid-palm	Height and upper forearm volume were found to influence maximum shoulder and elbow joint torques Models to estimate maximum shoulder and elbow joint torques were created using regression analysis. The models enable joint torque estimation for individuals using basic anthropometric measurements and do not require testing with a dynamometer. From the regression analysis, the parameters that have the greatest impact on maximum torque of the shoulder and elbow joints torque were known, males and females could be combined, and separate models for the maximum torque estimation of the shoulder and elbow joints could be created. The mean maximum shoulder joint torque was 47.69Nm and the standard deviation of the residuals was 13.05Nm for the shoulder.	This study found that height and upper forearm volume had an impact on maximum shoulder and elbow joint torques in individuals. Regression analysis was used to create models for estimating joint torques based on basic anthropometric measurements, without requiring dynamometer testing. Separate models were created for males and females and for shoulder and elbow joints.
Manzi et al., 2022 (2)	8-camera Raptor- E motion analysis system (Motion Analysis Corp)	Baseball fastballs throw	Peak normalized shoulder internal rotation torque (5.5% ± 1.0% vs 4.9% ± 0.7% body weight [BW] × body height [BH]; P = .008) was significantly greater for the low-accuracy group compared with the high-accuracy group. When comparing between the low-accuracy and high-accuracy groups, lead knee flexion at maximum shoulder external rotation (46.7 ± 13.5vs 38.9 ± 13.3 respectively; P = .028) and ball release (40.1 ± 16.3 vs 30.6 ±17.8 respectively; P= .023) were significantly greater in the low-accuracy group. The moderate-accuracy group had significantly greater trunk flexion at foot contact compared with the high-accuracy group (11.5 ± 12.6 vs 6.2 ±10.2 respectively; P = .031). Peak normalized shoulder internal rotation torque (5.5% ± 1.0% vs 4.9% ± 0.7% BW × BH; P = .008) was significantly greater for the low-accuracy group compared with the high-accuracy group. The low-accuracy group had significantly higher peak normalized shoulder internal rotation torque (5.5% ± 1.0% vs 5.0% ± 0.8% BW × BH; P = .031) than the moderate-accuracy group.	The study found that peak normalized shoulder internal rotation torque, normalized elbow varus torque, and normalized elbow medial force were significantly greater in the low-accuracy group compared to the high-accuracy group. Lead knee flexion at maximum shoulder external rotation and ball release were also significantly greater in the low-accuracy group. The moderate-accuracy group had significantly greater trunk flexion at foot contact compared to the high-accuracy group. The study also plotted values at key time points for comparison between subgroups. Low-accuracy group vs High-accuracy group: . Lead knee flexion at maximum shoulder external rotation was significantly greater in the low-accuracy group. . Ball release was significantly greater in the low-accuracy group. . Peak normalized shoulder internal rotation torque, normalized elbow varus torque, and normalized elbow medial force were significantly greater in the low-accuracy group. Moderate-accuracy group vs High-accuracy group: . Trunk flexion at foot contact was significantly greater in the moderate-accuracy group. . Peak normalized shoulder internal rotation torque, normalized elbow varus torque, and normalized elbow medial force were significantly greater in the low-accuracy group compared to the high-accuracy group.
Solomito et al., 2013	A fourth-order zero lag Butterworth filter with a cutoff frequency of 15 Hz was used to smooth the raw maker data used for joint kinematics. An additional 2 markers were placed on the ball to calculate ball speed and joint kinetics. Joint kinetics were calculated using standard inverse dynamic techniques written into custom Matlab code. Motion data were collected at 250 Hz using a Vicon 512 12-camera motion system (Vicon Motion Systems, Los Angeles, California, USA).	GH vertical AB/AD; GH rotation; GH horizontal AB/AD; Elbow Flx/Ext	The greatest glenohumeral and elbow moments were found when pitchers were pitching the fastball (mean + standard deviation: 80.8 + 15.5 and 79.2 + 16.9 Nm, respectively) and the lowest when pitching the change-up (73.2 + 14.5 and 71.6 +15.0 Nm, respectively). The moments produced by the slider/cutter and curveball were similar (74.9 +16.4 and 75.6 +15.5 Nm at the elbow, respectively) and significantly lower than the moments produced by the fastball ($P < .0001$). Peak moments at the elbow and glenohumeral joint were significantly greater with the fastball than for the other pitch types. The fastball generated the greatest peak elbow varus moments and peak glenohumeral internal rotation moments (79.2 + 16.9 and 80.8 + 15.5 Nm, respectively), while peak elbow and glenohumeral moments were lowest with the change-up (71.6 + 15.6 and 73.2 + 14.5 Nm, respectively). The peak elbow varus moment was significantly higher for the curveball and the slider/cutter compared with the change-up; however, the fastball still showed the greatest moments. The peak elbow and glenohumeral joint moments with the fastball were approximately 5% greater than with the curveball or slider and almost 10% greater than the change-up. The curveball and slider/cutter show very similar moments at these joints.	The study found that the greatest shoulder and elbow moments occurred when pitching the fastball and the lowest when pitching the change-up. The fastball also generated the greatest peak elbow varus moments and peak glenohumeral internal rotation moments. The curveball and slider/cutter had similar moments at these joints and were significantly lower than the moments produced by the fastball. Peak elbow and glenohumeral joint moments with the fastball were approximately 5% greater than with the curveball or slider and almost 10% greater than the change-up.

Goubault, et al., 2020	Participants were equipped with 10 electromyographic electrodes to record shoulder muscle activity during a manual handling task consisting of lifting a box (8 or 12 kg), instrumented with three six-axis force sensors, from hip to eye level. Three- dimensional trunk and upper limb kinematics, hand- to- box contact forces, and EMG were recorded. Then, joint contributions, activation levels, and muscle forces were calculated and compared between groups.	The participants were asked to move an instrumented box (height × width × length: 20.5 × 37.7 × 30.5 cm) from a table (height: 73 cm) to a storage shelf adjusted at each participants' eye level (height: 166.4 ± 3.2 cm), without any instruction on the working technique required to perform the lifting task. The table and the shelf were facing each other and separated by 1 meter. Shoulder Flx, Abd; Prone ext; External rotation	Sternoclavicular–acromioclavicular joint contributions were higher in experts at the beginning of the movement, and in novices at the end, whereas the opposite was observed for the glenohumeral joint. EMG activation levels were 37% higher for novices but predicted muscle forces were higher in experts. Sternoclavicular–acromioclavicular joint contribution was 8% lower in novices between 0% and 45% trial (pulling and lifting phases; ES = .57 [medium]; p < .001) and became 5% higher between 65% and 89% trial (deposit phase; ES = .43; p < .001). The glenohumeral joint contribution was 9% higher in novices between 48% and 58% trial (lifting phase; ES = .40; p = .001) and 9% lower between 77% and 99% trial (deposit phase; ES = .50; p < .001). Novices lifted the box earlier and held the box in a more elevated position longer (significant difference in box elevation between 28% and 79% trial [lifting and deposit phases; ES = .53 (medium); p < .001]). Note that at the end of the deposit phase, novices held the box slightly lower than experts (significant difference in box elevation between 90% and 97% trial [ES = .47; p = .025]). Novices held the box 1% further from their body between 33% and 55% trial (lifting phase; ES = .53 [medium], p = .001). At the end of the deposit phase (between 86% and 99% trial), novices kept the box 5% closer to their body (ES = .58 [medium], p = .001).	The study found that the contributions of different joints to lifting movements varied between novices and experts, with novices showing higher activation levels in EMG but lower predicted muscle forces. Pelvo-thoracic joint contributions were higher in novices at the beginning and end of the movement, while sternoclavicular-acromioclavicular joint contributions were higher in experts at the beginning and in novices at the end. The glenohumeral joint contribution was higher in novices during the lifting phase but lower during the deposit phase. Novices also lifted the box earlier, held it in a more elevated position longer, and kept it further from their body during the lifting phase, but held it closer to their body at the end of the deposit phase compared to experts. There was no mass-expertise interaction observed except for a slightly higher pelvo-thoracic joint contribution with the heavier box. These findings suggest that shoulder kinematics, EMG, and muscle forces could be used as ergonomic tools to identify inappropriate techniques and reduce the risk of shoulder injuries.
Thompson et al., 2017	Literature search	baseball pitching For shoulder horizontal motion, a positive value indicates the elbow is in front of the shoulder in the coronal plane, and a negative value indicates the elbow is behind the shoulder in the coronal plane. Individual data points were extracted from each study to compare all measured parameters, and the data were then aggregated to present an overall range from the included studies.	In studies of healthy youth baseball pitchers, progressive external rotation of the shoulder occurs throughout the start of the pitching motion, reaching a maximum of 166° to 178.2°, before internally rotating throughout the remainder of the cycle, reaching a minimum of 13.2° to 17°. Stride length is 66% to 85% of pitcher height. In comparison with a fastball, a curveball demonstrates less elbow varus torque (31.6 ± 15.3 vs 34.8 ± 15.4 N·m).	Studies show that maximum elbow valgus torque occurs just prior to maximum shoulder external rotation, with greater forces on the elbow and shoulder for the fastball compared to the curveball. In healthy youth baseball pitchers, progressive external rotation of the shoulder occurs throughout the start of the pitching motion before internally rotating throughout the remainder of the cycle, while elbow valgus torque reaches its highest level just prior to maximum shoulder external rotation and decreases throughout the rest of the pitch. Stride length is typically 66% to 85% of pitcher height, and a curveball shows less elbow varus torque than a fastball.
Chalmers et al., 2017	A review of current concept	Overhand baseball pitching	The pitching motion is a kinetic chain, in which the force generated by the large muscles of the lower extremity and trunk during the wind-up and stride phases are transferred to the ball through the shoulder and elbow during the cocking and acceleration phases. Numerous kinematic factors have been identified that increase shoulder and elbow torques, which are linked to increased risk for injury. Altered knee flexion at ball release, early trunk rotation, loss of shoulder rotational range of motion, increased elbow flexion at ball release, high pitch velocity, and increased pitcher fatigue may increase shoulder and elbow torques and risk for injury. In conclusion, several mechanical factors correlate with pitch injury: elbow valgus torque, knee flexion at front foot contact, pitcher fatigue, early thoracic rotation with loss of separation of the hips and shoulders and decrease in shoulder rotational range of motion. These factors can decrease pitch velocity and produce pitcher fatigue, leading to injury.	Motion analysis allows the calculation of in vivo kinetics. Within the upper extremity, kinetics are derived from inverse dynamics, which assume the human body is composed of inflexible segments linked at joints. Markered motion analysis with reflective markers has been used for most pitching motion analysis because of the accuracy, speed, and ease of data collection. Muscular activation can be measured with electromyography in synchrony with pitcher motion. Studies have demonstrated that pitching requires whole-body coordination, with precisely timed and balanced muscular coactivation of nearly every muscle group, including antagonists from the lower extremity, to the trunk, shoulder musculature, and forearm musculature These results suggest that neuromuscular activation plays a critical role in the normal pitching motion.
Barnamehei et al., 2020	The shoulder musculoskeletal model developed in OpenSim which includes 5 segments, 10◦ of freedom, 26 muscle-tendon units. The inverse kinematics was used to evaluate joint kinematics during OFS. Ten Vicon high-speed motion analysis cameras (Vicon MX, Oxford Metrics, United Kingdom, sampling frequency 200 Hz) and two force plate (Kistler, Winterthur, Switzerland, sampling frequency 2000 Hz) The trajectories of sixty surface reflective markers were filtered via fourth-order, low pass, Butterworth with cut-off frequency 10 Hz. EMG system (wireless Myon EMG system made in Switzerland with sampling frequency 2000 Hz) for electromyography muscle activities from five selective muscles: the biceps brachii, the infraspinatus, the supraspinatus, middle deltoid, and serratus anterior. The EMG, kinematic, and kinetics (force plate) data were recorded synchronously via Vicon Nexus software (Vicon, Oxford Metric, UK). The Joint Reaction tool in the OpenSim analysis tool was utilized to estimate joint reaction	badminton overhead forehand smash (OFS) angular position and angular velocity of the shoulder and elbow joint in flexion-extension, abduction-adduction, and rotation axis during the badminton overhead forehand smash executed by professional and amateur groups. shoulder extension-flexion, abduction-adduction, and internal-external rotation angles.	Significant differences between amateur and professional groups were observed for all muscles (p < 0.05) excepts for anterior deltoid (p = 0.558), subscapularis (p = 0.772), teres minor (p = 0.965), and coracobrachialis muscles (p = 0.097). Significant differences between amateur and professional groups all joint reaction forces were observed. The results of peak compressive joint reaction forces for the professional group from generic and scaled-generic (482.58 and 479.68, respectively) were higher than the amateur group (384.61 and 384.59, respectively). The results of mean superior joint reaction forces for the professional group from generic and scaled-generic (334.41 ± 112.51 and 331.34 ± 118.54, respectively) were higher than the amateur group (200.55 ± 98.41 and 200.53 ± 98.38, respectively). The root mean square error (RMSE) values were 0.41 ± 0.04, 0.46 ± 0.04, 0.32 ± 0.18, 0.29 ± 0.17, and 0.34 ± 0.11 for the biceps brachii, the infraspinatus, the supraspinatus, middle deltoid, and serratus anterior, respectively. In addition, adjusted R-squared were 0.68 ± 0.39, 0.80 ± 0.04, 0.78 ± 0.27, 0.61 ± 0.43, and 0.77 ± 0.11 for the biceps brachii, the infraspinatus, the supraspinatus, the middle deltoid, and the serratus anterior, respectively. RMSE values lower than 0.5 displays that the model can reasonably estimate the results truly. R-squared values of more than 0.75 is a very good value for presentation accuracy. R-squared values of the infraspinatus, the supraspinatus, and the serratus anterior only were more than 0.75. R-squared values of the biceps brachii and the middle deltoid muscles were lower than 0.75.	There were observed differences in amplitude and time between professional and amateur groups, affecting various muscle forces differently. While both groups showed small differences in the subscapularis, teres minor, and teres major muscles, there were large significant differences noted in most other muscles. The exceptions to this were the supraspinatus, teres minor, and coracobrachialis muscles, where the differences remained small. The major disparities were found in the lower and upper pectoralis major, teres major, and both the anterior and posterior deltoid muscles. The study examined the joint and muscle forces during the overhead forehand smash (OFS) in badminton for both amateur and professional athletes. The results showed significant differences in joint and muscle forces between generic and scaled-generic models, as well as between amateur and professional players. The study suggests that coaches and trainers can use this information to design effective training programs to improve athlete performance. The study also found differences in the timing and amplitude of joint angular velocities between the two groups. The root mean square error values and adjusted R-squared values for EMG data were also reported. The study suggests that this information can be used to identify high-risk sequences and joints in OFS and to validate the results of musculoskeletal modeling.

	load in the upper limb during OFS. Joint reaction load includes forces and moments were estimated for every five segments			

Table 5-3 Summary of Load Reduction /Injury Prevention Strategies

Study	Injury prevention
Megan Dutton et al 2022	To prevent injury during overhead throwing in cricketers, the following strategies can be implemented based on the findings of the study: 1. Consider using a run-up approach during throwing: The study found that using a run-up approach resulted in quicker arm acceleration and follow-through, which could help to reduce the risk of injury. 2. Focus on hip and lumbo-pelvic flexion: The study showed differences in hip and lumbo-pelvic flexion between the two approaches. Increasing hip and lumbo-pelvic flexion during throwing could help to reduce the risk of injury. 3. Optimize load distribution between shoulder and elbow muscles: The study found that different approaches resulted in different load distribution patterns in the shoulder and elbow muscles. Optimizing the load distribution could help to reduce the risk of injury. 4. Ensure proper technique and biomechanics during throwing: Proper technique and biomechanics during throwing are important for preventing injury. Coaches and trainers should work with cricketers to ensure that they are using proper technique and biomechanics during overhead throwing. Overall, to prevent injury during overhead throwing in cricketers, a combination of proper technique, biomechanics, load distribution, and approach may be necessary.
Kenzie et al 2022	To prevent injury to the shoulder joint in high school softball pitchers, the sequencing of segment motion between the relative forearm and upper arm segments should be examined to potentially minimize the risk of injury at the shoulder joint. The study also suggests that the increased elbow extension moment might further point to the biceps tendon as a location of injury and anterior shoulder pain among softball pitchers. Therefore, it is important to consider the role of the biceps tendon in assisting with shoulder and elbow flexion during the acceleration phase of the pitch. Additionally, greater elbow flexion velocity may have the potential to decrease movement of the upper arm segment and may subsequently decrease throwing shoulder distraction force, which could help reduce the risk of injury.
Lasse Mausehund et al 2021	The text contains several suggestions to prevent injury to the shoulder during bench press exercise. 1. Varying the lifting technique: The study found that experienced lifters tended to use a more vertical bar path, while less experienced lifters tended to use a more horizontal bar path. Using a vertical bar path may help prevent shoulder injuries during bench press. 2. Optimizing load distribution: The study found that women showed higher normalized peak elbow NJMs and mean elbow to shoulder NJM ratios than men, suggesting that optimizing the load distribution between the shoulder and elbow muscles could improve bench press performance and reduce the risk of shoulder injury. 3. Choosing grip width: The study suggests that the choice of grip width could be a technical factor affecting performance. Choosing the right grip width may help prevent shoulder injuries during bench press. 4. Avoiding powerlifting style bench press: The study found that performing a powerlifting style bench press might be suboptimal for strength adaptations and hypertrophy compared with a standard bench press. Therefore, it might be better to avoid powerlifting style bench press to reduce the risk of shoulder injuries.
KENZIE B. FRIESEN et al 2021	Based on the text, one way to prevent injury to the shoulder in baseball pitchers is to monitor their body composition. The study by Friesen and Oliver found that higher levels of body fat mass were associated with increased shoulder joint forces during the pitching motion, which could increase the risk of injury. Therefore, tracking and managing the body fat mass of baseball pitchers could be a key factor in reducing the risk of injury to their shoulder. Additionally, implementing proper training and conditioning programs, as well as monitoring pitch count and rest time, could also help prevent shoulder injuries in baseball pitchers.
André V. Brito et al 2022	1. Based on the text, there are several measures that can be taken to prevent shoulder injury in tennis players. The study found that long-term accumulated loads in different sports can lead to body asymmetries and upper-dominant limb dominance, which may increase the risk of injury. Therefore, coaches should be mindful of this and work to correct any imbalances through exercises and training programs that promote symmetrical development. 2. In addition, peripheral fatigue caused by unilateral and repeated tennis movements can cause disturbances in the player's performance, which may increase the risk of injury. Therefore, coaches should ensure that players have adequate rest periods and avoid overloading the shoulder joint with too many repetitions. 3. Furthermore, reducing the number of repetitions may also help reduce the risk of injury. The study found that after ten forehands, total work, maximal repetition total work, average power, average peak torque, and range of motion decreased, which may indicate fatigue and an increased risk of injury. Therefore, coaches should work with players to develop training programs that balance the number of repetitions with adequate rest periods to prevent fatigue and reduce the risk of injury. 4. Finally, coaches should emphasize proper technique and form to prevent unnecessary strain on the shoulder joint. This can include working on the player's range of motion, grip, and follow-through to ensure that the shoulder joint is properly aligned during forehand actions. Overall, the study suggests that coaches can play an important role in preventing shoulder injuries in tennis players by monitoring their training programs, correcting imbalances, managing fatigue, and emphasizing proper technique.
Alexander E. Weber et al 2014	Based on the given text, several measures can be taken to prevent shoulder injury in throwing athletes: 1. Proper activation of the anterior and medial deltoids, supraspinatus, and clavicular head of the pectoralis major during the wind-up phase to maintain the abducted and flexed position of the shoulders. 2. Strengthening of major elbow flexors, such as brachialis, biceps brachii, brachioradialis, to maintain the flexed position of the elbows during the wind-up phase. 3. Optimizing the strength and minimizing shoulder impingement during the arm acceleration phase by maintaining 90 degrees of coronal arm abduction. 4. Strengthening of the rotator cuff musculature to counteract GH distraction during the arm deceleration phase. 5. Generation of a posteriorly directed shoulder force of 400±90N to resist horizontal adduction and decelerate the arm during the arm deceleration phase. 6. Strengthening of the shoulder passive restraints to create a horizontal abduction torque of up to 97±25Nm to resist anterior translation of the humerus in relation to the glenoid during the arm deceleration phase.
Hamidreza Barnamehei et al 2020	To prevent shoulder joint injuries in badminton players, it is recommended to design training programs and injury prevention strategies based on the findings of this study. Since the study found that professional badminton players are at a higher risk of shoulder joint injuries compared to amateur players due to higher mean and peak glenohumeral joint reaction forces, it is important to ensure that the players are properly trained to handle the biomechanics of the overhead forehand smash. Coaches and trainers can work on improving the technique of players and adjust training intensity based on the skill level of the players to avoid excessive muscle and joint reaction forces. It may also be helpful to use subject-specific

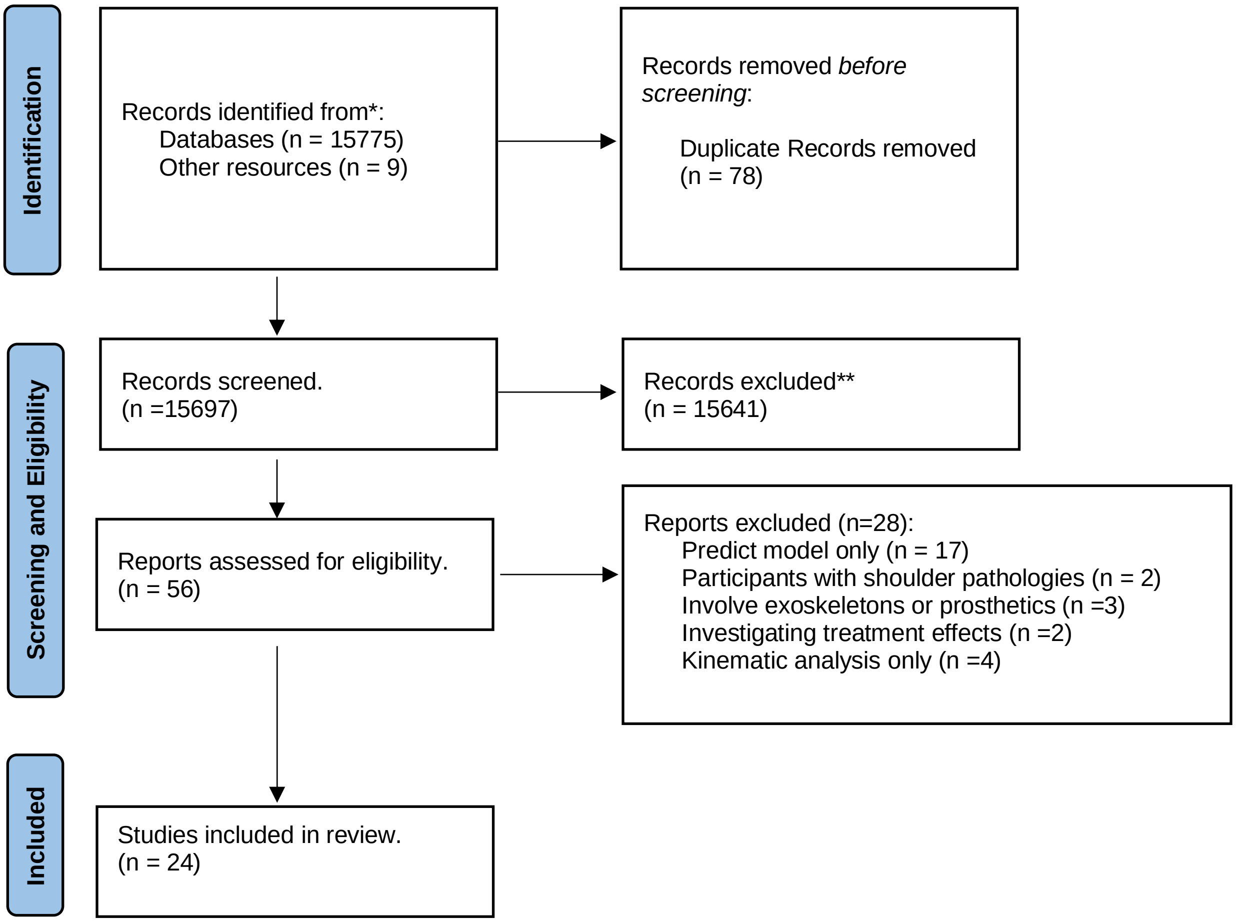
	musculoskeletal models for more accurate estimation of muscle forces. Additionally, players should be encouraged to warm up and stretch properly before playing and to use proper equipment, such as rackets that are suitable for their skill level and style of play, to reduce the risk of injury.
Chalmers et al., 2017	The text provided is related to the risk factors that increase the chances of shoulder injury in pitchers. However, it does not mention any specific measures that can be taken to prevent shoulder injury. Based on the text, the risk factors for shoulder injury during the pitching motion are: 1. Altered knee flexion at ball release 2. Early trunk rotation 3. Loss of shoulder rotational range of motion 4. Increased elbow flexion at ball release 5. High pitch velocity 6. Increased pitcher fatigue 7. Elbow valgus torque 8. Decrease in shoulder rotational range of motion 9. Early thoracic rotation with loss of separation of the hips and shoulders. 10. These factors increase shoulder and elbow torques and can lead to injury.
Thompson et al., 2017	The text does not provide specific recommendations for preventing shoulder injury. However, it does provide information on the forces and motions involved in pitching that contribute to the risk of shoulder injury. With this information, coaches, trainers, and pitchers can work together to modify pitching mechanics, limit pitch counts and intensity, and incorporate proper rest and recovery into training programs to reduce the risk of shoulder injury. Additionally, strengthening exercises and proper warm-up and cool-down routines can also help to prevent injury.
Solomito et al., 2013	1. Change-up generate the slowest speed. 2. Pitchers can prevent injury to the shoulder by reducing the number of fastballs they pitch. 3. Fastballs generated the greatest peak elbow varus moments and peak glenohumeral internal rotation moments, which can lead to injury. 4. The moments produced by the change-up were lower than the fastball and may be a safer pitch to use. 5. The curveball and slider/cutter had similar moments and were lower than the fastball, but still higher than the change-up.
Manzi et al., 2022	There is no clear recommendation or suggestion for injury prevention in the given text. The text mainly presents findings of a study comparing the pitching mechanics and accuracy between low-accuracy, moderate-accuracy, and high-accuracy groups of pitchers. The text reports several measurements related to shoulder and elbow torque and force, trunk flexion, and knee flexion at various key time points during the pitch.
Skovlund et al., 2022	1. Avoid lifting higher loads, as they are associated with higher muscular workload in both the low-back and neck/shoulder muscles. 2. Avoid lifting goods from low to high positions (low-back) or at high positions (neck/shoulder), as these positions are associated with higher muscular workload. 3. Use preventive initiatives to reduce physical workload during supermarket work, based on the study's results. 4. Be aware of the significant effect of load mass and start and end position of lifts on both the low-back and neck/shoulder muscles. 5. Consider the differences in low-back and neck/shoulder muscular workload between lifting start and end positions when planning lifting activities. 6. Avoid lifts performed from 'Low' start positions to 'High' end positions, as they demonstrate the highest low-back muscular workload. 7. Consider lifting heights, as 'High' start or end positions are generally associated with higher neck/shoulder muscular workloads compared to lifts that did not involve 'High' start or end positions.
Manzi et al., 2022	1. Focus on exercises to improve shoulder abduction. 2. Decrease elbow anterior force, elbow flexion torque, and shoulder adduction torque. 3. Work with a trainer or physical therapist to develop a strength training program targeting these areas. 4. Maintain pitching velocity while improving shoulder strength and reducing torque on the elbow and shoulder joints
Lin et al., 2022	Based on the text, here are some measures that can be taken to prevent injury to the shoulder: 1. Avoid using improper pitching mechanics, such as ETR, as they can result in higher shoulder joint loading and increased risk of shoulder injuries. 2. Work on proper pitching mechanics, including achieving the proper shoulder horizontal adduction angle in the acceleration phase and avoiding horizontal adduction lag, which can cause breakdown of the kinetic chain. 3. Address shoulder anatomy and pathology, and understand the possible pathomechanics and pathogenesis of the shoulder caused by improper pitching mechanics like ETR. 4. When treating throwers with shoulder injuries, focus not only on addressing shoulder anatomy and pathology but also on understanding the possible pathomechanics and pathogenesis of the shoulder caused by improper pitching mechanics like ETR. 5. Consider working with a trainer or physical therapist to develop a strength training program that targets areas such as improving shoulder abduction and reducing elbow anterior force, elbow flexion torque, and shoulder adduction torque. 6. Maintain pitching velocity while working on proper pitching mechanics and avoiding improper pitching mechanics like ETR.

Study	Injury prevention
Germain Faity et al 2021	Based on the findings of the study, to prevent injury to the shoulder during reaching, it may be helpful to take into consideration the role of the trunk in stabilizing the shoulder. Trunk involvement can increase when handling a heavy weight, and trunk restraint may reduce antigravity shoulder torque. Thus, it may be beneficial to include trunk stabilization exercises in rehabilitation or training programs for the shoulder. Additionally, individuals may be able to adapt to increased mechanical demands by reducing trunk recruitment, suggesting that gradual increases in weight or resistance may be helpful in preventing injury.
Philippe Gorce et al 2021	Based on the given text, to prevent injury to the shoulder during smartphone use, ergonomic interventions can be designed. The study suggests that increasing the weight of the smartphone and using a non-dominant hand increases shoulder joint torque and support reaction force. Therefore, using a lightweight smartphone and switching hands frequently can reduce the risk of shoulder injury. Additionally, the study found that shoulder abduction and elbow flexion were the most significant predictors of shoulder joint torque. Thus, individuals can avoid prolonged periods of arm abduction and elbow flexion while using their smartphones, which can help prevent shoulder injuries. Ergonomic interventions, such as using a smartphone stand or holder, can also reduce the strain on the shoulder joint and prevent injuries.
Colin Brown et al 2020	The text does not provide specific information on preventing shoulder injury in wheelchair propulsion. The study focuses on developing a validated, predictive computer simulation of wheelchair propulsion and optimizing the push time and torque required. However, a possible implication for injury prevention could be to consider the seat placement and optimize the technique to minimize the shoulder torque required during propulsion. Nonetheless, further research is needed to confirm this implication.
Anne-Sophie Saffert et al 2021	Based on the text, to prevent injury to the shoulder in violinists during legato-playing, it may be helpful to: 1. Focus on maintaining proper scapular upward rotation and posterior tilt to prevent excessive muscle activity in the upper trapezius and serratus anterior muscles. 2. Incorporate exercises or stretches to maintain proper external rotation of the humerus to reduce the risk of impingement syndrome. 3. Implement injury prevention and rehabilitation programs that specifically target the shoulder joint, such as shoulder strengthening exercises and shoulder mobility exercises. 4. Consider adjusting playing technique or positioning to reduce excessive demands on the shoulder joint during legato-playing. 5. Regularly monitor and assess shoulder health to catch any issues early on and prevent long-term damage.
Zohar Potash et al 2021	Based on the information provided, to prevent injury to the shoulder and low back, individuals should be cautious when removing, carrying, and depositing boxes of varying masses from shelves of varying heights. Specifically, individuals should pay attention to the distance between their lower back/shoulder joint and the box, as this distance is highly correlated with compression force and torque levels. It may also be important to ensure that lifting techniques minimize compression force to reduce the risk of injury, especially for individuals who have a higher risk of injury due to motion variability. Additionally, individuals should be aware that the quasi-static model used by DHM software may underestimate back torque, suggesting that alternative methods may need to be considered to accurately estimate torque levels during lifting tasks.
Xu Xu et al 2013	Based on the text, several measures can be taken to prevent shoulder injury among healthcare workers during medicine cart operations. First, reducing lane congestion can be helpful in minimizing peak shoulder joint moments during turning phases. Second, ensuring cart load stability can lower the peak shoulder joint moment and average shoulder elevation angle. Third, decreasing the distance from the starting position to the transition strip can help reduce the shoulder joint moment. Fourth, providing appropriate floor surface friction can also be helpful. Additionally, promoting proper posture and technique among healthcare workers, such as avoiding leaning into the cart, can also help prevent shoulder injuries. Overall, the study suggests that both environmental and user-related factors have significant effects on the risk of shoulder injury during medicine cart operations, and interventions targeting these factors can help prevent such injuries.
Petros Pandis et al 2015	1. Driving close to the wheel with bended elbow nearly 90 degrees. 2. Both hands on the wheel instead of one hand 3. Keep your hands below the "3 o'clock" and "9 o'clock" positions on the steering wheel when driving 4. Use left hand to turn right and vice versa. Same side of shoulder will experience the highest joint force during the turning (i.e. turn right cause highest force on the right shoulder joint) 5. Avoid twisting and awkward positions, such as reaching for objects in the back seat of a car from the front seat. 6. Use reacher to take out parking tickets 7. Strengthening exercises for the trapezius medial head, triceps medial head, deltoid medial head, supraspinatus, infraspinatus, and long head of biceps can also be beneficial in reducing the risk of injury during driving.
Goubault, et al., 2020	Experts solicited their lower limbs to a greater extent, limiting the contribution of the entire arm, while keeping the trunk in a more neutral position. This may represent a safer approach from the perspective of overuse injury prevention Based on the text, inappropriate techniques that could increase the prevalence of shoulder injuries include: 1. Novices lifting the box earlier and holding it in a more elevated position longer, which can increase the strain on the shoulder joint. 2. Novices holding the box further from their body during the lifting phase, which can increase the load on the shoulder joint. 3. Novices keeping the box too close to their body during the deposit phase, which can cause the shoulder to rotate inward excessively.
O'Sullivan et al., 2022	To prevent injury to the shoulder and elbow joints, models were created to estimate maximum joint torques using basic anthropometric measurements. Height and upper forearm volume were found to influence maximum shoulder and elbow joint torques. These models do not require testing with a dynamometer. The parameters that have the greatest impact on maximum torque of the shoulder and elbow joints were identified, and separate models for the maximum torque estimation of the shoulder and elbow joints were created. The mean maximum shoulder joint torque was found to be 47.69Nm with a standard deviation of 13.05Nm, while the mean maximum elbow joint torque was found to be 44.18Nm with a standard deviation of 14.22Nm.
Skovlund et al., 2022	1. Avoid lifting higher loads, as they are associated with higher muscular workload in both the low-back and neck/shoulder muscles. 2. Avoid lifting goods from low to high positions (low-back) or at high positions (neck/shoulder), as these positions are associated with higher muscular workload.

