PHYSIOTHERAPY AND POINT OF CARE ULTRASONOGRAPHY

POINT OF CARE ULTRASONOGRAPHY IN PHYSIOTHERAPY RESEARCH AND PRACTICE

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LAY ABSTRACT

Point of care ultrasound (POCUS) is an ultrasound scan that is performed by a health professional in a clinical setting. Physiotherapists are increasingly using POCUS in clinical practice and research. This thesis explores physiotherapist performed POCUS to address important gaps in knowledge to: (1) describe where physiotherapists are using POCUS, with which patients, and for what purpose; (2) describe the different types of training and education that physiotherapists received to perform POCUS; and (3) to compare a physiotherapist trained in POCUS to an expert sonographer in the performance and interpretation of POCUS scans for the assessment of joint bleeding in patients with a bleeding disorder called hemophilia. The findings of this thesis can inform future studies on education, training, and experience of physiotherapists using POCUS, and lends support to the integration of POCUS into physiotherapy practice with different patient populations and conditions.

ABSTRACT

Point of care ultrasonography (POCUS) is a non-ionizing imaging modality that is performed and interpreted by a primary health care professional in combination with a physical examination in a clinical setting. POCUS can provide time sensitive clinical information to assist in diagnosis of pathology and to monitor response to treatment. POCUS is emerging in physiotherapy clinical practice, education, and research. This dissertation explores physiotherapist performed POCUS and consists of two scoping reviews and an inter-professional agreement study.

The first scoping review systematically mapped the research literature to describe the breadth and depth of physiotherapists performed POCUS. Two hundred and nine studies were included, and the majority of the included studies were measurement studies that assessed the psychometric properties of POCUS in adult patients, were published in the United States of America, and imaged the abdominal lumbo-pelvic region. POCUS was found to be a recent application of sonography in physiotherapy practice. This review identified a wide variety of practice settings and a diverse number of patient conditions in which physiotherapists are performing POCUS. This breadth and depth of this review highlighted the need for improved reporting of study methodology and key areas of future research in physiotherapist performed POCUS.

The second scoping review explored physiotherapy pre- and post-licensure curricula and pedagogical approaches for POCUS. Fifteen studies were identified. These showed that progress in the development of physiotherapy-specific, competency based, standardized education curricula and pedagogical approaches for POCUS has been

limited. There was considerable variability both pre- and post licensure and further research is needed to assess the outcomes of different pedagogical approaches on theoretical knowledge and practical scanning competence. There is a need for internationally accepted terminology for physiotherapist performed POCUS and clear guidelines from local regulatory colleges and licensing bodies.

The third study was an inter-professional agreement pilot study between a physiotherapist and a sonographer for the assessment of acute hemarthrosis in 13 patients with hemophilia using POCUS. In this study, the physiotherapist participated in the McMaster University Mohawk College POCUS Training Program for Acute Hemarthrosis and Synovitis. The results indicated a high level of agreement between the physiotherapist and the sonographer performed POCUS for the binary decision on the presence or absence of blood within the joint. The physiotherapist-acquired images demonstrated quality comparable to an expert sonographer. This study provides support that following a short formal training program, a trained physiotherapist can become proficient in the acquisition and interpretation of POCUS images for the assessment of hemarthrosis in patients with hemophilia.

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF APPENDICES

LIST OF SUPPLEMENTARY FILES

LIST OF ABBREVIATIONS

AMED	Allied and Complementary Medicine Database
CAR	Canadian Association of Radiologists
CI	Confidence interval
CT	Computed tomography
CINAHL	Cumulative Index to Nursing and Allied Health Literature
CONSORT	Consolidated Standards for Reporting Studies
EMBASE	Excerpta Medica Database
EQUATOR	Enhancing the Quality and Transparency of Health Research
ICC	Intraclass correlation coefficient
K	Cohen's kappa coefficient
POCUS	Point of care ultrasonography
PT	Physiotherapy
PRISMA	Preferred Reporting Items for Systematic Reviews and Meta-Analysis
PRIMSA-ScR	Preferred Reporting Items for Systematic Reviews and Meta-Analysis Extension for Scoping Reviews
MRI	Magnetic resonance imaging
MSK	Musculoskeletal
n	Number
n/a	Not applicable
STARD	Standards for Reporting Diagnostic Accuracy Studies
STROBE	Strengthening the Reporting of Observational Studies in Epidemiology
UK	United Kingdom
USA	United States of America

LIST OF SYMBOLS

=	Equals
%	Percent
*	At sign
@	Asterisk
>	Greater than
/	Per

DECLARATION OF ACADEMIC ACHIEVEMENT

The following dissertation is a manuscript thesis consisting of an introduction, three manuscripts (Chapters 2, 3, and 4), and a discussion. Each manuscript was written in the format required of the peer reviewed journal. I, Karen Lindsey Strike, am the first author in all three manuscripts. At the time of presentation of this dissertation, Chapter 2 has been accepted for publication in *Physiotherapy*, Chapter 3 has been accepted for publication in *Physiotherapy Canada*, and Chapter 4 has been accepted for publication in the *Journal of Haemophilia Practice*. The contributions of the candidate and co-authors on the three manuscript chapters are outlined below.

CHAPTER 2:

Strike K, Chan AKC, Maly MR, Newman ANL, Solomon P. Physiotherapist performed point of care ultrasonography (POCUS): a scoping review of 209 studies. Accepted, *Physiotherapy*, https://doi.org/10.1016/j.physio.2022.11.005.

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Manuscript preparation: K. Strike

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CHAPTER 1

Thesis Introduction

Physiotherapy Practice in Canada

The goal of physiotherapy treatment is to restore, maintain, and maximize function, mobility, and wellness.[1,2] Physiotherapists study human movement, anatomy, and physiology, to assess and understand the cause of impairment, functional limitation, and disability.[1,2] Physiotherapists are primary care, autonomous health care professionals.[2] They are trained to provide "safe, quality client centred physiotherapy through a commitment to service availability, accessibility and excellence."[2] Within each province in Canada, physiotherapists adhere to ethical principles and scope of practice standards that are aligned with professional competency, integrity, and accountability.[2] Physiotherapists work in both private and public health care settings, with a variety of health care populations including but not limited to the following: pediatrics, geriatrics, oncology, women's health, pain, critical care, wound care, occupational health, and sports medicine.[2]

Physiotherapy programs in Canada are accredited by Physiotherapy Education Accreditation Canada and are offered at fourteen universities across the country.[2] Current entry level to practice standards require the completion of a professional, course based Master's program that combines both didactic pedagogies and experiential clinical education.[2] Canadian universities also offer advanced academic degrees including Masters and Doctoral Programs in Rehabilitation Science.[2]

Physiotherapy practice, education, and research are grounded in evidence-based practice and lifelong learning. The profession continues to evolve in response to the changing needs of patients and the health care system.[2] Physiotherapists provide care aligned with advances in technology and evolving science in emerging practice settings.[2] The expertise of the physiotherapy profession is increasingly being recognized; advanced practice and clinical specialist roles are evolving with competencies and skills, such as diagnostic imaging, laboratory testing, and screening for orthopedic surgery, becoming adopted by or delegated to its members.

Diagnostic Imaging

In clinical practice, physiotherapists often utilize the findings from diagnostic imaging to confirm a diagnosis, monitor response to treatment, or to ensure patient safety before initiating an intervention.[3] The most common diagnostic imaging modalities used in clinical practice are radiography, ultrasonography, computed tomography, and magnetic resonance imaging.[4] The selection of the most appropriate imaging modality depends on many factors including the presenting clinical concern, availability and accuracy of the tool, age of the patient, risks of the procedure including contrast agents and allergic reactions, and cost.[4] In Canada, computed tomography and magnetic resonance imaging present challenges due to long wait times and cost.[5] Although radiography is readily available, the ionizing radiation and low contrast resolution of x-rays present limitations to clear visualization of tissues.[4] Ultrasonography is commonly used due to its accessibility, low cost, high diagnostic sensitivity, and lack of ionizing radiation.[6] However, of all the diagnostic imaging modalities, ultrasonography is the most user dependent form of imaging and requires specialized training and experience.[6,7]

A traditional model for ultrasonography involves a referral from a qualified health care professional to a diagnostic imaging department.[6] In this model, the ultrasound scan is performed by a credentialed diagnostic medical sonographer and is interpreted by a radiologist.[6,8] In Canada, diagnostic ultrasound is guided by credentialing processes and standards set by the Canadian Association of Radiologists and discipline specific professional colleges or provincial governing bodies.[6] These standards include processes for documentation, image retention, communication of diagnostic imaging findings, training, and quality assurance.[6] With improvements in technology, ultrasound machines are becoming more affordable, user-friendly, compact, and portable.[6,7] As a result, more health care professionals, including physiotherapists, are integrating diagnostic ultrasound into clinical practice using the term, "point of care ultrasonography (POCUS)".

Point of Care Ultrasonography

POCUS is a form of diagnostic ultrasonography performed by a primary health care provider, in adjunct to a clinical examination, to assess for the presence or absence of a specific clinical finding, or to improve the safety and accuracy of an intervention.[6] POCUS should be limited in scope and should not be used to replace a diagnostic ultrasound that is performed and interpreted by an imaging specialist.[6] As POCUS is a user-dependent modality, there is a risk of adverse patient outcomes if used improperly or without sufficient training and competency assessment.[6-8] The Canadian Association of

Radiology suggests that POCUS users should be trained to the same standard as traditional imaging specialists for their specific application of POCUS.[6,9] They suggest that training programs include didactic and practical components incorporating assessments that demonstrate learning and user competency.[6,8,9]

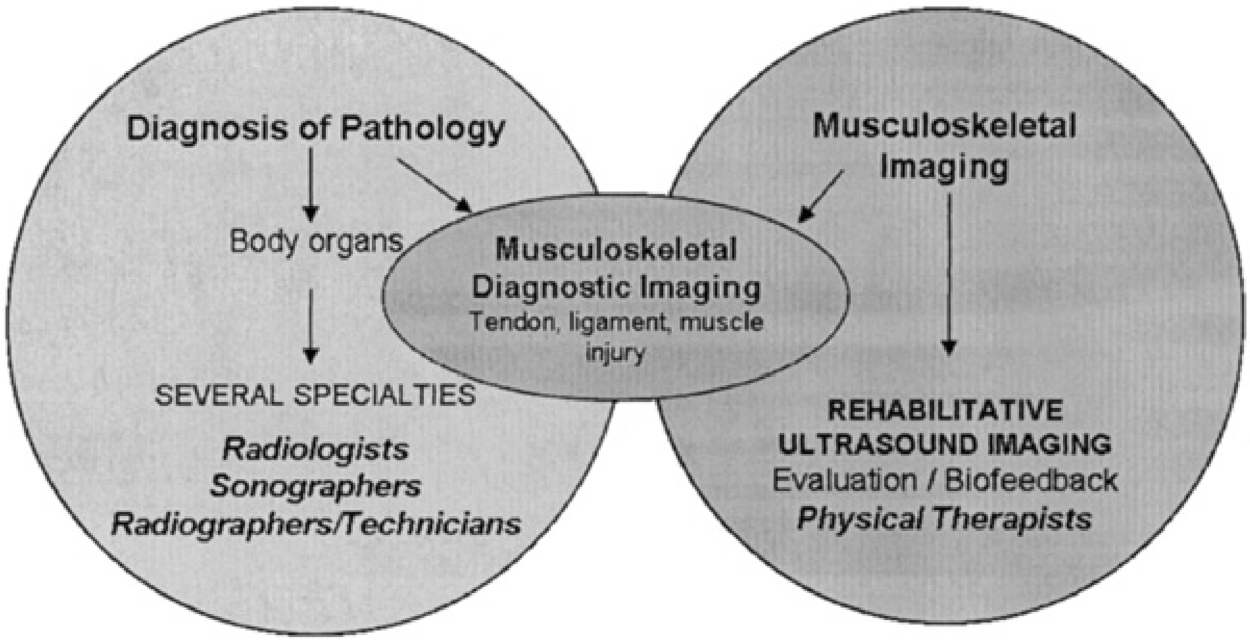
POCUS use is emerging in non-traditional clinical areas such as rheumatology, intensive care, emergency medicine, and pediatrics, and by allied health professions including midwifery, nursing, and physiotherapy.[6,10-12] Professional oversight regarding the use of POCUS, scope of practice, and the need for medical directives, rests with the provincial colleges and licensing bodies of each health discipline and local institutional requirements.[9]

Ultrasonography in Physiotherapy Practice

Diagnostic ultrasound was first reported in physiotherapy practice for the measurement of quadriceps muscle wasting in 1980 by Dr. Archie Young in the Rehabilitation Unit at the University of Oxford.[13] Work continued in the area of quadriceps morphology and function. In the 1990's, this foundational work expanded into ultrasound imaging of the musculature of the lumbar spine in patients with low back pain and as a modality to provide biofeedback during physiotherapy interventions that address impairments in neuromuscular function.[10,14-19] The first international meeting on diagnostic ultrasound in physiotherapy research and practice occurred in 2006 in San Antonio, Texas.[20] The purpose was to develop practice guidelines for using diagnostic ultrasound (termed rehabilitative ultrasound) for the assessment and management of abdominal, pelvic, and spinal musculature, and to establish collaborative goals for research.[20] This meeting produced two important outcomes: a consensus statement, and a diagram to visually represent how rehabilitative ultrasound fits in the larger field of ultrasound imaging (Figure 1). The consensus statement was supported by all delegates and was intended to guide physiotherapists in navigating professional boundaries with other health disciplines, with the goal of rehabilitative ultrasound imaging gaining acceptance in the diagnostic imaging community.[21] The consensus statement included:

> "Rehabilitative ultrasound imaging is a procedure used by physical therapists to evaluate muscle and soft tissue morphology and function during exercise and physical tasks. Rehabilitative ultrasound imaging is used to assist in the application of therapeutic interventions aimed at improving neuromuscular function. This includes providing feedback to the patient and physical therapist to improve clinical outcomes. Additionally, rehabilitative ultrasound imaging is used in basic, applied, and clinical rehabilitative research to inform clinical practice. Currently, the international community is developing education and safety guidelines in accordance with the World Federation for Ultrasound Imaging in Medicine and Biology. Dated 10 May 2006."[20(p.2-3)]

Figure 1: Position of rehabilitative ultrasound imaging in the field of diagnostic imaging. Reproduced from Teyhen (2006)[20]



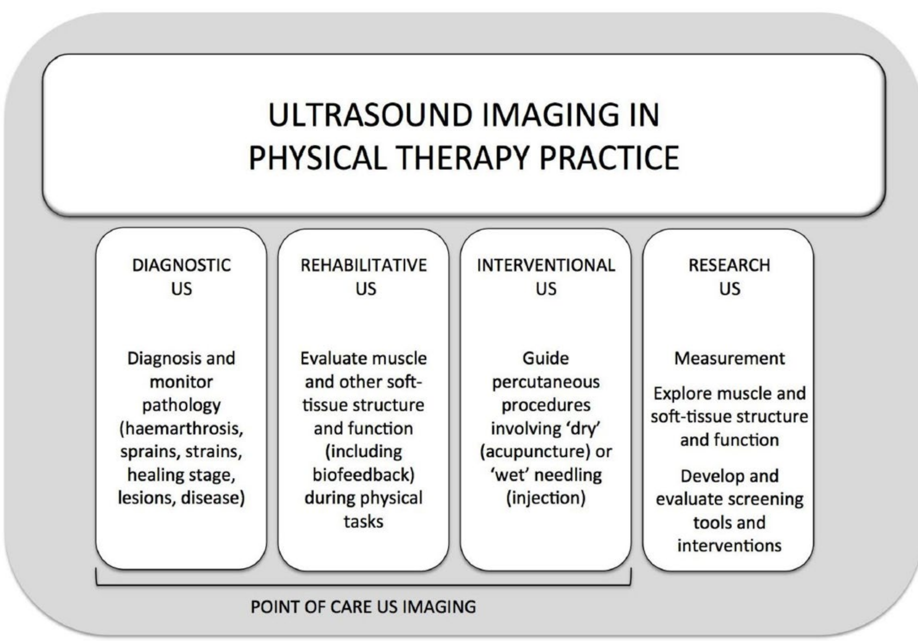
Since that time, rehabilitative ultrasound has been found to be a reliable and valid tool in physiotherapy research and practice. Early work in this area focused on rehabilitative ultrasound for low back pain. A literature review by Ghamkhar et al. in 2011 concluded that rehabilitative ultrasound has acceptable reliability and validity when differentiating patients with and without low back pain, and for monitoring response to physiotherapy interventions in patients with chronic low back pain.[22] A randomized controlled trial by Teyhen et al. in 2005 found clinically useful levels of intra-rater reliability for measuring lateral abdominal muscle activation.[23] In 2009, Koppenhaver et al., assessed intra- and inter-rater reliability of rehabilitative ultrasound measurements of transverse abdominus and lumbar multifidus thickness in patients with low back pain.[24]

The authors recommended using the mean of two measures and although intra-rater reliability was found to be superior to inter-rater reliability, both measures demonstrated acceptable reproducibility for use in physiotherapy research and clinical practice.[24] In 2009, Hebert et al. reported similar findings in a systematic review on the reliability of rehabilitative ultrasound for the measurement of the musculature of the abdomen and trunk.[25] Although the authors rated the overall quality of the included studies as poor, the authors reported acceptable reliability and precision of rehabilitative ultrasound when using mean measures, measures of muscle thickness were more reliable than measures of cross-sectional area, and higher levels of measurement error in novice examiners.[25]

Rehabilitative ultrasound has also been used as a form of biofeedback for both patients and physiotherapists. Ultrasound as biofeedback is used to assess muscle thickness, muscle function, and to facilitate performance or retention of an exercise intervention.[26-28] A 2021 systematic review by Valera-Calero et al. included eleven studies where rehabilitative ultrasound was used for biofeedback.[26] The majority of studies were of acceptable quality.[26] Seven studies assessed the muscles of the abdominal wall, two studies assessed the lumbar multifidus, one assessed the muscles of the pelvic floor, and one assessed the serratus anterior.[26] Overall, the results suggest that visual biofeedback with rehabilitative ultrasound may be more effective than tactile and/or verbal feedback for improving performance and retention of motor control exercises.[26]

Research has continued to emerge and expand beyond rehabilitative ultrasound imaging. In 2019, a narrative review by Whittaker et al. proposed a new framework for physiotherapist-performed ultrasound imaging that recognized additional categories beyond rehabilitative ultrasound imaging including diagnostic ultrasound imaging, interventional ultrasound imaging, and research ultrasound imaging (Figure 2).[10] Diagnostic ultrasound was defined as using ultrasound imaging to diagnose or monitor pathology.[10] Interventional ultrasound was defined as ultrasound imaging that is used to guide percutaneous procedures and research ultrasound was used to describe ultrasound imaging in basic, applied or clinical research.[10] By illustrating how the clinical categories of physiotherapist-performed diagnostic ultrasound are represented under the term POCUS, the areas of practice identified by Whittaker et al. helps to describe the expansion of POCUS in the profession. This is a helpful step to inform physiotherapy practice, education, research, and policy.

Figure 2: Categories of physiotherapy-performed diagnostic ultrasound. Reproduced from Whittaker et. al (2019)[10]



Although not included in the narrative review by Whittaker et al., diagnostic ultrasound of the lung and thorax has also been reported as a tool in physiotherapy practice and research.[29-32] Thoracic or lung ultrasound, involves the assessment of pleural, alveolar, and interstitial pathologies, and diaphragmatic function and movement.[29] Traditional outcome assessment tools in respiratory physiotherapy practice including auscultation and chest x-ray, have been found to have low inter-rater reliability, accuracy and sensitivity and specificity, for identifying pleural effusion, interstitial syndrome, and consolidation.[30] Lung ultrasound has advantages that it can be done in real-time, does not expose the patient to ionizing radiation, and has a high level of accuracy, sensitivity, and specificity when compared to computed tomography.[30] In addition to confirming clinical findings, lung ultrasound can be used to determine the appropriateness of physiotherapy interventions. [30] In two case studies, referral to physiotherapy was initiated based on suspicion of sputum retention on chest x-ray.[33,34] In both cases, the physiotherapist-performed lung ultrasound demonstrated large pleural effusions that were not amenable to physiotherapy intervention and were subsequently treated by the medical team resulting in positive patient outcomes.[33,34]

Physiotherapist-performed POCUS has also been reported in the assessment and management of patients with hemophilia.[8,35,36] Stephensen et al. studied the inter-rater reliability of physiotherapist performed POCUS using the Hemophilia Early Arthropathy Detection imaging protocol.[35] This study found a high level of agreement for the assessment of synovial hypertrophy, articular cartilage, and bone and suggested that physiotherapist-performed POCUS can be used to complement the physical examination.[35]

Training and Education for Physiotherapists in Diagnostic Ultrasonography

Currently there are no internationally accepted standard or guideline for curricula for physiotherapists for POCUS across areas of practice, with continuing education and mentoring opportunities varying widely across countries, and no minimal competency requirements for clinical care.[10] To capitalize on the benefits of POCUS there is a need for standardized training specific to physiotherapists.[10] In Canada, the Physiotherapy Association of British Columbia developed a post-graduate training course on the clinical application of rehabilitative ultrasound for lumbopelvic dysfunction.[37] McMaster University and the Mohawk College Medical Radiation Sciences Program partnered to develop the Point-of-Care Ultrasound in the Management of Hemophilia Training Program. This training program is a novel academic education and certification of competency program for physiotherapists in hemophilia care on the application of POCUS for the assessment and management of acute hemarthrosis and muscle hematoma.[8,36,38-40]

Professional Oversight and Legislation for Physiotherapist-Performed Diagnostic Ultrasonography in Canada

Although physiotherapists in several provinces in Canada have, or are in the process of, obtaining autonomy in the ordering of diagnostic imaging, legislation and professional oversight for performance and interpretation of POCUS varies.[41] For example, in Ontario amendments to the Regulated Health Professionals Act and the

Healing Arts and Radiation Protection Act are in process to allow physiotherapists to order diagnostic imaging. However the performance and interpretation of POCUS by physiotherapists is not included in these amendments and physiotherapists can only perform POCUS under a medical directive from a health care provider who has the authority to perform diagnostic imaging.[3,42,43] Physiotherapists in Alberta were previously permitted to order diagnostic imaging; however in March 2020, the Ministry of Health removed this authority from physiotherapists, chiropractors, and audiologists.[44] Current legislation in Alberta also restricts the application of POCUS by physiotherapists unless the physiotherapist performs the imaging under medical supervision.[45]

Evidence gaps

Despite increasing evidence to support physiotherapist-performed POCUS, variations in terminology and reporting of where, how, and with whom physiotherapists are using POCUS across the profession remain.[10] Consolidating the literature to understand the current status of physiotherapy performed POCUS is an important next step to advance the scope of the profession. While a previous narrative review provided an important summary and framework for POCUS in physiotherapy practice, it lacked a systematic methodology for the selection of included articles and did not include all known applications of physiotherapist-performed POCUS, such as thoracic and lung ultrasound.[10] To build upon this foundation, the next step was to conduct a review with a systematic methodology. Following a systematic approach provides methodological transparency, minimizes potential bias, and provides reliable results, all of which help enhance confidence in the review findings. Studies that follow a rigorous methodology are needed to collate and map the different applications of diagnostic ultrasound as performed by physiotherapists in research and practice.

The framework proposed four distinct categories of physiotherapy-performed diagnostic ultrasound: rehabilitative, diagnostic, interventional, and research ultrasound. This framework is helpful to illustrate different applications of POCUS in physiotherapy practice, however it does not consider the implications of separating these into different categories. Rather than promote the use of diagnostic ultrasound under a unified term, this categorization may result in physiotherapists using different terminology (i.e., rehabilitative ultrasound, bedside ultrasound, real-time ultrasound) to describe the use of diagnostic ultrasound in clinical practice and research, which may create challenges for legislation, scope of practice, and development of clinical practice guidelines. In Canada, each physiotherapy provincial/territorial professional college is responsible for providing guidance on scope of practice; however despite its use, many provinces have yet to communicate practice advice on the role of POCUS to its members.[41] To make progress on the role of POCUS and diagnostic imaging in the physiotherapy profession, clear and consistent guidelines from regulatory and professional associations are needed.[10] Understanding the breadth and depth of physiotherapist-performed POCUS may assist in this process and advance advocacy efforts for the inclusion of POCUS into physiotherapy scope of practice and policy.

Improved clarity and consolidation of the literature will also assist in the development of curriculum and educational programmes for physiotherapists who are using POCUS in clinical practice or research. As stated above, The Canadian Association of Radiology advocates that all users of POCUS should be held to the same training and quality assurance standards as qualified traditional imaging specialists for their specific application of POCUS.[6,9] Training programs should include pedagogical approaches and evaluations that demonstrate learning and user competency within each professions scope of practice.[6,8,9] As POCUS is an operator dependent modality, there is consensus that physiotherapists need to be trained to ensure safe and appropriate use, however information on pedagogical approaches pre- and post-licensure for physiotherapist performed POCUS remains sparse. [20,28] To move the profession forward in this area of diagnostic practice, it will be important to understand the current status of POCUS in physiotherapy education and training. An important first step will be to determine what curricula is included in physiotherapy education, what pedagogical approaches are being used, and the outcomes of training on theoretical and practical knowledge.

Studies of inter-professional agreement and evaluation of image quality are important measures of competency and acceptable use of POCUS. POCUS is being used by a variety of health care professionals in many different clinical areas such as the emergency department, intensive care unit, pediatrics, sports medicine, and rheumatology.[6] POCUS is also emerging as a novel tool in the management of hemophilia.[46] As the musculoskeletal experts of the comprehensive care team physiotherapists are ideally suited to perform POCUS for the assessment and management of joint and muscle bleeding in patients with hemophilia. In 2021, a global survey of POCUS use found that 70% of POCUS scans were completed by physiotherapists.[46] Several researchers have studied diagnostic ultrasound and the correlation with disease activity and hemophilic arthropathy however, inter-professional agreement and an evaluation of image quality for physiotherapist performed POCUS in patients with acute hemarthrosis in patients with hemophilia has not been investigated.[35,47-51] Valuable information can be gained from studies that investigate the measurement properties of novel clinical tools to ensure adequate quality and psychometric properties when comparing physiotherapists who have received training for POCUS, with traditional users of diagnostic ultrasonography including radiologists and sonographers.

Rationale and Overview of Thesis Chapters

Given the above gaps, the overall goal of this thesis was to add to the emerging literature on physiotherapist performed POCUS. Two scoping reviews and an inter-professional agreement study were done to address this objective. A brief rationale for each study and an overview of each manuscript are presented below.

Chapter 2: Physiotherapist Performed Point of Care Ultrasonography (POCUS): A Scoping Review of 209 Studies

The objective of the first manuscript was to systematically map the peer-reviewed research literature to understand the current state of physiotherapist performed POCUS across physiotherapy practice. Specifically, my research questions were (1) In which countries are physiotherapists reporting the use of POCUS? (2) In which settings are physiotherapists investigating POCUS? (3) For which patient population(s)/disease condition(s) are physiotherapists studying POCUS? (4) What types of studies on physiotherapist performed POCUS are reported in the peer-reviewed research literature?

This scoping review followed the standardized scoping review methodology developed by Arksey and O'Malley and the extensions proposed by Levac, Colquhoun, and O'Brien.[52,53] The Preferred Reporting Items for Systematic Reviews and Meta-analysis Extension for Scoping Reviews (PRISMA-ScR) was used to inform the writing of the manuscript.[54] Following electronic database searching, two reviewers independently screened 18,217 titles, abstracts, and full text citations. An a priori calibration of reviewer agreement demonstrated a strong level of agreement (k=0.886). Studies were included if it was clearly reported that the POCUS scan was performed by a physiotherapist or if the ultrasound operator was trained to use POCUS by a physiotherapist. This process identified 209 studies of physiotherapist-performed POCUS and were included in this scoping review. Overall, this study found physiotherapists are using POCUS in over 27 countries in a wide variety of practice settings and patient populations. Most included studies were measurement studies that assessed the psychometric properties of physiotherapist performed POCUS of the musculoskeletal system or the abdominal lumbo-pelvic region in healthy adult patients and were published in the United States of America. Eighty-two percent of studies were published in the last 10 years. The breadth and depth of this review highlight the need for improved reporting of study methodology in studies of physiotherapists using POCUS. This is the first known scoping review of physiotherapist performed POCUS that included all areas of physiotherapy practice and can be used to inform the conduct of future studies. This review identified opportunities for research and professional collaboration in this emerging area of physiotherapy practice. This manuscript has been accepted for publication in Physiotherapy (*Physiotherapy*, https://doi.org/10.1016/j.physio.2022.11.005).

Chapter 3: Scoping review of curricula and pedagogical approaches for physiotherapist performed point of care ultrasonography

To ensure safe and effective use of POCUS in physiotherapy clinical practice, there is need to establish standards for competency, training, and education.[6,8] Building on the findings from the scoping review presented in Chapter 2, the objective of the second manuscript was to systematically collate and map physiotherapy pre- and post-licensure curricula and pedagogical approaches for POCUS. This scoping review included studies that provided information on POCUS curriculum or training approaches for physiotherapy students in professional degree programs or for physiotherapists in clinical practice. Research questions were (1) what curricular and pedagogical approaches have been used in pre-licensure physiotherapy degree programs to teach POCUS; (2) what curricular and pedagogical approaches have been used in post-licensure physiotherapy continuing education courses to teach POCUS; and (3) how were the pre- and post-licensure curricular and pedagogical approaches assessed and what were the results?

Fifteen studies met the inclusion criteria. Thirteen studies were published from 2010-2019, however the analysis identified minimal research and progress in the development of physiotherapy-specific curricula both pre- and post-licensure. This scoping review found considerable variability in pedagogical approaches. Most studies included content on the theoretical aspects of POCUS principles, however few included practical teaching. Regardless of pedagogical approach, all studies reported an improvement in theoretical knowledge. The findings can inform physiotherapy educators and support the inclusion of POCUS in pre- and post-licensure curriculum. This scoping review can also inform physiotherapy regulatory colleges and licensing bodies to assist in the development of guidelines for practice, competency assessment, and quality assurance processes. The manuscript was accepted for publication in Physiotherapy Canada (*Physiother Can* 2022; e20210079; advance access article; doi:10.3138/ptc-2021-0079).