	3. Use preventive initiatives to reduce physical workload during supermarket work, based on the study's results. 4. Be aware of the significant effect of load mass and start and end position of lifts on both the low-back and neck/shoulder muscles. 5. Consider the differences in low-back and neck/shoulder muscular workload between lifting start and end positions when planning lifting activities. 6. Avoid lifts performed from 'Low' start positions to 'High' end positions, as they demonstrate the highest low-back muscular workload. 7. Consider lifting heights, as 'High' start or end positions are generally associated with higher neck/shoulder muscular workloads compared to lifts that did not involve 'High' start or end positions.

5.8 List of Figure

Figure 5-1. PRISMA Flow Diagram



5.9 Appendix

5.9.1 Search Keywords

Embase

1	biomechanics.mp. or biomechanics/	122113
2	shoulder.mp. or shoulder/	109255
3	shoulder joint.mp. or shoulder joint/	5047
4	Glenohumeral.mp.	8451
5	acromioclavicular joint/ or Acromioclavicular.mp.	3694
6	sternoclavicular joint/ or Sternoclavicular.mp.	2154
7	2 or 3 or 4 or 5 or 6	111814
8	joint loading.mp. or biomechanics/	112231
9	joint force.mp. or biomechanics/	111235
10	1 or 8 or 9	123442
11	7 and 10	6513
12	limit 11 to yr="2012 -Current"	3969

Ovid MEDLINE(R)

1	biomechanics.mp. or biomechanics/	113541
2	shoulder.mp. or shoulder/	59778
3	shoulder joint.mp. or shoulder joint/	17805
4	Glenohumeral.mp.	5512
5	acromioclavicular joint/ or Acromioclavicular.mp.	2128
6	sternoclavicular joint/ or Sternoclavicular.mp.	1105
7	2 or 3 or 4 or 5 or 6	61448
8	joint loading.mp. or biomechanics/	105838
9	joint force.mp. or biomechanics/	105391
10	1 or 8 or 9	114121
11	7 and 10	6143
12	limit 11 to yr="2012 -Current"	3631

Pubmed
(((biomechanics) OR (joint loading)) OR (joint force) AND ((y_10[Filter]) AND (review[Filter]))) AND (((((shoulder) OR (Glenohumeral joint)) OR (acromioclavicular)) OR (scapulothoracic)) OR (sternoclavicular) AND ((y_10[Filter]) AND (review[Filter]))) Filters: in the last 10 years

CINAHL
(MH "Shoulder Joint") OR (MH "Glenohumeral Joint") OR (MH "shoulder") AND "biomechanics AND joint load"

Web of Science
ALL=(biomechanics) AND ALL=(shoulder joint) AND ALL=(joint loading)

Google scholar
(((biomechanics) OR (joint loading)) OR (joint force) AND (((((shoulder) OR (Glenohumeral joint)) OR (acromioclavicular)) OR (scapulothoracic)) OR (sternoclavicular)

Chapter 6

6. Assessment of Shoulder Range of Motion Using Video-Based Movement Analysis Software - A Kinematic Analysis and Measurement Validation Study.

Abstract

Background: Shoulder arthritis, a common joint disorder causing inflammation and cartilage degeneration, can lead to pain, stiffness, and restricted range of motion. A joint protection program can be beneficial in reducing stress on the affected shoulder joint and improving function. Studying shoulder kinematics during daily activities is pivotal to this end, as it allows the identification and modification of movements that exacerbate the condition. Technologies like Dartfish, a 2D video-based motion analysis software, and MediaPipe, which excels in Pose Estimation and Hand Tracking, can be used to capture and track kinematic information.

Objectives: The primary aim was to describe shoulder movement patterns during Joint Protection Behaviour Assessment (JPBA) via video-based movement analysis. The secondary aim was to contrast natural shoulder movements and those performed post-education during joint behavior assessment. Lastly, we aimed to evaluate and compare the concurrence between Dartfish and MediaPipe in analyzing shoulder movement patterns.

Methods: This observational cross-sectional study examined the kinematic data of shoulder movements in individuals scheduled for shoulder replacement surgery. Two video-based motion analysis tools, Dartfish (video with user-driven software analysis) and MediaPipe (video with AI-driven software analysis), were employed to capture movements during JPBA tasks, emulating daily activities. Shoulder flexion, abduction, internal, and external rotation were recorded. Descriptive statistics were calculated as means and standard deviations. The paired sample t-test was employed to examine the disparity in movement patterns between participants' natural movement during the JBPA tasks and the modified pattern observed after joint protection education (the before-and-after measurements). By utilizing Bland & Altman plots with mean difference and the 95% limits of agreement (LoA), we summarized the measurement agreement of the shoulder flexion and abduction angles between Dartfish and MediaPipe.

Results: This study involved 13 participants waiting for shoulder joint replacement (8 males and 5 females) with a mean age of 60 years. The ROM required for each task varied. For moving a kettle near a sink, the average shoulder abduction was 22°, flexion was 23°, and rotation from an overview was 31°. When transferring the fry pan from a countertop to the sink's edge, the average motions were 19°, 26°, and 34° for abduction, flexion, and rotation, respectively. Moving the pan to a lower oven showed averages of 18° for abduction, 46° for flexion, and 44° for rotation. After educating participants on shoulder joint protection, significant reductions in movement arcs, approximately 7°, were observed for abduction and flexion during tasks involving the kettle and fry pan near the sink. Most measurements between Dartfish and MediaPipe showed non-significant mean differences with the majority of arc of motion differences remaining within a -5 to 5°.

Conclusion: The study's results suggested that participants were capable of adjusting their movement patterns to incorporate joint protection strategies immediately after instruction, which provides proof of principle that joint protection instruction can change kinematics. This may reduce joint loading if the new behaviours are maintained. Two different video-based kinematic assessment approach, user-driven and AI-driven, demonstrated sufficient precision and agreement for clinical assessment of activities of daily life.

Keywords: Shoulder arthritis, joint protection program, shoulder kinematics, daily activities, 2D video-based motion analysis software, MediaPipe, shoulder movement patterns, joint behavior protection assessment, measurement agreement

6.1 Introduction

Shoulder arthritis is a prevalent joint disorder characterized by the inflammation and degeneration of the cartilage lining the shoulder joint.[1,2] As a consequence, individuals experience pain, stiffness, and a restricted range of motion in the affected joint. The condition may develop either due to the natural wear and tear over time, referred to as osteoarthritis, or as a result of an autoimmune disorder, such as rheumatoid arthritis. [1,2] Additional factors contributing to shoulder joint arthritis include previous joint injuries, a family history of the condition, and repetitive use of the shoulder joint. [1,2] As the condition progresses, the cartilage gradually degrades, resulting in a rough and uneven surface, leading to joint stiffness, bland inflammatory condition, and pain. Furthermore, advanced stages of the condition may lead to the formation of bone spurs, further limiting mobility and causing additional discomfort.[1,3,4]

Managing shoulder joint arthritis typically involves a comprehensive approach, including medications, physical therapy, and lifestyle adjustments.[5] In severe cases, surgical intervention may be necessary to replace the damaged joint with an artificial one.[6] Early diagnosis and prompt treatment are essential in effectively managing shoulder joint arthritis and preserving joint function.[1,3,4]

To protect the affected joint and improve overall function, implementing a joint protection program for shoulder arthritis involves adopting various strategies to reduce stress on the shoulder joint.[7] For instance, implementing measures to avoid repetitive overhead motions and heavy lifting, as well as utilizing adaptive equipment, can effectively reduce stress on the affected shoulder joint.[7,8] Additionally, supporting the affected shoulder with a pillow or cushion while sitting or lying down can help alleviate pressure.[8]

Studying shoulder kinematics during daily activities is crucial in reducing shoulder pain from arthritis as it enables the identification and modification of movements that could worsen the condition. Certain movements, such as overhead shoulder motion, unsupported reaching, and repetitive shoulder movements, can exert additional stress on the already compromised joint, leading to increased pain and potential further damage.[7,9] By understanding and analyzing this kinematics, healthcare professionals can design personalized shoulder joint protection programs to alleviate stress on the affected joint, minimize discomfort, and prevent any additional harm.

Such tailored approaches empower individuals with shoulder arthritis to engage in activities that are less likely to aggravate their condition, improving their overall well-being and joint health.

Dartfish is a widely utilized 2D, video with user-driven software analysis, extensively employed in athletics to provide task-based feedback.[10] Offering a high level of detail, encompassing angles, displacement, and elapsed time, Dartfish assists athletes in enhancing their competitive performance. [10,11] Within the Dartfish software, kinematic information can be captured and tracked using two different methods: (1) the automatic marker function and (2) a distance calibration tool developed by the software developers. Previous studies have demonstrated Dartfish's reliability in evaluating various tasks across different assessment contexts. The motion estimates obtained with Dartfish are particularly valid for single plane movements.[11]

MediaPipe is a video with artificial intelligence (AI) - driven software analysis, Notably, MediaPipe excels in Pose Estimation, accurately determining human body poses in real-time, identifying essential points like joints and body parts. Additionally, it demonstrates proficiency in Hand Tracking, effectively recognizing hand gestures and movements, facilitating applications such as sign language recognition and virtual hand interactions.[12] However, it is important to note that as of the current iteration of MediaPipe has not been specifically designed or validated for the measurement of shoulder joint poses. We hypothesized that integrating biomechanics and motion tracking system data with the real-time tracking of MediaPipe could provide an efficient and user-friendly approach to provide clinicians and patients with more valid and accurate information about their shoulder kinematics.

The primary objective of this study was to utilize video-based analysis software to depict the kinematic information of shoulder movement patterns during JBPA. The secondary aim was to analyze and compare the kinematic changes observed in shoulder movements during JBPA between natural shoulder movement patterns and the shoulder movements performed after receiving education. The third objective was to assess and compare the measurement agreement between Dartfish and MediaPipe in analyzing the shoulder movement patterns.

6.2 Methods

6.2.1 Design

This research was a single session cross-sectional analysis, forming a segment of a extensive study examining shoulder movement across JPBA. The participants were conveniently selected from patients at the Roth|McFarlane Hand and Upper Limb Centre situated at St. Joseph's Healthcare, London, ON. Western University Health Science Research Ethics Board (HSREB-12608) and Lawson Health Research Board (ReDA-121356) approved this project.

6.2.2 Participants

The inclusion criteria are:

1. Age 50 years old or greater
2. Individuals who are on waiting list for shoulder replacement surgery
3. Fluency in English language to follow the instructions of the tests and interventions
4. Sufficient capacity to consent for participation

The exclusion criteria for this research are:

1. Any severe medical condition such as neurological disorders or other severe motion restriction that prohibits the participant from performing Fit-Hansa test and daily life activities

6.2.3 Study procedures

After obtaining informed consent, kinematic information, including shoulder flexion, abduction, internal, and external rotation, was collected from participants at the Hand and Upper Limb Centre Clinical Research Lab prior to shoulder joint replacement surgery.

Participants were instructed to carry out a series of shoulder movements following a new evaluative method that encompasses three distinct movement sequences, henceforth termed the Joint Protection Behavior Assessment (JPBA), detailed further in the subsequent sections. This JPBA method finds its roots in a validated assessment tool initially developed for individuals with hand arthritis, adapted here to focus on shoulder joint behaviors pertinent to the present study. Tasks deemed to necessitate minimal shoulder engagement were excluded from this assessment. The three activities selected were moving a kettle filled with water, moving a fry pan, and placing a fry pan into the oven. Four cameras were oriented to capture the shoulder movement from frontal, left sagittal, right sagittal, and overview perspectives. Each task was performed four times and filmed without audio using the cameras. Participants were asked to perform each activity twice, using their natural approach as they would typically do in their daily lives. After the first two trials, research staff instructed participants on how to perform the tasks in a modified manner to reduce shoulder joint loading and protect their shoulder joint.[7] The participants repeated the tasks twice after the modification.

Joint Protection Behavior Assessment (JPBA) Tasks and Standardization

Task 1. Move kettle with water (MK)

Before the assessment, a top-handle kettle should be filled with 0.5 Liters of water and placed on the table. Participants need to move the kettle close to the sink which was located 1 meter away. They will then pretend to pour the water out of the kettle. The total mass of the metal kettle with 0.5 liters of water was equal to 1.62 kg. approximately. See Figure 1

Joint protection strategies: Participants were asked to slide the kettle on the countertop to finish the task while keeping their arm close the object. They were cued to tuck their elbows against the body throughout the task. They were also asked to keep the kettle lower than usual when they attempt to pour the water.

Task 2. Move pan (MP)

The pan was placed on the countertop. The participants then moved the pan from the starting point towards to the water sink which is 1 meter away. Participants were instructed to move the pan in the same manner as they do in daily life. Saucepan was equal to 0.5 kg approximately. See Figure 2

Joint protection strategies: Participants were asked to slide the pan on the countertop to finish the task while keeping their arm close the object, and elbows tucked against the body throughout the movement. Instead of rotating the upper body, they were cued to move their legs to approach the sink.

Task 3. Move pan into lower-level oven (PO)

Participants were asked to remove pan from on the table at start of assessment. They then transferred the pan to a lower level, placing it into a grill pan on the open board that simulated an oven. The weight of Saucepan was equal to 0.5 kg approximately. See Figure 3.

Joint protection strategies: Participants were asked to slide the pan to the edge of the countertop instead of lifting it up. They were asked to use the opposite hand to support the pan underneath during the transferring stage. They were cued to keep the elbow tucked against their body as much as possible during the movement. Participants then bent through the hip or squatted down (if permitted by absence of other pathologies such as knee problems or osteoporosis) to move the saucepan onto the grill pan.

6.2.4 Data Acquisition

Video data was collected using four GoPro cameras (GoPro 9) positioned on separate tripods. These cameras were oriented towards the study participants in the frontal and two sagittal planes. Additionally, a fourth camera was mounted overhead on the ceiling to obtain an overview of the scene. The recorded video files were saved in MPED-V AVC format after the data collection process. The recorded video files were subjected to thorough analyses employing Dartfish ProSuite software (Version) and MediaPipe.

6.2.5 Data Extraction

The data extraction process was carried out by an operator who had undergone the necessary Dartfish training, including practice sessions with test files, before performing the actual data extraction. All video files were uploaded into the Dartfish ProSuite software and the MediaPipe stream app. The video data was categorized and identified based on the Participant ID, movement, planes, and series number of trails.

For extracting kinematic variables, the Dartfish Analyzer Module was utilized. Additionally, the Angle Tracking feature within Dartfish was applied to extract kinematic data from all three camera positions.

The MediaPipe is a video AI driven analysis software developed by the HULC clinical research lab.[13] The software utilized open-source code as its foundation. The current version, tailored for shoulder movement tracking and its user-interface, was developed by the second author (JF). Adjustments to the landmarks for tracking shoulder segments were made based on clinical range of motion measurements, in consultation with the first author (SL). The MediaPipe algorithm inherently incorporates abduction estimations derived from the frontal view; consequently, only video files captured from this perspective were uploaded to MediaPipe's online portal. The program then automatically initiated the analysis function. Once the analysis was completed, shoulder flexion and abduction data, along with their corresponding time stamps, were saved to the computer server. The software utilized open-source code as its foundation. The current version, tailored for shoulder movement tracking and its user-interface, was developed by the second author, JF. Adjustments to the landmarks for tracking shoulder segments were made based on clinical range of motion measurements, in consultation with the first author, SL.

Angle Tracking

Defining Shoulder Angles

Concordant with the clinical criteria for measuring shoulder range of motion (ROM),[14] shoulder flexion, abduction and rotation angles were documented as follows:

In the process of measuring the shoulder angle, the first step involves identifying the relevant anatomical landmarks, specifically the midpoint of the humeral head and the lateral epicondyle.[11,15] Next, a straight line is drawn connecting these two points. Subsequently, a second line is drawn parallel to the trunk's midline. Apart from measuring flexion and abduction, the rotation angles including internal and external rotation were tracked by identifying the olecranon process of the ulna. Two lines were used for this purpose: one parallel trunk horizontally and the other connecting the ulnar side of the forearm from the axis point to the ulnar styloid process. To avoid the perspective error in the 2D video analysis[11], flexion data was extracted from the sagittal view, abduction data from the frontal view, and rotation data from the overview camera angle. By utilizing different camera perspectives for each specific joint movement, potential inaccuracies caused by perspective distortion were minimized, ensuring more reliable and precise measurements. [11,15] See Table 1 for details.

Tracking Shoulder Angles

The initiation of participants' movement towards the objects (fry pan or kettle) was identified through visual inspection to determine the start frame. The frame at which the participants' hands left the objects was considered the end frame. To exclude unnecessary video frames with extraneous motions, the start frame was designated as the Cue in time point, and the end frame as the Cue out time in Dartfish. By using this method, manual selection of relevant frames was facilitated, enabling the exclusion of unwanted video segments and ensuring accurate analysis of the desired movements.

The Dartfish software utilizes pixel recognition to track specific marker locations. However, when marker points representing similar pixels move closely together, the tracking function may fail, causing the angle landmarks to jump to random points. Consequently, the auto-tracking function, used for tracking angles, often deviates from the predetermined landmarks, necessitating manual correction. When such deviations occur, auto-tracking is suspended, and the shifted marker points are repositioned to their defined positions manually. Inaccurate data is removed from the Data Table before reactivating the Angle tracking feature. To minimize bias, manual corrections are performed frame by frame (every 0.03 seconds).

Since MediaPipe is an Artificial Intelligence (AI) machine learning program, manual correction cannot be performed within the software. As a result, any landmark deviation encountered was documented along with the corresponding time stamp. To address the inaccuracies, angle data was manually removed from the output file with visual inspection of the video clips.

6.2.6 Data analysis

All the Excel spreadsheet including angles were consolidated and imported to SPSS formatted as '.dta' file. All measures were calculated using SPSS v27.0 (IBM Corporation, Armonk, NY).

Measures

Shoulder movement patterns

The data obtained from the Frontal Camera position represents the shoulder abduction angles, while the shoulder flexion angle, including both left and right sides, was obtained from the Sagittal Camera position. The rotation angles, encompassing both internal and external shoulder rotation, were recorded from the overview perspective. To describe the ROM for shoulder angles during all three tasks, the arc of motion (calculated as the difference between maximum and minimum angles) has been employed. Additionally, the shoulder movement patterns are described using the arc of motion, maximum angles, and minimum angles. These metrics provide valuable insights into the variability and extent of shoulder movements during the specified activities.

Statistical Analyses

Analysis was conducted using SPSS. Descriptive statistics were calculated as means and standard deviations for continuous variables. The paired sample t-test was employed to examine the disparity in movement patterns between participants' natural movement during the JBPA tasks and the modified pattern observed after joint protection education. Shapiro-Wilk test was applied to check the normal distribution assumption between the paired observations (the before-and-after measurements) for paired sample t-test. All statistical tests were 2-tailed, and an effect was considered significant if $p<0.05$. By utilizing Bland & Altman plots, we summarized the measurement agreement of the shoulder flexion and abduction angles (average of arc of motion, maximum, and minimum values) between Dartfish and MediaPipe. This was accomplished by calculating the mean difference and the 95% limits of agreement (LoA), which were obtained by taking ±1.96 times the standard deviation. During the Bland & Altman analysis, the angle information obtained from Dartfish served as the reference value. A histogram was created to visually inspect the measurement error. The sample size estimation yielded a total of 13 pairs for comparison, utilizing an effect size of 0.8, a significance level of 0.05, and a power of 0.80.

6.3 Results

6.3.1 Demographics

The participant sample (n=13) for this study represented male (n= 8) and female (n=5) with a mean age of 60 (±8) years. Eight participants had their right shoulders affected, while five participants had their left shoulders affected. See Table 2.

6.3.2 Shoulder movement patterns

Table 3 presents a summary of shoulder angles (in degrees) extracted from separate frames using Dartfish. The kinematic information including shoulder joint arc, maximum and minimum ROMs illustrates the movement requirements of the shoulder during three daily activity tasks.

Observing the task execution from frontal and sagittal camera positions, to assess the performance of the moving a kettle filled with 0.5 Liters of water close to the water sink. Our results indicated that the mean arc of movement necessary for shoulder abduction was 22°, with an SD of 9°, and observed values ranging between 14° and 41°. The mean values for the maximum and minimum angles recorded were 35° (with an SD of 10°) and 13° (with an SD of 6°), respectively. Similarly, for shoulder flexion, the average arc of motion was 23° (SD of 7°), ranging from 12° to 34°. The average of maximum and minimum angles was 44 (SD of 14°) and 21 (SD of 13°). Furthermore, the average arc of motion for rotation angles from overview perspective was determined to be 31° (SD of 9°), ranging from 16° to 43°.

During the task of moving the fry pan from the countertop to the edge of the sink, participants exhibited an average arc of motion of 19° (SD of 9°) for shoulder abduction, ranging from 11° to 35°. The average of maximum and minimum angles was 33 (SD of 11°) and 14 (SD of 5°). Furthermore, the average angle for shoulder flexion was noted to be 26° (SD of 12°), with a range spanning from 12° to 50° during the activity. The respective mean maximum and minimum angles were 42° (SD of 15°) and 16° (SD of 13°). Moreover, when viewed from an overview perspective, the average arc of motion for rotation angles during the task was found to be 34° (SD of 18°), ranging from 14° to 79°.

During the task of transferring the fry pan to the lower-level oven, participants exhibited an average angular motion of 18 degrees (SD of 7°) for shoulder abduction, spanning a range of 11° to 38°. The means for the maximum and minimum angles were 32° (SD of 9°) and 14° (SD of 7°), respectively. Moreover, during the task, shoulder flexion was observed at an average angle of 46 degrees (SD of 16°), ranging from 19° to 72°. The average for the maximum and minimum angles were 58° (SD of 15°) and 12° (SD of 12°), respectively. Additionally, when considering an overview perspective, the average arc of motion for rotation angles was found to be 44 degrees (SD of 14°), ranging from 27° to 66°.

After providing movement education on shoulder joint protection, we observed a statistically significant decrease in the arc of motion, approximately 7°, for both shoulder abduction and flexion, as evidenced by the paired sample t-test. Similar reductions in motion were noted during the task of moving the fry pan to the edge of the sink, with a 6° reduction in shoulder abduction and an 8° decrease in shoulder flexion. However, when it came to moving the pan to the oven, no significant differences were found, except for the maximum angle of shoulder abduction. See Table 4.

6.3.3 Measurement agreement

The arc of motion for shoulder abduction and flexion extracted from Dartfish and MediaPipe did not show any significant difference (mean of difference ranging from -1° to 1°), except for the arc of flexion during the task of moving the pan to the lower-level oven with a mean difference of -13°. A similar pattern (mean of difference ranging from -4° to 3°), was observed when comparing the movement after joint protection education, as no significant difference was detected. All bland and Altman plots can be found in the Appendix 3.

Nevertheless, statistically significant differences were observed in a few specific maximum and minimum shoulder angles. Specifically, during the task of moving the pan to the lower-level oven, the mean difference of maximum shoulder flexion between MediaPipe and Dartfish was -14°, with corresponding LoA values ranging from -43° to 14°. See in Table 5.

Upon visual inspection of the Bland and Altman plot for the measurement discrepancy, it was evident that as the angles increased, the disparity between MediaPipe and Dartfish decreased for maximum flexion angles during the task of moving the pan to the oven. See Figure 4.

Although a significant difference was revealed for the arc of shoulder flexion between Dartfish and MediaPipe, the majority of the angle differences observed in the plot were within the range of -10 to 10°. Notably, there was one significant deviation of -44°, indicating an outlier in the data. See Figure 5.

Upon examining the error histogram, the majority of measurement deviations were found to range between -5 and 5° for all three tasks. Refer to Figure 6 for an illustration. All histograms of errors can be found in the Appendix 3.

6.4 Discussion

The present study investigated the kinematic characteristics of shoulder movements during Joint Protection Behavior Assessment (JPBA) tasks, which aimed to simulate activities resembling daily life movements. The kinematic data of participants were collected using two motion analysis software tools, Dartfish and MediaPipe, before their scheduled shoulder joint replacement surgery. The description of the shoulder movement during JPBA tasks identified that participants' performance of moving a kettle and a fry pan, demonstrated similar shoulder abduction, flexion, and rotation patterns. The average arc of motion values ranged from 18° to 46° across the tasks.

The results revealed significant differences between the natural shoulder movements during the JPBA tasks and the movements after participants received joint protection education. Notably, after education on joint protection strategies, participants demonstrated reduced arc of motion for shoulder abduction and flexion during the tasks, indicating successful implementation of the instructed techniques. This outcome confirms the previously established result as a cross-sectional, clinical observational study investigated the effects of hand osteoarthritis and method of performance on the range of motion (ROM) in the thumb, index, and middle digits during activities of daily living (ADLs) revealed a statistically significant decrease in ROM was found during tasks in the flex/ext direction followed by instruction on joint protection techniques.[16]

Despite being educated on joint protection strategies, participants still exhibited altered movement patterns during the tasks. The significant deviations in the execution of the tasks suggest that adapting to the instructed movement patterns might require further practice or additional guidance. Though the joint protection education was informative, participants might require additional time to fully incorporate these strategies into their regular routines. This is supported by a prior randomized controlled trial studying joint behavior change in patients with Hand OA, where significant behavioral shifts in joint protection were observed after four sessions.[17] Providing written instructions prior to the learning assessment would be beneficial, as the instructions conveyed verbally in a brief time frame might lack the clarity or detail necessary to sufficiently address the task's requirements. Further research could explore effective methods for enhancing the application of joint protection behavior during daily activities and post-surgery rehabilitation, thus optimizing shoulder function and outcomes.

Our research affirmed the concordance in measuring the arc of motion between the MediaPipe and Dartfish software when extracting kinematic data. The Bland & Altman plots indicated a satisfactory level of agreement in the measurements undertaken by the two platforms across a majority of the arc of motion. The comparison between Dartfish and MediaPipe revealed significant differences in several maximum and minimum shoulder angles. However, it is essential to note that the majority of these discrepancies were influenced by extreme movement patterns, suggesting overall consistency between the two software tools. In other terms, MediaPipe generally provided reliable and robust results, with only a few instances of extreme movement patterns affecting the measurement agreement between them. When compared to prior studies that used a Wireless Inertial Motion Capture Device to measure shoulder ROM, their measurement agreement surpassed the acceptable 5 degrees. MediaPipe, in contrast, demonstrated its advantage as most of its LoA, when compared with Dartfish, remained within ±5°.[18]

For the task of moving the pan into the lower-level oven, the differences between natural and educated movements were not found to be significant, except for the maximum angle of shoulder abduction. This finding suggests that participants might have been already employing efficient joint protection techniques during this particular task in their daily lives. However, it is essential to consider the possibility of measurement errors caused by limitations in Dartfish's analysis.[19] The observed discrepancies could be attributed an unclear view over the shoulder, which may have influenced the accuracy of Dartfish measurements in this specific movement. While the dark color of the cloth may pose challenges for landmark tracking in Dartfish and Medipipe, potential solutions include attaching a brightly colored tape to the anatomical position or instructing participants to wear a cloth with a lighter color. These approaches can help improve the tracking process and enhance accuracy in the analysis. Implementing these strategies can lead to a noticeable enhancement in the tracking process and significantly improve the accuracy of data analysis. Additionally, for future studies, it is crucial to further refine data acquisition methods, such as optimizing camera positioning and ensuring precise participant positioning. These improvements will help increase overall precision and minimize any potential measurement errors, making the research outcomes more reliable and robust.

These findings underscore the significance of taking joint protection behavior into account, particularly in individuals experiencing shoulder pain during daily activities due to their shoulder condition. Understanding and implementing effective joint protection strategies can play a crucial role in mitigating pain and improving joint function.[20,21] By incorporating such strategies into their daily routines, these individuals may experience reduced discomfort and enhanced overall shoulder function, ultimately leading to better quality of life.

It is worth noting that this study had some limitations. The sample size was relatively small, and the participants were recruited from a waiting list for shoulder replacement surgery, which may not fully represent the broader population. Additionally, the study focused on specific JPBA tasks, and the generalizability of the findings to other activities may require further investigation.

In conclusion, the study's results provide valuable insights into the kinematic characteristics of shoulder movements during JPBA tasks. The findings suggest that participants were capable of adjusting their movement patterns to incorporate joint protection strategies, which could be beneficial in post-surgery rehabilitation and shoulder function improvement. The use of motion analysis software tools, MediaPipe, demonstrated reliable results, indicating their usefulness for future kinematic analyses in similar studies. Overall, this study contributes to the understanding of joint protection behavior and its potential implications for shoulder joint replacement surgery and rehabilitation. Further research in this area could expand our knowledge and contribute to optimizing patient outcomes and enhancing shoulder function in clinical settings.

6.5 References

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6.6 List of Tables

Table 6-1 Measurement Criteria of Shoulder Angles

	Axis location	Stationary arm	Movement arm
Shoulder flexion from sagittal frame	middle of humeral head laterally	parallel with the trunk	in line with the midline of the humerus (lateral epicondyle)
Shoulder abduction from frontal frame	inferior lateral coracoid process	parallel with the trunk	in line with the midline of the humerus
Shoulder external rotation from overview frame	olecranon process of the ulna	Parallel with trunk horizontally	in line with the ulnar side of the forearm from the axis point to the ulnar styloid process

Table 6-2 Demographic information of the participants

		Patients Mean ± SD; n
Age		60±8
Sex	Woman	5
	Man	8
Affected side	L	5
	R	8

Table 6-3 Summary of Kinematic Information during Joint Protection Behavior Assessment (JPBA) Tasks

	Minimum	Maximum	Mean	Stand deviation
MK_ABD_ARC_natural	14	41	22	9
MK_ABD_MAX_natural	20	52	35	10
MK_ABD_MIN_natural	4	22	13	6
MK_ABD_ARC_POST	9	25	15	4
MK_ABD_MAX_POST	19	33	27	5
MK_ABD_MIN_POST	3	20	13	5
MK_FLEX_ARC_Natural	12	34	23	7
MK_FLEX_MAX_Natural	14	63	44	14
MK_FLEX_MIN_Natural	2	39	21	13
MK_FLEX_ARC_POST	8	25	16	6
MK_FLEX_MAX_POST	15	56	33	13
MK_FLEX_MIN_POST	2	32	17	10
MK_ROT_ARC_Natural	16	43	31	9
MK_ROT_ARC_POST	21	50	35	9
MP_ABD_ARC_natural	11	35	19	9
MP_ABD_MAX_natural	17	50	33	11
MP_ABD_MIN_natural	6	23	14	5
MP_ABD_ARC_POST	6	18	12	3
MP_ABD_MAX_POST	18	43	26	8
MP_ABD_MIN_POST	5	31	14	7
MP_FLEX_ARC_Natural	12	50	26	12
MP_FLEX_MAX_Natural	14	62	42	15
MP_FLEX_MIN_Natural	1	41	16	13
MP_FLEX_ARC_POST	4	31	18	8
MP_FLEX_MAX_POST	11	45	29	12
MP_FLEX_MIN_POST	1	25	12	6
MP_ROT_ARC_Natural	14	79	34	18
MP_ROT_ARC_POST	18	65	32	14
PO_ABD_ARC_natural	11	38	18	7
PO_ABD_MAX_natural	18	50	32	9
PO_ABD_MIN_natural	2	28	14	7
PO_ABD_ARC_POST	11	20	14	3
PO_ABD_MAX_POST	13	39	27	8
PO_ABD_MIN_POST	2	26	13	7
PO_FLEX_ARC_Natural	19	72	46	16
PO_FLEX_MAX_Natural	21	73	58	15
PO_FLEX_MIN_Natural	0	32	12	12

PO_FLEX_ARC_POST	16	69	37	16
PO_FLEX_MAX_POST	22	84	55	20
PO_FLEX_MIN_POST	1	59	18	17
PO_ROT_ARC_Natural	27	66	44	14
PO_ROT_ARC_POST	15	61	35	15
MK: Move kettle with water MP: Move pan PO: Move pan into lower-level oven ABD: Abduction FLEX: Flexion ROT: Rotation ARC: arc of range of motion MAX: maximum MIN: minimum Natural: natural approach as they would typically do in their daily lives to complete the tasks POST: modified approaches that reduce shoulder joint loading and protect the shoulder joint				

Table 6-4 Pared sample t-test between natural and modified approaches

Movement		Mean	Standard deviation	Significance	95% Confidence Interval of the Difference	
MK					lower	upper
ARC	ABD	6.6	6.5	0.01	2.3	11.0
	FLEX	6.8	5.0	0.00	3.4	10.1
	ROT	-2.1	9.2	0.47	-8.2	4.1
MAX	FLEX	6.7	6.7	0.01	2.2	11.2
	ABD	10.3	9.9	0.01	3.6	16.9
MIN	ABD	0.1	3.1	0.92	-2.0	2.1
	FLEX	3.5	11.6	0.34	-4.3	11.3
MP						
ARC	ABD	6.2	7.6	0.02	1.1	11.3
	FLEX	8.4	11.0	0.03	1.0	15.7
	ROT	2.3	10.8	0.47	-4.5	9.2
MAX	ABD	6.6	9.9	0.05	0.0	13.3
	FLEX	12.6	6.8	0.00	8.0	17.2
MIN	ABD	0.5	4.7	0.76	-2.7	3.6
	FLEX	4.2	10.4	0.21	-2.8	11.2
PO						
ARC	ABD	3.9	7.6	0.12	-1.3	9.0
	FLEX	8.9	18.7	0.13	-3.0	20.8
	ROT	8.2	11.7	0.05	-0.2	16.6
MAX	ABD	4.9	5.9	0.02	0.9	8.9
	FLEX	3.3	14.0	0.43	-5.6	12.2
MIN	ABD	0.5	5.5	0.75	-3.2	4.3
	flex	-5.6	21.4	0.39	-19.2	8.0

MK: Move kettle with water
MP: Move pan
PO: Move pan into lower-level oven
ABD: Abduction
FLEX: Flexion
ROT: Rotation
ARC: arc of range of motion
MAX: maximum
MIN: minimum
Natural: natural approach as they would typically do in their daily lives to complete the tasks
POST: modified approaches that reduce shoulder joint loading and protect the shoulder joint

Table 6-5 Bland & Altman Analysis between Dartfish and MediaPipe on Shoulder abduction and flexion extracted from frontal frame

				LoA	
	Mean of difference	Std. Deviation	Sig. (2-tailed)	Lower	Upper
MK_ABD_ARC_NAT	1.0	6.3	0.6	-11.3	13.2
MK_ABD_ARC_POST	1.6	3.7	0.2	-5.6	8.8
MK_ABD_MAX_NAT	-1.9	8.0	0.5	-17.6	13.9
MK_ABD_MAX_POST	-4.6	4.0	0.0	-12.4	3.2
MK_ABD_MIN_NAT	-2.8	7.3	0.2	-17.2	11.5
MK_ABD_MIN_POST	-6.2	4.9	0.0	-15.8	3.4
MK_FLEX_ARC_NAT	3.0	5.5	0.1	-7.7	13.6
MK_FLEX_ARC_POST	-0.3	5.7	0.9	-11.5	10.9
MK_FLEX_MAX_NAT	-7.9	12.9	0.1	-33.2	17.5
MK_FLEX_MAX_POST	-4.4	6.7	0.1	-17.5	8.7
MK_FLEX_MIN_NAT	-10.8	12.8	0.0	-35.8	14.2
MK_FLEX_MIN_POST	-4.1	6.3	0.1	-16.3	8.2
MP_ABD_ARC_NAT	2.4	4.6	0.2	-6.6	11.4
MP_ABD_ARC_POST	0.4	2.2	0.6	-4.0	4.8
MP_ABD_MAX_NAT	-2.6	4.1	0.1	-10.5	5.4
MP_ABD_MAX_POST	-4.7	8.3	0.1	-21.1	11.7
MP_ABD_MIN_NAT	-4.9	4.2	0.0	-13.2	3.3
MP_ABD_MIN_POST	-5.1	8.0	0.1	-20.8	10.6
MP_FLEX_ARC_NAT	-1.9	5.0	0.3	-11.7	8.0
MP_FLEX_ARC_POST	-3.4	6.3	0.1	-15.6	8.9
MP_FLEX_MAX_NAT	-4.4	4.6	0.0	-13.3	4.6
MP_FLEX_MAX_POST	-2.7	5.1	0.2	-12.7	7.2
MP_FLEX_MIN_NAT	-2.5	4.1	0.1	-10.6	5.6
MP_FLEX_MIN_POST	0.7	2.7	0.5	-4.6	6.0
PO_ABD_ARC_NAT	-0.4	3.9	0.7	-8.0	7.2
PO_ABD_ARC_POST	3.2	6.5	0.1	-9.6	15.9
PO_ABD_MAX_NAT	-6.1	6.8	0.0	-19.5	7.2
PO_ABD_MAX_POST	-0.8	8.8	0.8	-18.1	16.4
PO_ABD_MIN_NAT	-5.3	7.4	0.0	-19.8	9.3
PO_ABD_MIN_POST	-4.0	5.8	0.0	-15.3	7.3
PO_FLEX_ARC_NAT	-12.5	16.2	0.0	-44.2	19.3
PO_FLEX_ARC_POST	-1.1	10.7	0.7	-22.2	19.9
PO_FLEX_MAX_NAT	-14.1	14.5	0.0	-42.5	14.2
PO_FLEX_MAX_POST	-1.8	9.3	0.5	-20.1	16.5
PO_FLEX_MIN_NAT	-1.7	7.8	0.5	-16.9	13.5

PO_FLEX_MIN_POST	-0.6	4.7	0.7	-9.8	8.5

MK: Move kettle with water
MP: Move pan
PO: Move pan into lower-level oven
ABD: Abduction
FLEX: Flexion
ROT: Rotation
ARC: arc of range of motion
MAX: maximum
MIN: minimum
Natural: natural approach as they would typically do in their daily lives to complete the tasks
POST: modified approaches that reduce shoulder joint loading and protect the shoulder joint
LoA: Limits of Agreement

6.7 List of Figures

Figure 6-1. Joint protection behaviour assessment task: Move kettle with water (MK)

Figure 6-2. Joint protection behaviour assessment task: Move pan (MP)

Figure 6-3. Joint protection behaviour assessment task: Move pan into lower-level oven (PO)

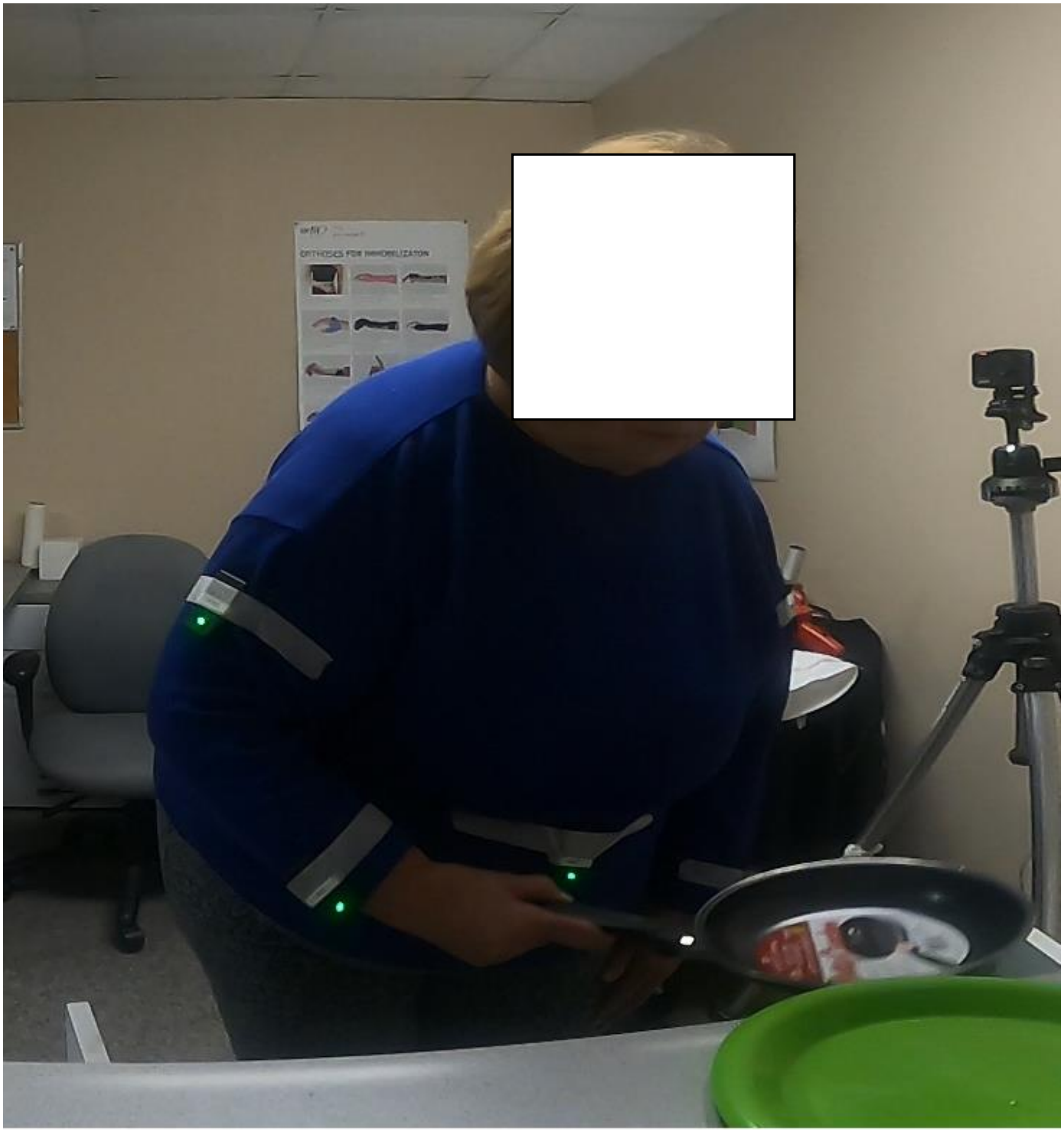


Figure 6-4 Bland & Altman plot of the maximum shoulder flexion angles between Dartfish and MediaPipe during moving pan to lower-level oven

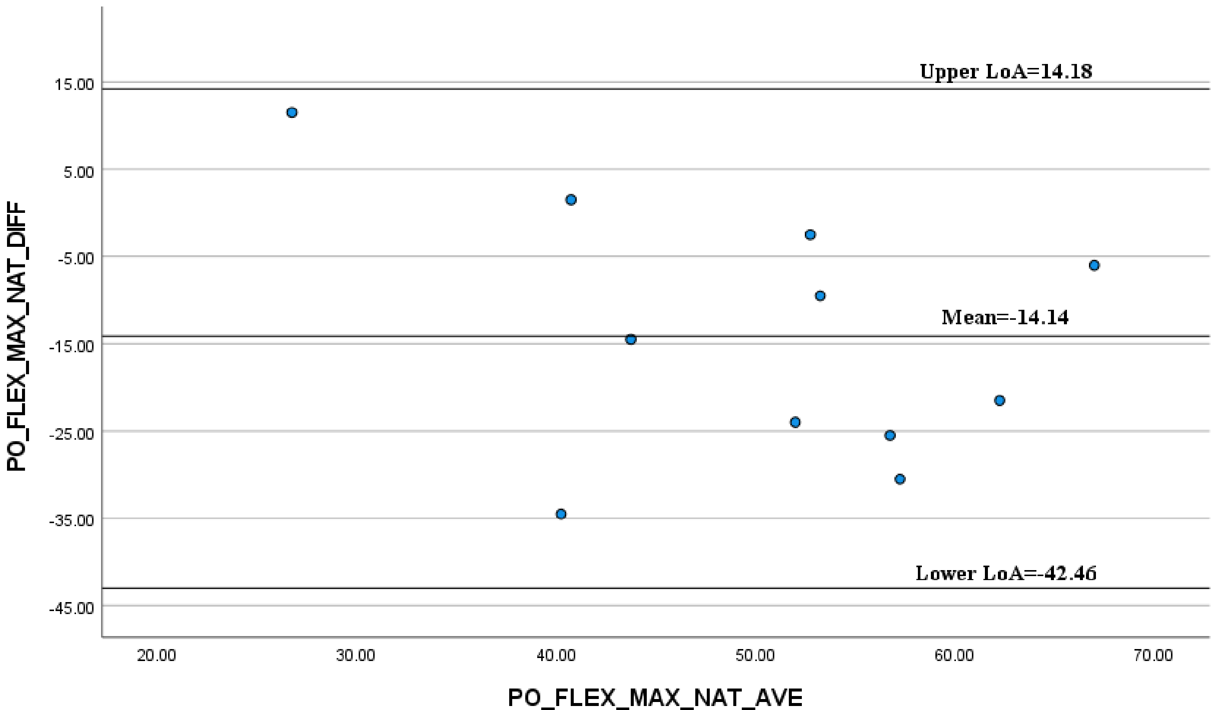


Figure 6-5 Bland & Altman plot of the arc of shoulder flexion angles between Dartfish and MediaPipe during moving pan to lower-level oven

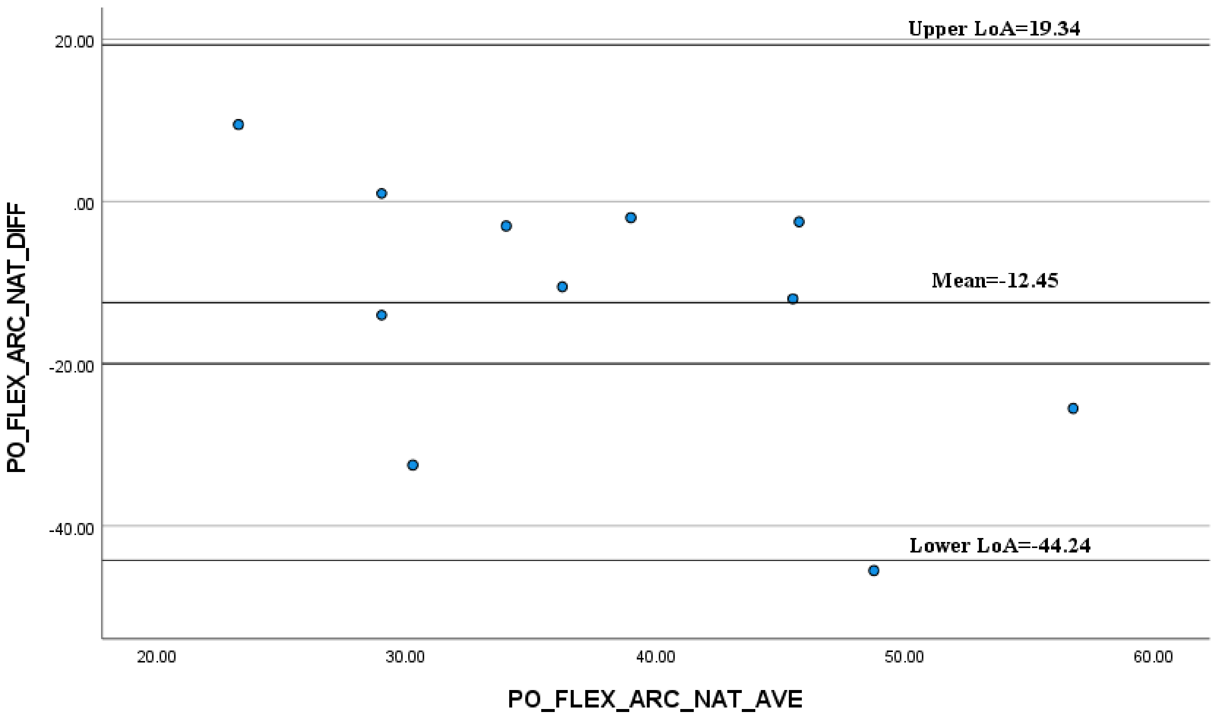
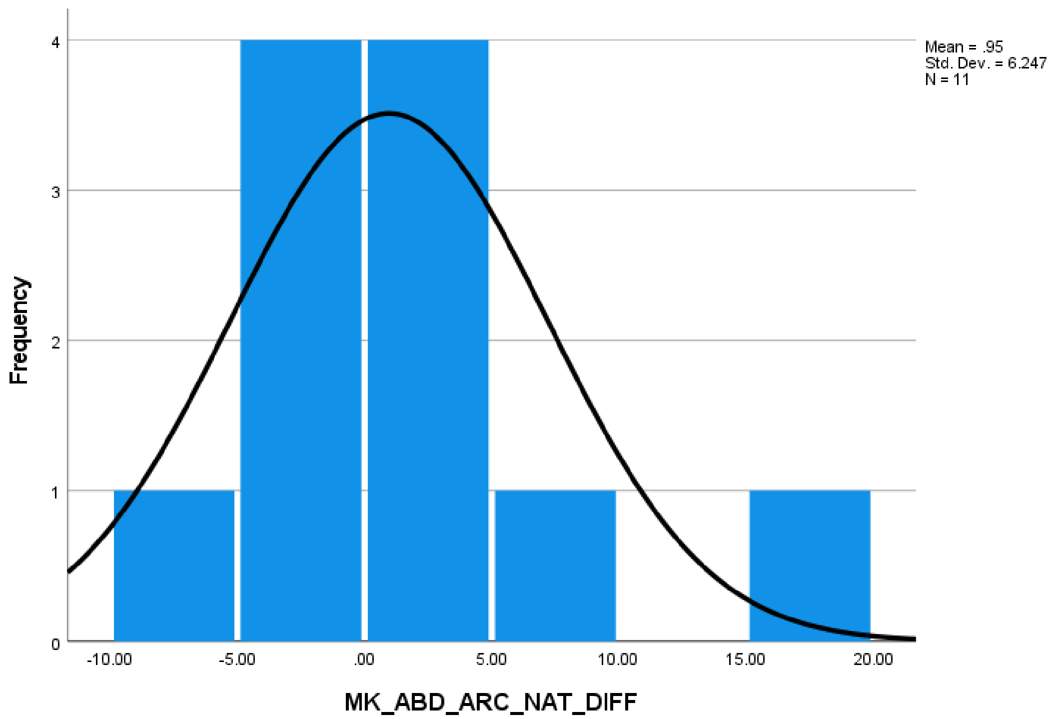
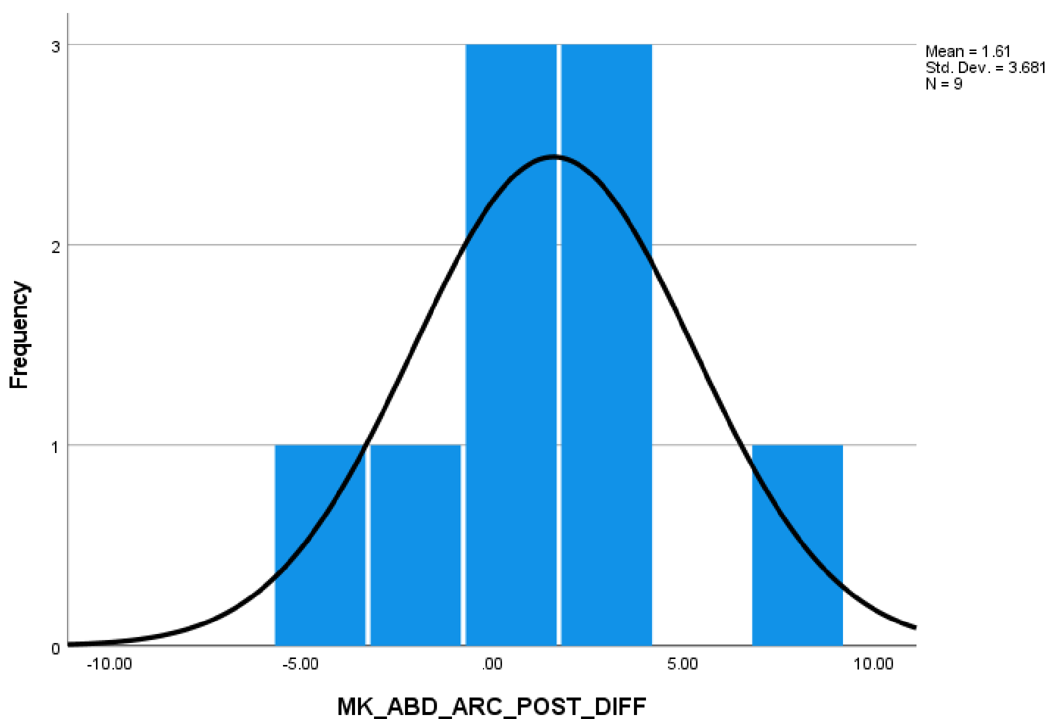


Figure 6-6 Histograms of measurement discrepancies of the arc of shoulder abduction angles between Dartfish and MediaPipe during moving kettle tasks





6.8 List of Appendices

6.8.1 Letter of Information and Consent

Project Title: Development of wearables sensors in motion shirts for assessment and rehabilitation of shoulder arthritis and joint replacement

Investigators

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What is the purpose of this study?
You are being invited to participate in this study because you are a patient at the Hand and Upper Limb Clinic of St. Joseph's Hospital. . We are testing whether a new shirt with wearable sensors is a reliable method of measuring every day movements and tracking shoulder movement before and during recovery from surgery. We hope that this shirt will help us to better understand how the rehabilitation and recovery process progresses in shoulder joint replacement patients. We will link biomechanics, motion tracking data, and clinical data obtained from patients to aid in developing a system that provides clinicians and patients with more precise information on their shoulder rehabilitation process. We will also compare data from patients to healthy participants.

Recruitment
Inclusion: Individuals with sufficient capacity to consent, who are aged 50 or over, can speak fluent English and are on the waitlist of shoulder joint replacement surgery.

Exclusion: People who are not generally healthy or they are suffering from a kind of major disease and disability.

Study Procedures

1- You will be provided with comprehensive information about the study and your potential questions will be addressed.
2- If you are still willing to participate, you will sign this consent form.

Pre-op phase:

3- Appointments for data collection sessions will be set up. The sessions will take place at St. Joseph's Hospital in the Hand and Upper Limb Clinical Research Lab.
4- You will fill out a series of questionnaires about your shoulder and everyday life along with some demographic information.

5- A study team member will demonstrate and administer two physical tests called the FIT HaNSA and Joint Protection behavior Assessment (JPBA) tests where you will be asked to move your arms and hands in different ways.
6- You will wear the motion shirt to do the FIT-HaNSA and JPBA tests while also being video recorded.
7- This visit is expected to take 1 to 2 hours.
8- You will return to the lab in the next 5-7 days to repeat the FIT-HaNSA test for reliability assessment purposes.

Post-op phase:

9- You will return to the lab for a morning visit at 1, 4, 6, 9, and 12 months after your surgery. We will ensure that the shirt fits comfortably and that the sensors are working.
10- You will re-perform the Fit-HaNSA and JPBA tests in the lab that is expected to maximally take 1 hour of your time.
11- You will then keep the shirt on for the rest of the day and go about your normal activities at home and in the community until bedtime when you can take the shirt off. at different times after your operation. These visits are in the morning. You are supposed to not take off the shirt during your daily life activities until your sleep time. In this regard, the motion shirt will record daily motion activities of you for a day. You can take off the shirt at night.
12- You will mail the shirt back to the lab for analysis using a prepaid envelope.

Participation to the Study:
Participating in this study is voluntary. You will receive a copy of the letter of information and consent form for your records. You do not waive any of your legal rights by signing the consent form. You may refuse to participate, refuse to answer any questions or withdraw from the study at any time with no effect to your future care. You will continue to receive standard care, i.e., routine checkups with your doctor. If you DO decide to stop your participation in our study, we will ask you how you would like us to handle the data collected up to that point. You have the right to withdraw all data collected for the study. If you have concerns or would like to withdraw, you may contact the principal investigator, Dr. Joy MacDermid or research assistant, Katrina Munro.

What are the benefits of this study?
There are no direct benefits to you associated with your participation in this study. But your study participation will have societal benefits by helping improve knowledge about the recovery process of shoulder arthroplasty surgery.

Are there any risks or discomfort associated with this study?
There is a potential for a privacy breach, as identifying information is being collected. However, identifying information will be kept separate from the data. Instead, the data will be de-identified.

How many people in this study?
There will be approximately 50 people in this study.

Is there any compensation if I participate?
There is no monetary reimbursement for participation in this study. If needed, we can arrange to compensate parking expenses.

Will my results be kept confidential?
Your individual results will be held in strict confidence. No person, other than the study team, treating clinician, Western's Health Sciences Research Ethics Board and its representatives, and Lawson Quality Assurance and Education Program will have access to your identifiable information which will include your name, sex, contact information, and date of birth.

Upon study recruitment, you will be given a unique numerical identifier (Participant ID) that will be entered on all data collection forms containing personal information in lieu of your name. The study investigators will keep a master copy of the unique identifier assigned to each participant. This list will be stored on the SJHC secure G drive. Your contact information and consent forms will also be collected and stored separately from the master list of unique identifiers. All paper files will be stored in a locked file cabinet in the HULC clinical research lab, and all electronic files will be stored on a password-protected computer on the secure hospital network. A brief summary of this study will be put on our lab website for public viewing; however, this would not identify you in any way. Representatives of the University of Western Ontario Health Sciences Research Ethics Board and Lawson Quality Assurance and Education Program may contact you or require access to your study-related records to monitor the conduct of research and to ensure that proper policies and guidelines are being followed. The studies investigators will retain your identifiable information and study data for 15 years.

Publication
If the results of the study are published, your name will not be used. If you would like to receive a copy of any potential study results, please provide your name and contact number on a piece of paper separate from the Consent Form.

Whom may you contact to find out more about this study?
You will be given a copy of this letter. If you have questions about taking part in this study, you can directly contact:

Dr. Joy MacDermid, Principal Investigator, can be contacted at 519-646-6000 x64636.

Katrina Monroe, Co-Investigator can be contacted at 519-646-6100 x64544.

Sohrob Milani, Co-Investigator can be contacted at smilaniz@uwo.ca

Leila Amirfakhrian, Co-Investigator, can be contacted at lamirfak@uwo.ca

If you have any other questions about your rights as a research participant or about the conduct of the study you may contact: St Joseph's Health Care London Patient Relations Consultant at 519-646-6100 ext 64727
Consent to Participate In: Development of wearables sensors in motion shirts for assessment and rehabilitation of shoulder arthritis and joint replacement.

Investigators:

Dr. Joy MacDermid, PT PhD (Principal Investigator)
Department of Physical Therapy, Western University
Email: jmacderm@uwo.ca

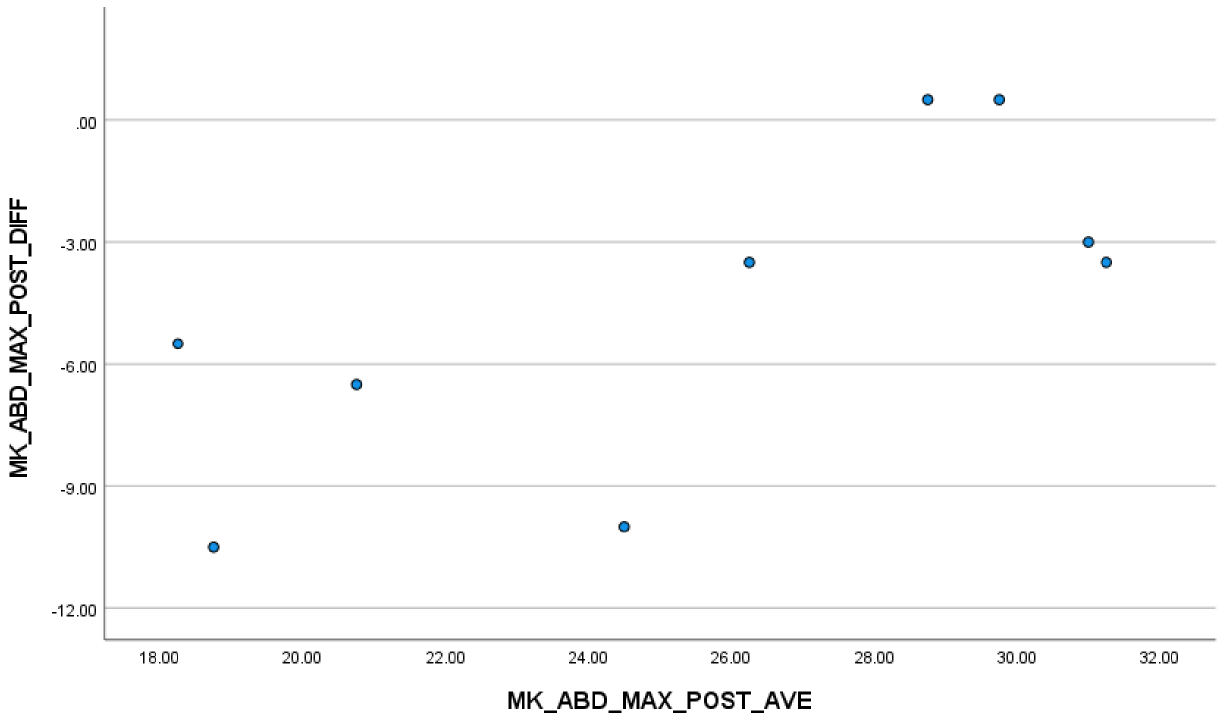
- I have read the letter of the information, have had the nature of study explained to me and I agree to participate. All questions have been answered to my satisfaction.

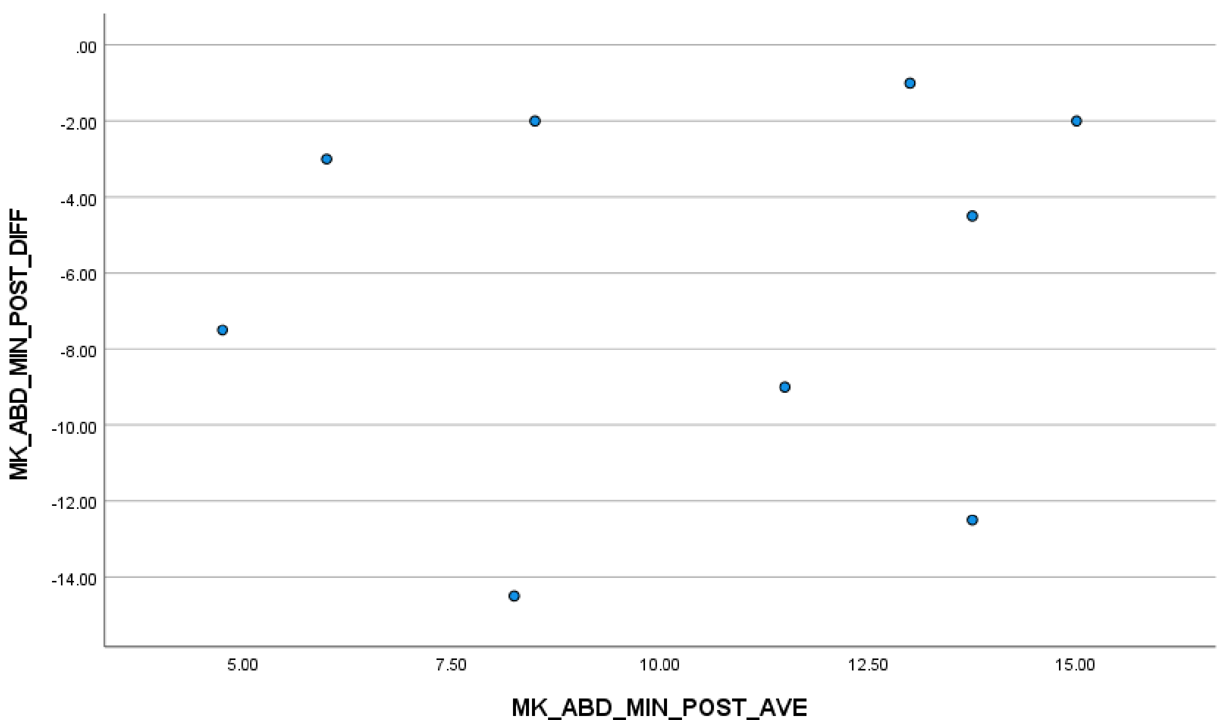
Signature of Participant	Print Name of Participant	Date

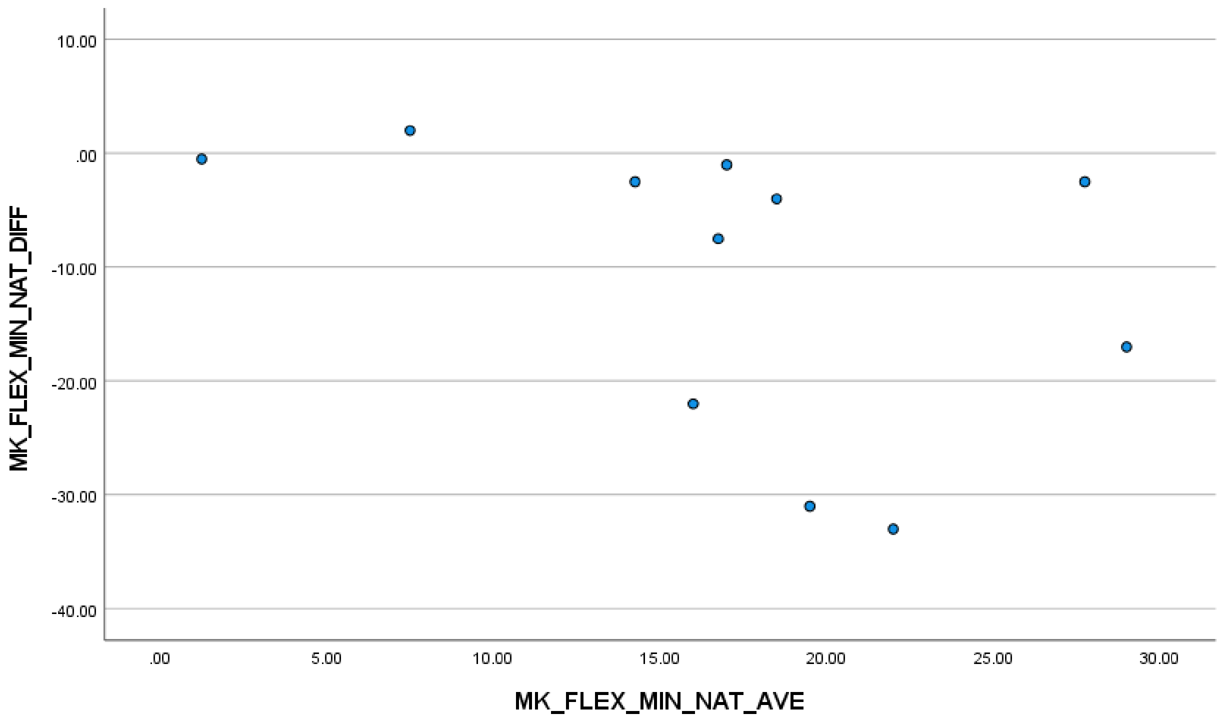
My signature means that I have explained the study to the participant named above. I have answered all questions.