Chapter 4: Point of care ultrasonography in patients with hemophilia and acute hemarthrosis: a physiotherapist and sonographer inter-professional agreement pilot study

Hemophilia is a x-linked recessive, hematological disease that primarily presents with episodes of joint and muscle bleeding.[55] Recurrent joint bleeds, also known as hemarthroses, have the potential to cause long term joint damage.[55] Recent evidence suggests that the clinical examination alone is not sensitive to detect small amounts of blood within a joint.[56-58] In conjunction with the clinical examination, POCUS can be used by physiotherapists to assess acute bleeding episodes and to monitor for early signs of joint disease including synovial and osteochondral changes.[59]

As suggested in Chapter 3, to ensure appropriate implementation of physiotherapy-performed POCUS there needs to be an infra-structure of training and competency evaluation.[7,8,36] McMaster University and the Mohawk College Medical Radiation Sciences Program partnered to develop a novel, post-licensure, academic training and certification program for physiotherapists in hemophilia care on the application of POCUS for the assessment and management of acute hemarthrosis.[8,36,38,39] The training program combined online didactic modules and practical training to evaluate the attainment of competencies set out by Sonography Canada for this specific application of POCUS.[38]

The primary objective of the third manuscript was to determine the level of agreement between a physiotherapist who received training in the McMaster University Mohawk College POCUS Training Program, and an expert sonographer for the assessment of acute hemarthrosis in people with hemophilia A and B. The secondary objective was to compare the quality of the ultrasound images obtained by the physiotherapist to those obtained by the sonographer.

This pilot study yielded two important findings that support the emerging literature on the proficiency and quality of physiotherapist-performed POCUS. The first is that a physiotherapist who received a short period of training was able to perform and interpret POCUS for the presence and absence of blood within the joint, to an acceptable and comparable level of that of an expert sonographer. The second important finding was that the physiotherapist was able to produce high quality images with optimal ultrasound settings, and correct annotation and documentation. This study can be used to inform the development of educational curricula and training programs for physiotherapists working with patients in other conditions. This manuscript is published in the Journal of Haemophilia Practice (*J Haem Pract* 2022; 9(1). doi: 10.2478/jhp-2022-0008).

Summary

This introductory chapter highlights diagnostic ultrasonography, specifically POCUS, in physiotherapy practice in Canada. Variations in terminology, training, and applications of POCUS in physiotherapy practice were also described. This chapter also provides a brief synopsis of each study included in this dissertation. Chapters 2-4 provide the full manuscripts of each study. The fifth and final chapter of this thesis is a discussion on how this work contributes to the emerging role of diagnostic imaging in physiotherapy research, education, and practice.

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CHAPTER 2

Physiotherapist Performed Point of Care Ultrasonography (POCUS): A Scoping Review of 209 Studies

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Physiotherapist Performed Point of Care Ultrasonography (POCUS): A Scoping Review of 209 Studies

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TITLE

Physiotherapist Performed Point of Care Ultrasonography (POCUS): A Scoping Review of 209 Studies

ABSTRACT

Background: Point of care ultrasonography (POCUS) is a non-ionizing imaging technique that is emerging in physiotherapy practice.

Objective: To systematically map the research literature on physiotherapist performed POCUS.

Data sources: Following PRISMA-ScR guidelines, OVID Medline, CINAHL, AMED, and EMBASE were searched.

Eligibility criteria: Peer-reviewed publications of physiotherapist performed POCUS were included.

Data extraction and data synthesis: Data collected included: title, author(s), journal, year of publication, design of included studies, sample size, age category of the sample, anatomical area of POCUS, geographical location of research, study setting, and disease condition/patient population. Data analysis consisted of descriptive statistics for the key characteristics of each research question.

Results: A total of 18 217 titles and abstracts and 1 372 full-text citations were screened, with 209 studies included. Most included studies were measurement studies that assessed the psychometric properties of POCUS in adult patients, were published in the United States of America and imaged the abdominal lumbo-pelvic region. Eighty-two percent of studies were published in the last 10 years.

Limitations: Non-English language, review articles and grey literature were excluded for feasibility. Studies were excluded if it was not clearly reported that a physiotherapist performed the POCUS.

Conclusion: This review identified a wide variety of practice settings and a diverse number of patient conditions in which physiotherapists are performing POCUS. This breadth and depth of this review highlighted the need for improved reporting of study methodology and key areas of future research in physiotherapy performed POCUS.

Contribution of Paper:

- This is the first known scoping review of physiotherapist performed POCUS that included all areas of physiotherapy practice
- This review highlighted the wide variety of practice settings and diverse number of patient conditions in which physiotherapists are performing POCUS
- The most common study design were measurement studies, with most measurement studies investigating the reliability of physiotherapy performed POCUS of the musculoskeletal system or the abdominal lumbo-pelvic region, in healthy adult subjects.

Keywords: ultrasonography, physical therapists, physical therapy modalities, rehabilitation, review, point of care systems

INTRODUCTION

Point of care ultrasonography (POCUS) is a non-ionizing imaging technique that is rapidly emerging in clinical practice. POCUS is an ultrasound examination that is performed and interpreted by a primary healthcare provider in combination with the physical examination in a clinic setting [1, 2]. POCUS is a safe, effective, and dynamic imaging modality that can assist in the assessment of presenting symptoms and to monitor response to treatment over time [1, 2]. Healthcare professionals who receive proper training can learn to perform POCUS for the evaluation of a specific organ, pathology, or procedure within their area of expertise [1].

Ultrasound, as an imaging modality, was introduced to the physiotherapy profession in 1980 by Dr. Archie Young from the University of Oxford [2, 3]. With the increasing affordability and portability of ultrasound imaging machines, more physiotherapists are embracing this technology to improve quality, efficiency, and individualization of care [2]. A narrative review by Whittaker et al. outlined a range of clinical and research purposes for POCUS in physiotherapy practice and identified heterogeneity in terminology, gaps related to scope of practice and the need for specialised training [2]. Four categories of physiotherapist performed POCUS were proposed: diagnostic, interventional, rehabilitative, and research ultrasound [2]. The review revealed many clinical areas in which physiotherapists are performing POCUS and was a valuable step in understanding the status of POCUS in physiotherapy practice. In contrast to narrative reviews, the advantages of systematic scoping reviews include a comprehensive literature search to allow for replication and future updates, and minimization of selection bias, both of which enhance confidence in the review findings [4]. To assist with the formal integration of POCUS into clinical practice, educational curriculum, and scope of practice, the nature, extent, and scope of physiotherapist performed POCUS requires an evidence-based, systematic review of the research literature.

Scoping reviews are a form of knowledge synthesis exploring research questions to methodologically map existing literature and summarize the main sources and types of evidence available on a specific body of knowledge that is heterogeneous in nature [5, 6]. The aim of a scoping review is to synthesize the evidence to inform clinical practice, policy, knowledge gaps, and directions for future research [6]. Scoping reviews are a preferred methodology in emerging areas of practice [6]. While one scoping review of thoracic ultrasound performed by physiotherapists [7] exists, there is no comprehensive review of physiotherapist performed POCUS encompassing all areas of practice. For these reasons, a scoping review methodology was chosen to investigate the breadth and depth of physiotherapist performed POCUS. The purpose of this review is to systematically map the peer-reviewed research literature on physiotherapist performed POCUS.

MATERIALS AND METHODS

Research Questions:

1. In which countries are physiotherapists reporting the use of POCUS?
2. In which settings are physiotherapists investigating POCUS?

3. For which patient population(s)/disease condition(s) are physiotherapists studying POCUS?
4. What types of studies on physiotherapist performed POCUS are reported in the peer-reviewed research literature?

Data Sources and Searches

This study followed the standardized scoping review methodology by Arksey & O'Malley and Levac, Colquhoun, and O'Brien [8, 9]. The Preferred Reporting Items for Systematic Reviews and Meta-Analysis Extension for Scoping Reviews (PRIMSA-ScR) was used as a framework for reporting [5]. Search strategies were developed in consultation with a health research librarian and refined through team discussion. OVID Medline, Cumulative Index to Nursing and Allied Health Literature (CINAHL), Allied and Complementary Medicine Database (AMED), and Excerpta Medica Database (EMBASE) were searched from January 1, 1980, the year of the first reported use of POCUS by physiotherapists, to November 10, 2019 [2]. The search strategies are included in Appendices 1-4.

Citations were imported into EndNote X8 to remove duplicates and then exported to Covidence (2020 Veritas Health Innovation, Melbourne, Australia). Prior to screening, two reviewers (K.S. and A.N.) performed a calibration exercise of 40 citations to evaluate reviewer agreement using Cohen's kappa statistic. A value of greater than 0.80, which indicates a strong level of agreement, was required [10].

Two reviewers (K.S. and A.N.) independently reviewed all titles, abstracts, and full-text citations for inclusion and consensus was necessary to progress a citation through the scoping review process. Conflicts were first resolved by discussion of the two reviewers. If consensus could not be reached, the conflict was resolved with the assistance of a third reviewer (P.S.).

Study Selection

Peer-reviewed publications were included if POCUS imaging was performed by a physiotherapist or if the ultrasound operator was trained to use POCUS by a physiotherapist. Studies were excluded if they were non-English language, review articles, studies of therapeutic ultrasound, or grey literature.

Data Extraction

Data collection and analyses were performed by the first author and another reviewer (A.N.). A data collection form was developed by the first author and piloted on the first ten manuscripts to ensure consistency. For the remaining citations, the first author independently extracted the data from all the included publications. The second reviewer (A.N.) independently reviewed the data collection forms for accuracy. The data collected from each included manuscript included: title, author(s), journal, year of publication, design of included studies, sample size, age group of the sample (adult vs. paediatric or both), anatomical area of POCUS, geographical location of the research, study setting, and disease condition/patient population. Conflicts were resolved with discussion and if consensus could not be achieved, the conflict was resolved in consultation with a third reviewer (P.S.).

Data Synthesis and Analysis

Data analysis was completed by two reviewers (K.S. and A.N.) and consisted of descriptive statistics for the key characteristics of each research question. Descriptive statistics, including counts and percentages, were applied to the numerical data. Descriptive numerical summary included year of publication, design of included studies, sample size, age group of the sample, geographical location of the research, study setting, and patient population/disease condition. The anatomical area of the scan was also grouped into categories across patient population/disease conditions.

RESULTS

Database searching identified 19 455 potential studies. Following the removal of duplicates (n=1 238), 18 217 titles and abstracts were screened, and 209 studies met the inclusion criteria (Figure 1). The 209 included studies were published in 81 different peer-reviewed journals with 10 357 (median 30, interquartile range 39) subjects enrolled. One hundred and eighty-nine studies (90%) were completed in a sample of adult subjects who were over 18 years of age, seven studies included paediatric subjects (3%), nine studies (4%) included both adult and paediatric subjects. In four studies the age of the sample was not reported. Forty-eight percent (n=101) of included studies were published from 2015-2019 and 82% (n=171) were published from 2010-2019 (Figure 2). Full details of included studies are provided in Supplementary File 1.

Reviewer Agreement

Prior to title and abstract screening, the calibration exercise for reviewer agreement resulted in a Cohen's kappa of 0.89 indicating a strong level of agreement.

Geographical Location

The included studies were completed in 27 different countries. The top six countries accounted for 148 (71%) of included studies: United States of America (USA) (n=56, 27%), Australia (n=31, 15%), United Kingdom (n=25, 12%), Spain (n=15, 7%), Japan (n=11, 5%), and Canada (n=10, 5%). Four studies (2%) were collaborations between two or more countries (Figure 3).

Study Setting

Physiotherapists investigated POCUS in a wide variety of health care, research, and educational settings. To aid in classification, all studies that were completed in a research laboratory, be it at a university, hospital, or military research laboratory, were classified as research setting (n=97, 46%). Thirty-six studies were completed in community physiotherapy clinics (n=36, 17%). Studies that were completed in an outpatient clinic/unit or department, physiotherapy-led speciality clinic or occupational health centre were reported as hospital-outpatient setting (n=22, 11%). Studies that were completed in a medical, surgical, rehabilitation ward, adult or paediatric intensive care unit were included as hospital-inpatient setting (n=10, 5%). The remaining studies were classified as amateur and sport team setting (n=3, 1%), outpatient military departments/clinics (n=2, 1%), schools (n=2, 1%), a Pilates studio (n=1, 0.50%), and a remote military location (n=1, 0.50%). Thirty-five studies (17%) did not state the setting or were unclear and were not able to be classified due to limited reporting (Figure 4).

Patient Population/Disease Condition

Physiotherapists have reported using POCUS over a wide range of anatomical areas and disease conditions. The largest single type of studies (n=98, 47%) imaged the abdominal and lumbo-pelvic region (Table 1). Musculoskeletal impairments of the upper extremities (n=43, 21%), lower extremities (n=34, 16%), and the spine, sternum, and thorax (n=9, 4%), were the next most-imaged regions. Four studies (2%) imaged the diaphragm and lungs, while another six (3%) were on the nervous system, which included assessing the excursion of peripheral nerves. To guide research and clinical practice, physiotherapists performed POCUS on healthy subjects and assessed impairments in patients with various conditions across different anatomic areas (Table 1). Twenty studies investigated POCUS in physiotherapy practice and education and were classified as not applicable. Of these, nine studies were surveys, one a focus group and 10 assessed POCUS use in education, training, and curriculum development, rather than in a specific patient population or disease condition.

Designs of Included Studies

The largest single type of studies were measurement studies (n=53, 25%) that reported on measures of reliability, validity, agreement, diagnostic accuracy, and/or minimal detectable change, of physiotherapist performed POCUS. Randomized controlled trials also included randomized cross-over trials and were the second most common study design (n=35, 17%), followed by cohort (n=20, 10%), cross-sectional (n=19, 9%), case report/case series (n=19, 9%), case control (n=15, 7%), and descriptive (n=15, 7%) studies. There were ten (5%) non-controlled trials, ten (5%) observational trials, nine (4 %) quasi-experimental trials in which groups are not randomly assigned, and two (1%) correlational studies. There was also one qualitative and one single subject experimental study (Figure 5).

The largest single body of literature on POCUS relates to physiotherapists undertaking measurement studies (n=53). Most of the measurement studies were studies of the reliability (n=43, 81%) of physiotherapist performed POCUS with a further 6 studies (11%) of reliability and validity, and a single study of reliability and minimal detectable change (2%). Ninety-six percent of all the measurement studies (n=51) investigated musculoskeletal applications of POCUS (n=29, 55%) or the abdominal, lumbo- pelvic region (n=22, 42%). The majority of measurement studies were completed in healthy subjects (n=32, 60%), followed second by studies completed in patients with low back pain (n=6, 11%). Almost all the measurement studies were completed in an adult population (n=48, 91%), two studies included both adult and paediatrics (4%), and three studies investigated paediatrics alone (6%).

DISCUSSION

Using the PRISMA-ScR [5], this scoping review systematically mapped the peer-review research literature and found 209 studies of physiotherapist performed POCUS from over 27 countries. The largest single type of studies were performed with adult patients in a research setting, were published in the USA, and were of the abdominal lumbo-pelvic region. The majority were reported in the last 10 years, confirming physiotherapist performed POCUS as an emerging area of physiotherapy professional practice. The most common study design were measurement studies, with most measurement studies investigating the reliability of physiotherapy performed POCUS in healthy adult subjects. Ninety-six percent of the measurement studies assessed musculoskeletal POCUS or were of the abdominal lumbo-pelvic region.

There was considerable heterogeneity in the studies across geographical location, study setting, patient population, disease condition, and study design (Figures 3-5, Table 1). Similar heterogeneity was found in a scoping review of thoracic ultrasound by physiotherapists [7]. In the current review, the degree of heterogeneity presented challenges for data synthesis and analysis, but also provided evidence to support the need for this research to consolidate and illustrate the breadth and depth of physiotherapy performed POCUS across all areas of practice.