Signature of person obtaining consent	Print name of person obtaining consent	Date

6.8.2 Bland and Altman Plots between Dartfish and Mediapipe



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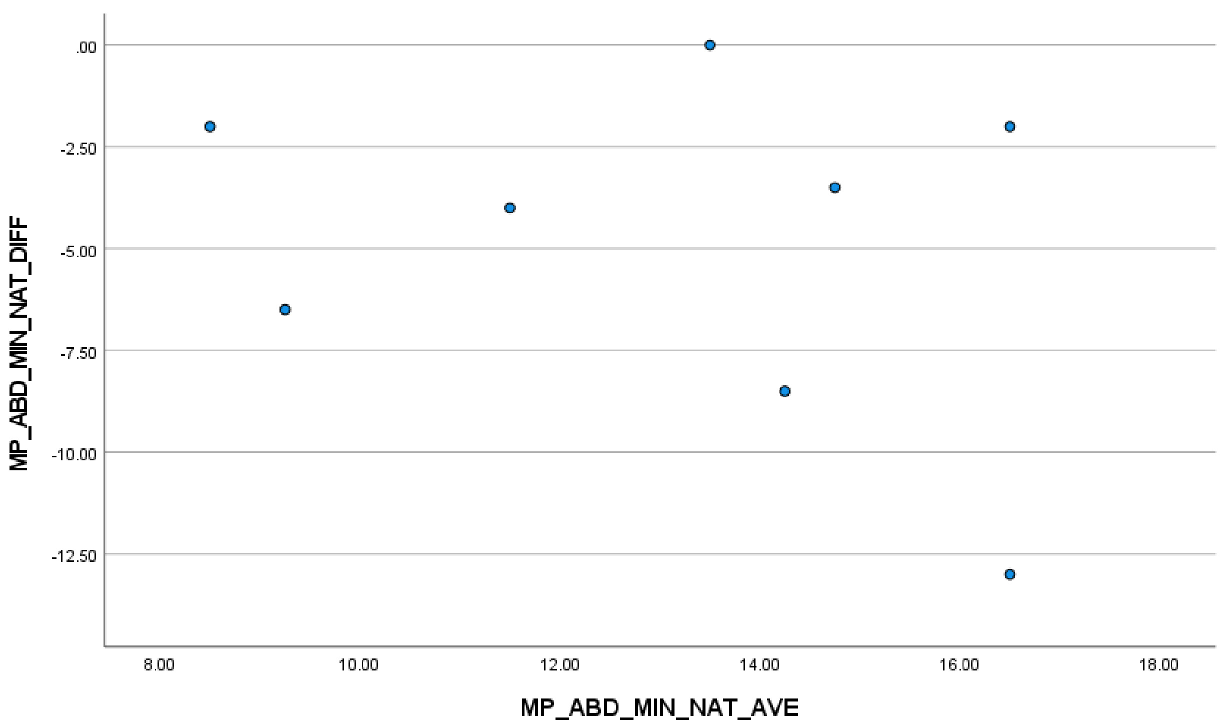
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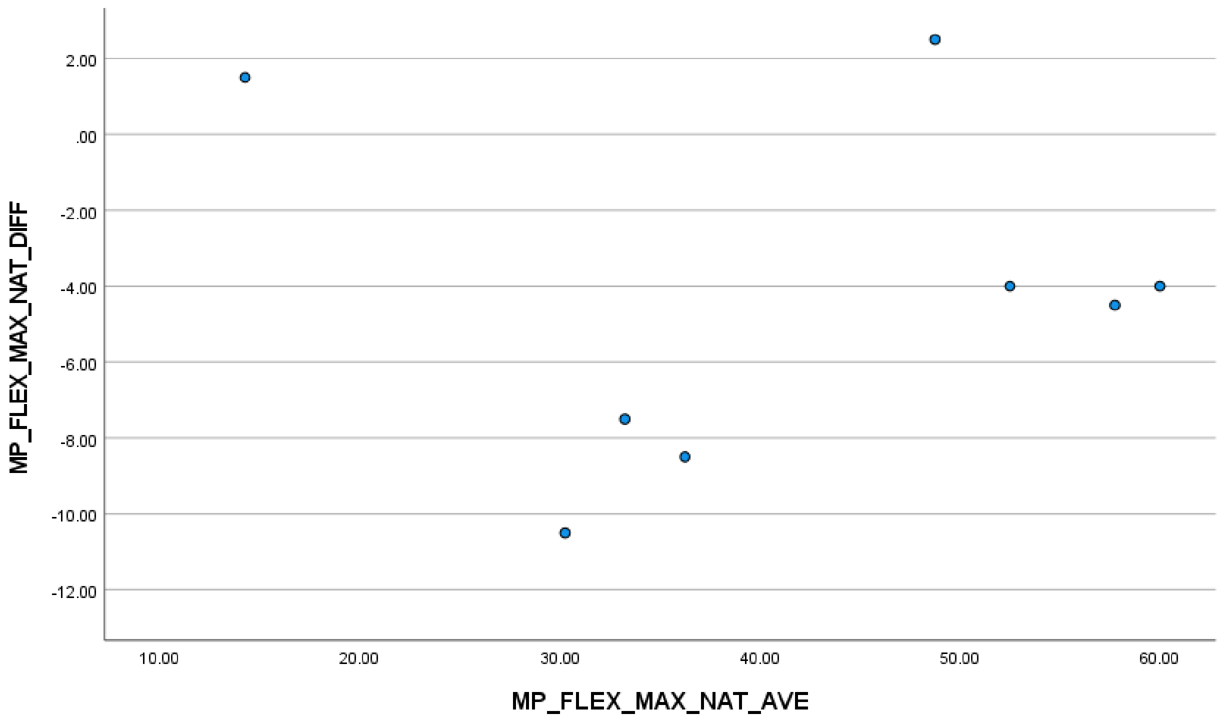
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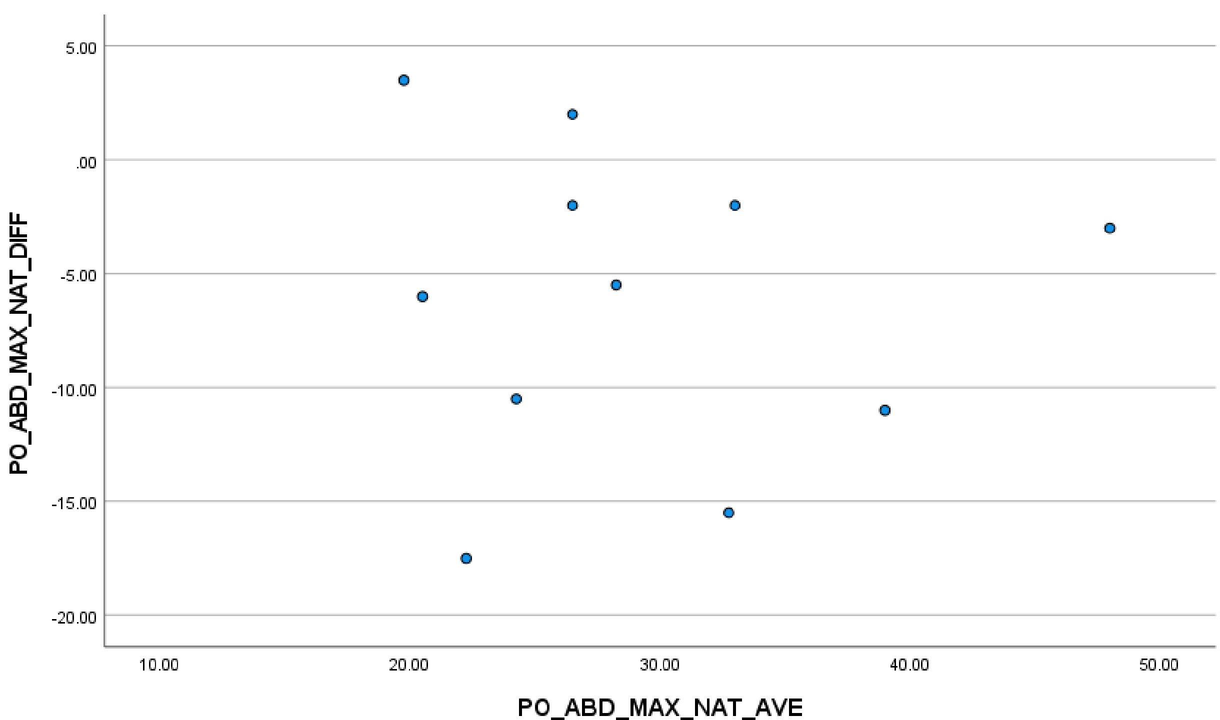
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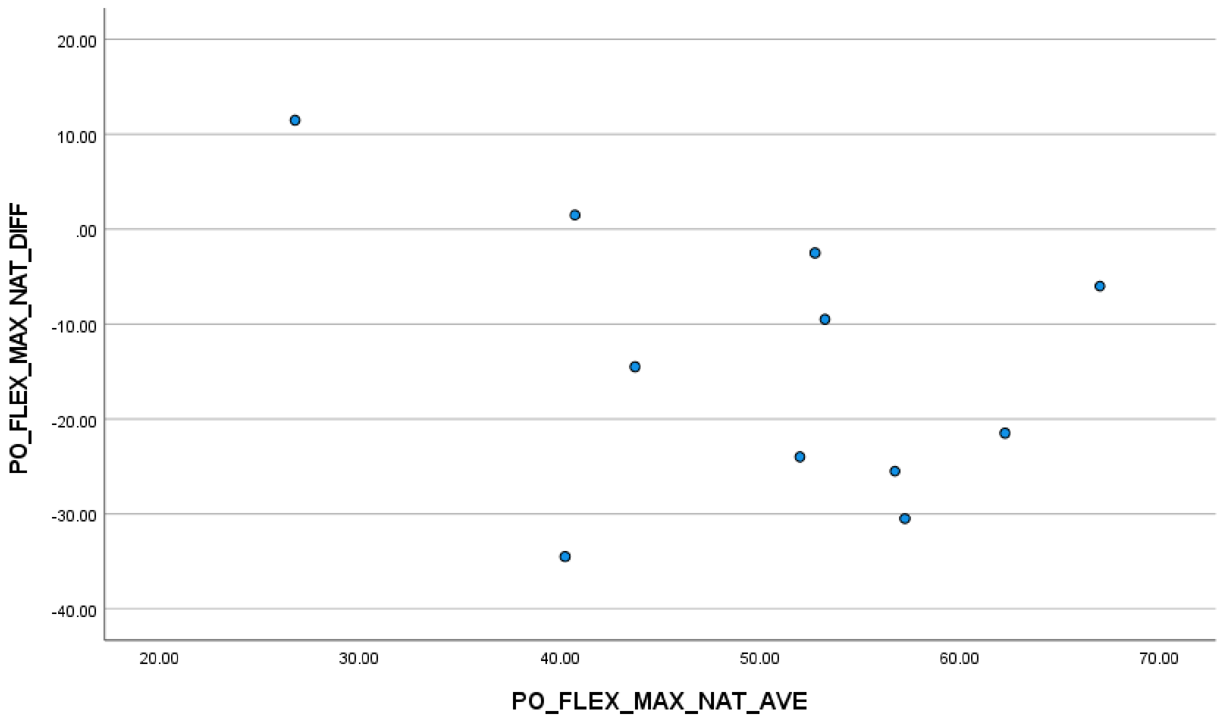

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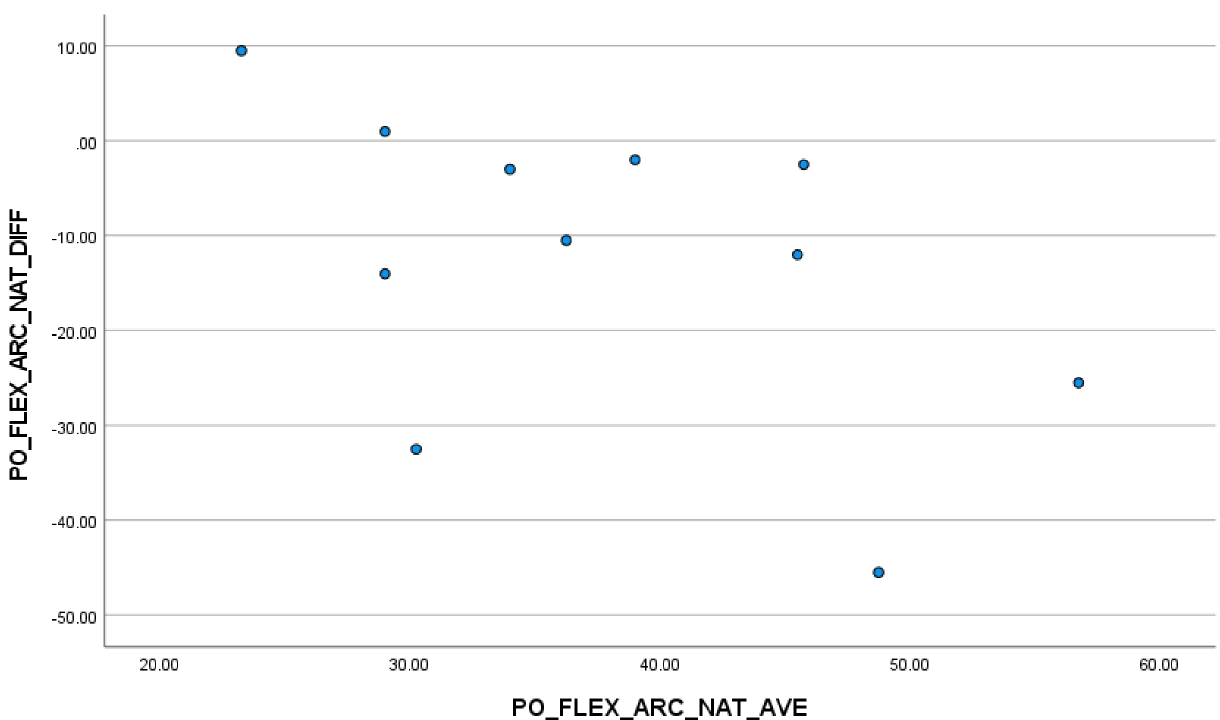

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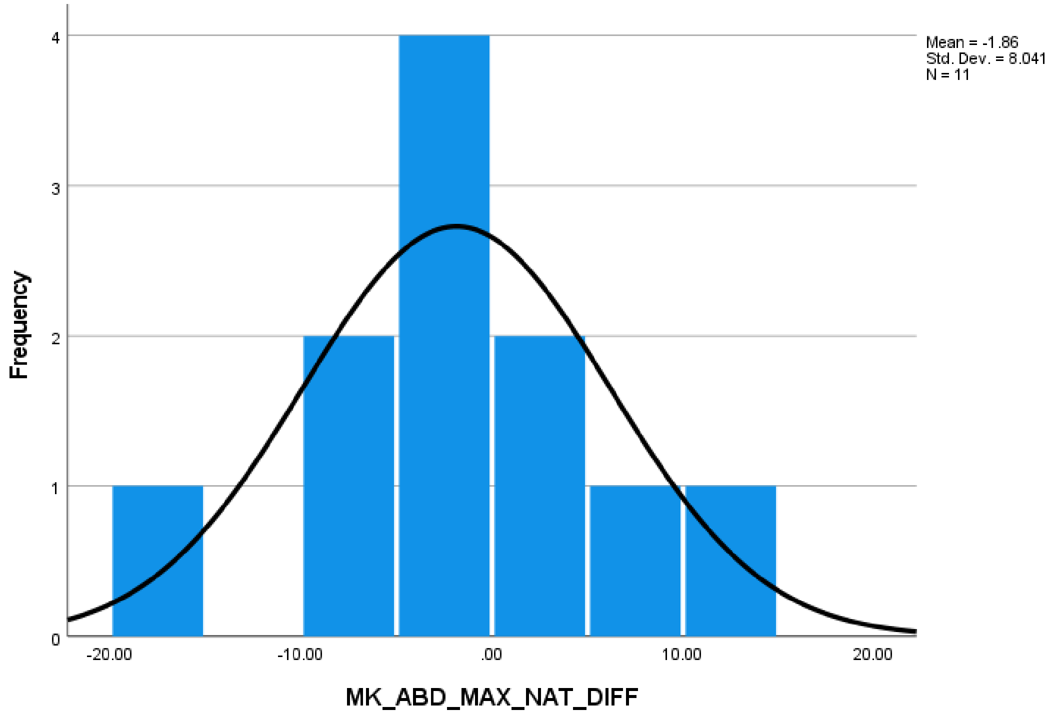
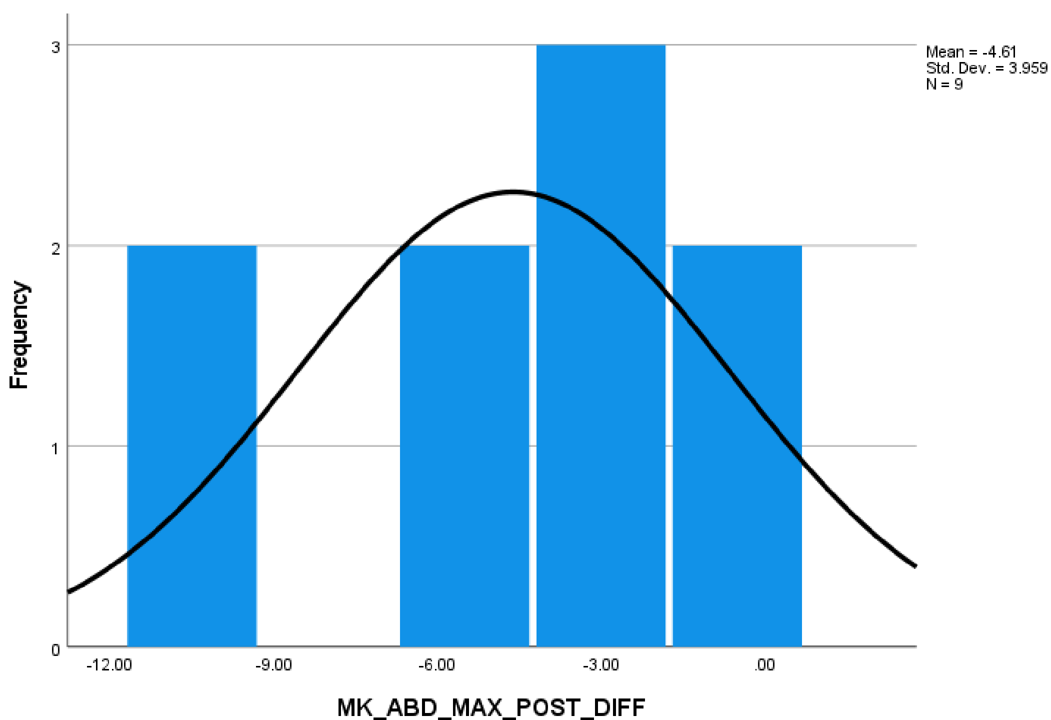
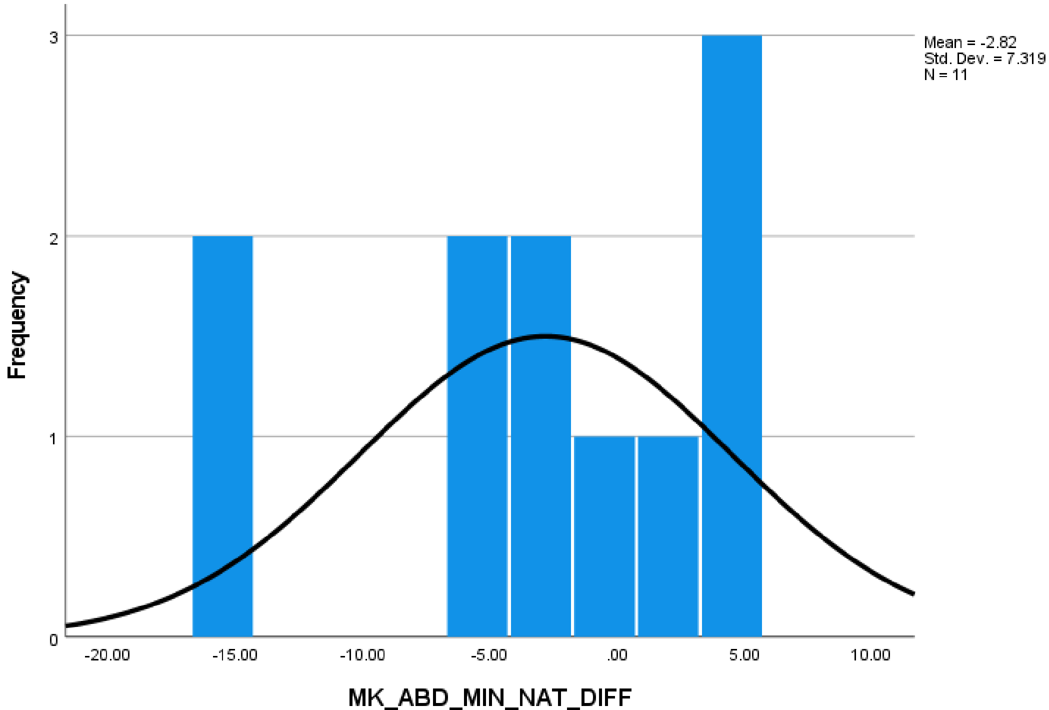
6.8.3 Histograms of measurement discrepancies between Dartifsh and MediaPipe