Integration of novel modalities into clinical practice requires an assessment of the levels of evidence to inform best practices. Central to this process is the evaluation of the psychometric properties of the tool [11]. Fifty-three of the included studies were measurement studies that assessed the psychometric properties of physiotherapy performed POCUS. As physiotherapist performed POCUS is a novel tool, it is encouraging that measurement studies are the most common study design as there is a need to establish reliability and validity before investigating effectiveness. Following this process should help physiotherapists who are performing POCUS to establish expertise and credibility in the community.

Qualitative studies are also important to help understand real world situations, such as patient and provider experience with a new technology [12]. In this scoping review, there was only one qualitative study. Qualitative studies will be an important area of future research on physiotherapist performed POCUS to assess the patient and provider perspective on the use of the modality in practice. Qualitative research may also help explain why some interventions are effective and are successfully implemented into practice, while others are not [12].

Safe and effective use of POCUS in clinical practice is dependent on operator skill and training [1, 13]. Ten of the included studies investigated POCUS in physiotherapy education and training. Nine surveys and one focus group study assessed POCUS in practice. A recent scoping review by Strike et al. of curricula and pedagogical approaches for physiotherapist performed POCUS found that the creation of a physiotherapy-specific, standardized, competency-based curricula for POCUS remains in the early stages of development with no accepted standard or credentialing process for the use of POCUS in any area of physiotherapy practice [14]. As variability in training may impact the psychometric properties of POCUS, education and competency assessment will be important areas for future study [14].

The majority of included studies were in adults, which may limit generalizability to paediatric patients. This finding is not unexpected in emerging technologies and modalities, as it is common practice for research to first be completed in adult patients before being studied in children. However, there may be unique considerations regarding the psychometric properties, effectiveness, and tolerability of physiotherapist performed POCUS in paediatric patients that warrants further study.

Although, the majority of studies were completed in six high income countries, research from 27 countries was included in this review with four studies representing collaborations between physiotherapists in two or more countries. Coordinated global action and collaborations between developed and developing countries are important aims of the World Health Organization's recommendations for rehabilitation in health systems [15]. It is promising that physiotherapy researchers, educators and clinicians have already initiated this process, which may increase global attention and awareness of physiotherapist performed POCUS.

Physiotherapist performed POCUS studies are being performed in a wide variety of settings with a diverse set of disease conditions and patient populations. However, this scoping review found many of the included studies lacked detail in reporting of methodology. During the full-text review of 1 372 studies, 476 (35%) studies were excluded as the authors did not state who performed the POCUS and 184 (13%) studies were excluded as the POCUS was performed by an operator with no discipline provided (Figure 1). Therefore, the number of included studies may be an under-estimation of physiotherapist performed POCUS. Also, in 35 (17%) of included studies, the study setting was not stated or was unclear which limited classification. The limitations in reporting of study methodology found in this review is not uncommon in physical therapy research. A recent meta-analysis of the use of reporting guidelines in high impact rehabilitation journals reported a small minority of authors declared the use of reporting guidelines and 50% used the guidelines inappropriately [16]. Studies that follow reporting guidelines available through the EQUATOR (Enhancing the Quality and Transparency of Health Research) Network allow readers to evaluate study methodology and generalizability to inform clinical decision making and evaluation of novel modalities in physical therapy practice.[17] Improved reporting may also lead to creation of a common language for physiotherapist performed POCUS, which may facilitate the development of a community of practice to increase dialogue and information sharing among physiotherapists [18].

This is the first known scoping review of physiotherapist performed POCUS that included all areas of physiotherapy practice. Strengths of this scoping review include a comprehensive search strategy and the use of the PRISMA-ScR reporting guidelines to ensure a comprehensive and systematic approach to guide this scope of inquiry [8]. Completion of the a priori calibration exercise demonstrated a strong level of agreement between reviewers, which provided a high level of consistency to the study methodology and data extraction. With 209 included studies, this scoping review demonstrated the breadth and depth of physiotherapist performed POCUS around the world and identified key evidence gaps that provide important opportunities for future research and professional collaboration.

Limitations

Given that over 19 000 studies were identified through database searching, non-English language, review articles and grey literature were excluded for feasibility which may limit generalizability. This scoping review was completed during the global COVID-19 pandemic and many libraries worldwide were closed with limited access to inter-library loans resulting in 16 missing studies. Also, this review took a conservative approach by including only those studies that clearly reported that POCUS imaging was performed by a physiotherapist or if the ultrasound operator was trained to use POCUS by a physiotherapist. Studies in which the authors were from several health professions including physiotherapy were excluded if it could not be confirmed that the physiotherapist was the operator performing the scan. This may have resulted in missed studies. The difficulties with the classification of physiotherapist performed POCUS means there is the possibility that a study may have been misclassified. In future studies, these limitations can be minimized with increased utilization of study reporting guidelines and obtaining an evidence-based international consensus on common terminology and language for physiotherapist performed POCUS.

CONCLUSIONS

The purpose of this scoping review was to investigate the breadth and depth of physiotherapist performed POCUS. Two hundred and nine studies identified a wide variety of practice settings and a diverse number of patient conditions in which physiotherapists are performing POCUS. Most studies were published in the last 10 years, confirming POCUS as an emerging area of physiotherapy practice. Despite the heterogeneity of the included studies, the results suggest that the largest body of literature on physiotherapist performed POCUS are measurement studies, with most of these investigating the reliability of physiotherapy performed POCUS of the musculoskeletal system or the abdominal lumbo-pelvic region, in healthy adult subjects. The results of this scoping review highlight the need for improved reporting of study methodology and identify key areas of future research in physiotherapy performed POCUS.

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ETHICS APPROVAL

Ethics approval was not required for this scoping review.

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CONFLICT OF INTEREST

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FIGURES

Figure 1. PRISMA flow diagram

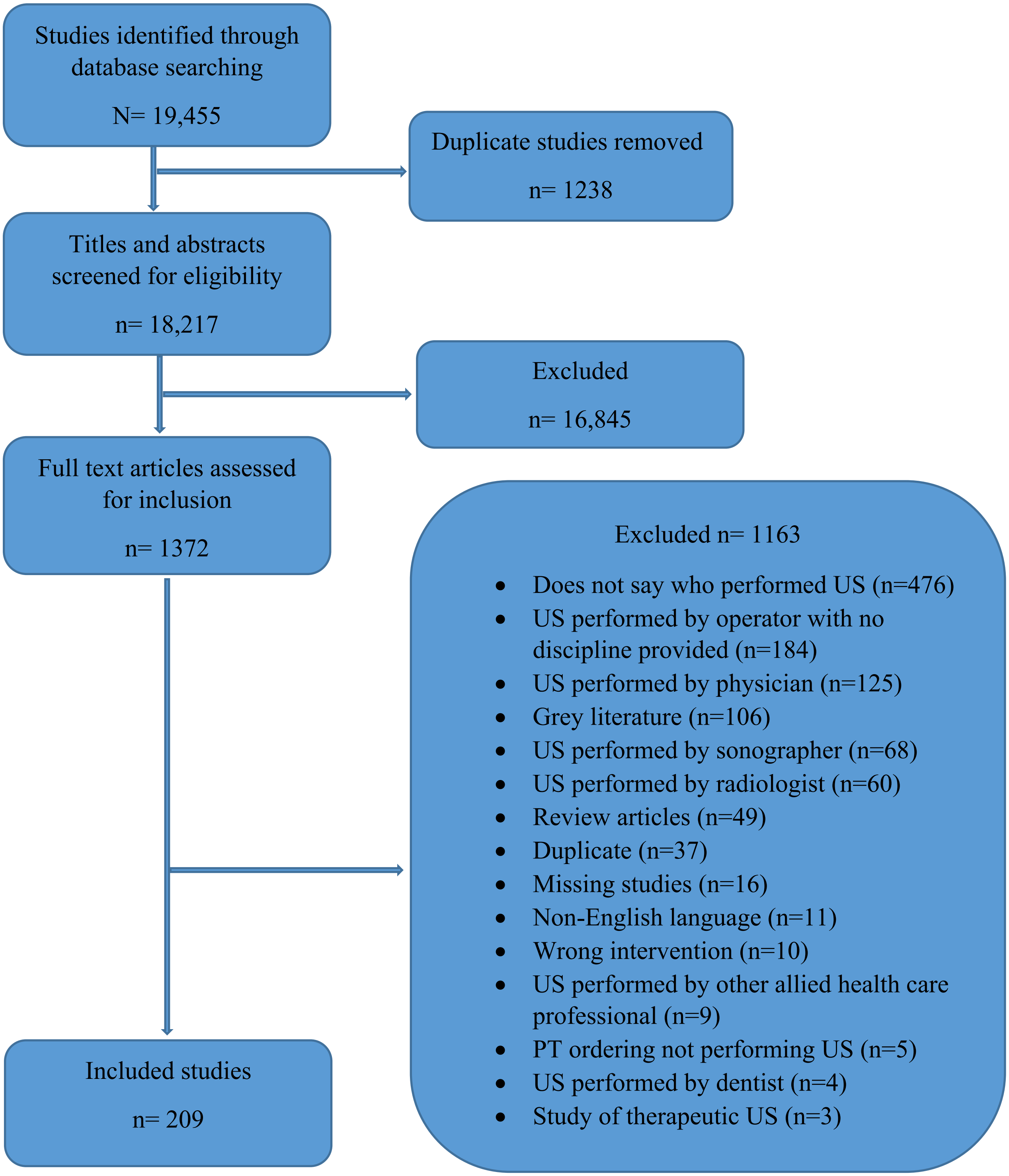
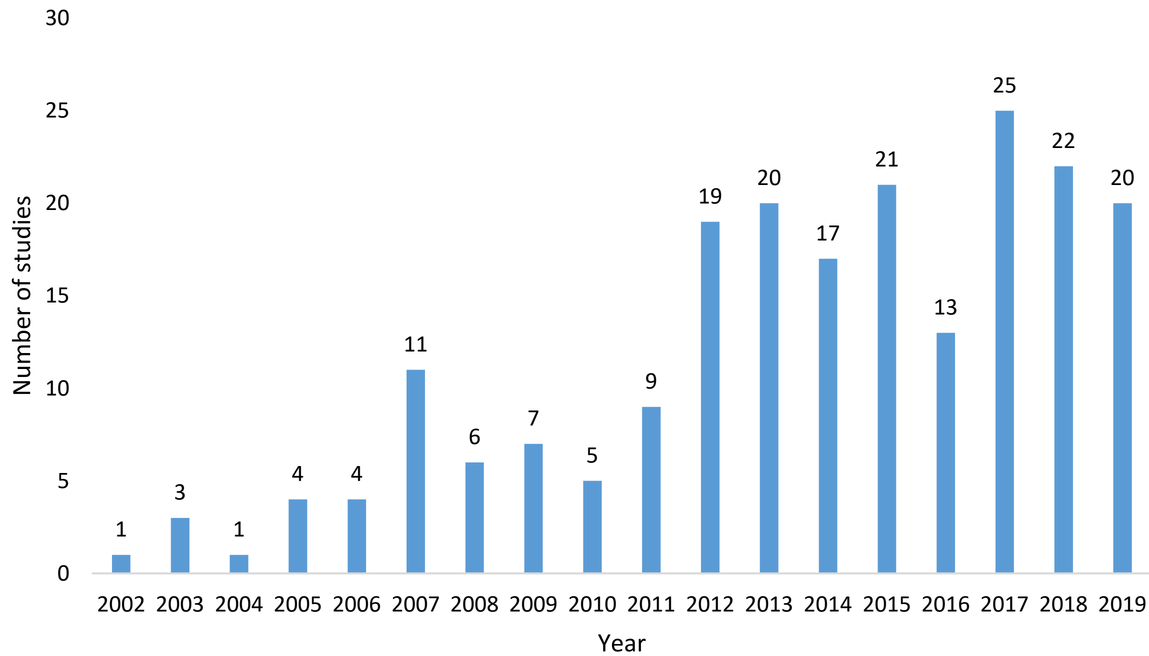


Figure 2. Year of publication of included studies



*One included study from 1987

Figure 3. Geographical location of included studies

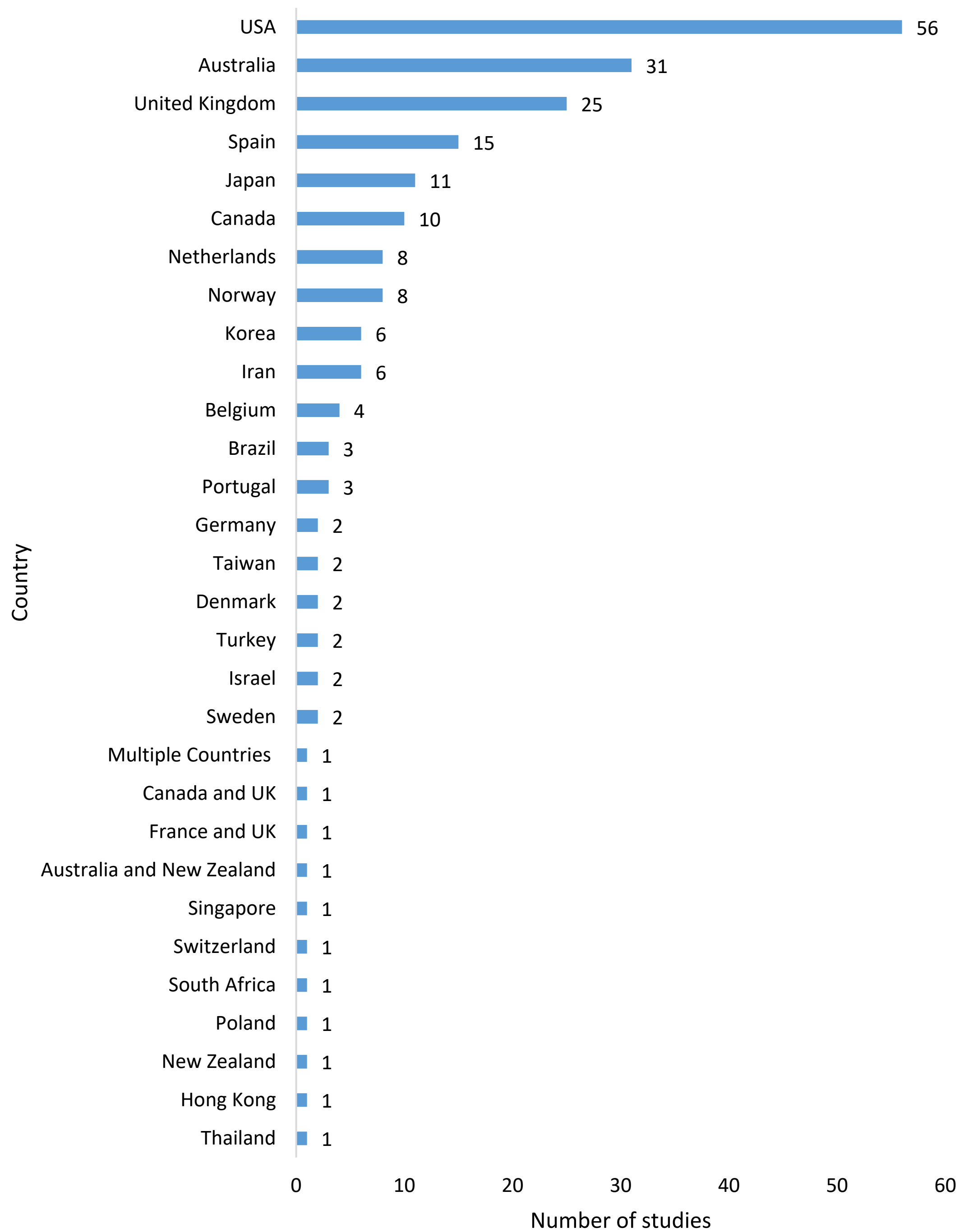


Figure 4. Study setting of included studies

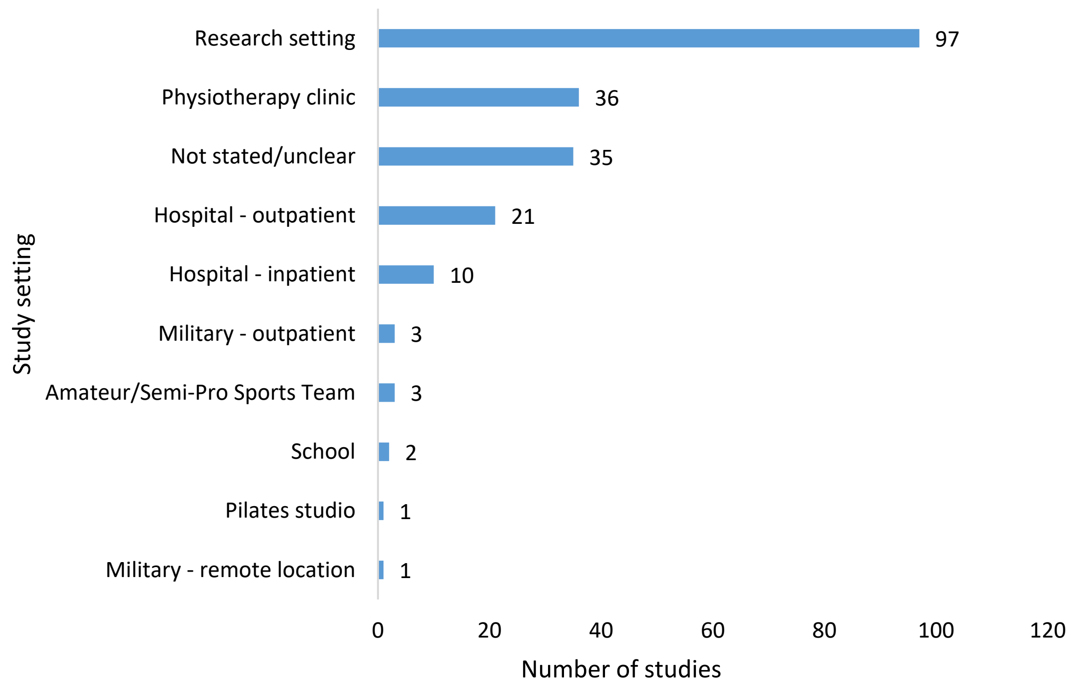
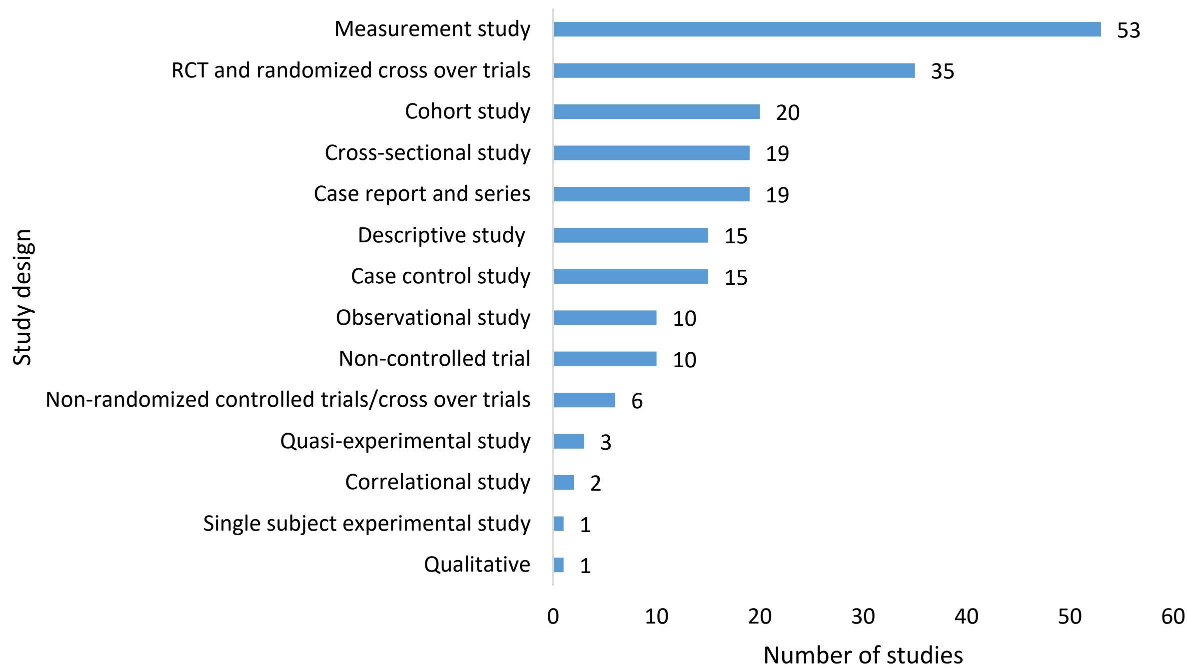


Figure 5. Design of included studies



TABLES

Table 1. Anatomical area of POCUS across disease conditions

Anatomical Area	Disease Conditions
Abdominal, lumbo-pelvic region (n=98)	- Transverse abdominus muscle thickness in patient with cerebellar ataxia post acquired brain injury - Urinary incontinence in patients with chronic obstructive pulmonary disease or cystic fibrosis - Pelvic floor, abdominal muscle architecture and function in patients with low back pain, chronic low back pain, hip pain, healthy participants, athletes, exercising women, older adults, Pilates participants, military personnel, post op lumbar disc surgery, pregnancy, post-partum women, scoliosis - Pelvic floor muscle function and urinary incontinence in patients with prostate cancer - Urogynecological disorders including urinary incontinence, pelvic organ prolapse, lumbo-pelvic pain, pelvic girdle pain - Diastasis rectus abdominus - Sports injuries including chronic low back pain
Diaphragm and Lung (n=4)	- Critical care/Intensive care unit patients - Spinal cord injury - Athletes with and without lumbo-pelvic pain
Musculoskeletal – lower extremity (n=34)	- Ankle sprains and chronic ankle instability - Distal fibula fracture - Muscle architecture, tendon thickness, joint laxity, morphology in healthy participants, patients with cerebral palsy, chronic obstructive pulmonary disease, mechanically ventilated critically ill children, healthy athletes, spinal cord injury, hallux valgus, patellofemoral pain, plantar fasciitis - Leg length discrepancy in chronic low back pain - Joint health in patients with hemophilia - Sports injuries including injury to the fibular collateral ligament, displaced fracture of the fifth metatarsal and distal fibular stress fracture - Synovial thickness in patients with osteoarthritis - Osteoporosis (tibia) in patients with traumatic brain injury

Musculoskeletal – spine, sternum, thorax (n=9)	- Segmental lumbar spine flexion/extension and interspinous process distance in healthy participants - Shearwave elastography of the pectoralis minor - Scapular insertion of levator scapulae in patients with whiplash syndrome - Dry needling of the iliacus muscle in healthy participants - Cervical spine in patients with cervicogenic headache - Sternal micromotion and instability in patients following cardiac surgery
Musculoskeletal – upper extremity (n=43)	- Acromioclavicular, acromion-greater tuberosity, acromial humeral distance, subacromial deltoid bursa, dynamic impingement, glenohumeral separation/movement, shoulder range of motion in healthy participants, patients post stroke, sub-acromial impingement, Ehlers-Danlos syndrome, hypermobility spectrum disorder, athletes - Tendon/muscle architecture in healthy participants, healthy athletes, Ehlers-Danlos syndrome, hypermobility spectrum disorder, lateral epicondylalgia, shoulder tendinopathy - Joint health in patients with hemophilia - Prognostic model for new patients with shoulder pain - Osteoporosis (radius) in patients with traumatic brain injury - Post op sub-acromial impingement surgery, posterior labral repair - Confirm clinic diagnosis for patients with shoulder impairments including sub-acromial impingement, tendinopathy, calcification, partial thickness tears - Muscle hardness using elastography - Ultrasound guided hydrodistension in patient with adhesive capsulitis - Ultrasound guided sub-acromial corticosteroid injection in patients with sub-acromial impingement syndrome - Dry needling and muscle thickness of infraspinatus - Sports injuries including lateral elbow pain, acromiohumeral distance in overhead athletes, shoulder impingement - Synovial blood flow in patients with rheumatoid arthritis - Lymphedema in patients with breast cancer
Neurology (n=6)	- Median nerve excursion in patients with carpal tunnel, healthy participants

	- Nerve lesions/injury (median, sciatic, ulnar, peroneal, brachial plexus, suprascapular) - Sciatic nerve in healthy participants

*n=20 studies were classified as not applicable and were excluded from this table
**n=5 studies evaluated more than one disease condition and were counted in more than one category in the table above

APPENDICES

Appendix 1. Search strategy OVID Medline: 1980 – November 10, 2019

1. exp Physical Therapists/
2. exp Physical Therapy Modalities/
3. exp Physical Therapy Specialty/
4. physiotherap*.mp.
5. physical therap*.mp.
6. 1 or 2 or 3 or 4 or 5
7. exp Ultrasonography/
8. dg.fs
9. ultraso*.mp.
10. sonography.mp.
11. 7 or 8 or 9 or 10
12. 6 and 11
13. point of care.mp or exp Point-of-Care Systems/
14. sports medicine.mp or exp Sports Medicine/
15. orthopedics.mp or exp Orthopedics/
16. respiratory*.mp or exp Respiratory System/
17. chest physi*.mp
18. atelectasis.mp or exp Pulmonary Atelectasis/
19. rotator cuff*.mp or exp Rotator Cuff/
20. pelvic*.mp or exp Pelvic Floor/

21. h?emophilia*.mp
22. exp Hemophilia A/
23. exp Hemophilia B/
24. neuropathy.mp
25. acupuncture.mp or exp Acupuncture/
26. rheumatology.mp or exp Rheumatology/
27. exercise therap*.mp or exp Exercise Therapy/
28. therapeutic exercise.mp
29. musculoskeletal*.mp or exp Musculoskeletal System/
30. exp Musculoskeletal Diseases/
31. exp Musculoskeletal injur
32. 14 or 15 or 16 or 17 or 18 or 19 or 20 or 21 or 22 or 23 or 24 or 25 or 26 or 27 or 28
33. 29 and 11 and 13
34. 30 or 12
35. Limit 31 to (English language and yr="1980-Current")

Appendix 2. Search strategy CINAHL: 1980 – November 10, 2019

1. physical therapists/
2. exp physical therapy/
3. exp physiotherapy, evidence database/
4. physical therapy practice, evidence-based/
5. exp research, physical therapy

6. physiotherap*.mp.
7. physical therap*.mp.
8. 1 or 2 or 3 or 4 or 5 or 6 or 7
9. exp ultrasonography
10. ultraso*.mp.
11. sonography.mp.
12. 9 or 10 or 11
13. 8 and 12
14. exp “point of care testing” or “point of care”.mp
15. sports medicine.mp or exp sports medicine/
16. orthopedics.mp or exp orthopedics/
17. respiratory*.mp
18. chest physi*.mp or exp chest physical therapy
19. atelectasis.mp or exp pulmonary atelectasis/
20. rotator cuff*.mp or exp rotator cuff/
21. exp rotator cuff injuries/
22. pelvic*.mp or exp pelvic floor muscles/
23. h?emophilia*.mp or exp hemophilia/
24. exp Hemophilia B/
25. neuropathy.mp
26. acupuncture.mp or exp Acupuncture/
27. rheumatology.mp or exp Rheumatology/

28. exercise therapy.mp or exp therapeutic exercise/
29. musculoskeletal.mp or exp musculoskeletal system/
30. 15 or 16 or 17 or 18 or 19 or 20 or 21 or 22 or 23 or 24 or 25 or 26 or 27 or 28 or 29
31. 30 and 12 and 14
32. 31 or 13
33. Limit 32 to (English language and yr=”1980-Current”)

Appendix 3. Search strategy for AMED: 1980 – November 10, 2019

1. exp physiotherapists/
2. exp physical therapy modalities/
3. exp physical therapy specialty/
4. physiotherap*.mp.
5. physical therap*.mp.
6. 1 or 2 or 3 or 4 or 5
7. exp Ultrasonography/
8. ultraso*.mp.
9. sonography.mp.
10. 7 or 8 or 9
11. 6 and 10
12. point of care.mp
13. sports medicine.mp or exp Sports Medicine/
14. orthopedics.mp or exp Orthopedics/

15. respiratory*.mp or exp respiratory muscles/
16. chest physiotherapy.mp or exp chest physiotherapy/
17. atelectasis.mp or exp atelectasis/
18. rotator cuff*.mp or exp Rotator Cuff/
19. pelvic*.mp or exp Pelvic Floor/
20. h?emophilia*.mp exp Hemophilia/
21. neuropathy.mp
22. acupuncture.mp or exp Acupuncture/
23. rheumatology.mp or exp rheumatic disease/
24. exercise therapy.mp or exp Exercise Therapy/
25. musculoskeletal.mp or exp Musculoskeletal System/
26. 13 or 14 or 15 or 16 or 17 or 18 or 19 or 20 or 21 or 22 or 23 or 24 or 25
27. 26 and 10 and 12
28. 27 or 11
29. Limit 28 to (English language and yr=”1980-Current”)

Appendix 4. Search strategy for EMBASE: 1980 – November 10, 2019

1. exp physiotherapist/
2. exp physiotherapy/
3. exp physiotherapy practice/
4. physiotherap*.mp.
5. physical therap*.mp.
6. 1 or 2 or 3 or 4 or 5

7. exp ultrasound/
8. exp echography/
9. ultraso*.mp.
10. sonography.mp.
11. 7 or 8 or 9 or 10
12. 6 and 11
13. exp “point of care testing” or “point of care”.mp
14. sports medicine.mp or exp sports medicine/
15. orthopedics.mp or exp orthopedics/
16. respiratory*.mp
17. chest physi*.mp
18. atelectasis.mp or exp atelectasis/
19. rotator cuff*.mp or exp rotator cuff injury/
20. pelvic*.mp or exp pelvic floor muscle training/
21. h?emophilia*.mp
22. exp hemophilia A/
23. exp Hemophilia B/
24. neuropathy.mp or exp neuropathy/
25. acupuncture.mp or exp Acupuncture/
26. rheumatology.mp or exp Rheumatology/
27. exercise therapy.mp or exp kinesiotherapy/
28. musculoskeletal.mp or exp musculoskeletal system/

29. 15 or 16 or 17 or 18 or 19 or 20 or 21 or 22 or 23 or 24 or 25 or 26 or 27 or 28 or 29