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5.00
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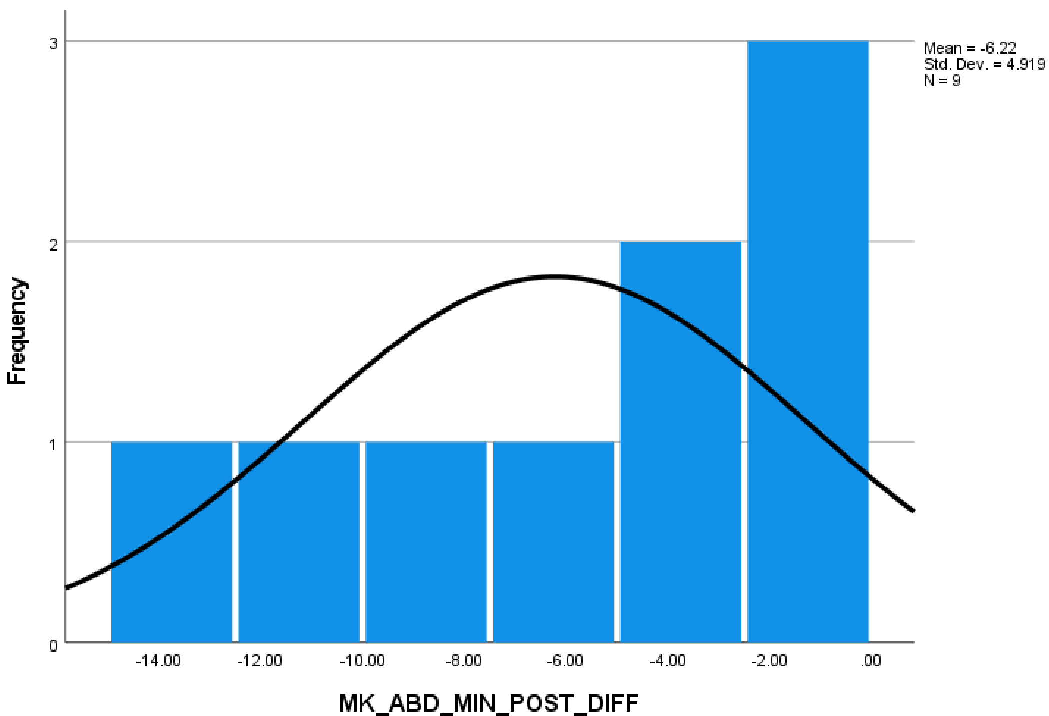
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.00
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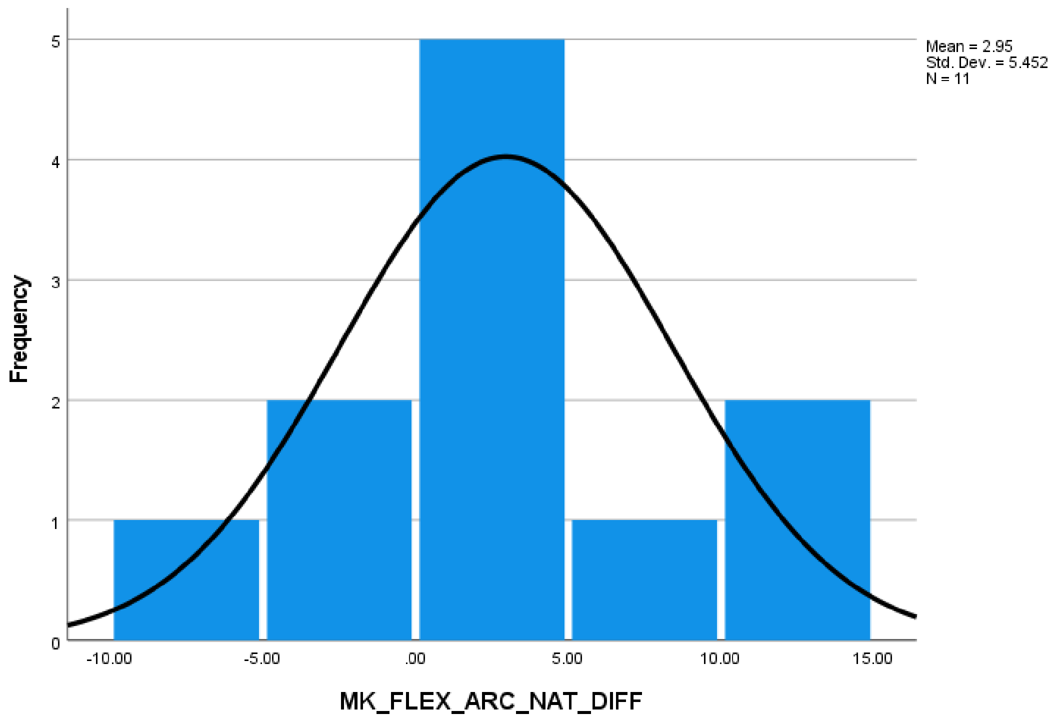
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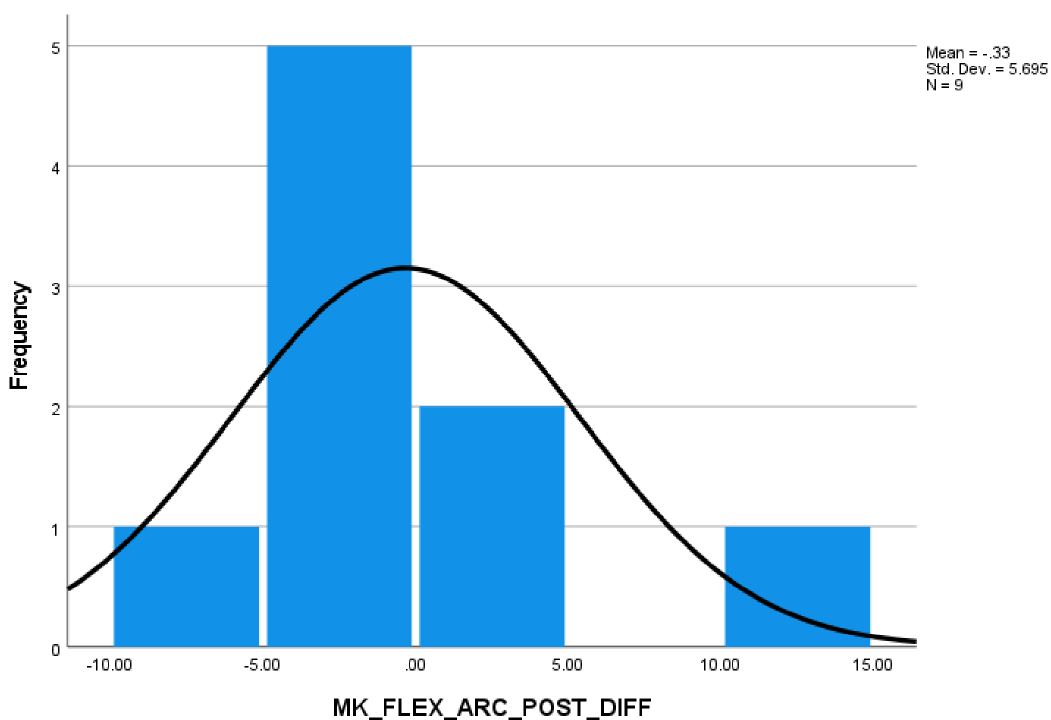
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Std. Dev. = 5.695
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.00
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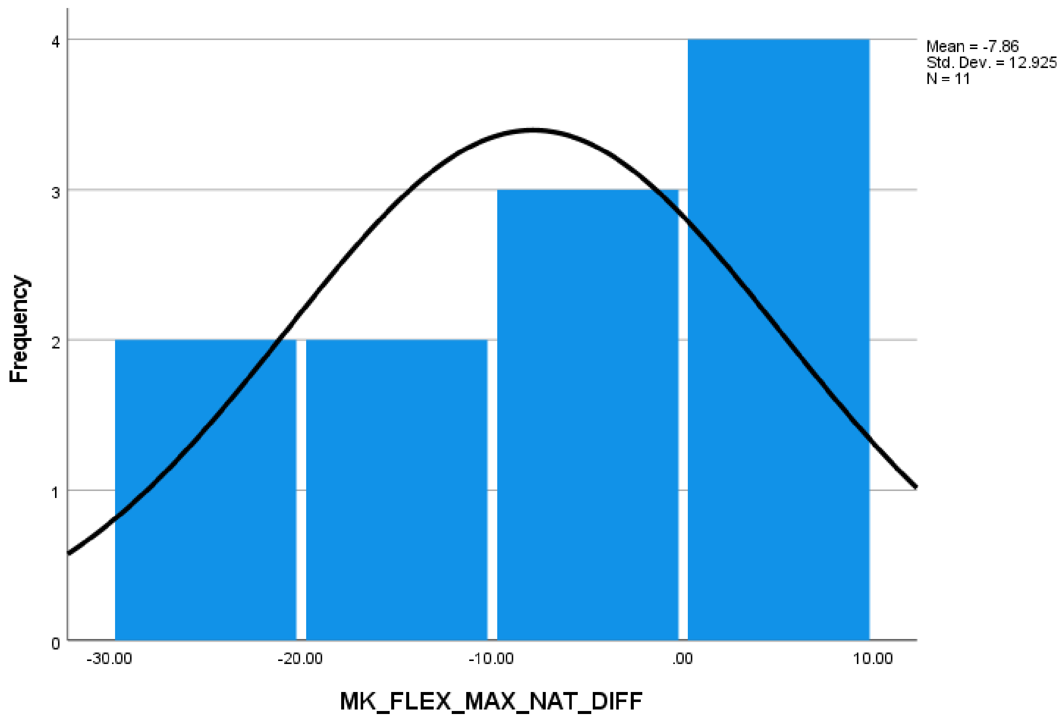
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Std. Dev. = 12.925
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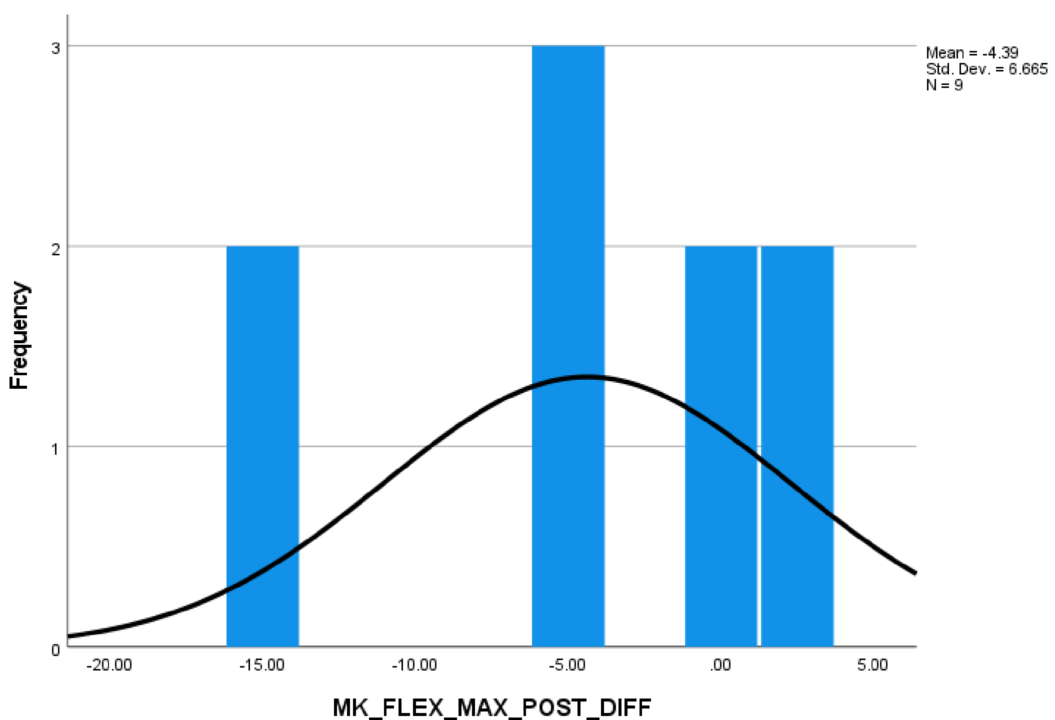
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Std. Dev. = 6.665
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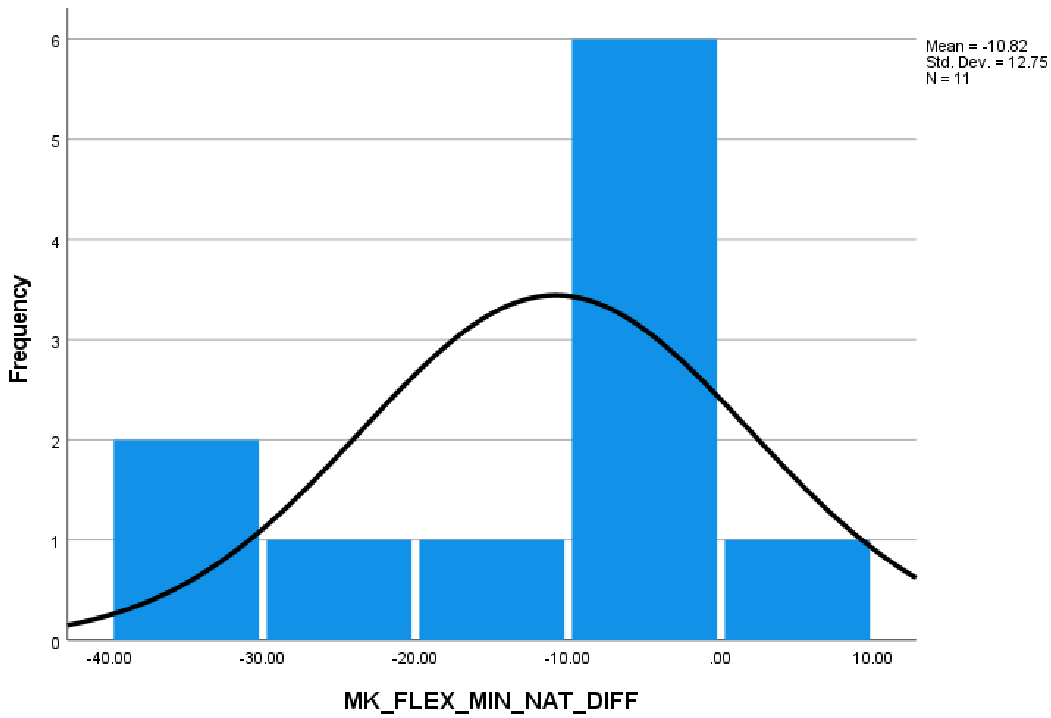
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Std. Dev. = 12.75
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Frequency
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.00
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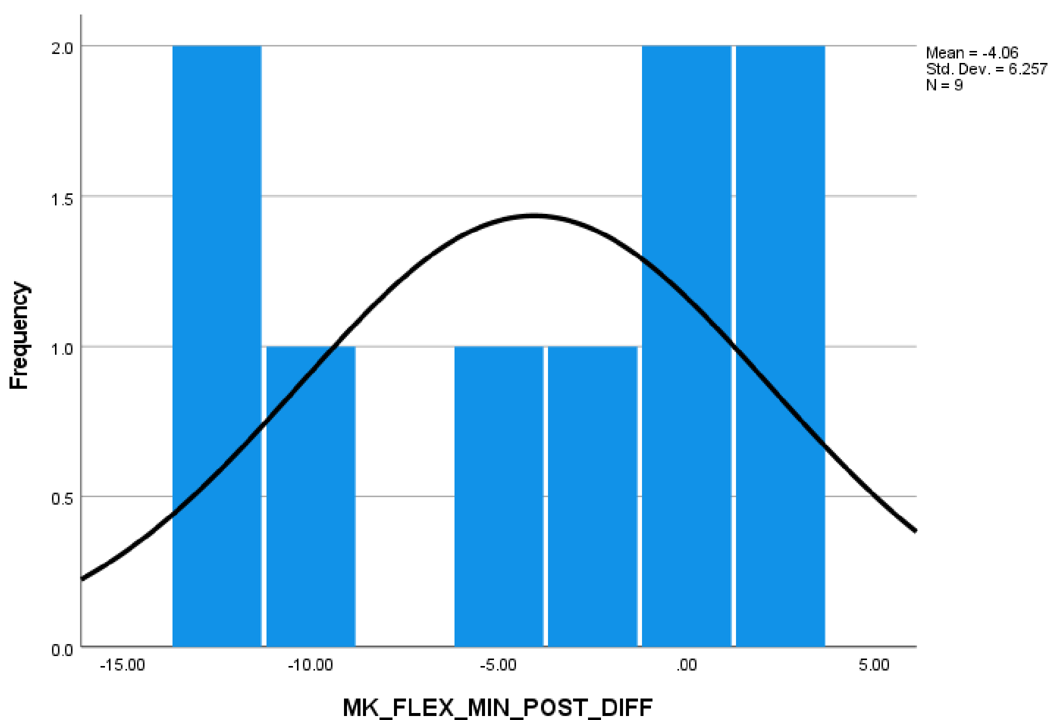
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Std. Dev. = 6.257
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-5.00
.00
5.00
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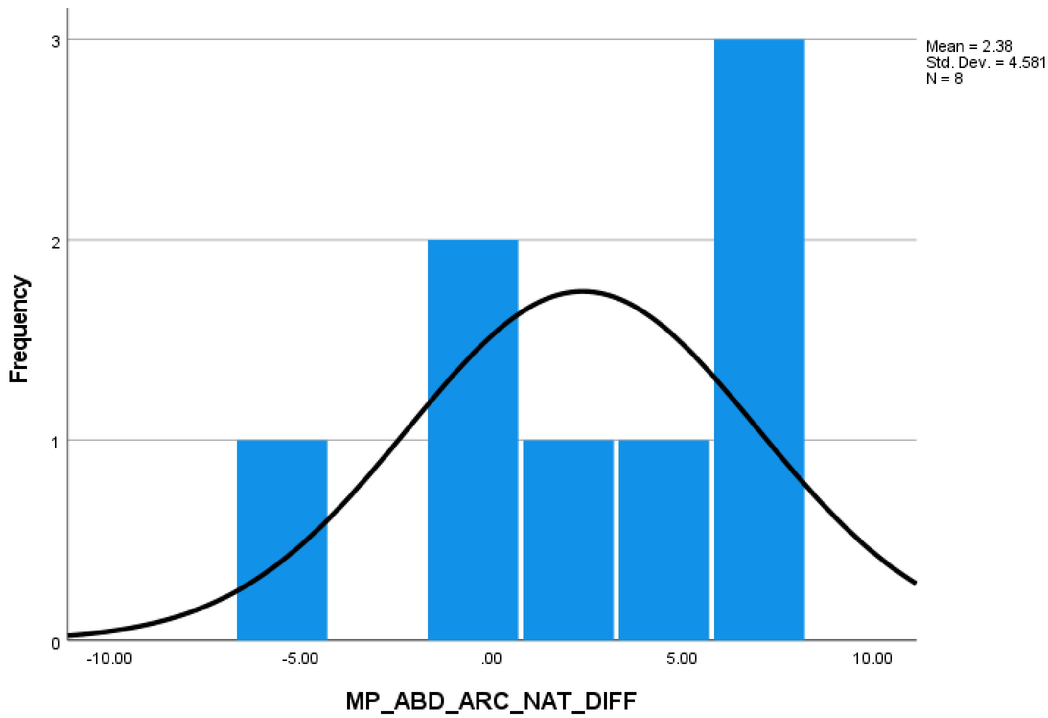
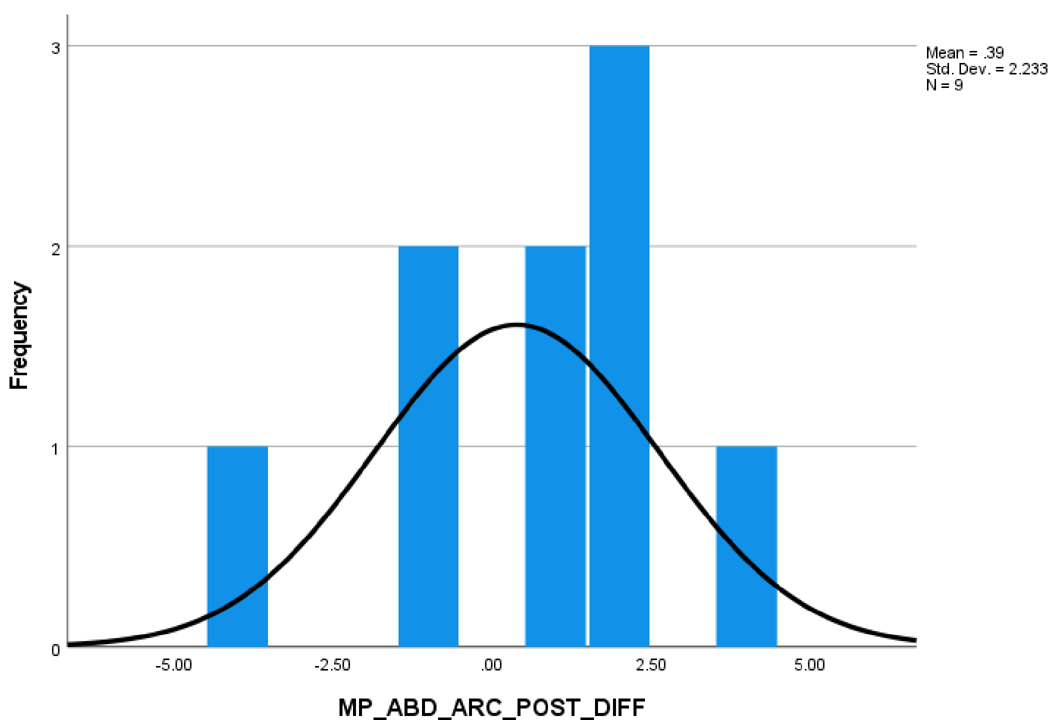

Mean = 2.38
Std. Dev. = 4.581
N = 8
Frequency
MP_ABD_ARC_NAT_DIFF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Std. Dev. = 2.233
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Frequency
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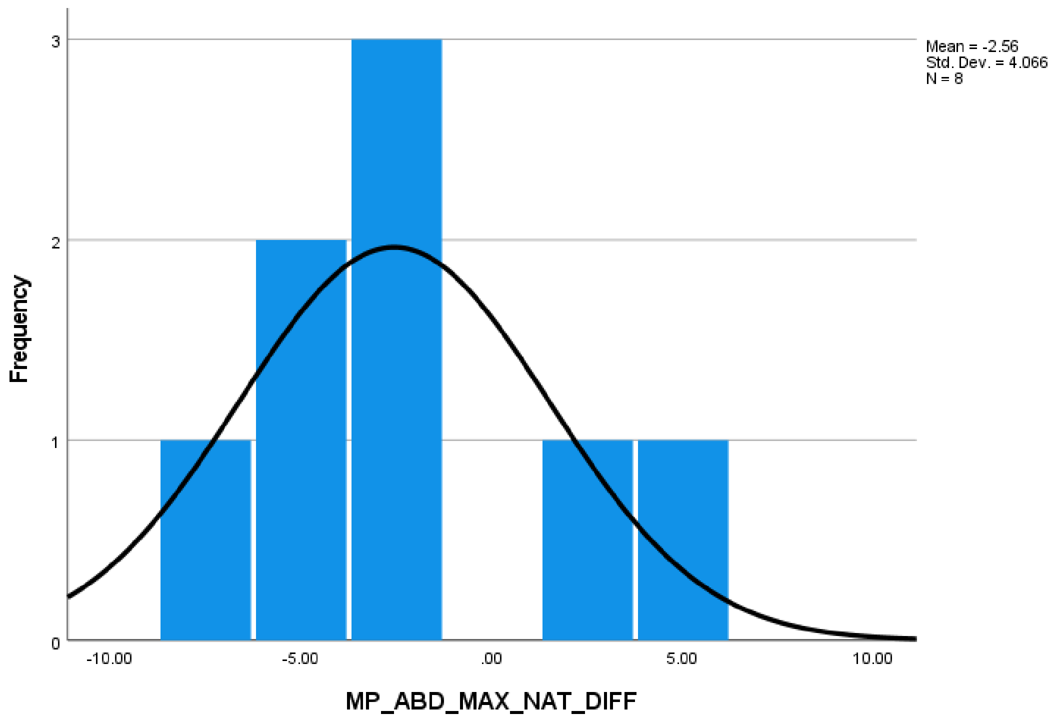
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Std. Dev. = 4.066
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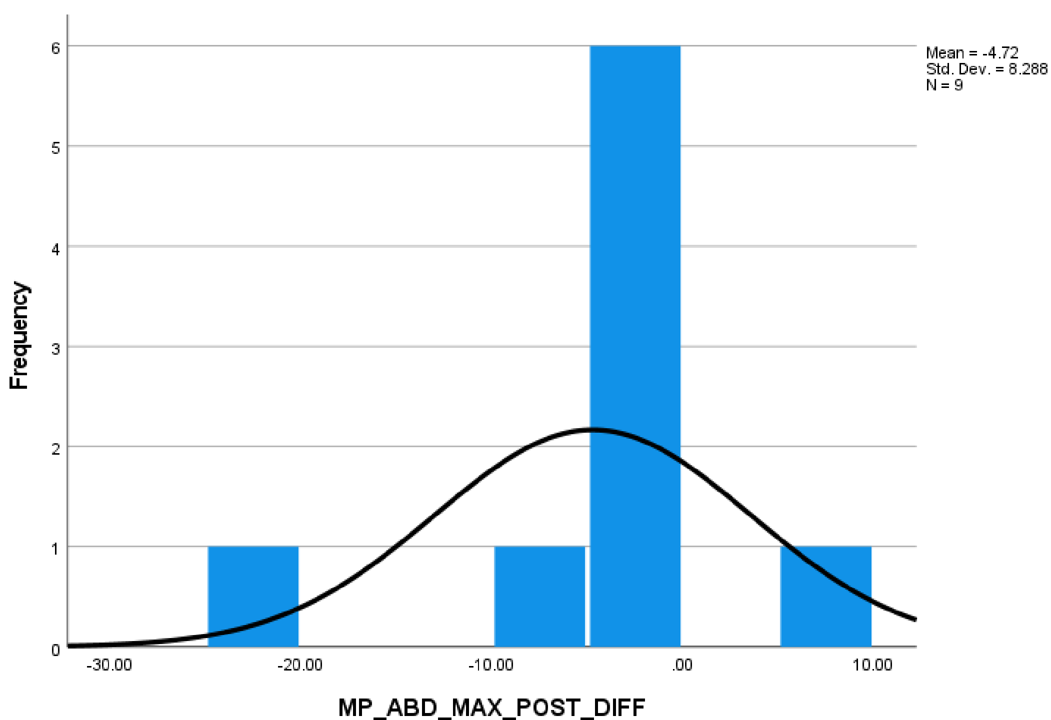
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Std. Dev. = 8.288
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.00
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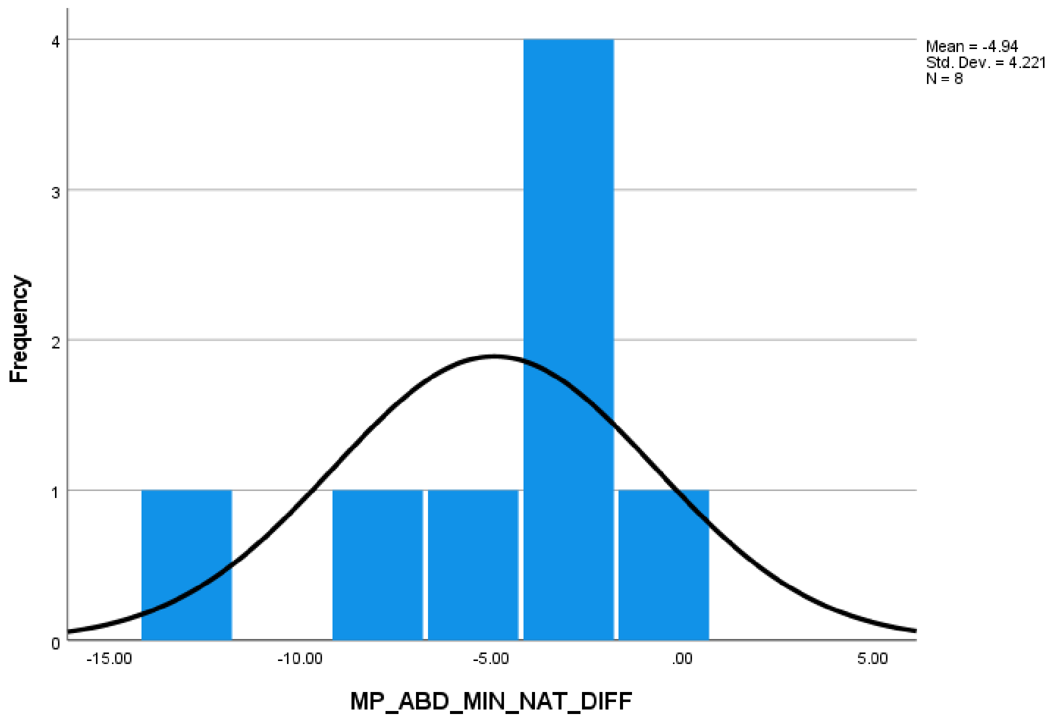
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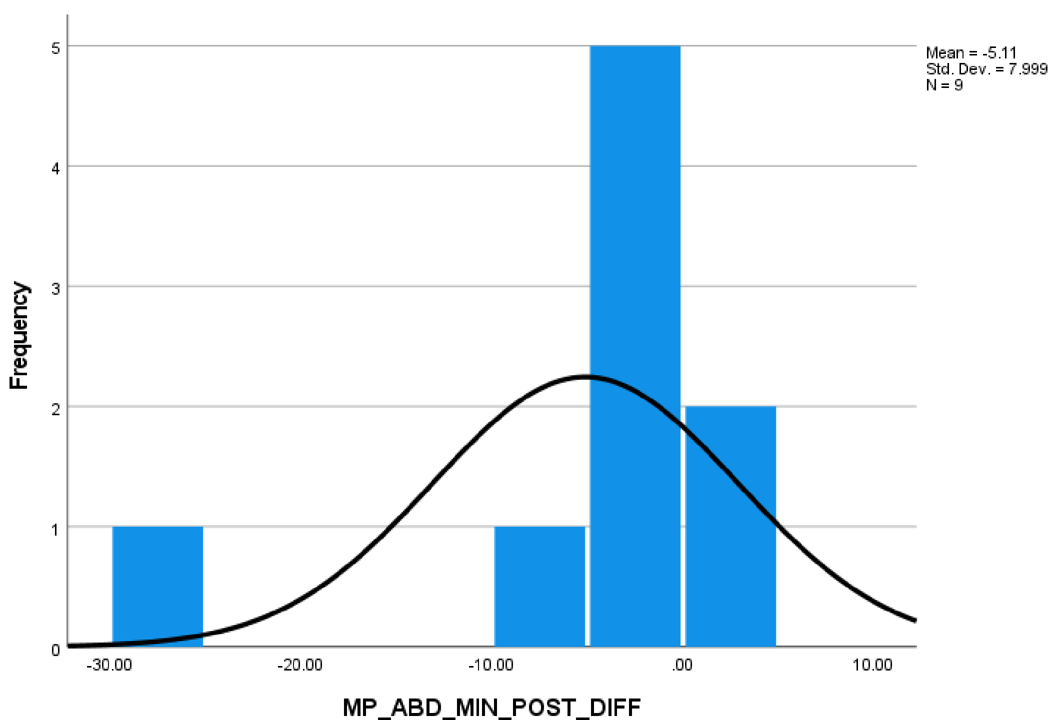
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Std. Dev. = 7.999
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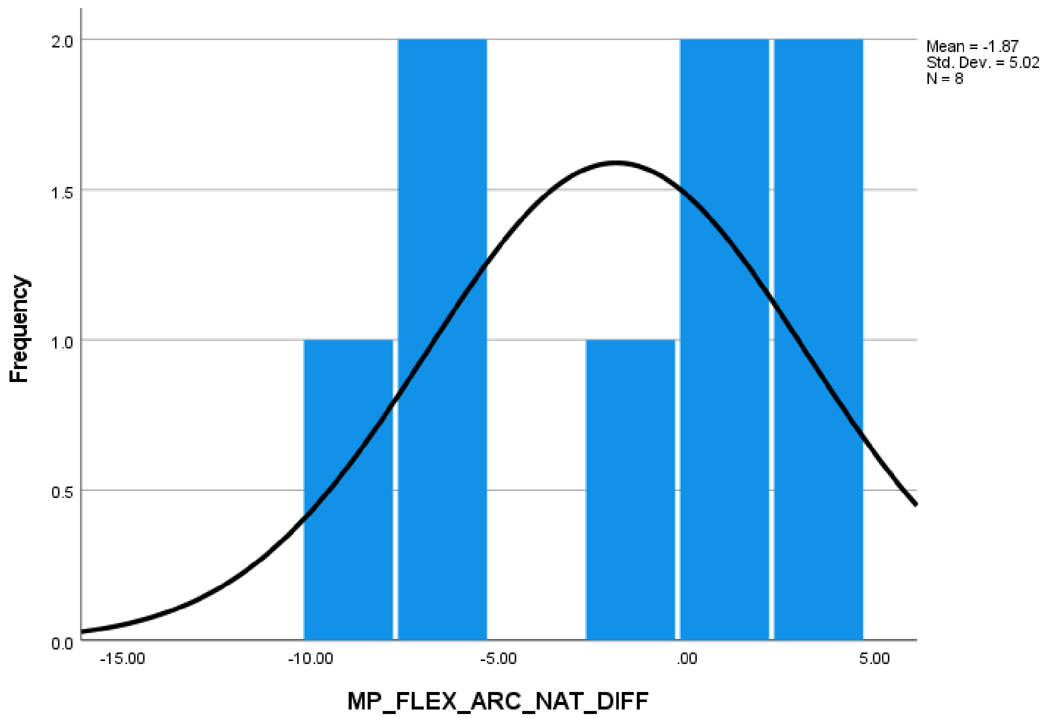

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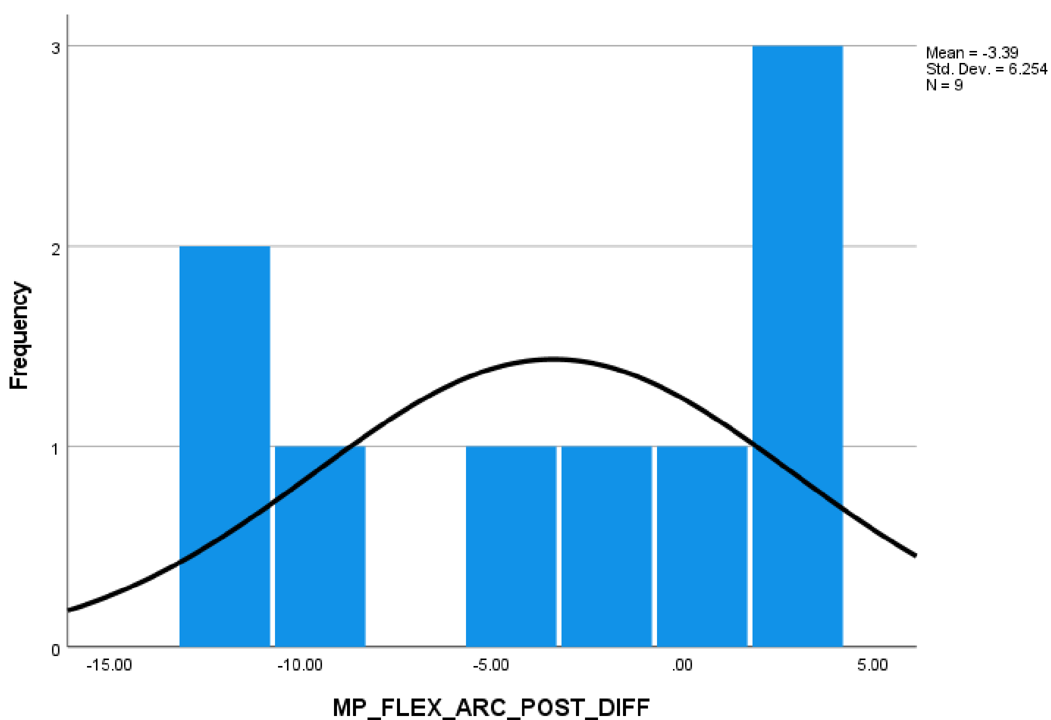

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Std. Dev. = 6.254
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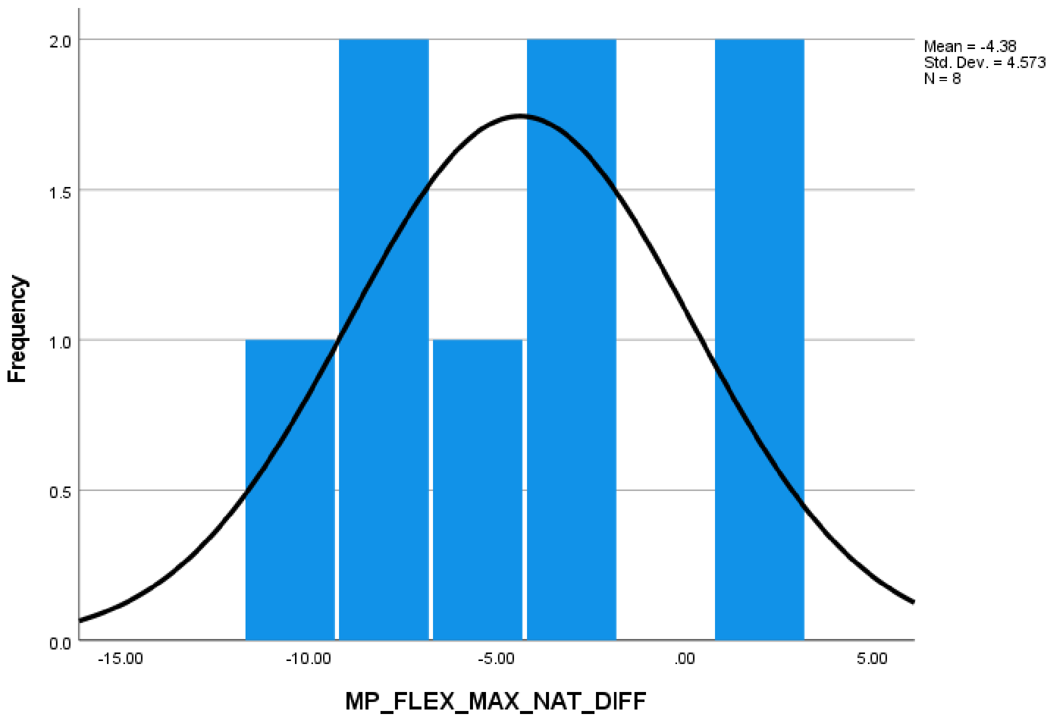

Mean = -4.38
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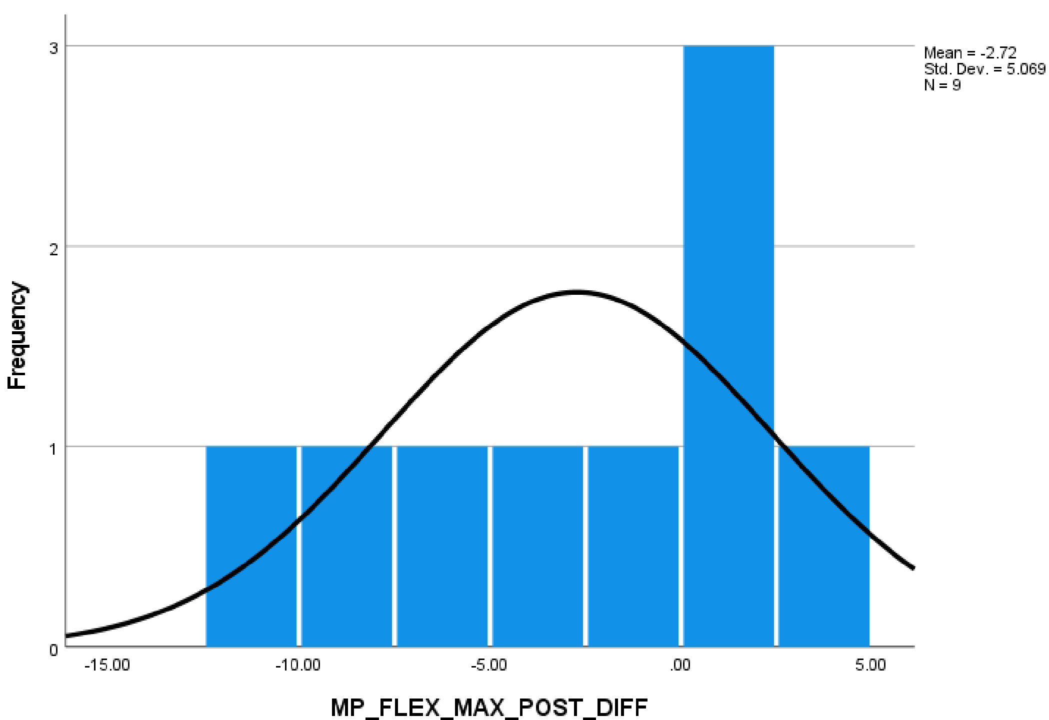