30. 29 and 11 and 13

31. 30 or 12

32. Limit 31 to (English language and yr="1980-Current")

Supplementary Files

Supplementary File 1: Details of included studies

	Title	Author(s)	Journal	Year	Study design	Sample size	Age group: Adult (>18), Pediatric (<18) or Both	Anatomical area of scan	Country	Study setting	Disease condition/ patient population
1	Changes in muscle architecture of biceps femoris induced by eccentric strength training with nordic hamstring exercise	Alonso-Fernandez, D. Docampo-Blanco, P. Martinez-Fernandez, J.	Scandinavian Journal of Medicine and Science in Sports	2018	Cohort study	23	Adult	MSK – lower extremity	Spain	Research setting - university/ hospital/military	Healthy
2	Changes in rectus femoris architecture induced by the reverse nordic hamstring exercises	Alonso-Fernandez, D. Fernandez-Rodriguez, R. Abalo-Nunez, R.	Journal of Sports Medicine & Physical Fitness	2019	Cohort study	26	Adult	MSK – lower extremity	Spain	Research setting - university/ hospital/military	Healthy
3	Effects of the Nordic hamstring exercise on the architecture of the semitendinosus	Alonso-Fernandez, D Gutierrez-Sanchez, Á Garcia-Remeseiro, T Garganta, R	Isokinetics & Exercise Science	2018	Cohort study	23	Adult	MSK – lower extremity	Spain	Research setting - university/ hospital/military	Healthy
4	Real-time ultrasound feedback and abdominal hollowing exercises for people with low back pain	Anderson Worth SG Henry, SM Bunn, JY	New Zealand Journal of Physiotherapy	2007	Randomized controlled trial	19	Adult	Abdominal, lumbo-pelvic region	United States of America	Physiotherapy clinic	Low back pain
5	Use of Dynamic Ultrasound Imaging for Assessment of the Fibular Collateral Ligament of the Knee	Angelopoulou, K. McReynolds, K.	Journal of Orthopaedic and Sports Physical Therapy	2019	Case report	1	Adult	MSK – lower extremity	United States of America	Physiotherapy clinic	Sports injury - knee pain
6	Correlation of digital palpation and transabdominal ultrasound for assessment of pelvic floor muscle contraction	Arab, A. M. Behbahani, R. B. Lorestani, L. Azari, A.	Journal of Manual and Manipulative Therapy	2009	Correlational study	19	Adult	Abdominal, lumbo-pelvic region	Iran	Research setting - university/ hospital/military	Urinary incontinence and low back pain
7	Assessment of pelvic floor muscle function in women with and without low back pain using transabdominal ultrasound	Arab, A. M. Behbahani, R. B. Lorestani, L. Azari, A.	Manual Therapy	2010	Cross sectional study	40	Adult	Abdominal, lumbo-pelvic region	Iran	Research setting - university/ hospital/military	Low back pain

8	Reliability of ultrasound measurement of automatic activity of the abdominal muscle in participants with and without chronic low back pain	Arab, A. M. Rasouli, O. Amiri, M. Tahan, N.	Chiropractic and Manual Therapies	2013	Measurement study	20	Adult	Abdominal, lumbo-pelvic region	Iran	Research setting - university/ hospital/military	Chronic low back pain
9	Use of transabdominal ultrasound imaging in retraining the pelvic-floor muscles of a woman postpartum	Ariail, A. Sears, T. Hampton, E.	Physical Therapy	2008	Case report	1	Adult	Abdominal, lumbo-pelvic region	United States of America	Physiotherapy clinic	Urinary incontinence
10	Ultrasound-Guided Percutaneous Electrical Nerve Stimulation of the Radial Nerve for a Patient with Lateral Elbow Pain: A Case Report With a 2-Year Follow-up	Arias-BurÍa, JL. Cleland, JA. El Bachiri, YR. Plaza-Manzano, G Fernandez-De-Las-Penas, C	Journal of Orthopaedic and Sports Physical Therapy	2019	Case report	1	Adult	MSK – upper extremity	Spain	Physiotherapy clinic	Sports injury - lateral elbow pain
11	A blended learning approach to palpation and ultrasound imaging skills through supplementation of traditional classroom teaching with an e-learning package	Arroyo-Morales, M. Cantarero-Villanueva, I. Fernandez-Lao, C. Guirao-Pineyro, M. Castro-Martin, E. Diaz-Rodriguez, L.	Manual Therapy	2012	Randomized controlled trial	46	Adult	n/a	Spain	Research setting - university/ hospital/military	n/a
12	Comparison of joint status in children with haemophilia A using ultrasound and physical examination	Aspdahl, M Viljakainen, H Petrini, P Ranta, S	European Journal of Physiotherapy	2018	Correlational study	32	Pediatric	MSK – upper extremity and lower extremity	Sweden	Hospital - outpatient department/unit/ clinic	Hemophilia
13	Mechanisms of Shoulder Range of Motion Deficits in Asymptomatic Baseball Players	Bailey, L. B. Shanley, E. Hawkins, R. Beattie, P. F. Fritz, S. Kwartowitz, D. Thigpen, C. A.	American Journal of Sports Medicine	2015	Randomized controlled trial	60	Both	MSK – upper extremity	United States of America	Research setting - university/ hospital/military	Asymptomatic athletes
14	Is ultrasound a reliable and precise measure of sternal micromotion in acute patients after cardiac surgery?	Balachandran, S Sorohan, M Denehy, L Lee, A Royse, A Royse, C Ali, K El-Ansary, D	International Journal of Therapy & Rehabilitation	2017	Measurement study	20	Adult	MSK - spine, sternum, thorax	Australia	Hospital – inpatient	Cardiac surgery

15	The relative risk to the femoral nerve as a function of patient positioning: potential implications for trigger point dry needling of the iliacus muscle	Ball, A. M. Finnegan, M. Koppenhaver, S. Freres, W. Dommerholt, J. Mayoral del Moral, O. Bron, C. Moore, R. Ball, E. E. Gaffney, E. E.	Journal of Manual and Manipulative Therapy	2019	Cross sectional study	25	Adult	MSK - spine, sternum, thorax	United States of America	Research setting - university/ hospital/military	Healthy
16	Prevalence of low bone mineral density in inpatients with traumatic brain injury receiving neuro-behavioural rehabilitation: a postoperative, observational study	Banham-Hall, N. Kothwal, K. Pipkin, J. Bentley, J. Dickens, G. L.	Physiotherapy	2013	Observational study	51	Adult	MSK – lower extremity	United Kingdom	Hospital – inpatient	Osteoporosis in traumatic brain injury
17	Transabdominal ultrasound to assess pelvic floor muscle performance during abdominal curl in exercising women	Barton, A. Serrao, C. Thompson, J. Briffa, K.	International Urogynecology Journal	2015	Cross sectional study	90	Adult	Abdominal, lumbo-pelvic region	Australia	Research setting - university/ hospital/military	Exercising women
18	Changes in Lateral Abdominal Muscle Thickness During an Abdominal Drawing-In Maneuver in Individuals with and Without Low Back Pain	Beazell, JR. Grindstaff, TL. Hart, JM. Magrum, EM. Cullaty, M Shen, FH.	Research in Sports Medicine	2011	Observational study	39	Adult	Abdominal, lumbo-pelvic region	United States of America	Physiotherapy clinic	Low back pain
19	Immediate Effects of Thoracic Spine Manipulation Upon Shoulder Functionality in Patients with Sutured Rotator Cuff Repair: A Prospective Study	Belon-Perez, P Cuesta-Vargas, AI	Journal of Manipulative and Physiological Therapeutics	2018	Quasi-experimental study	32	Adult	MSK – upper extremity	Spain	Hospital - outpatient department/unit/ clinic	Post op sub-acromial impingement surgery
20	What is the most effective verbal instruction for correctly contracting the pelvic floor muscles?	Ben Ami, N. Dar, G.	Neurourology & Urodynamics	2018	Randomized controlled trial	56	Adult	Abdominal, lumbo-pelvic region	Israel	Research setting - university/ hospital/military	Healthy
21	Effects of Low-Load Motor Control Exercises and a High-Load Lifting Exercise on Lumbar	Berglund, L. Aasa, B. Michaelson, P. Aasa, U.	Spine	2017	Randomized controlled trial	65	Adult	Abdominal, lumbo-pelvic region	Sweden	Hospital - outpatient department/unit/ clinic	Low back pain

	Multifidus Thickness										
22	Tendon thickness and depth from skin for supraspinatus, common wrist and finger extensors, patellar and achilles tendons: Ultrasonography study of healthy subjects	Bjordal, J. M. Demmink, J. H. Ljunggren, A. E.	Physiotherapy	2003	Measurement study	40 tendons (10 subjects) included in reliability study. 448 tendons (56 subjects) in second part of study on tendon thickness	Adult	MSK – upper extremity and lower extremity	Norway	Research setting - university/ hospital/military	Healthy
23	Transabdominal ultrasound measurement of pelvic floor muscle activity when activated directly or via a transversus abdominis muscle contraction	Bo, K. Sherburn, M. Allen, T.	Neurourology & Urodynamics	2003	Observational study	20	Adult	Abdominal, lumbo-pelvic region	Australia	Research setting - university/ hospital/military	Healthy
24	Musculoskeletal Ultrasonography to Detect a Displaced Fracture of the Fifth Metatarsal	Boggs, R. G. Nitz, A. J.	Journal of Orthopaedic and Sports Physical Therapy	2018	Case report	1	Adult	MSK – lower extremity	United States of America	Physiotherapy clinic	Sports injury - lower leg/foot fracture
25	Diagnostic and procedural imaging curricula in physical therapist professional degree programs	Boissonnault, W. G. White, D. M. Carney, S. Malin, B. Smith, W.	Journal of Orthopaedic and Sports Physical Therapy	2014	Descriptive study	Faculty from 155 PT programs	Not reported	n/a	United States of America	Research setting - university/ hospital/military	n/a
26	The effect of low-frequency electrical stimulation on denervation atrophy in man	Boonstra, A. M. van Weerden, T. W. Eisma, W. H. Pahlplatz, V. B. Oosterhuis, H. J.	Scandinavian Journal of Rehabilitation Medicine	1987	Randomized controlled trial	73 patients with 81 nerve lesions	Both	Neurology	Netherlands	Hospital - outpatient department/unit/ clinic	Nerve lesions
27	Improved activation of lumbar multifidus following spinal manipulation: a case report applying rehabilitative ultrasound imaging	Brenner, A. K. Gill, N. W. Buscema, C. J. Kiesel, K.	Journal of Orthopaedic and Sports Physical Therapy	2007	Case report	1	Adult	Abdominal, lumbo-pelvic region	United States of America	Not stated/unclear	Low back pain
28	The effectiveness of ultrasound guided hydrodistension and	Bryant, M. Gough, A. Selfe, J.	Shoulder And Elbow	2017	Cohort study	33	Adult	MSK – upper extremity	United Kingdom	Hospital - outpatient department/unit/ clinic	Frozen shoulder/ adhesive capsulitis

	physiotherapy in the treatment of frozen shoulder/adhesive capsulitis in primary care: a single centre service evaluation	Richards, J. Burgess, E.									
29	Prevalence, impact and specialised treatment of urinary incontinence in women with chronic lung disease	Button, B. M. Holland, A. E. Sherburn, M. S. Chase, J. Wilson, J. W. Burge, A. T.	Physiotherapy	2019	Cohort study	10	Adult	Abdominal, lumbo-pelvic region	Australia	Hospital - outpatient department/unit/ clinic	Chronic obstructive pulmonary disease and cystic fibrosis
30	Ultrasonography comparison of diaphragm thickness and excursion between athletes with and without lumbopelvic pain	Calvo-Lobo, C Almazan-Polo, J Becerro-de-Bengoa-Vallejo, R Losa-Iglesias, Me Palomo-Lopez, P Rodriguez-Sanz, D. Lopez-Lopez, D	Physical Therapy in Sport	2019	Case control study	40	Adult	Diaphragm, thoracic, lung	Spain	Amateur and semi-professional athletes teams	Lumbopelvic pain
31	Evaluation of e-learning as an adjunctive method for the acquisition of skills in bony landmark palpation and muscular ultrasound examination in the lumbopelvic region: a controlled study	Cantarero-Villanueva, I. Fernandez-Lao, C. Galiano-Castillo, N. Castro-Martin, E. Diaz-Rodriguez, L. Arroyo-Morales, M.	Journal of Manipulative and Physiological Therapeutics	2012	Randomized controlled trial	50	Adult	n/a	Spain	Research setting - university/ hospital/military	n/a
32	Does pelvic floor muscle training abolish symptoms of urinary incontinence? A randomized controlled trial	Celiker Tosun, O. Kaya Mutlu, E. Ergenoglu, A. M. Yeniel, A. O. Tosun, G. Malkoc, M. Askar, N. Itil, I. M.	Clinical rehabilitation	2015	Randomized controlled trial	130	Adult	Abdominal, lumbo-pelvic region	Turkey	Hospital - outpatient department/unit/ clinic	Urinary incontinence
33	Association between plantar fascia vascularity and morphology and foot dysfunction in individuals with chronic plantar fasciitis	Chen, H. Ho, H. M. Ying, M. Fu, S. N.	Journal of Orthopaedic and Sports Physical Therapy	2013	Non-randomized controlled trial	59	Adult	MSK – lower extremity	Hong Kong	Research setting - university/ hospital/military	Plantar fasciitis

34	A survey of electrophysical agents' curricula in entry-level physiotherapy programs in Australia and New Zealand	Chipchase, LS Williams, MT Robertson, VJ	New Zealand Journal of Physiotherapy	2005	Descriptive study	13 participants representing all 18 entry level PT programs in Australia and New Zealand	Not reported	n/a	Australia and New Zealand	Research setting - university/ hospital/military	n/a
35	Measurement of segmental lumbar spine flexion and extension using ultrasound imaging	Chleboun, G. S. Amway, M. J. Hill, J. G. Root, K. J. Murray, H. C. Sergeev, A. V.	Journal of Orthopaedic and Sports Physical Therapy	2012	Measurement study	6	Adult	MSK - spine, sternum, thorax	United States of America	Research setting - university/ hospital/military	Healthy
36	Instructing pelvic floor contraction facilitates transversus abdominis thickness increase during low-abdominal hollowing	Critchley, D.	Physiotherapy Research International	2002	Observational study	20	Adult	Abdominal, lumbo-pelvic region	United Kingdom	Research setting - university/ hospital/military	Healthy
37	Dry Needling Increases Muscle Thickness in a Subject with Persistent Muscle Dysfunction: A Case Report	Cross, K. M. McMurray, M.	International Journal of Sports Physical Therapy	2017	Case report	1	Adult	MSK – upper extremity	United States of America	Physiotherapy clinic	Post-op posterior labral tear shoulder surgery
38	Anterior Talocrural Joint Laxity: Diagnostic Accuracy of the Anterior Drawer Test of the Ankle	Croy, T. Koppenhaver, S. Saliba, S. Hertel, J.	Journal of Orthopaedic and Sports Physical Therapy	2013	Measurement study	86	Adult	MSK – lower extremity	United States of America	Not stated/unclear	Lateral ankle sprain
39	Differences in lateral ankle laxity measured via stress ultrasonography in individuals with chronic ankle instability, ankle sprain copers, and healthy individuals	Croy, T. Saliba, S. Saliba, E Anderson, M. W. Hertel, J.	Journal of Orthopaedic and Sports Physical Therapy	2012	Cross sectional study	60	Adult	MSK – lower extremity	United States of America	Research setting - university/ hospital/military	Ankle sprain and chronic ankle instability
40	Scapular Muscle Performance in Individuals with Lateral Epicondylalgia	Day, JM. Bush, H Nitz, AJ. Uhl, TL.	Journal of Orthopaedic and Sports Physical Therapy	2015	Case control study	56	Adult	MSK – upper extremity	United States of America	Research setting - university/ hospital/military	Lateral epicondylagia
41	Low impact weight bearing exercise in an upright posture increases the	Debuse, D Birch, O St Clair Gibson,	Physiotherapy Theory and Practice	2013	Observational study	12	Adult	Abdominal, lumbo-pelvic region	United Kingdom	Not stated/unclear	Healthy

	activation of two key local muscles of the lumbo-pelvic region	A Caplan, N									
42	Conservative correction of leg-length discrepancies of 10mm or less for the relief of chronic low back pain	Defrin, R Benyamin, S.B. Aldubi, R.D. Pick, C.G.	Archives of Physical Medicine and Rehabilitation	2005	Randomized controlled trial	33	Adult	MSK – lower extremity	Israel	Physiotherapy clinic	Chronic low back pain
43	Ultrasound measures of tendon thickness: Intra-rater, Inter-rater and Inter-machine reliability	Del Bano-Aledo, M. E. Martinez-Paya, J. J. Rios-Diaz, J. Mejias-Suarez, S. Serrano-Carmona, S. de Groot-Ferrando, A.	Muscles, Ligaments and Tendons Journal	2017	Measurement study	14	Adult	MSK – upper extremity and lower extremity	Spain	Research setting - university/ hospital/military	Healthy
44	Characterization of humeral head displacements during dynamic glenohumeral neuromuscular control exercises using quantitative ultrasound imaging: A feasibility study	Desroches, G. Desmeules, F. Gagnon, D. H.	Musculoskeletal Science and Practice	2017	Observational study	10	Adult	MSK – upper extremity	Canada	Not stated/unclear	Healthy
45	Ultrasound-based motor control training for the pelvic floor pre- and post-prostatectomy: Scoring reliability and skill acquisition	Doorbar-Baptist, S. Adams, R. Rebbeck, T.	Physiotherapy Theory and Practice	2017	Measurement study	91	Adult	Abdominal, lumbo-pelvic region	Australia	Physiotherapy clinic	Prostate cancer
46	Trunk stabilisation exercises reduce sternal separation in chronic sternal instability after cardiac surgery: a randomised cross-over trial	El-Ansary, D. Waddington, G. Adams, R.	Australian Journal of Physiotherapy	2007	Randomized controlled trial	9	Adult	MSK - spine, sternum, thorax	Australia	Physiotherapy clinic	Cardiac surgery
47	Relationship between pain and upper limb movement in patients with chronic sternal instability following cardiac surgery	El-Ansary, D. Waddington, G. Adams, R.	Physiotherapy Theory and Practice	2007	Measurement study	8	Adult	MSK - spine, sternum, thorax	Australia	Physiotherapy clinic	Cardiac surgery
48	The effect of isometric exercise	Ellegaard, K. Torp-Pedersen,	Rheumatology International	2013	Case control study	42	Adult	MSK – upper extremity	Denmark	Hospital - outpatient department/unit/	Rheumatoid arthritis

	of the hand on the synovial blood flow in patients with rheumatoid arthritis measured by color Doppler ultrasound	S. Lund, H. Pedersen, K. Henriksen, M. Danneskiold-Samsoe, B. Bliddal, H.								clinic	
49	Exploring the clinical use of ultrasound imaging: A survey of physiotherapists in New Zealand	Ellis, R. De Jong, R. Bassett, S. Helsby, J. Stokes, M. Cairns, M.	Musculoskeletal Science and Practice	2018	Descriptive study	415	Adult	n/a	New Zealand	Research setting - university/ hospital/military	n/a
50	Transversus abdominis and obliquus internus activity during pilates exercises: measurement with ultrasound scanning	Endleman, I. Critchley, D. J.	Archives of Physical Medicine and Rehabilitation	2008	Descriptive study	26	Adult	Abdominal, lumbo-pelvic region	United Kingdom	Pilates studio	Pilates participants
51	The effectiveness of a mobile application for the development of palpation and ultrasound imaging skills to supplement the traditional learning of physiotherapy students	Fernandez-Lao, C. Cantarero-Villanueva, I. Galiano-Castillo, N. Caro-Moran, E. Diaz-Rodriguez, L. Arroyo-Morales, M.	BMC medical education	2016	Randomized controlled trial	49	Adult	n/a	Spain	Research setting - university/ hospital/military	n/a
52	Comparison of general exercise, motor control exercise and spinal manipulative therapy for chronic low back pain: A randomized trial	Ferreira, M. L. Ferreira, P. H. Latimer, J. Herbert, R. D. Hodges, P. W. Jennings, M. D. Maher, C. G. Refshauge, K. M.	Pain	2007	Randomized controlled trial	240	Adult	Abdominal, lumbo-pelvic region	Australia	Hospital - outpatient department/unit/ clinic	Low back pain
53	Measurement of transversus abdominis activation in chronic low back pain patients using a novel standardized real-time ultrasound imaging method	Flavell, C. A. Marshman, L. G. Gordon, S. J.	Ultrasound	2019	Measurement study	17	Adult	Abdominal, lumbo-pelvic region	Australia	Hospital - outpatient department/unit/ clinic	Chronic low back pain
54	Effect of test position on pelvic floor muscle assessment	Frawley, H. C. Galea, M. P. Phillips, B. A. Sherburn, M. Bo, K.	International Urogynecology Journal	2006	Observational Study	20	Adult	Abdominal, lumbo-pelvic region	Australia	Not stated/unclear	Healthy

55	Continued recovery in an adult with cerebellar ataxia	Freund, J. E. Stetts, D. M.	Physiotherapy Theory and Practice	2013	Case report	1	Adult	Abdominal, lumbo-pelvic region	United States of America	Research setting - university/ hospital/military	Cerebellar ataxia post traumatic brain injury
56	Ultrasound Evaluation of the Abdominal Wall and Lumbar Multifidus Muscles in Participants Who Practice Pilates: A 1-year Follow-up Case Series	Gala-Alarcon, P. Calvo-Lobo, C. Serrano-Imedio, A. Garrido-Marin, A. Martin-Casas, P. Plaza-Manzano, G.	Journal of Manipulative and Physiological Therapeutics	2018	Case series	17	Adult	Abdominal, lumbo-pelvic region	Spain	Research setting - university/ hospital/military	Pilates participants
57	A randomised controlled trial of transabdominal ultrasound biofeedback for pelvic floor muscle training in older women with urinary incontinence	Galea, M. P. Tisseverasinghe, S. Sherburn, M	Australian & New Zealand Continence Journal	2013	Randomized controlled trial	22	Adult	Abdominal, lumbo-pelvic region	Australia	Hospital - outpatient department/unit/ clinic	Urinary incontinence
58	A novel approach in the treatment of acute whiplash syndrome: Ultrasound-guided needle percutaneous electrolysis. A randomized controlled trial	Garcia Naranjo, J. Barroso Rosa, S. Loro Ferrer, J. F. Liminana Canal, J. M. Suarez Hernandez, E.	Orthopaedics & traumatology, surgery & research	2017	Randomized controlled trial	100	Adult	MSK - spine, sternum, thorax	Spain	Physiotherapy clinic	Whiplash syndrome
59	Atrophy of the Quadriceps Is Not Isolated to the Vastus Medialis Oblique in Individuals with Patellofemoral Pain	Giles, L. S. Webster, K. E. McClelland, J. A. Cook, J.	Journal of Orthopaedic and Sports Physical Therapy	2015	Cross sectional study	70	Adult	MSK – lower extremity	United States of America	Not stated/unclear	Patella femoral pain
60	The effects of running in place in a limited area with abdominal drawing-in maneuvers on abdominal muscle thickness in chronic low back pain patients	Gong, W.	Journal of Back & Musculoskeletal Rehabilitation	2016	Randomized controlled trial	30	Adult	Abdominal, lumbo-pelvic region	Korea	Research setting - university/ hospital/military	Chronic low back pain
61	Transversus abdominis function: a reliability study using ultrasound imaging to measure changes in muscle thickness	Greene, G. Green, A.	Physiotherapy Ireland	2009	Measurement study	20	Adult	Abdominal, lumbo-pelvic region	United Kingdom	Research setting - university/ hospital/military	Healthy
62	Clinimetric analysis of pressure biofeedback and transversus	Grooms, D. R. Grindstaff, T. L. Croy, T.	Journal of Orthopaedic and Sports Physical Therapy	2013	Descriptive study	49	Adult	Abdominal, lumbo-pelvic region	United States of America	Research setting - university/ hospital/military	Low back pain

	abdominis function in individuals with stabilization classification low back pain	Hart, J. M. Saliba, S. A.									
63	The effect of traditional bridging or suspension-exercise bridging on lateral abdominal thickness in individuals with low back pain	Guthrie, R. J. Grindstaff, T. L. Croy, T. Ingersoll, C. D. Saliba, S. A.	Journal of Sport Rehabilitation	2012	Randomized controlled trial	51	Adult	Abdominal, lumbo-pelvic region	United States of America	Research setting - university/ hospital/military	Low back pain
64	Diagnostic thoracic ultrasound imaging - An exploration of respiratory physiotherapists' interest and use in clinical practice: A national survey	Hayward, S. Smith, M. Innes, S.	Ultrasound	2019	Descriptive study	133 surveys were returned with 31 reporting that they use thoracic US imaging.	Not reported	n/a	United Kingdom	Hospital – inpatient	n/a
65	Thoracic ultrasound can optimise the sequence of medical and physiotherapy treatments during an opaque hemithorax (whiteout): A case report	Hayward, S Hayward, L	Physiotherapy Practice & Research	2019	Case report	1	Adult	Diaphragm, thoracic, lung	United Kingdom	Hospital - inpatient	Critical care
66	Early multimodal rehabilitation following lumbar disc surgery: a randomised clinical trial comparing the effects of two exercise programmes on clinical outcome and lumbar multifidus muscle function	Hebert, J. J. Fritz, J. M. Thackeray, A. Koppenhaver, S. L. Teyhen, D.	British Journal of Sports Medicine	2015	Randomized controlled trial	61	Adult	Abdominal, lumbo-pelvic region	United States of America	Hospital - outpatient department/unit/ clinic	Post op lumbar spine surgery
67	The use of real-time ultrasound feedback in teaching abdominal hollowing exercises to healthy subjects	Henry, S. M.; Westervelt, K. C.	Journal of Orthopaedic and Sports Physical Therapy	2005	Randomized controlled trial	48	Adult	Abdominal, lumbo-pelvic region	United States of America	Not stated/unclear	Healthy
68	Influence of feedback schedule in motor	Herbert, W. J. Heiss, D. G. Basso, D. M.	Physical therapy	2008	Randomized controlled trial	30	Adult	Abdominal, lumbo-pelvic region	United States of America	Research setting - university/ hospital/military	Healthy

	performance and learning of a lumbar multifidus muscle task using rehabilitative ultrasound imaging: A randomized clinical trial										
69	Determining the most effective feedback method in teaching subjects to selectively activate the transversus abdominis: A randomized controlled trial	Herlocker, A Coffman, N Mainer, M Pertain, Sb Wofford, N Campbell, M Mincer, Ab Lake, D	Orthopaedic Physical Therapy Practice	2014	Randomized controlled trial	38	Adult	Abdominal, lumbo-pelvic region	United States of America	Research setting - university/ hospital/military	Healthy
70	Ultrasound imaging assessment of abdominal muscle function during drawing-in of the abdominal wall: an intrarater reliability study	Hides, J. A. Miokovic, T. Belavy, D. L. Stanton, W. R. Richardson, C. A.	Journal of Orthopaedic and Sports Physical Therapy	2007	Measurement study	19	Adult	Abdominal, lumbo-pelvic region	Australia	Research setting - university/ hospital/military	Healthy
71	Can motor control training lower the risk of injury for professional football players?	Hides, J. A. Stanton, W. R.	Medicine & Science in Sports & Exercise	2014	Randomized controlled trial	46	Adult	Abdominal, lumbo-pelvic region	Australia	Research setting - university/ hospital/military	Healthy athletes
72	Effect of stabilization training on multifidus muscle cross-sectional area among young elite cricketers with low back pain	Hides, J. A. Stanton, W. R. McMahon, S. Sims, K. Richardson, C. A.	Journal of Orthopaedic and Sports Physical Therapy	2008	Non-randomized controlled trial	26	Adult	Abdominal, lumbo-pelvic region	Australia	Amateur and semi-professional athletes teams	Low back pain
73	Distal Fibular Stress Fracture in a Female Recreational Runner: A Case Report with Musculoskeletal Ultrasound Imaging Findings	Hoglund, L. T. Silbernagel, K. G. Taweel, N. R.	International Journal of Sports Physical Therapy	2015	Case report	1	Adult	MSK – lower extremity	United States of America	Physiotherapy clinic	Sports injury - lower leg/foot fracture
74	Ultrasound Imaging Measurement of the Transversus Abdominis in Supine, Standing, and under Loading: A Reliability Study of Novice Examiners	Hoppes, C. W. Sperier, A. D. Hopkins, C. F. Griffiths, B. D. Principe, M. F. Schnall, B. L. Bell, J. C. Koppenhaver, S. L.	International Journal of Sports Physical Therapy	2015	Measurement study	33	Adult	Abdominal, lumbo-pelvic region	United States of America	Research setting - university/ hospital/military	Healthy - military personnel

75	Intra-rater and inter-rater reliability of the standardized ultrasound protocol for assessing subacromial structures	Hougs Kjaer, B Ellegaard, K. Wieland, I. Warming, S. Juul-Kristensen, B.	Physiotherapy Theory and Practice	2017	Measurement study	46	Adult	MSK – upper extremity	Denmark	Hospital - outpatient department/unit/ clinic	Sports injury - shoulder impingement
76	Comparison of the efficacy of different long-term interventions on chronic low back pain using the cross-sectional area of the multifidus muscle and the thickness of the transversus abdominis muscle as evaluation indicators	Huang, Q Li, D Zhang, J Yang, D Huo, M Maruyama, H	Journal of Physical Therapy Science	2014	Non-randomized controlled trial	12	Adult	Abdominal, lumbo-pelvic region	Japan	Not stated/unclear	Chronic low back pain
77	The intervention effects of different treatment for chronic low back pain as assessed by the cross-sectional area of the multifidus muscle	Huang, Q Li, D Yokorsutka, N Zhang, Y Ubukata, H Huo, M Maruyama, H	Journal of Physical Therapy Science	2013	Non-controlled trial	13	Adult	Abdominal, lumbo-pelvic region	Japan	Not stated/unclear	Chronic low back pain
78	The reliability of rehabilitative ultrasound imaging of the cross-sectional area of the lumbar multifidus muscles in the PNF pattern	Huang, Q Li, D Zhang, Y Hu, A Huo, M Maruyama, H	Journal of Physical Therapy Science	2014	Measurement study	15	Adult	Abdominal, lumbo-pelvic region	Japan	Not stated/unclear	Chronic low back pain
79	The intervention effects of different treatments for chronic low back pain as assessed by the thickness of the musculus transversus abdominis	Huang, Q Li, D Zhang, Y Rui, G Huo, M Maryuma, H	Journal of Physical Therapy Science	2014	Non-controlled trial	12	Adult	Abdominal, lumbo-pelvic region	Japan	Not stated/unclear	Chronic low back pain
80	Musculoskeletal ultrasound imaging - An exploration of physiotherapists' interests and use in practice	Innes, S. Jackson, J.	Musculoskeletal Science and Practice	2019	Descriptive study	75 questionnaires 11 semi-structured interviews	Adult	n/a	United Kingdom	Research setting - university/ hospital/military	n/a