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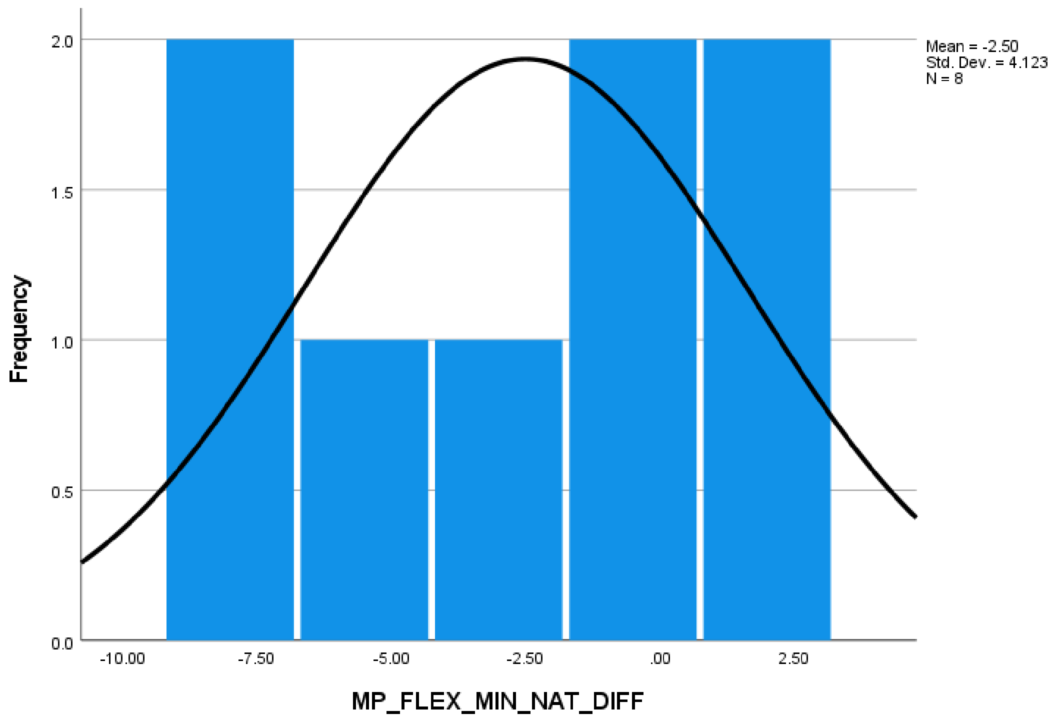

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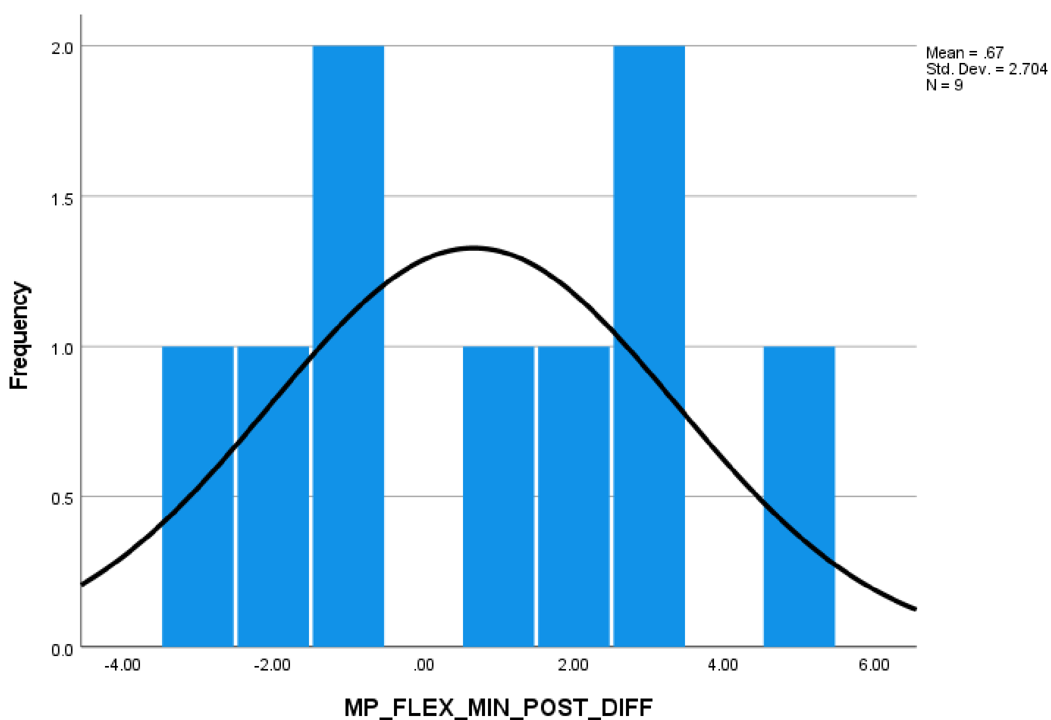

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Std. Dev. = 2.704
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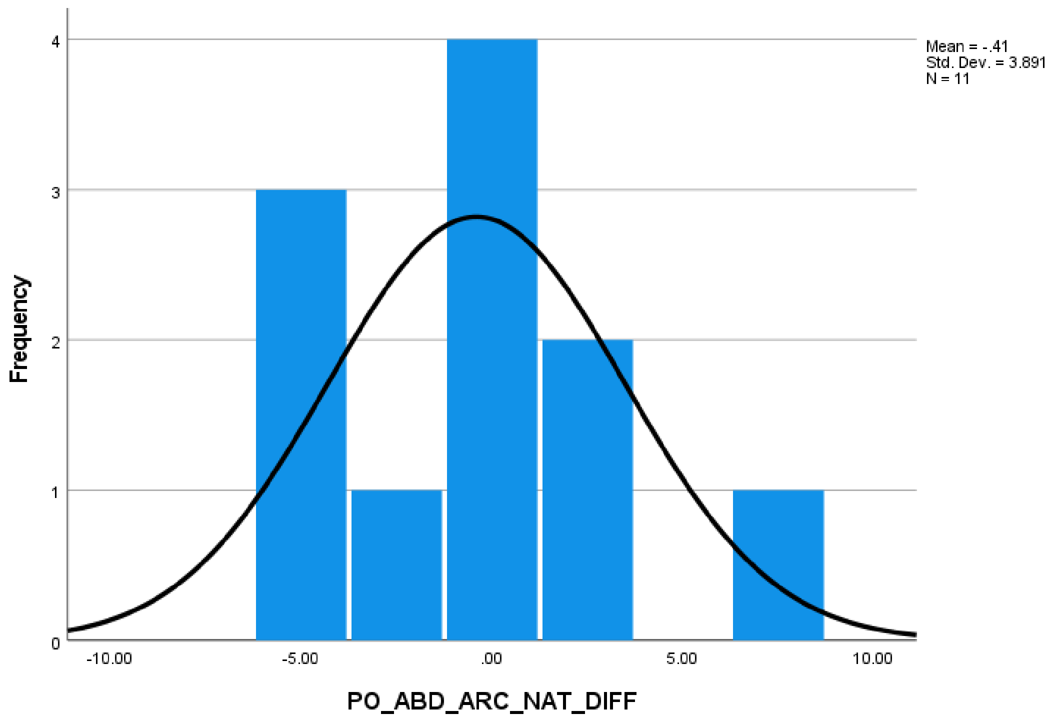

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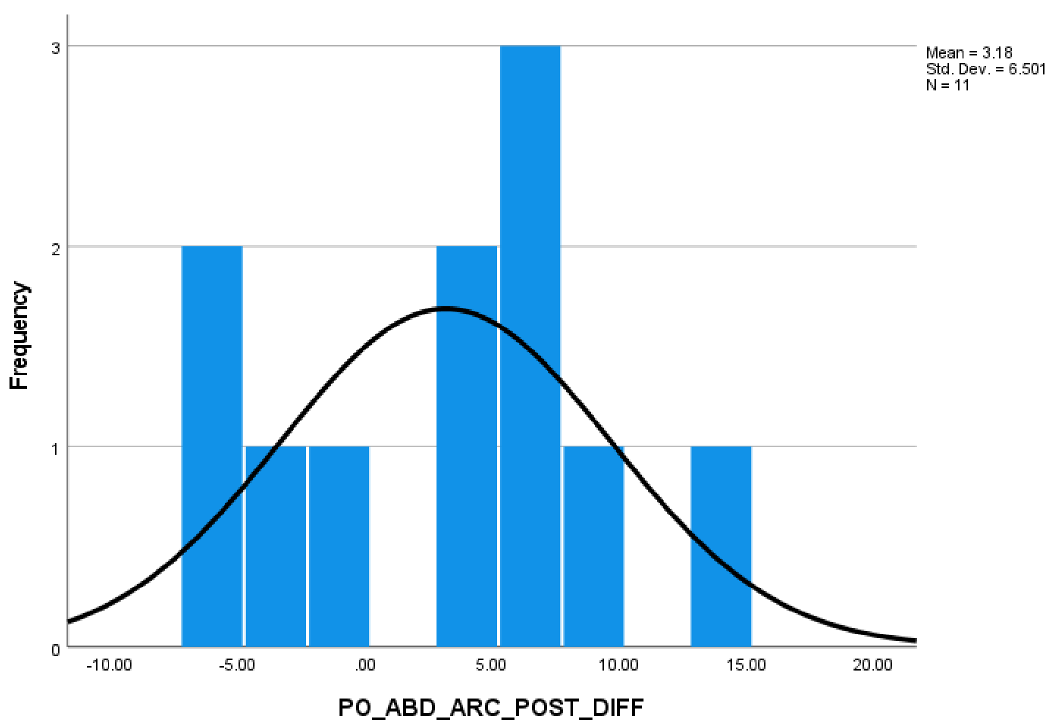

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Std. Dev. = 6.501
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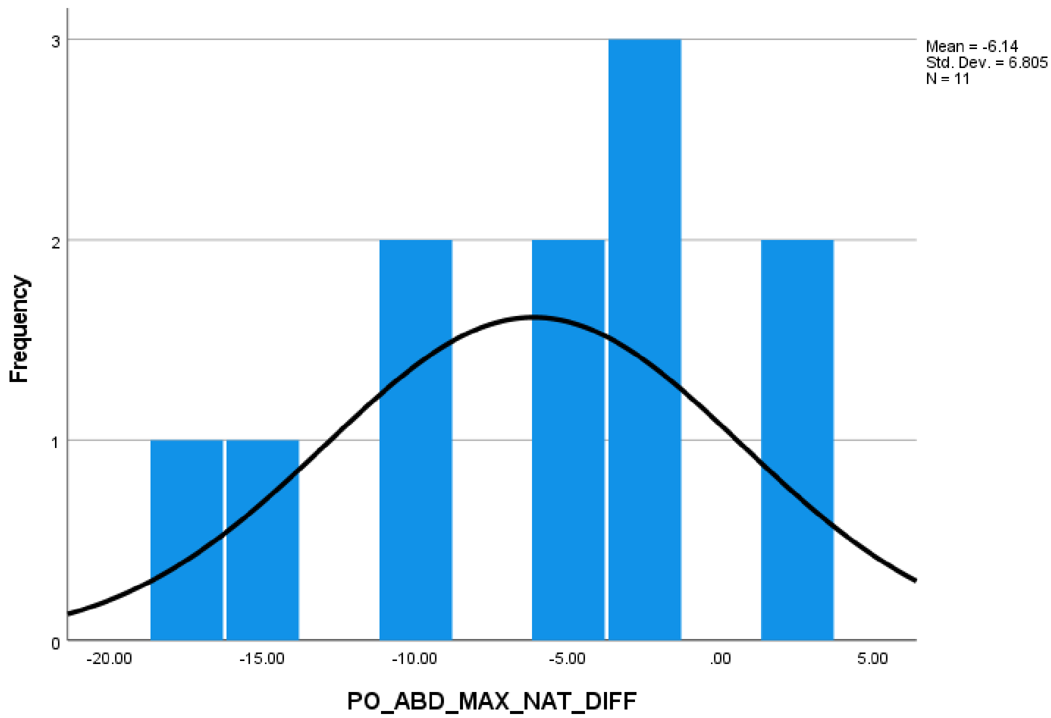
PO_ABD_ARC_POST_DIFF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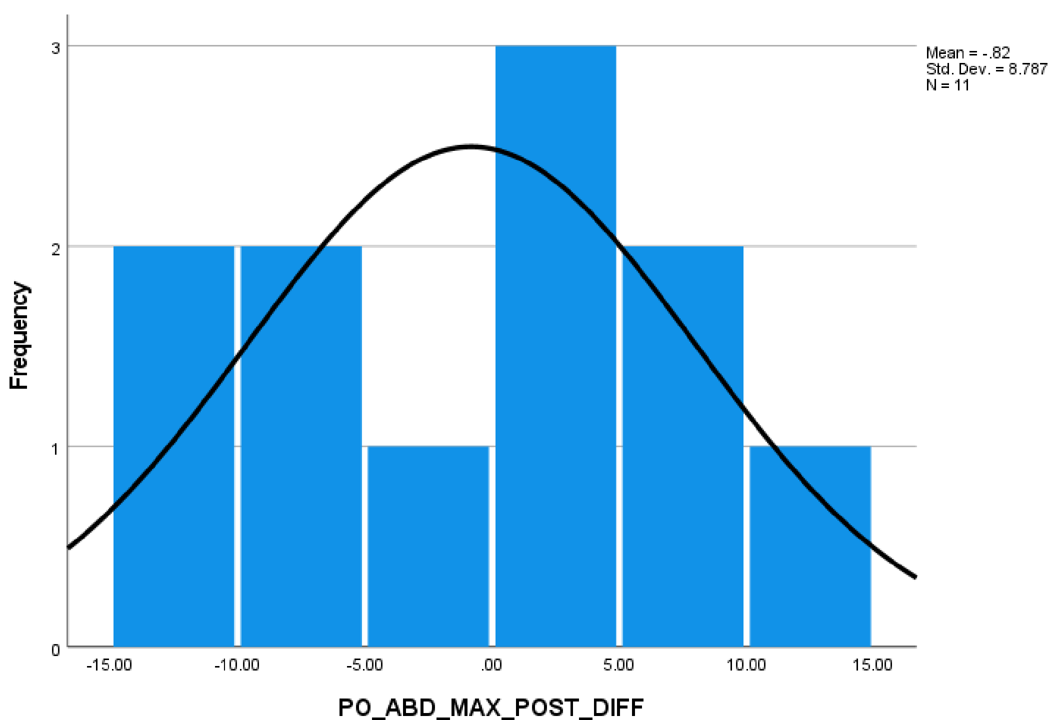
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Std. Dev. = 8.787
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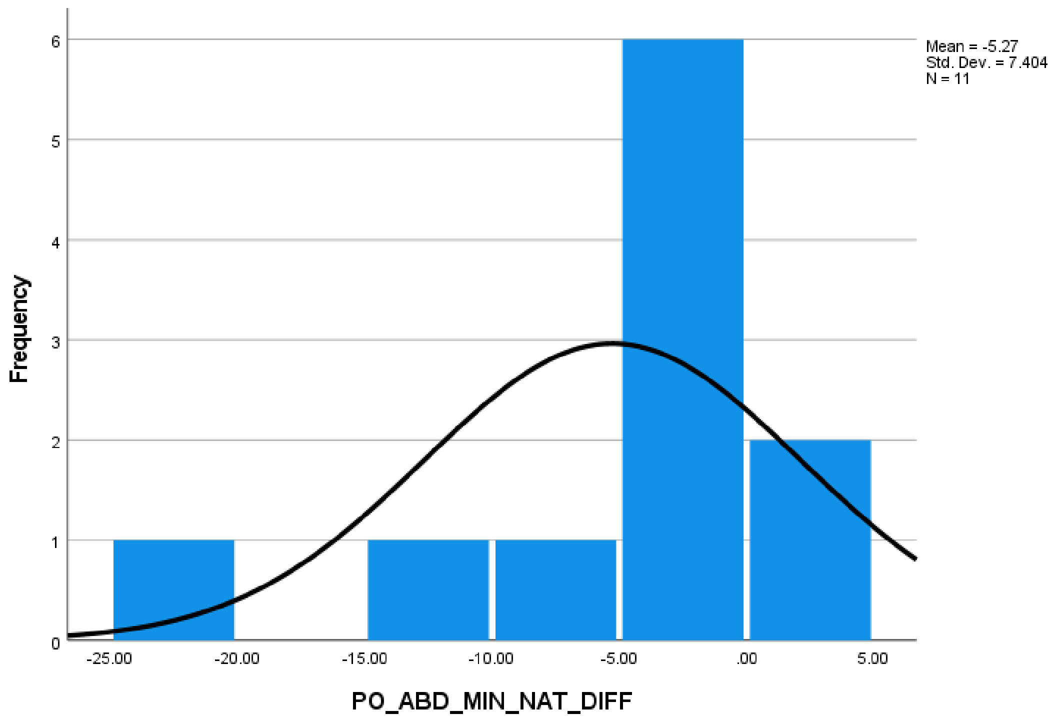
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Std. Dev. = 7.404
N = 11
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3
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.00
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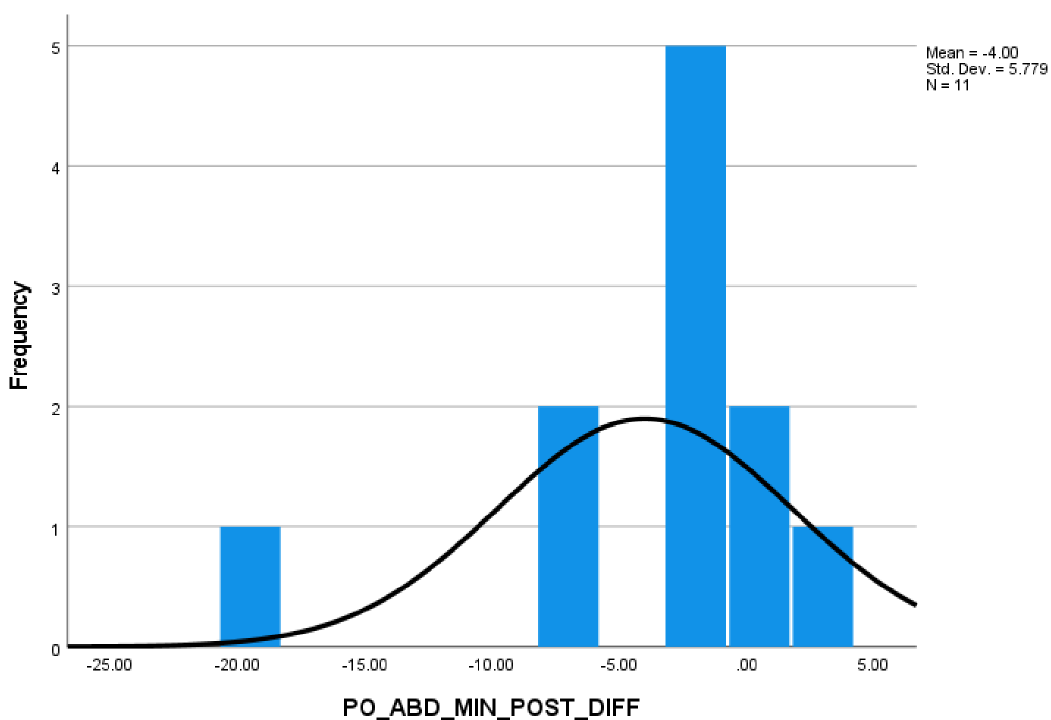
PO_ABD_MIN_NAT_DIFF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N = 11
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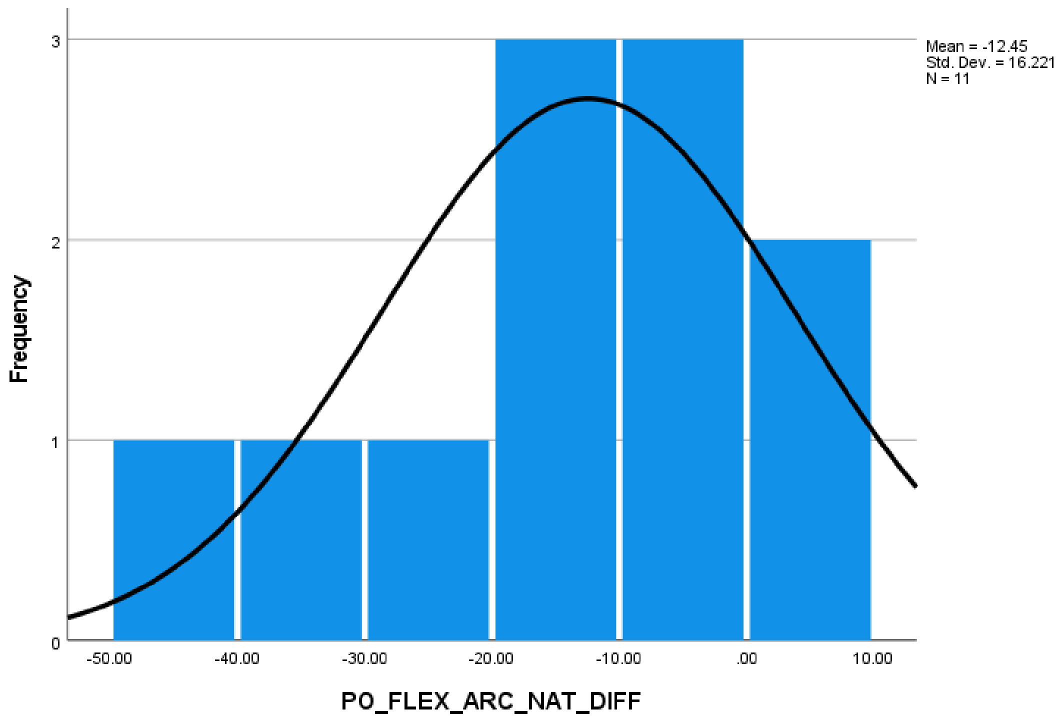
PO_ABD_MIN_POST_DIFF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Std. Dev. = 16.221
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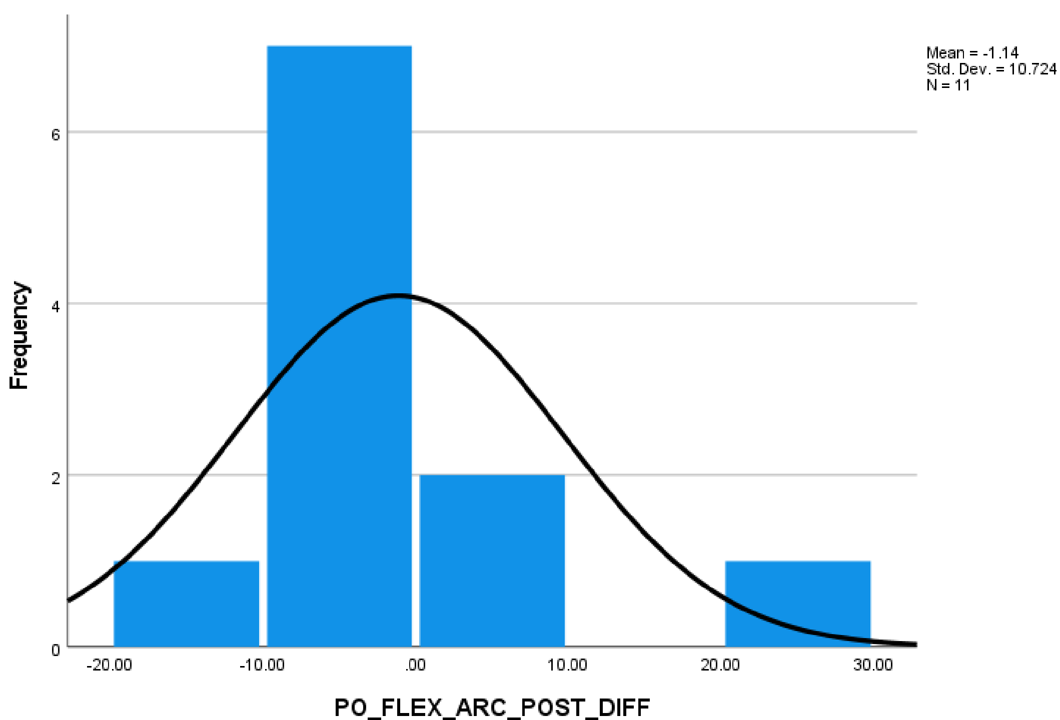
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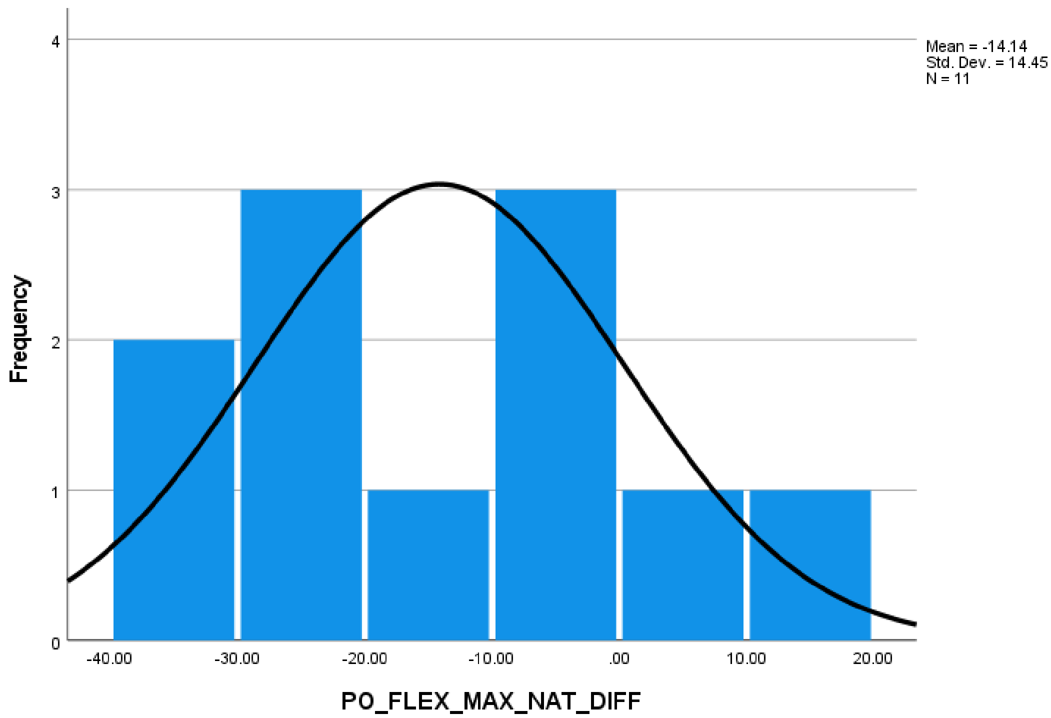
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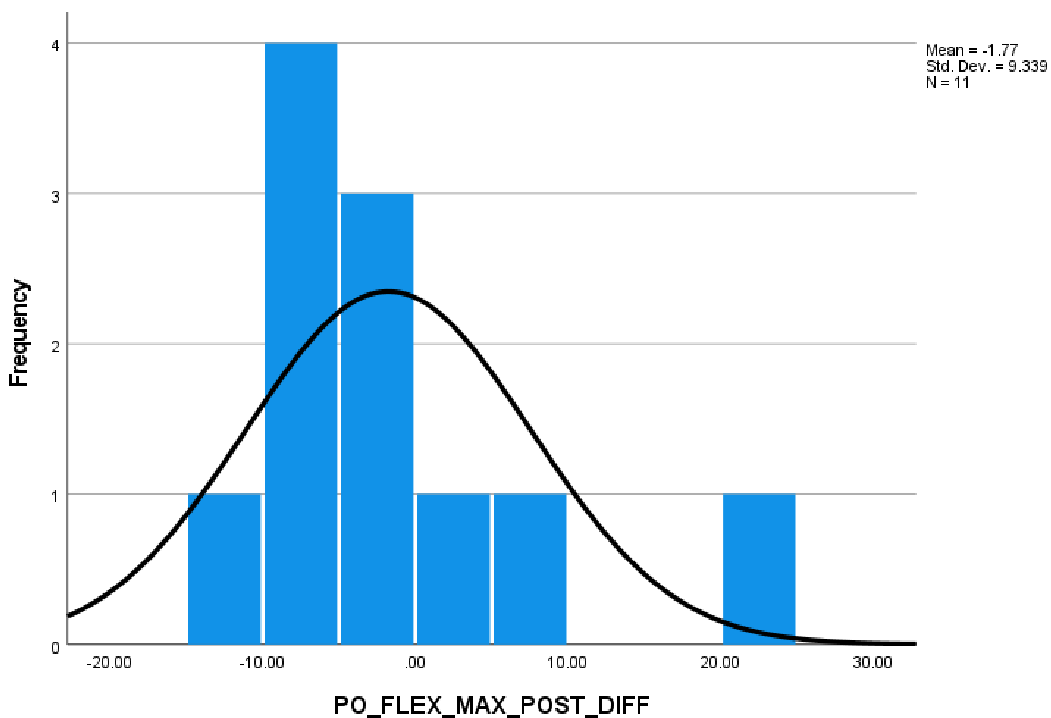
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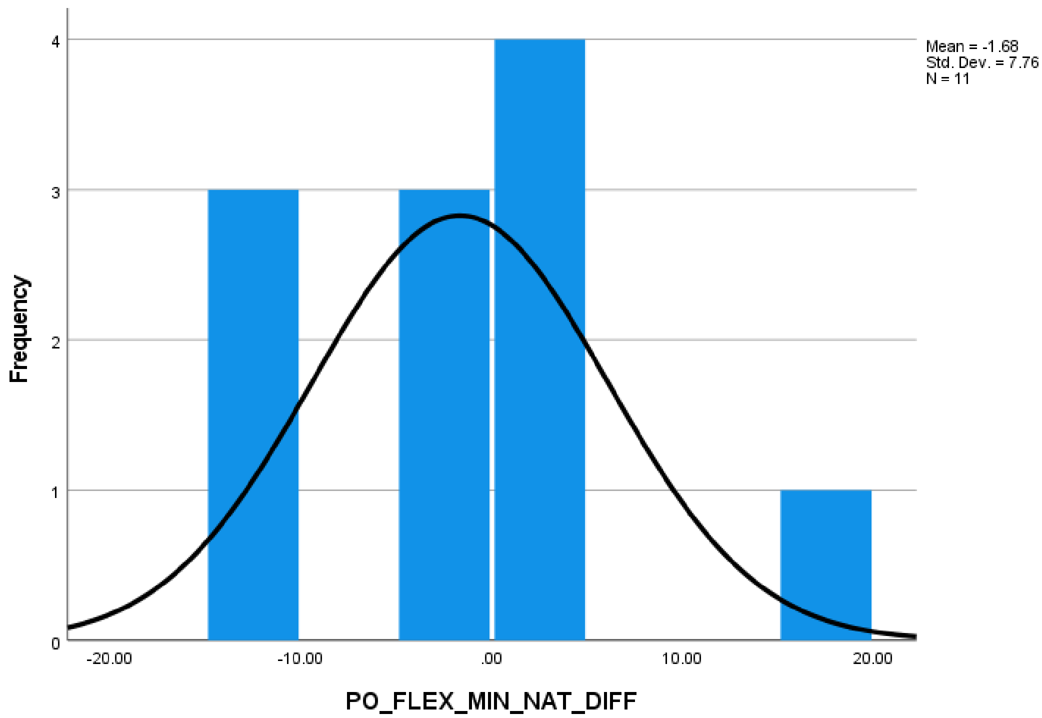
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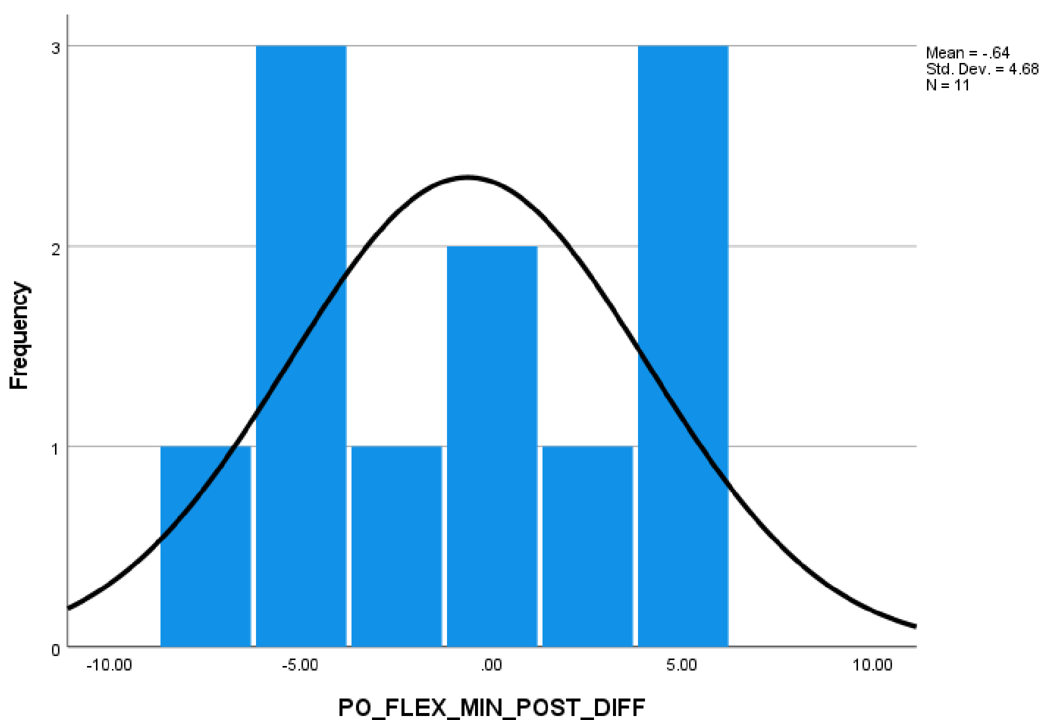
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Chapter 7

7. Developing Digital Resources for Shoulder Joint Protection Program for People with Shoulder Arthritis

Abstract

Background: Shoulder joint arthritis, a common disorder resulting from inflammation and degeneration of joint cartilage, leads to pain, stiffness, and decreased range of motion. Current management involves medications, exercise therapy, lifestyle modifications, and in severe cases, surgery. To further enhance treatment, the development of a personalized shoulder joint protection program (SJPP) is underlined, incorporating strategies to minimize joint stress, improve function, and involve patient education. However, scientific evidence supporting specific daily activity modifications remains limited. Therefore, the study objective was to develop an optimized SJPP for wider clinical application, fostering overall shoulder joint function and mitigating further joint damage.

Methods: The development involved a comprehensive process utilizing literature review, digital resources, and expert insights. The preliminary SJPP was constructed in three sections covering general principles of joint protection, daily activity suggestions, and simple shoulder exercises, using information from generic evidence/principles on hand joint protection, shoulder specific biomechanical evidence synthesis and expert input. It was then amended based on expert panel feedback, focusing on user-friendly language, content comprehensibility, and alternative shoulder protection strategies. The developed program was produced into written and digital resources, and then underwent a usability study based on cognitive interviewing principles in a descriptive qualitative approach. Participants, including patients diagnosed with shoulder arthritis and healthcare providers, were selected by convenience sampling from St. Joseph's Health Care in London, Canada for the useability analysis. The SJPP was introduced to participants, followed by semi-structured interviews about their perceptions and suggestions for improvements. These interviews were audio-recorded, transcribed, and analyzed using a descriptive content analysis technique, assessing the practicality, clarity, inclusiveness, face validity, and content scope of the SJPP.

Results: The interviewed patients (n= 5), had been living with shoulder arthritis for 5 to 33 years. According to the interview, the SJPP demonstrated a commendable balance of practicality, addressing real-world challenges faced by shoulder arthritis patients, and clarity, with its content being straightforward and easily comprehensible. It embraces inclusiveness by offering both digital and print versions, catering to varied user preferences. The program's development, informed by literature and expert consultations, affirms its face validity, while cognitive interviews underline its comprehensive and relevant content. Suggestions for improvement mainly focused on expanding the instruction to include a wider range of activities including sports and recreational activities. Patients provided many practical tips for masking tasks easier that were not gleaned from evidence reviews or experts.

Conclusions: This study underscores the value of evidence-based, user-friendly resources like the SJPP for patients with shoulder arthritis; and an iterative co-design that includes basic science and clinical evidence integrated with clinician and patient goals, needs and preferences. It emphasizes the importance of clear, practical, positive language. The SJPP prototype was well-received but could be further enriched with instruction on a wider range of activities moving beyond activities of daily life to include work, sports and recreation.

Keywords: Shoulder joint arthritis, Shoulder Joint Protection Program (SJPP), Cognitive interviewing principles, Descriptive content analysis, Daily activity management

7.1 Introduction

Shoulder joint arthritis is a common joint disorder characterized by inflammation and degeneration of the cartilage that lines the shoulder joint.[1,2] This results in pain, stiffness, and reduced range of motion in the joint. It can occur as a result of normal wear and tear over time (osteoarthritis) or due to an autoimmune disorder (rheumatoid arthritis).[1–3] Other factors that may contribute to the development of shoulder joint arthritis include joint injuries, family history of the condition, and repetitive use of the joint.[2] The shoulder joint is a complex ball-and-socket joint.[3] The joint is lined with cartilage, a smooth, rubbery tissue that cushions the joint and allows for smooth movement.[3] In shoulder joint arthritis, the cartilage gradually deteriorates and becomes rough and uneven, leading to inflammation and pain. As the condition progresses, bone spurs may develop, further limiting mobility and causing additional pain.[1–3]

The management of shoulder joint arthritis typically involves a combination of medications, exercise therapy, and lifestyle modifications.[4–6] In severe cases, surgery may be necessary to replace the damaged joint with an artificial joint.[7,8] Early diagnosis and treatment are important in managing shoulder joint arthritis and preserving joint function.[1–3]

A joint protection program for shoulder arthritis can involve a variety of strategies to minimize stress on the affected joint and improve overall function.[9–12] It is crucial to highlight the importance of incorporating a joint protection program for shoulder arthritis, in addition to exercise and modifying daily activities.[9,10] For instance, avoiding repetitive overhead motions and heavy lifting, and using adaptive equipment can effectively reduce stress on the affected shoulder joint.[9,10,13] Furthermore, in instances of shoulder arthritis, using a supportive pillow or cushion while sitting or lying down can also reduce pressure on the affected shoulder.[13] While there are general principles that are widely recommended by healthcare professionals to reduce stress on the affected joint, there is limited scientific evidence to support specific modifications to daily activities for shoulder arthritis. When developing a shoulder joint protection program (SJPP), it is important to consider several factors. These include the underlying cause of the shoulder joint problem, the patient's lifestyle and daily activities, the patient's level of function, patient education, and patient compliance.[14] The program should be designed to minimize the impact of daily activities on the shoulder joint while allowing the patient to continue necessary and meaningful tasks. It should also include exercises and activities appropriate for the patient's strength and physical abilities.[14]

Patients stand to gain immensely from a more profound understanding of how to care for their shoulder joint. With heightened awareness and knowledge about the significance of joint protection, they can adopt improved self-management behaviors that can dramatically impact their daily lives. This knowledge isn't merely theoretical; it equips patients with practical skills and guidelines to carry out everyday activities in a manner that safeguards their joint health.[13,14] Ultimately, a joint protection program should be tailored to the individual patient's needs to improve overall shoulder joint function and minimize further joint damage. [13,14]

Involving patients and clinicians is a crucial step in the development of educational interventions intended to promote self-management, such as joint protection programs.[15] Their input can help identify areas of knowledge gaps and ensure that the program meets the specific needs of patients, while also minimizing the overuse of protective measures that patients may not value.[15,16]

This interview study aims to inform and improve a novel shoulder joint protection program and ensure that it meets the specific needs of patients, while also minimizing the overuse of protective measures that patients may not value. Ultimately, the final shoulder joint protection program will be tested for effect and implemented in clinical practice if there is evidence it can improve overall shoulder joint function and minimize further joint damage.

7.2 Objectives

The objectives of this study were to 1) develop an evidence based SJPP for patient with shoulder joint arthritis incorporating the preferences of both patients and clinicians; 2) assess the face and content coverage of the developed SJPP through a cognitive interview with patients.

7.3 Material and methods

7.3.1 Development of the SJPP

The Shoulder Joint Protection Program (SJPP) was meticulously crafted, drawing from an array of resources. Our foundation stemmed from a comprehensive literature review and established digital assets, complemented by insights from a focus group comprised of our research team and seasoned clinicians. Key contributors in the review process were clinicians, handpicked by the first author (SL) and senior author (JM) due to their extensive clinical experience, spanning over a decade. All participants were well-versed in shoulder arthritis and joint protection, bringing expertise from varied backgrounds including physiotherapy (PT), occupational therapy (OT), and surgery. This diverse pool of knowledge was instrumental in creating a thorough SJPP, providing crucial insights into shoulder joint biomechanics and preventive strategies for injuries. After drafting the SJPP, it underwent two review cycles for refinement. The resulting SJPP was not only compiled into a written format but was also transformed into digital resources for broader accessibility. The written form of the SJPP and digital resources can be located in the Appendix 1.

7.3.2 Usability study design

The Western University Health Science Research Ethics Board (HSREB-13583) and Lawson Health Research Board (ReDA-123258) approved this project.

We used a descriptive qualitative approach grounded in cognitive interviewing principles to explore participant interpretation of terms, phrases, and constructs within the SJPP. Cognitive interviewing involves a "think aloud" approach during semi-structured interviews, supplemented by probing techniques.[16] In the effort to deeply understand participant comprehension of the SJPP digital resources, we encouraged participants to vocalize their thoughts during their “think aloud” interactions the interviewer.[16] This "think aloud" method allows researchers to access valuable insights into the cognitive mechanisms that guide participant responses. By exploring the thought processes participants undergo when reviewing the SJPP, we can identify areas of potential confusion or misinterpretation. In conjunction, we utilized probing techniques to gain further insights into participants' thought processes and to clarify any ambiguities or uncertainties, mapping responses onto a framework intended assist in classifying concerns raised in the cognitive interview process.[16,17]. Based on the feedback collected, a final version of the SJPP digital resources was crafted for implementation in filed testing.

7.3.3 Participants

We used a convenience sampling method to include participants who had been diagnosed with shoulder arthritis and had received or were about to receive rehabilitation interventions. Healthcare providers, such as physical therapists, occupational therapists and surgeons experienced in treating patients with shoulder arthritis, were also invited to participate in the study. Our sample was recruited from the Hand and Upper Limb Centre (HULC) at St. Joseph's Health Care in London, Canada. Patients and therapists who expressed interest in participating in our study were provided with a letter of information and a consent form. Enrollment continued until content saturation was reached.[18]

7.3.4 Data Collection

The surgeons introduced the study to potential participants. If patients expressed interest, a research assistant met with them and provided a detailed explanation of the study. Once the patients agreed to participate, they received a link to the SJPP program for preview, provided they had access to the online website. For those without online access, a printed version of the entire program was given. On the day of consent, a date for the in-person or on-line virtual interview was established. Patients were given at least 2-3 days before the interview to review the entire program and form their initial impressions. During this time, the patients independently previewed the SJPP program. The interviews were conducted by the first author (SL), following an interview guide that included questions about the participants' experiences with the SJPP, their thoughts on its clarity/comprehension, relevance, inadequate response definition, and perspective modifiers.[17] Patients were encouraged to provide suggestions to further improve the content of the SJPP.

To guarantee the precision of the data collected, the interviews were captured through audio recordings and transcribed verbatim. These transcripts were subsequently checked for accuracy, and any information that could identify participants was redacted to preserve their confidentiality. Both audio and video recordings were transcribed by the student investigator, with any potential identifiers removed and pseudonyms assigned.

7.3.5 Data Analysis

Demographic data for patients, encompassing variables such as age, gender, and occupational status, alongside the duration of symptom manifestation and laterality of affliction were collected. The collected data is presented in Table 1.

Following the semi-structured interviews, the investigator (SL) transcribed and analyzed the original audio materials. A deductive descriptive content analysis technique was then deployed to yield an extensive, in-depth depiction of the participants' opinions regarding the practicality, clarity, and inclusiveness of the elements and statements in rehabilitation decision aid.[19] This analytical method enabled us to sort and categorize extracts from the transcriptions. The outcomes of these interviews were studied with respect to face validity and content scope of the SJPP.[17,20]

We considered face validity by synthesizing participant feedback on its visual appeal, structure, presentation mode (online or print), and overall pertinence to the target demographic.

All interviews were conducted and analyzed by SL, a PhD student in rehabilitation science with an existing background in physiotherapy. The student interviewer engaged in critical reflection on his disciplinary perspectives and positionality as a researcher during the interviews and analysis activities.

7.4 Results

7.4.1 Development of the SJPP

The preliminary edition of the joint protection program was prepared by the first author (SL) utilizing consolidated data from literature reviews and adapting existing hand joint protection program.[9,10] The initial draft comprised three sections: 1) general principles of joint protection, 2) suggestions for daily activities including dressing, grooming, kitchen related activities, cleaning and tidying, working, driving, carrying heavy objects, sleeping, computer & desk set-up, using smartphone, and 3) simple shoulder exercises.

Following multiple expert panel discussions, which included a) Ph.D. committee members representing the fields of physiotherapy, occupational therapy and orthopedic surgery, b) physical therapists, and c) other graduate students in rehabilitation science conducting musculoskeletal research, the initial draft was amended according to their feedback and suggestions.

The experts primarily gave their insights on the content, alternative strategies for shoulder protection, and the use of patient-friendly language. An expert underscored the importance of conveying the concept of shoulder joint protection in a manner that's easily grasped by the general population. It's also crucial to provide a concise introduction to the entire SJPP at the outset, to clearly outline the structure of the SJPP. Another expert proposed adopting a positive tone throughout the program, in line with current literature which cautions against creating a nocebo effect through the use of language that characterizes movements and anatomy as dangerous, delicate, damaged, or requiring protection. She also provided explicit word choices to mitigate this effect. Constructive feedback was given by the experts on refining sections dealing with kitchen activities, driving, and sleep-related behaviors. The inclusion of online interactive resources in the program's advantage section was also suggested to improve accessibility. Adjustments were suggested to simplify the SJPP language and terminology to improve readability and comprehensibility. Another suggestion was to correlate the joint protection strategies with the potential outcomes they have demonstrated effectiveness in improving.

7.4.1 Participants

We conducted interviews with five patients who have been diagnosed with shoulder arthritis. Each patient has had a diagnosis for a minimum of five years, with the range extending up to 33 years. Only one patient reported arthritis in bilateral shoulders, while the remaining four patients experienced the condition in one shoulder. Our sample included two men, with an average age of 73.5 years, and three women, with an average age of 65 years. See Table 1.

7.4.2 Cognitive interview results

Overall language, comprehensibility, clarity, and readability of the SJPP

The participants thought the program was easy to understand and they stressed the importance of thoroughly reading and applying the information to get the full benefit. No missing elements were identified by participants, and they appreciated the program's straightforward approach. No major revisions or simplifications to the language were suggested. *"... I think it makes sense. People need to take time to read it. Basically, the whole program is easy to understand. You need to read it and try it on yourself. You cannot just scan it and say it is not useful…"* Patient #4, a 53-year-old woman with left shoulder arthritis for 20 years.

"…This program focuses on the daily activities with different components. I don't think any items are not necessary or redundant. And also, I think the program is quite clear and adequately covers the topics that are important for me considering a joint protection in the daily life…" Patient #3, a 73-year-old woman with bilateral shoulder arthritis for 33 years.

"...I believe the program is straightforward and truly comprehensive. Everything seems relevant, and I appreciate principles such as 'respect pain.' As you know, when you have arthritis, you must adjust your activities according to your pain. Otherwise, your day could be ruined…" Patient#2, a 81-year-old man with right shoulder arthritis for 8 years.

Adaptive Strategies and Lifestyle Modifications in Response to Shoulder Arthritis

During the interview, all the participants expressed making substantial lifestyle modifications in response to their shoulder arthritis. These modifications touched upon a spectrum of daily activities, including dressing, grooming, kitchen chores, cleaning tasks, professional work, and the handling of heavy items. For those dealing with shoulder conditions, coming up with an appropriate pacing and planning and setting aside more time has become a common approach to carry out daily activities.

"…My shoulder, it would hurt. And when I sat. Like on the edge of the bed or sat on a chair, my shoulder would hurt and it would go into my neck. You know, I'd have to like lay back. Like wipe reaching my back, wipe my butt. You know, it was just a lot of everyday activities really. I had a hard time with washing, reaching my back and sometimes reaching my hair. Even doing dishes, right, sometimes it would hurt because, uh, if I had to scrub something with that arm, it hurt…" Patient #1, a 66-year-old woman with right shoulder arthritis for 6 years.

"…Shaving with a safety razor with your non-affected hand is awful. So, I only do it once every five or six days. For the kitchen chores, I don't even like to move the frying pan. We got those big, heavy I iron frying pans, and I don't use them at all.…" Patient #2, a 53-year-old woman with left shoulder arthritis for 20 years.

"…Well, as a housewife and farmer's wife, reaching is something I have to do. For instance, I often start my day trying to deal with laundry that before so I can no longer hang anything on the line because I can't get my arms up. And to get anything out of the top cabinets of my kitchen cupboard was very difficult for me to do because I couldn't lift things down. I broke more dishes in the last three or four years. Don't put a roast in the oven. Don't put chicken in the oven. So, it changed our eating habits. Holding anything above my head, I just haven't been able to help my husband in farming. Another thing I didn't mention was like to do simple things like wash my hair and dry my hair. Yeah, that's style. I used to have longer, much longer hair and I just had to whack it off because I couldn't do it. That makes a big difference in mental health. feels like you can go

out and look decent but not, you know, just have to depend upon other people to help you with the everyday things of life…" Patient #4, a 53-year-old woman with left shoulder arthritis for 20 years.

To keep your knife sharp is a common suggestion provided by 4 out of 5 participants during the interview. Patient #5 mentioned:

"…keeping your knife super sharp is a total game changer, trust me! It's going to save you a ton of effort and spare your shoulder when you're cooking. I bet heaps of people would back me up on this one. Maybe that's something you could add to your program? …"

Two of the patients customize their clothes for easy donning due to the shoulder discomfort. Patient #2 mentioned:

"…I had some old t-shirts that I just, uh, ripped up and, and got some big, safety pins and I wore those for several days if my shoulder hurt a lot…"

"…When my shoulder pain got really bad, I'd just rip up some of my old tees and use big safety pins to hold them together…" Patient #5, a 69-year-old woman with left shoulder arthritis for 16 years.

The interviews also revealed shifts in the use of technology and adaptive equipment. Despite adopting these alterations, participants still encountered hurdles and physical limitations, particularly when undertaking tasks that demanded strength or induced pain.

All patients conveyed that they would never subject their shoulder to excessive weight. They mentioned that it's essential to only handle a limited weight to prevent straining themselves. They refrain from using their shoulder as a means of support during standing and other activities. Their emphasis was on the importance of avoiding undue physical stress.

To mitigate their condition, they adopted strategies like circumventing certain activities, leaning on others for assistance, and utilizing long-handled tools. Moreover, participants introduced specific changes in their kitchen, laundry, and cleaning routines to lessen the burden on their shoulders.

"…The ability to do things from my waist to upper level, and over my head was pretty much impossible. Lifting things out of the oven became a little bit dangerous because I just didn't have the strength or the stability to do it properly and I got my husband to do that…" Patient #4, a 53-year-old woman with left shoulder arthritis for 20 years.

"Sure, I use those long-handled tools you talked about - they're pretty handy. But hanging the hairdryer on a hook? That's new to me, never tried that one…" Patient #5, a 69-year-old woman with left shoulder arthritis for 16 years.

Lastly, adjustments to sleeping patterns were implemented to minimize discomfort and optimize rest, underscoring the all-encompassing impact of shoulder arthritis on daily living.

"… I had to sleep upright, and I had to have shoulders propped up with pillows, like right up against the pillows. I would sleep up type thing. I have my pillows propped up where I could lie back in it but fully on my back. Like sitting up…" Patient #1, a 66-year-old woman with right shoulder arthritis for 6 years.

"… I got three pillows underneath my head. I'm elevated quite a bit on the higher part of my body…" Patient #2, an 81-year-old man with right shoulder arthritis for 8 years.

"…When it comes to sleep, I've got my routine down. Always shove a pillow under my sore shoulder. Mostly, I just lie on my back or chill out in my recliner. Oh man, that recliner's been a total game changer for my shoulder pain. And, get this, when I need to sit up, I just use my abs and give my legs a little swing, way better than straining my shoulder. Took some trial and error, but I figured it out…" Patient #5, a 69-year-old woman with left shoulder arthritis for 16 years.

General recommendations

All the participants expressed agreement that the SJPP is relevant and comprehensive, covering the fundamental daily activities they encounter in their lives. They found no items that were repetitive or superfluous, underlining the program's efficiency in addressing pertinent issues.

Participants favored the printed format of the program over the digital alternatives. They also emphasized the importance of incorporating protection strategies for sports and recreational activities.

"...It would be great to include some recommendations for recreational activities like golf, swimming..." Patient #2, a 53-year-old woman with left shoulder arthritis for 20 years.

7.5 Discussion

The goals of the study included the creation of an evidence-based joint protection program for patients experiencing shoulder arthritis, considering the preferences of both the patients and clinicians. In addition, an assessment of the SJPP's face and content coverage was conducted through cognitive interviews with a diverse panel consisting of patients, clinicians, and domain experts.

The development of the SJPP involved synthesizing evidence from a broad range of sources including literature reviews, existing digital resources, and knowledge shared by a focus group consisting of the research team and domain experts. This wealth of information resulted in a comprehensive SJPP which covers crucial aspects of shoulder joint protection strategies and shoulder joint biomechanics. The program was designed for universal accessibility, available in both a written format and as digital resources.

Panel discussions with domain experts were instrumental in shaping the content and structure of the program. The emphasis was on the use of simple, patient-centric language and an optimistic tone to prevent the occurrence of a nocebo effect. They deemed it crucial to introduce the program in a clear and succinct manner that can be comprehended by a broad audience. Previous research has reported that low health literacy can obstruct effective patient education. A recommended solution to this problem involves the creation and provision of patient education materials written in plain, accessible language. This approach ensures that the information is easily understood by a wide range of audiences, improving overall health literacy.[21] Additionally, they suggested incorporating online interactive resources to improve accessibility and cater to a diverse patient demographic. The experts also highlighted the significance of connecting joint protection strategies with potential benefits, to strengthen the program's credibility and relevance in real-world scenarios.[21]

By including participant viewpoints, we aimed to ensure the SJPP was visually pleasing, easy to navigate, and tailored to meet the specific needs and preferences of individuals with shoulder arthritis. Patient interviews provided unique insights into the lived experiences of those with shoulder arthritis. During the interview, participants highlighted the lifestyle modifications that these individuals had to make, impacting activities such as dressing, grooming, household chores, professional work, and even handling heavy items. The participants commended the program's successful balance between text and graphics, enhancing the program's readability and understandability. They emphasized, however, the need to thoroughly read and apply the program to benefit fully from it. All participants acknowledged the SJPP as relevant and comprehensive, covering crucial everyday activities and offering no superfluous or repetitive elements. The preference of most participants for the printed version of the program over digital resources emphasizes the need for joint protection programs to be flexible and tailored to a diverse range of ages and accessibility preferences. Since shoulder joint replacement is typically performed in older adults, the technology comfort and competence may be different that health care problems that affect a younger population. But this varies by individual. Therefore, providing alternatives like printed materials for those who are less technologically inclined, while maintaining online versions for tech-savvy individuals, supports the program's widespread accessibility. By targeting “the right delivery to the right patient” we might enhance the program's reach, adherence and efficacy. However, they noticed a gap in the program's content concerning sports and other recreational activities. Participants pointed out that these activities often form a crucial part of life for many individuals, and guidance on how to manage shoulder arthritis during these activities could be beneficial. This feedback can be instrumental in refining the program's content to better meet the needs of its target audience.

The interplay between mental health and shoulder arthritis is intricate.[22] This study suggested a potential link between shoulder arthritis and its psychological effects, noting that the condition might somewhat limit an individual's ability to maintain their personal aesthetic appearance. However, this relationship is not firmly established. This limitation, which can be perceived as a loss of independence, may contribute to the stress experienced by patients perioperatively and during recovery.[23,24] Such an association between arthritis and mental health disorders has been corroborated by a cross-national study, which concluded that individuals with arthritis are more likely to experience mood and anxiety disorders.[23] This association's strength remains consistently across different types of disorders and geographic locations worldwide. Such finding suggests that the arthritis affects not only physical health, but it also has a substantial impact on mental well-being.[23] To address the intertwined concerns of mental health and arthritis, enhancing self-efficacy emerges as a promising solution. Self-efficacy, or one's belief in their capability to execute behaviors necessary to produce specific performance attainments, plays a pivotal role in how individuals approach challenges, tasks, and stressors.[25] By strengthening self-management skills, particularly in areas such as joint protection, individuals not only gain better control over their physical symptoms but also experience a boost in their mental well-being. Over time, this empowerment can translate to a more positive mental outlook, lessening feelings of anxiety or depression linked to the condition. Thus, focusing on building self-efficacy can have a dual benefit, enhancing both physical health and psychological resilience.

The presence of comorbidities can significantly impact daily activities what shoulder joint protection principles will work for different individuals. For instance, individuals with hip or knee arthritis may not be able to bend through their lower back or knees, which could conflict with the strategy suggested for reducing shoulder loading while carrying objects. Thus, it is essential to provide multiple options in the program and to acknowledge that users may need to experiment with different strategies depending on their body size, sex and other health problems.[26] Fear of movement, also known as kinesiophobia, can be an important factor when dealing with individuals who have various comorbidities, including chronic pain.[26,27]. This avoidance behavior could inhibit the individual's engagement with the SJPP and their overall physical activity, which is crucial for maintaining joint health and general wellbeing. Therefore, the SJPP should include strategies to address and alleviate this fear. This could involve explaining the safety of the exercises, encouraging gradual exposure to feared activities, and incorporating pain management techniques.[28] Furthermore, given the important contribution of psychological factors in the fear of movement[26] review of the program recommendations by a mental health professional could provide additional refinements.

It's important to recognize that our study has certain limitations that could potentially impact the generalizability and validity of our findings. Firstly, a potential limitation could be the sufficiency of data collected during the interview phase. Although we endeavored to include enough participants to attain data saturation, we acknowledge that full saturation may not have been achieved.[18] The determination of data saturation was based on iterative analysis and team discussions. Different researchers or additional participants representing more diverse subgroups might have added further unique perspectives and insights.

The second limitation pertains was the absence of clinicians' feedback during the cognitive interview phase. While we included clinicians during the co-design including review texts/components, they did formally evaluate the full final prototype. Their contributions would provide a more rounded understanding of the real-world application of the SJPP, improving the program's overall quality and effectiveness.

The single interviewer could potentially lead to biases. These biases might include confirmation bias[29] considering that SL developed the tool, conducted the interviews, created and analyzed the transcripts without any direct participation from other researchers or analysts. However, the student researcher engaged in conscious consideration and reflection on his role and biases during the analysis, striving to increase the openness and accuracy any interpretations, and discussed findings iteratively with a team of experts.

Cognitive interviews are useful, but not the only way to assess useability. An area of future research could involve conducting a study dedicated to assessing the usability of the digital resources associated with the SJPP. Key metrics such as learnability, memorability, error rate, user satisfaction, simplicity, and comprehensibility could be explored in-depth.[30–34] The learnability of the digital resources would examine how easily new users could understand and utilize the platform. Memorability would gauge how well users could recall how to use the platform after a certain period of non-use.[30] The error metric would identify the number and types of mistakes users made while navigating the platform, as well as how they were able to recover from them. [30] User satisfaction would assess how pleasant and satisfying the platform was to use, while simplicity would explore how effectively the platform met users' needs without unnecessary complexity. [30] Lastly, comprehensibility would determine how well users understood the information and instructions provided in the SJPP. [30] Such an investigation could provide valuable insights into the effectiveness of the SJPP in its digital format and identify areas for improvement. By refining these aspects, we can enhance the overall usability of the SJPP digital resources, making it more accessible and effective for a wider range of patients. The end goal is to ensure that the digital resources of the SJPP can effectively cater to the diverse needs of the users, thereby potentially improving adherence to the program and ultimately leading to better patient outcomes.[30,32]

To refine the SJPP, it's crucial to conduct a series of evaluations. A formal health literacy assessment will ensure that the program's content is clear and accessible to all, regardless of their health knowledge background.[35] An equity analysis will examine the program's impact across different demographic groups, ensuring no group is disproportionately underserved.[36] Finally, a cultural competency evaluation will ensure the program's content and approach respect and resonate with diverse cultural beliefs and practices related to health.[37] These combined evaluations will bolster the SJPP's accessibility, relevance, and effectiveness for a wide array of patients.

In the future, the program’s accessibility could be expanded with the development of applications for mobile devices, tablets, and computers. By offering downloadable content like videos and podcasts, individuals with limited internet bandwidth can still access and review the educational materials at their leisure, even during instances of unstable or unavailable internet connectivity. Moreover, the inclusion of education about Orthopedic Supports, such as various types of braces, should be explored and incorporated into the program.

In conclusion, this study illustrates the importance of developing evidence-informed, user-friendly resources like the SJPP to cater to the needs of patients with shoulder arthritis. It highlights the necessity of considering the patients’ perspective, their lived experiences, and the need for clear, practical, and positive language. The study also emphasizes the role of expert input in refining and enhancing such resources. Overall, the SJPP represents a notable contribution to the resources for patients with shoulder arthritis, designed to enhance their quality of life and enable them to navigate their everyday activities with greater ease and less discomfort. Further enhancements, including content on sports and recreational activities, could serve to make it even more comprehensive and beneficial.

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7.7 List of tables

Table 7-1 Demographic information of the participants in the cognitive interview

		Patients mean ± SD; n
Age		68 ± 9
Sex	Woman	3
	Man	2
Duration of shoulder arthritis		17 ± 10 Ranging from 6 to 33 years
Affected side	L	2
	R	2
	B/L	1
Previous treatment	Conservative management	4
	Surgical management	4
	injections	2

*Conservative management includes physiotherapy, massage therapy, acupuncture, chiropractic, and pain medications.

*Surgical management includes rotator cuff repair and total shoulder arthroplasty and its reversed type.

7.8 List of Appendices

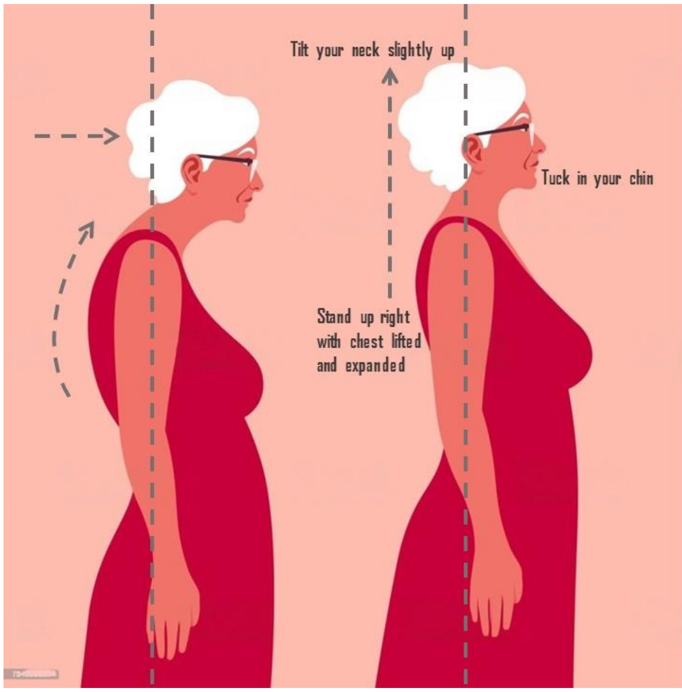
7.8.1 Appendix 7-1 Written Format of Shoulder Joint Protection Program (SJPP)

General principles (to do more with less pain)

- Respect pain. If an activity causes you discomfort, try doing the task in a new way, take a break, or ask for help. If you experience pain for an hour or longer after completing an activity, try shortening how long you spend doing it the next time. If you can, it is best to **STOP before you have pain!**
- Avoid holding your arms in raised positions for prolonged periods of time. Adjust the height of your work surface to ease pressure on your shoulder joints.
- Opt for a smooth, circular motion when doing activities like dusting or washing a car. Limit repetitive arm motions, particularly sudden back-and-forth movements. Switch up your activities often to prevent pain and fatigue.
    - When you hold bag or tool, try to stretch your shoulder every 10 minutes. This can reduce stiffness and cramping.
- Avoid weight-bearing through your arms and use adaptive equipment if needed:
    - For getting on and off a chair, try using a high, firm chair, a raised cushion or chair blocks.
    - Use a shower or try a bathchair rather than getting in and out of the bathtub
    - Using a raised toilet seat can make it easier to get on and off the toilet.
- Exercise a little and often.
    - It is good to continue everyday activities. It helps to keep your shoulders moving.

Positioning your shoulders for good posture and less pain

- Relax your arms at your sides
- Stand up right with chest lifted and expanded and tilt your neck slightly up
- Pull you shoulder blades back & down (like you were tucking them in a pocket)
- Tuck in you chin with your head balanced over your body



Suggestions for daily activities

- **Dressing:**
  - Wear loose fitting clothing. Avoid tight turtlenecks and pullover sweaters.
  - Dress your most painful arm first and undress it last.

- **Grooming:**

  - Try adapted equipment to extend your reach, such as a long-handled comb, brush or sponge.
  - Use a hook to hang the blow-dryer or get a blow dryer stand so that you don't have to hold it constantly.
  - Applying make-up, shaving etc.: Use your "good" arm to support the weight of the sore arm
  - Use an electric toothbrush to avoid repetitive back & forth motion
  - Use a long-handled sponge to reach your back

- **Kitchen related activities.**

  - When you invite family or friends for dinner, plan in advance. Prepare some things the day before. Ask others for help.
  - Bring the rack out and then use oven gloves to take a hot dish out of the oven. Use both hands to keep the dish stable. Do not tilt. You can also ask somebody to help Bend through the hip or squat down to reach the dish in the oven.
  - To serve a hot meal from a pan, leave the pan on top of the stove. Spoon it out from there.
  - To carry a tray or kettle: slide it on the countertop.
    - i. Your elbow should be tucked against the body throughout the movement.
    - ii. Instead of reaching out with your arms, take a couple of side-steps to walk towards your destination.
  - Use lighter objects, like plastic bowls and lighter kettles.
  - Use electric appliances or a reacher to help you work: Electric knife, can opener, blender, food processor, electric screwdriver and table saw.
    - i. Keep your knives sharp.

- **Cleaning and tidying**
  - To plan jobs around the house, give your shoulders a rest every 10 to 15 minutes.
  - Use your good arm to support the weight of the laundry basket. Use your bad arm on top to stabilize. Pick up dirty clothes and put them in the laundry basket, which is placed close to the washing machine. Take them from there until laundry time.
  - While sweeping the floor, keep the broom close to your body and keep your elbow tucked in. Use your good arm to handle the dustpan as you move around. Avoid heavy vacuum machines, or ask somebody else to do that.
  - Stand close and use both arms to open the drawer. Ensure that your drawer slides open easily. Hold your clothes with your good arm, while placing your bad arm on top.
  - To close a drawer, push it closed with your hip or thigh. To close a drawer, push it closed with your hip or thigh
  - To iron clothes, slide the iron from the iron rest to the board. Try rocking from your hips instead of reaching across your body to iron.
  - When cleaning the inside of windows, keep your shoulders close to the window as you wipe in circles. Don't raise your hands above head level.

- **Working**
  - Storage:

i. Try to avoid over-reaching. Plan your worktop and storage areas so that items you use frequently are stored close to you, at a convenient height (between your shoulders and your knees).
ii. Store heavy items around waist height.
iii. Carry heavy items close to your body, supporting the weight against your body.
iv. Use a wheeled cart or office chair to move heavy items.

- Surface Height:
  i. Your work surface is too high if it causes you to raise or hike your shoulders. Your desk height is correct if your shoulders are held in a relaxed position when your elbows are bent to 90°and your forearms are supported on your desk.
  ii. If you need to work above shoulder level, position yourself as close as you can to your work, e.g. sit on a high stool to work at a bench or use a stepstool to reach an item from a shelf.

➢ **Driving**

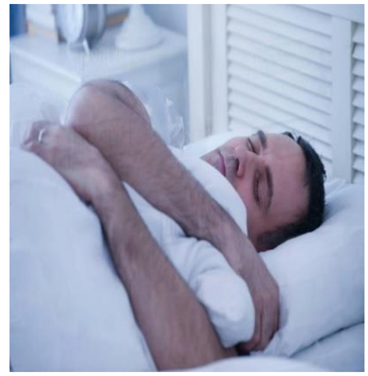
- When driving, move your seat forward to keep your body close to the steering wheel. This will keep your arms in a relaxed position with your elbows bent nearly 90 degrees.
  i. Keep both hands on the steering wheel.
  ii. Keep your hands below the "3 o'clock" and "9 o'clock" positions on the steering wheel when driving.
- Use your left hand to turn right and vice versa
  i. Same side of shoulder will experience the highest joint force during the turning (i.e. turn right cause highest force on the right shoulder joint)
- Avoid twisting and awkward positions, such as reaching for objects in the back seat of a car from the front seat.
- To prevent overreaching, you might want to seek assistance from others when fastening your seat belt.
- Use adaptive equipment
  i. Use a reacher to retrieve parking garage receipts from the machine.
  ii. Use a telescopic-handle snow brush to clean the windshield.

➢ **Carrying Heavy Objects**

- Use a wheeled trolley or cart.
  i. Use both arms to push the cart.
  ii. Leave enough space for turning.
  iii. Lower the pushing level and standing close to the cart to avoid keeping your arms raised too high.
- Use lightweight equipment.
- Use both arms to carry grocery bags and keep the bags close to your body.
- Crouch or bend with your legs before reaching to pick up an item from the floor
- Use a "fanny" pack, a backpack with a hip belt or pockets, and cargo shorts to carry items.
- Consider a delivery service or asking a friend or a family member to assist with bringing heavier items home.

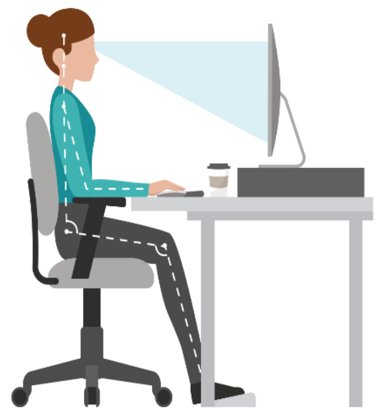
➢ **Sleeping:**

- If your shoulder is painful at night, use a pillow to support the full length of your arm or try a body pillow.
- Avoid sleeping on the same side as your painful shoulder. If both shoulders are painful and you are not comfortable sleeping on your back, try a partial or " three-quarter" side lying position with a pillow in front of you to support the weight of your arm and maintain a neutral shoulder position.
- A 2-inch thick foam pad on top of your mattress can help to accommodate the painful, bony parts of your shoulder joints.
- Use your abdominal muscles and swing your legs off the bed first to sit up, instead of pushing up with your arms.
    i. Consider using a motorized bed can also position you in an easier position to rise from bed.



➢ **Computer & desk set-up**

- Keep regularly used items within easy reach.
- Raise the computer monitor to a height where your eyes line up with the top 1/3 of the screen.
- Adjust your chair and/or keyboard tray so that you can type and mouse with your elbows bent to about 90° and your upper arms relaxed by your sides.
- Take frequent breaks to stretch and "reset" your posture.
    - Bring your shoulder blades down and back as if they are tucked in pockets on your back
    - Chin tucked; an imaginary string is pulling you straight up from the top of your
    - Use your chair armrests to support your arms when you take a break from typing
- If you find yourself straining your head and neck position while wearing bifocals to focus on the computer screen, consider using computer glasses. These glasses can adjust the position of the bifocal lens and promote better posture while using the screen.



➢ **Using smartphone**

- Choose a lightweight smartphone and switching hands frequently.
- When use smartphone, try to keep arm close to the body.
- Avoid holding the phone between your neck and shoulder while answering a phone call.
- If you must use the phone for prolonged periods, consider a hands-free headset.
    i. A smartphone stand or holder can also prevent shoulder injury.
- Move the phone to your better side to avoid reaching with the painful arm.
- Make the font size on your screen a little larger so it is easier to read.

7.8.2 Appendix 7-2 Digital resource of Shoulder Joint Protection Program

https://storage.googleapis.com/sjpp/shoulder-joint-protection-program-raw-N8hBgPLA/content/index.html

7.8.3 Appendix 7-3 Letter of Information Letter of Information and Consent for Patients with Shoulder Arthritis

Project Title: Exploring Digital Resources for Shoulder Joint Protection Program: A Usability Study

Investigators

Dr. Joy MacDermid, PT Ph.D. (Principal Investigator)

Department of Physical Therapy, Western University

Email: jmacderm@uwo.ca

Ze(Steve) Lu, PT Ph.D. Candidate (Co-investigator)

Hand & Upper Limb Centre Clinical Research Lab, St. Joseph's Health Care

Email: steve.lu@sjhc.london.on.ca

Co-Investigators: Dr. Kenneth Faber & Dr. George Athwal

Hand & Upper Limb Centre, St. Joseph's Health Care

Research Staff and Students: Mr. Steve Lu, Mr. Erfan Shafiee, and Mrs. Katrina Munro.

What is the purpose of this study?

This study focuses on the development of a shoulder joint protection program (SJPP) aimed at assisting patients and healthcare providers in making informed decisions about rehabilitation interventions for shoulder arthritis. The program holds the potential to assist in reducing stress on the affected joint, preventing shoulder injuries during daily activities, and enhancing overall function. However, it is important to acknowledge that the program is still under development and has not yet undergone testing.

We invite you to participate in this study because your condition of shoulder arthritis. Your participation in the interview will help us determine the validity, usefulness, and comprehensibility of the joint protection program we have developed. It's important to note that participation in the interviews is optional and participants have the choice to participate or not.

Study objectives

The objectives of this study are as follows:

1. To assess the usability of the shoulder joint protection program (SJPP) through cognitive interviews conducted with patients and healthcare providers.
2. To identify any areas of confusion or misunderstanding in the questions within the SJPP.
3. To gather feedback from patients and healthcare providers regarding the SJPP, including suggestions for improvements or additional information.

Recruitment

We will require to have approximately 6-10 patients and 5 healthcare providers:
1. Diagnosed with shoulder arthritis,
2. Had received or will be about to receive rehabilitation interventions for their condition.
3. Can speak, read/write in English
4. Consent to participate in this study

Study Procedures

This study is an interview about the usability of the shoulder joint protection program that has been developed by our research team. You are always welcome to ask any questions you might have about your participation in this study, via email addresses or phone numbers that are provided at the end of this letter.

1. The surgeons will introduce the study to you. If you have interest, one of the research assistants will meet you and provide a detailed explanation of the study.
2. If you are willing to participate, please sign this consent form.
3. If you choose to participate, you will receive a link to the SJPP program in your email for preview. Once you receive the link, you can click on it and download the document when you are available. Please review the program document item by item. If you do not have access to online resources, a printed version of the entire program will be provided to you.
4. You can choose the location of the interview, either in person (D0-139 at St. Joseph's Hospital) or through an online platform like WebEx. You will be given at least 2-3 days before the interview to review the entire program and form your initial impressions. Reviewing the SJPP (Shoulder Joint Protection Program) will require approximately 20-30 minutes of your time. The interview will take 30-40 minutes to complete.
5. To ensure the accuracy of the collected data, the interviews will be audio-recorded and transcribed verbatim. The transcripts will then be checked for accuracy, and any identifying information will be removed to maintain participant confidentiality. The recorded data stored on the encrypted voice recorder will be transferred to the HULC clinical research lab computer's G drive for secure storage.
6. The student investigator will transcribe each interview into a Word document and ensure that no personal identifiers are included in the recorded voice or resulting document. Any personal identifiers, such as names or contact information, will be removed or replaced with pseudonyms. The resulting transcripts will be used for data analysis and securely stored on the G drive of the HULC clinical research lab.

Participation in the Study:

Participating in this study is voluntary. You will receive a copy of the letter of information and consent form for your records. You do not waive any of your legal rights by signing the consent form. You may refuse to participate, refuse to answer any questions or withdraw from the study at any time with no effect to your future care. You will continue to receive standard care, i.e., routine checkups with your doctor. If you DO decide to stop your participation in our study, we will ask you how you would like us to handle the data collected up to that point. You have the right to withdraw all data collected for the study until it is published. If you have concerns or would like to withdraw, you may contact the principal investigator, Dr. Joy MacDermid or research assistant, Steve Lu.

What are the benefits of this study?

There are no direct benefits to you associated with your participation in this study
The results of this study will help improve the shoulder joint protection program and ensure that it meets the specific needs of patients, while also minimizing the overuse of protective measures that patients may not value. Ultimately, the final shoulder joint protection program resulting from this study will be implemented in clinical practice to enhance overall shoulder joint function and prevent further joint damage.

Are there any risks or discomfort associated with this study?

Although we always make the best efforts to keep the study files and documents safe in locked cabinets or in password-protected computers, there is always a potential for a privacy breach. However, identifying information will be kept separate from the study data.

How many people are in this study?

There will be approximately 15 people in this study, however, for qualitative research, data collection will stop when we reach theoretical saturation, meaning we are not learning any new information from the participants.

Is there any compensation if I participate?

There is no monetary reimbursement for participation in this study. If needed, we can arrange to compensate parking expenses.

Will my results be kept confidential?

No personal information will be collected from you. All interview responses will be kept confidential. Your identity will remain anonymous, and your responses will be used for research purposes only. We will not share any individual responses with anyone outside of the research team. All data collected will be stored on a secure hospital network on a password-protected computer and data will be kept for 15 years.

Publication

If you wish to receive a copy of the research outcomes, we will provide it to you after its publication.

Whom you may contact to find out more about this study?

You will be given a copy of this letter. If you have questions about taking part in this study, you can directly contact:

Dr. Joy MacDermid, Principal Investigator, can be contacted at 519-646-6000 ext 64636

Katrina Munro, Study Research Associator, can be contacted at 519-646-6100 ext 64544

Steve Lu, Student Investigator, can be contacted at 519-646-6100 ext 64544

Erfan Shafiee, Study Research Assistant, can be contacted at 519-646-6100 ext 64544

If you have any other questions about your rights as a research participant or about the conduct of the study, you may contact: St Joseph's Health Care London Patient Relations Consultant at 519-646-6100 ext. 64727

Consent to Participate In the Project Titled: Exploring Digital Resources for Shoulder Joint Protection Program: A Usability Study

Investigators:

Dr. Joy MacDermid, PT PhD (Principal Investigator)
Department of Physical Therapy, Western University
Email: jmacderm@uwo.ca

- I have read the letter of the information, have had the nature of study explained to me and I agree to participate. All questions have been answered to my satisfaction.

______________________	______________________	__________
Signature of Participant	Print Name of Participant	Date

My signature means that I have explained the study to the participant named above. I have answered all questions.

______________________	______________________	__________
Signature of person obtaining consent	Print name of person obtaining consent	Date

7.8.4 Appendix 7-4 Letter of Information and Consent for Healthcare Providers

Project Title: Exploring Digital Resources for Shoulder Joint Protection Program: A Usability Study

Investigators

Dr. Joy MacDermid, PT Ph.D. (Principal Investigator)

Department of Physical Therapy, Western University

Email: jmacderm@uwo.ca

Ze(Steve) Lu, PT Ph.D. Candidate (Co-investigator)

Hand & Upper Limb Centre Clinical Research Lab, St. Joseph's Health Care

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What is the purpose of this study?

This study focuses on the development of a shoulder joint protection program (SJPP) aimed at assisting patients and healthcare providers in making informed decisions about rehabilitation interventions for shoulder arthritis. The program holds the potential to assist in reducing stress on the affected joint, preventing shoulder injuries during daily activities, and enhancing overall function. However, it is important to acknowledge that the program is still under development and has not yet undergone testing.

We invite you to participate in this study because you are a healthcare provider (surgeon, physiotherapists, or researchers) treating patients with shoulder arthritis. Your participation in the interview will help us determine the validity, usefulness, and comprehensibility of the joint protection program we have developed. It's important to note that participation in the interviews is optional and participants have the choice to participate or not.

Study objectives

The objectives of this study are as follows:

1. To assess the usability of the shoulder joint protection program (SJPP) through cognitive interviews conducted with patients and healthcare providers.
2. To identify any areas of confusion or misunderstanding in the questions within the SJPP.
3. To gather feedback from patients and healthcare providers regarding the SJPP, including suggestions for improvements or additional information.

Recruitment

We will require to have approximately 6-10 patients and 5 healthcare providers:
1. Working as a physiotherapists, surgeons or researchers treating patients with shoulder arthritis,
2. Can speak, read/write in English
3. Consent to participate in this study

Study Procedures

This study is an interview about the usability of the shoulder joint protection program that has been developed by our research team. You are always welcome to ask any questions you might have about your participation in this study, via email addresses or phone numbers that are provided at the end of this letter.

1. The PI, Dr. Joy MacDermid will introduce the study to the administrator, and the research opportunity will be included in the departmental weekly email as well. If you receive the email and would like to participate, you can contact research team and will be provided with the letter of information and consent form by researcher-student (Steve Lu).
2. If you are willing to participate, please sign this consent form.
3. If you choose to participate, you will receive a link to the SJPP program in your email for preview. Once you receive the link, you can click on it and download the document when you are available. Please review the program document item by item. If you do not have access to online resources, a printed version of the entire program will be provided to you. Reviewing the SJPP (Shoulder Joint Protection Program) will require approximately 20-30 minutes of your time.
4. You can choose the location of the interview, either in person (D0-139 at St. Joseph's Hospital) or through an online platform like WebEx. You will be given at least 2-3 days before the interview to review the entire program and form your initial impressions. The interview will take 30-40 minutes to complete.
5. To ensure the accuracy of the collected data, the interviews will be audio-recorded and transcribed verbatim. The transcripts will then be checked for accuracy, and any identifying information will be removed to maintain participant confidentiality. The recorded data stored on the encrypted voice recorder will be transferred to the HULC clinical research lab computer's G drive for secure storage.
6. The student investigator will transcribe each interview into a Word document and ensure that no personal identifiers are included in the recorded voice or resulting document. Any personal identifiers, such as names or contact information, will be removed or replaced with pseudonyms. The resulting transcripts will be used for data analysis and securely stored on the G drive of the HULC clinical research lab.

Participation in the Study:

Participating in this study is voluntary. You will receive a copy of the letter of information and consent form for your records. You do not waive any of your legal rights by signing the consent form. You may refuse to participate, refuse to answer any questions or withdraw from the study at any time with no effect on your employment. If you DO decide to stop your participation in our study, we will ask you how you would like us to handle the data collected up to that point.

You have the right to withdraw all data collected for the study until it is published. If you have concerns or would like to withdraw, you may contact the principal investigator, Dr. Joy MacDermid or research assistant, Steve Lu.

What are the benefits of this study?

There are no direct benefits to you associated with your participation in this study
The results of this study will help improve the shoulder joint protection program and ensure that it meets the specific needs of patients, while also minimizing the overuse of protective measures that patients may not value. Ultimately, the final shoulder joint protection program resulting from this study will be implemented in clinical practice to enhance overall shoulder joint function and prevent further joint damage.

Are there any risks or discomfort associated with this study?

Although we always make the best efforts to keep the study files and documents safe in locked cabinets or in password-protected computers, there is always a potential for a privacy breach. However, identifying information will be kept separate from the study data.

How many people are in this study?

There will be approximately 15 people in this study, however, for qualitative research, data collection will stop when we reach theoretical saturation, meaning we are not learning any new information from the participants.

Is there any compensation if I participate?

There is no monetary reimbursement for participation in this study.

Will my results be kept confidential?

No personal information will be collected from you. All interview responses will be kept confidential. Your identity will remain anonymous, and your responses will be used for research purposes only. We will not share any individual responses with anyone outside of the research team. All data collected will be stored on a secure hospital network on a password-protected computer and data will be kept for 15 years.

Publication

If you wish to receive a copy of the research outcomes, we will provide it to you after its publication.

Whom you may contact to find out more about this study?

You will be given a copy of this letter. If you have questions about taking part in this study, you can directly contact:

Dr. Joy MacDermid, Principal Investigator, can be contacted at 519-646-6000 ext 64636

Katrina Munro, Study Research Associator, can be contacted at 519-646-6100 ext 64544

Steve Lu, Student Investigator, can be contacted at 519-646-6100 ext 64544

Erfan Shafiee, Study Research Assistant, can be contacted at 519-646-6100 ext 64544

If you have any other questions about your rights as a research participant or about the conduct of the study, you may contact: St Joseph's Health Care London Patient Relations Consultant at 519-646-6100 ext. 64727

Consent to Participate in the Project Titled: Exploring Digital Resources for Shoulder Joint Protection Program: A Usability Study

Investigators:

Dr. Joy MacDermid, PT PhD (Principal Investigator)
Department of Physical Therapy, Western University
Email: jmacderm@uwo.ca

- I have read the letter of the information, have had the nature of study explained to me and I agree to participate. All questions have been answered to my satisfaction.

Signature of Participant	Print Name of Participant	Date

My signature means that I have explained the study to the participant named above. I have answered all questions.

Signature of person obtaining consent	Print name of person obtaining consent	Date

7.8.5 Appendix 7-5 Interview guide

Hi, thank you for accepting to participate in this interview. The goal of this interview is to collect your feedback on a tool that helps patients with shoulder arthritis to protect the joint and prevent the injury in their daily life. This tool is called shoulder joint protection program (SJPP).
We want to make sure that the tool makes sense to you and covers all the important aspects. Your input is really valuable to us, so please share as much as you can. During the interview, if you would like to skip any of the questions, please simply say "skip." Do you have any questions? If not, I will begin the recording.

1. Could you please provide age and gender identity? When were you diagnosed with shoulder arthritis? Have you received any treatment, and could you please share your experience with the treatment?
2. Can you describe your typical daily activities and any challenges you face due to your shoulder arthritis?
3. Can you explain your understanding of the shoulder joint protection program?
4. Please read the instructions provided for the SJPP. Do they make sense to you? Is there anything that could be clarified or improved?
5. Are there any items (content) that are difficult to understand or confusing? If so, can you explain why?
6. Are there any items (content) that you feel are missing from the program? If so, what are they and why do you think they should be included?
7. Are there any items (content) that you feel are not necessary or redundant? If so, what are they and why do you think they should be removed?
8. After reviewing the program, do you think it adequately covers the topics that are important for you considering joint protection in daily life? Why or why not?
9. Is there anything else you would like to share about your experiences protecting your shoulder joint?
10. Do you have any other comments or suggestions for improving the SJPP?
11. Thank you for participating in this interview. Your feedback is invaluable to the revising our program. If you have any further questions or comments, please do not hesitate to contact us.

Chapter 8

8. General Discussion and Future Directions

8.1 Overview of dissertation

This chapter integrates and reflects upon the findings from all 6 studies embedded in the thesis, all aimed at understanding the diverse aspects of patient rehabilitation and outcome evaluation for shoulder arthritis. Collectively, these findings shed light on the impact of physiotherapy, the value of patient-reported outcome measures, the intricacies of shoulder biomechanics, and the importance of joint protection behavior. Through the interweaving of these discrete yet interconnected strands of research, this discussion seeks to offer a multifaceted view of patient management within the context of shoulder arthroplasty, while also highlighting how the complete body of this thesis contributes to the existing knowledge base, theory, and methods in this area.

The overarching objective of this doctoral thesis was to devise the Shoulder Joint Protection Program (SJPP). This comprehensive program is aimed at enhancing independence in daily activities and minimizing discomfort for individuals experiencing difficulties, particularly those related to shoulder joint conditions such as shoulder joint arthritis.

The narrative review offered a critical examination of the latent constructs and item-level content of frequently utilized patient-reported outcome measures (PROMs) in TSA. A significant finding was the variation among PROMs, with a greater emphasis on activity and participation than on the patient's perceptions of body structure and function. This discrepancy points to the potential under-representation of critical aspects of patient experiences, particularly those related to psychological health. The narrative review further stressed the need for clarity and consistency in the conceptual frameworks underlying PROMs, thereby improving their usability and validity. This finding indicates a pressing need for more nuanced and representative tools to capture patient experiences, which could contribute to more personalized and patient-centered care in clinical practice.

Two systematic reviews consolidated evidence from 37 studies that examined the effect of postoperative physiotherapy (PT) following TSA and rTSA. Despite evidencing improvements in pain, functional enhancement, and increased range of motion, the lack of randomized controlled trials (RCTs) and comparative studies between physiotherapy and non- physiotherapy treatments makes it challenging to definitively attribute these improvements to PT alone or to natural recovery. The reviews also spotlighted significant heterogeneity across PT protocols and highlighted a host of limitations that pervade the existing research landscape, such as non-randomized observational studies and potential publication bias. These complexities underscore the challenges of formulating one-size-fits-all guidelines and illuminate the imperative need for more rigorous, comprehensive, and diverse research trials in the future.

The scoping review added another layer to the discussion by scrutinizing shoulder biomechanics within a broad range of contexts, from specific sports to everyday activities. Drawing from 24 distinct studies, this review emphasized the crucial role of proper technique, load distribution, muscle coordination, and rest periods in preventing shoulder injuries. Although it uncovered limitations in the current biomechanical analysis methods, its findings have implications for a wide range of individuals, from athletes and manual laborers to those engaged in daily activities involving repetitive shoulder movements. These insights hint at the potential for an integrated approach, combining biomechanical knowledge with PT strategies, to optimize injury prevention and improve long-term shoulder health.

In further examining the daily kinematics of shoulder movements, a movement analysis study was conducted. This research utilized the Joint Protection Behavior Assessment (JPBA) tasks to replicate the activities that shoulder arthroplasty patients might perform routinely. Utilizing advanced motion analysis software tools, Dartfish and MediaPipe, kinematic data were collected from patients scheduled for shoulder joint replacement surgery. The study revealed the capacity of patients to adjust their shoulder movement patterns following education on joint protection strategies, indicating successful incorporation of the instructed techniques. Despite the positive changes, participants still demonstrated altered movement patterns, suggesting that fully integrating these new strategies might require additional practice, guidance, or perhaps more time. The measurement agreement between Dartfish and MediaPipe was deemed acceptable, barring a few instances of extreme movement patterns. This result points to the reliability of MediaPipe in capturing shoulder kinematics, a crucial factor in understanding the real-world application and benefits of joint protection strategies.

These findings collectively suggest the potential significance of education on joint protection and its hypothetical role in enhancing self-efficacy among patients. The results indicate a possibility that patients could have an active role in their own recovery and rehabilitation processes. Additionally, they hint at the potential value of technologies such as MediaPipe in offering objective and reliable data that could assess the effectiveness of educational interventions and the practical application of protective behaviors in real-world scenarios.

8.2 Clinical and research implications

Clinical Implications:

The Shoulder Arthritis Joint Protection Program (SJPP) has significant potential clinical implications that may contribute to better patient outcomes. These include effective pain management, as the program teaches patients safer, more efficient ways to use their joints, thus reducing strain and pain. Improved mobility is another key potential benefit, with patients able to perform daily tasks with greater ease. The SJPP could also play a role in slowing the progression of the disease by minimizing joint stress and damage, thus preserving joint integrity. This program is also intended to positively impact the individual's quality of life by helping manage pain and preserve function, enabling them to stay active and independent. Lastly, SJPP could lead to reduced healthcare costs by decreasing the need for expensive interventions like surgery or intensive physical therapy.

The SJPP was designed to be a comprehensive education resource for patients, aiding them in understanding their condition and managing it more effectively. It offers insights into the biomechanics of the shoulder, which can assist patients in understanding why certain movements or activities might exacerbate their pain or contribute to further joint damage. The program also provides specific techniques and strategies for performing daily activities in ways that protect the shoulder joint, thus aiding in pain management and potentially slowing the progression of arthritis. In addition, the SJPP provides guidelines for lifestyle modifications, like balanced rest and activity, proper posture, and safe use of assistive devices, which can play a key role in joint protection.

The design of the SJPP as both a written and digital resource increases its accessibility to a broad range of patients. Those who are less comfortable with technology or do not have regular internet access can utilize the printed materials. Conversely, tech-savvy patients might find the digital resources more convenient and engaging. This flexibility ensures that the SJPP can reach a wide demographic, regardless of technological proficiency or access. The digital platform can also be continually updated with new research findings or feedback from users, ensuring the program stays relevant and effective over time.

Chronic conditions like shoulder arthritis can have a significant impact on a patient's mental health, contributing to mood disorders, anxiety, and a lower overall quality of life. The SJPP addresses this by offering strategies that can help manage and reduce pain, improve function, and increase independence in daily activities. By empowering patients with the knowledge and skills to better manage their condition, it may contribute to reducing stress, enhancing self-efficacy, and improving mental well-being. Furthermore, by acknowledging the mental health impact of shoulder arthritis, it creates an opportunity for healthcare providers to screen for these issues and provide appropriate support or referrals.

Research Implications:

Evaluating the impact of the SJPP can provide crucial insights into patient education and joint protection strategies. By examining how patients respond to the program and how it affects their pain levels, function, and quality of life, researchers can identify which strategies are most effective. Additionally, exploring patients' preferences and how these align with the program's content can further illuminate the factors that contribute to successful patient education and engagement. It's crucial to research factors affecting patient adherence to the program, to understand how best to encourage consistent and correct application of the techniques learned. This research can then inform future iterations of the SJPP, as well as similar programs for other types of joint arthritis.

As the SJPP includes both written and digital resources, it provides a unique opportunity for usability research. Researchers can assess the learnability, memorability, error rate, and user satisfaction of the digital platform, as well as its simplicity and comprehensibility. Understanding how these factors impact patient engagement and program adherence can help improve the design of digital health resources, making them more effective and user-friendly. This is particularly important as digital health becomes increasingly prevalent. Meanwhile, implementation science principles can also drive mobilization of the SJPP into practice.

The creation and evaluation of the SJPP necessitates collaboration between different fields, including biomechanics, rehabilitation science, clinical medicine, health education, and mental health. This interdisciplinary approach allows for a more holistic understanding of joint protection, considering the physical, psychological, and lifestyle aspects. Such collaboration can lead to richer research insights and more comprehensive care strategies. In addition, it provides a model for future research, demonstrating the value of integrating knowledge from different disciplines.

As technology advances, the SJPP could serve as a basis for developing more sophisticated digital health solutions. For example, incorporating elements of artificial intelligence or virtual reality could provide personalized feedback or more engaging educational experiences. Researching the effectiveness of these technologies in the context of joint protection education could provide valuable insights for the future of digital health.

The long-term effects of the SJPP on joint health and overall quality of life are important areas for investigation. This can help validate whether the program has sustained benefits and whether it can prevent or delay the need for surgery. Studies to examine the cost-effectiveness of the SJPP, in comparison to other interventions, would provide valuable information for healthcare decision-making.

As the study identified the potential influence of comorbidities on joint protection behavior, future research could delve deeper into these relationships. Understanding how other health conditions affect joint protection strategies and how the SJPP can be adapted to account for these factors can provide a more nuanced understanding of patient care.

In summary, an SJPP has the potential to improve patient outcomes, contribute to the development of personalized care, and stimulate further research in the fields of joint protection and patient education.

8.3 Limitations

This research on the Shoulder Joint Protection Program (SJPP) had several limitations that should be acknowledged when interpreting the findings and considering their implications.

Firstly, the development of the SJPP is a complex process that demanded a substantial amount of time and resources. Due to the limited timeframe of this project, it was not feasible to conduct extensive testing and validation of the SJPP within a clinical practice setting. However, we highly recommend future research efforts to pursue a validation study to assess the effectiveness of the SJPP in real-world clinical settings. Additionally, the joint protection program shoulder acknowledge that each patient is unique in their symptoms, comorbidities, lifestyle, and needs. By offering a variety of strategies and techniques, it allows for personalized care. For instance, some patients may have other health conditions that affect their ability to use certain joint protection strategies, or they may have different physical demands based on their job or daily routine. However, healthcare providers can utilize the SJPP as a foundation to create a personalized care plan that caters to these specific factors.

Secondly, our study's recruitment of participants including both clinicians and patients was limited due to various factors. Despite endeavors to engage a larger sample size, the number of patients who participated in the cognitive interview was smaller than initially intended. This may have influenced the generalizability of the findings and the representativeness of the sample. Additionally, the COVID-19 pandemic presented obstacles for face-to-face interviews and assessments, further limiting patient recruitment.

Thirdly, while our recruitment of a diverse range of patients and therapists from different parts of the world provides a broader perspective on shoulder joint protection strategies, it could also be viewed as a potential limitation. The SJPP, with its recommendations, could vary across different cultures, which could affect its usability and efficacy. Therefore, we strongly recommend future researchers to consider necessary cultural adaptations when implementing the SJPP in different countries.

Finally, another limitation of the study was that we did not evaluate the SJPP's effectiveness in the clinical setting. Although the program was based on the most recent available evidence and designed to adapt to the preferences and needs of patients and therapists, its effectiveness in clinical practice remains unclear. The SJPP needs to be tested in a clinical setting to determine its impact on patient outcomes.

In conclusion, while this study contributes valuable insights to the development of a shoulder joint protection program, these limitations should be considered when interpreting the results. Future studies should focus on addressing these limitations, including evaluating the effectiveness of the SJPP in a clinical setting, recruiting a larger and more diverse sample of patients, and revising the components of the current program, if indicated by such work.

8.4 Future directions and suggestions

We strongly advise conducting further studies to evaluate the effectiveness of the Shoulder Joint Protection Program (SJPP). These investigations should delve into multiple areas including the impact of patient education, the implementation of joint protection strategies, and the degree of patient satisfaction resulting from the use of SJPP. These research initiatives will augment our knowledge of the SJPP's implications, practicality, and its contribution to patient care for those suffering from shoulder arthritis.

The next logical progression would be to commission a study evaluating the influence of the SJPP on changes in joint protection behaviors. This could take the form of a randomized controlled trial with patients with shoulder arthritis. Outcomes such as patient understanding, engagement, and adherence to joint protection strategies could be evaluated to ascertain the effectiveness of the SJPP in enhancing patient education and encouraging the application of joint protection strategies.

In addition, assessing the integration of the SJPP into regular clinical practice would be invaluable. This could be accomplished by conducting feasibility studies or implementation research, exploring the practicalities of incorporating the program into standard patient care. This research could help identify any potential obstacles or facilitators to the adoption of the SJPP by healthcare providers and patients with shoulder arthritis. Exploring factors such as usability, acceptability, and integration into clinical workflow would provide insights into how to successfully implement the SJPP in real-world clinical settings.

Given the significance of patient satisfaction, an additional avenue for research could focus on assessing the level of satisfaction patients derive from the SJPP. This could involve conducting qualitative interviews or surveys to collect patients' views on their experiences with the SJPP, their levels of satisfaction, and perceived advantages or disadvantages. A comprehensive understanding of the SJPP's impact on patient satisfaction will offer valuable insights into its efficacy and potential areas for improvement.