81	Musculoskeletal ultrasound imaging - Integration with the biopsychosocial model	Innes, S. Jackson, J.	Musculoskeletal Science and Practice	2019	Descriptive study	75 questionnaires 11 semi-structured interviews	Adult	n/a	United Kingdom	Research setting - university/ hospital/military	n/a
82	Influence of inward pressure of the transducer on lateral abdominal muscle thickness during ultrasound imaging	Ishida, H. Watanabe, S.	Journal of Orthopaedic and Sports Physical Therapy	2012	Non-controlled trial	30	Adult	Abdominal, lumbo-pelvic region	Japan	Research setting - university/ hospital/military	Healthy
83	Changes in lateral abdominal muscles' thickness immediately after the abdominal drawing-in maneuver and maximum expiration	Ishida, H Watanabe, S	Journal of Bodywork and Movement Therapies	2013	Case control study	30	Adult	Abdominal, lumbo-pelvic region	Japan	Not stated/unclear	Healthy
84	The development and validation of a custom built device for assessing frontal knee joint laxity	Ismail, S. A. Simic, M. Clarke, J. L. Lopes, T. J. A. Pappas, E.	Knee	2017	Measurement study	25	Adult	MSK – lower extremity	Australia	Research setting - university/ hospital/military	Healthy
85	Effects of repetitive shortwave diathermy for reducing synovitis in patients with knee osteoarthritis: an ultrasonographic study	Jan, M. Chai, H. Wang, C. Lin, Y. Tsai, L.	Physical Therapy	2006	Non-randomized controlled trial	36 subjects with 44 knees	Adult	MSK – lower extremity	Taiwan	Research setting - university/ hospital/military	Osteoarthritis
86	The effect of experimental groin pain on abdominal muscle thickness	Jansen, J. A. Poot, B. Mens, J. M. Backx, F. J. Stam, H. J. Jansen, Jaap A. C. G. Poot, B. Mens, J. M. A. Backx, F. J. G. Stam, H. J.	Clinical Journal of Pain	2010	Non-controlled trial	14	Adult	MSK – lower extremity	Netherlands	Not stated/unclear	Healthy athletes
87	The availability and usage frequency of real time ultrasound by physiotherapists in South Australia: an observational study	Jedrzejczak, A. Chipchase, L. S.	Physiotherapy Research International	2008	Descriptive study	664	Adult	n/a	Australia	Research setting - university/ hospital/military	n/a

88	Increased palpation tenderness and muscle strength deficit in the prediction of tendon hypertrophy in symptomatic unilateral shoulder tendinopathy: an ultrasonographic study	Joensen, J. Couppe, C. Bjordal, J. M.	Physiotherapy	2009	Cross sectional study	64	Adult	MSK – upper extremity	Norway	Physiotherapy clinic	Shoulder tendinopathy
89	Ultrasound and Clinical Measures for Lymphedema	Johnson, K. C. DeSarno, M. Ashikaga, T. Dee, J. Henry, S. M.	Lymphatic Research & Biology	2016	Non-controlled trial	17	Adult	MSK – upper extremity	United States of America	Physiotherapy clinic	Breast cancer
90	Bladder-neck effective, integrative pelvic floor rehabilitation program: follow-up investigation	Junginger, B. Seibt, E. Baessler, K.	European Journal of Obstetrics & Gynecology and Reproductive Biology 1	2014	Cohort study	55	Adult	Abdominal, lumbo-pelvic region	Germany	Hospital - outpatient department/unit/ clinic	Urinary incontinence
91	Distal fibula fracture diagnosed with ultrasound imaging	Kardouni, J.R.	Journal of Orthopaedic and Sports Physical Therapy	2012	Case report	1	Adult	MSK – lower extremity	United States of America	Military remote location	Lower leg/foot fracture
92	Physiotherapy for patients with shoulder pain in primary care: a descriptive study of diagnostic- and therapeutic management	Karel, Y. H. J. M. Scholten-Peeters, G. G. M. Thoomes-de Graaf, M. Duijn, E. van Broekhoven, J. B. Koes, B. W. Verhagen, A. P.	Physiotherapy (United Kingdom)	2017	Cohort study	125 physiotherapists 389 patients	Adult	MSK – upper extremity	Netherlands	Physiotherapy clinic	Shoulder pain
93	Does the outcome of diagnostic ultrasound influence the treatment modalities and recovery in patients with shoulder pain in physiotherapy practice? Results from a prospective cohort study	Karel, Yhjm Miranda, A. Thoomes-de Graaf, M. Scholten-Peeters, G. G. Ottenheijm, R. P. Koes, B. W. Verhagen, A. P.	Musculoskeletal Science and Practice	2019	Cohort study	389	Adult	MSK – upper extremity	Netherlands	Physiotherapy clinic	Shoulder pain
94	Development of a Prognostic Model for Patients With Shoulder Complaints in Physical Therapist Practice	Karel, Yhjm Verhagen, A. P. Thoomes-de Graaf, M. Duijn, E. van den Borne, M. P. J. Beumer, A.	Physical therapy	2017	Cohort study	389	Adult	MSK – upper extremity	Netherlands	Physiotherapy clinic	Shoulder pain

		Ottenheijm, R. P. G. Dinant, G. J. Koes, B. W. Scholten-Peeters, G. G. M.									
95	Healthy adults can more easily elevate the pelvic floor in standing than in crook-lying: An experimental study	Kelly, M. Tan, B. K. Thompson, J. Carroll, S. Follington, M. Arndt, A. Seet, M.	Australian Journal of Physiotherapy	2007	Randomized controlled trial	65	Adult	Abdominal, lumbo-pelvic region	Australia	Not stated/unclear	Healthy
96	Intra-rater reliability of transverse abdominus measurement by a novice examiner: Comparison of "freehand" to "probe force device" method of real-time ultrasound imaging	Kennedy, V.L. Flavell, C.A. Doma, K	Ultrasound	2019	Measurement study	33	Adult	Abdominal, lumbo-pelvic region	Australia	Research setting - university/ hospital/military	Healthy
97	Benefits of utilising real-time ultrasound imaging in the rehabilitation of the lumbar spine stabilising muscles following low back injury in the elite athlete - A single case study	Kermode, F.	Physical Therapy in Sport	2004	Case report	1	Adult	Abdominal, lumbo-pelvic region	Australia	Physiotherapy clinic	Sports injury – low back pain
98	Inter-Rectus Distance Measurement Using Ultrasound Imaging: Does the Rater Matter?	Keshwani, N. Hills, N. McLean, L	Physiotherapy Canada	2016	Measurement study	17	Adult	Abdominal, lumbo-pelvic region	Canada	Research setting - university/ hospital/military	Healthy
99	A comparison of select trunk muscle thickness change between subjects with low back pain classified in the Treatment-Based Classification system and asymptomatic controls	Kiesel, K. B. Underwood, F. B. Matacolla, C. Nitz, A. J. Malone, T. R.	Journal of Orthopaedic and Sports Physical Therapy	2007	Cross sectional study	76	Adult	Abdominal, lumbo-pelvic region	United States of America	Physiotherapy clinic	Low back pain
100	Manual palpation of lumbo-pelvic landmarks: a validity study	Kilby, J. Heneghan, N. R. Maybury, M.	Manual Therapy	2012	Measurement study	3 models and 9 physiotherapists	Adult	Abdominal, lumbo-pelvic region	United Kingdom	Research setting - university/ hospital/military	Healthy

101	A comparison of ultrasonography measurement on the abdominal muscle thickness between adolescent idiopathic scoliosis and healthy subjects	Kim, D. K. Kim, C. Y. Lee, B. K. Seo, D.	Journal of Back & Musculoskeletal Rehabilitation	2018	Case control study	65	Both	Abdominal, lumbo-pelvic region	Korea	Not stated/unclear	Scoliosis
102	Real-time ultrasound imaging biofeedback training is diaphragmatic function in non-traumatic cervical spinal cord injury: a single-subject experimental study	Kim, Ji-Seon Oh, Duck-Won	European Journal of Physiotherapy	2017	Single subject experimental study	1	Pediatric	Diaphragm, thoracic, lung	Korea	Hospital – inpatient	Spinal cord injury
103	Investigation of supraspinatus muscle architecture following concentric and eccentric training	Kim, S. Y. Ko, J. B. Farthing, J. P. Butcher, S. J.	Journal of Science & Medicine in Sport	2015	Randomized controlled trial	13	Adult	MSK – upper extremity	Canada	Not stated/unclear	Healthy
104	Effect of the scapula-setting exercise on acromio-humeral distance and scapula muscle activity in patients with subacromial impingement syndrome	Kim, SY Weon, JH Jung, DY Oh, JS	Physical Therapy in Sport	2019	Cross sectional study	28	Adult	MSK – upper extremity	Korea	Research setting - university/ hospital/military	Sub-acromial impingement syndrome
105	Subacromial space outlet in female patients with multidirectional instability based on hypermobile Ehlers-Danlos syndrome and hypermobility spectrum disorder measured by ultrasound	Kjaer, B. H. de Wandele, I. Spanhove, V. Juul-Kristensen, B. Cools, A. M.	Journal of Shoulder and Elbow Surgery	2019	Cross sectional study	29	Adult	MSK – upper extremity	Belgium	Research setting - university/ hospital/military	Ehlers-Danlos syndrome and hypermobility spectrum disorder
106	Investigation of abdominal muscle thickness changes after spinal manipulation in patients who meet a clinical prediction rule for lumbar stabilization	Konitzer, L. N. Gill, N. W. Koppenhaver, S. L.	Journal of Orthopaedic and Sports Physical Therapy	2011	Case series	19	Adult	Abdominal, lumbo-pelvic region	United States of America	Military - outpatient department/unit/ clinic	Low back pain

107	Reliability of rehabilitative ultrasound imaging of the transversus abdominis and lumbar multifidus muscles	Koppenhaver, S. L. Hebert, J. J. Fritz, J. M. Parent, E. C. Teyhen, D. S. Magel, J. S.	Archives of Physical Medicine and Rehabilitation	2009	Measurement study	30	Adult	Abdominal, lumbo-pelvic region	United States of America	Physiotherapy clinic	Low back pain
108	Four weeks of functional electrical stimulated cycling after spinal cord injury: a clinical cohort study	Kuhn, D. Leichtfried, V. Schobersberger, W.	International Journal of Rehabilitation Research	2014	Cohort study	30	Adult	MSK – lower extremity	Germany	Hospital - inpatient	Spinal cord injury
109	Reliability and validity of ultrasonographic measurements of acromion-greater tuberosity distance in post stroke hemiplegia	Kumar, P. Bradley, M. Gray, S. Swinkels, A.	Archives of Physical Medicine and Rehabilitation	2011	Measurement study	26	Adult	MSK – upper extremity	United Kingdom	Hospital - inpatient	Stroke
110	Within-day and day-to-day intrarater reliability of ultrasonographic measurements of acromion-greater tuberosity distance in healthy people	Kumar, P. Bradley, M. Swinkels, A.	Physiotherapy Theory and Practice	2010	Measurement study	32	Adult	MSK – upper extremity	United Kingdom	Research setting - university/ hospital/military	Healthy
111	Interrater and intrarater reliability of ultrasonographic measurements of acromion-greater tuberosity distance in healthy people	Kumar, P. Chetwynd, J. Evans, A. Wardle, G. Crick, C. Richardson, B.	Physiotherapy Theory and Practice	2011	Measurement study	20	Adult	MSK – upper extremity	United Kingdom	Research setting - university/ hospital/military	Healthy
112	Intra-rater and inter-rater reliability of ultrasonographic measurements of acromion-greater tuberosity distance in patients with post-stroke hemiplegia	Kumar, P. Cruziah, R. Bradley, M. Gray, S. Swinkels, A.	Topics in Stroke Rehabilitation	2016	Measurement study	16	Adult	MSK – upper extremity	United Kingdom	Hospital - inpatient	Stroke
113	Assessment of glenohumeral subluxation in post stroke hemiplegia: comparison between ultrasound and fingerbreadth palpation methods	Kumar, P. Mardon, M. Bradley, M. Gray, S. Swinkels, A.	Physical therapy	2014	Measurement study	105	Adult	MSK – upper extremity	United Kingdom	Hospital - outpatient department/unit/ clinic	Stroke
114	Inter-rater reliability of ultrasound measurements of	Kumar, P Attwood, M	Musculoskeletal Care	2018	Measurement study	11	Adult	MSK – upper extremity	United Kingdom	Research setting - university/ hospital/military	Healthy

	acromion–greater tuberosity distance between experienced and novice raters in healthy people										
115	Acute effect and time course of extension and internal rotation stretching of the shoulder on infraspinatus muscle hardness	Kusano, K. Nishishita, S. Nakamura, M. Tanaka, H. Umehara, J. Ichihashi, N.	Journal of Shoulder and Elbow Surgery	2017	Non-randomized controlled trial	20	Adult	MSK – upper extremity	Japan	Not stated/unclear	Healthy
116	Intra- and inter-rater reliabilities for novel muscle thickness assessment during Co-contraction with dual-rehabilitative ultrasound imaging	Lee, H. J. Ha, H. G. Hahn, J. Lim, S. Lee, W. H.	Physical Therapy in Sport	2018	Measurement study	36	Adult	MSK – lower extremity	Korea	Research setting - university/ hospital/military	Healthy
117	Physiotherapist-initiated lung ultrasound to improve intensive care management of a deteriorating patient and prevent intubation: a case report	Leech, M. Bissett, B. Kot, M. Ntoumenopoulos, G.	Physiotherapy Theory and Practice	2015	Case report	1	Adult	Diaphragm, thoracic, lung	Australia	hospital – inpatient	Critical care
118	The Relationships Between Inter-recti Distance Measured by Ultrasound Imaging and Abdominal Muscle Function in Postpartum Women: A 6-Month Follow-up Study	Lih-Jiun, L Miao-Ju, H Chien-Fen, L Mei-Fang, L Ar-Tyan, H	Journal of Orthopaedic and Sports Physical Therapy	2011	Cohort study	60	Adult	Abdominal, lumbo-pelvic region	Taiwan	Research setting - university/ hospital/military	Post-partum women
119	Intra-rater reliability of B-mode ultrasound imaging of the abdominal muscles in healthy adolescents during the active straight leg raise test	Linek, P. Saulicz, E. Wolny, T. Mysliwiec, A.	Pm & R	2015	Measurement study	39	Pediatric	Abdominal, lumbo-pelvic region	Poland	School	Healthy
120	Ultrasound evaluation of intrinsic plantar muscles and fascia in hallux valgus A case-control study	Lobo, C. C. Marn, A. G. Sanz, D. R. Lopez, D. L. Lopez, P. P.	Medicine (United States)	2016	Case control study	40	Adult	MSK – lower extremity	Spain	Research setting - university/ hospital/military	Hallux valgus

		Morales, C. R. Corbalon, I. S.									
121	Ultrasonography Comparison of Peroneus Muscle Cross-sectional Area in Subjects with or Without Lateral Ankle Sprains	Lobo, C. C. Morales, C. R. Sanz, D. R. Corbalan, I. S. Marin, A. G. Lopez, D. L.	Journal of Manipulative and Physiological Therapeutics	2016	Case control study	56 feet, 28 with lateral ankle sprain and 28 controls	Adult	MSK – lower extremity	Spain	Research setting - university/ hospital/military	Lateral ankle sprain
122	Physiotherapists utilizing diagnostic ultrasound in shoulder clinics. How useful do patients find immediate feedback from the scan as part of the management of their problem?	Lumsden, G. Lucas-Garner, K. Sutherland, S. Dodenhoff, R.	Musculoskeletal Care	2018	Descriptive study	103	Adult	n/a	United Kingdom	Hospital - outpatient department/unit/ clinic	n/a
123	Reliability of Abdominal Muscle Stiffness Measured Using Elastography during Trunk Rehabilitation Exercises	MacDonald, D. Wan, A. McPhee, M. Tucker, K. Hug, F.	Ultrasound in Medicine & Biology	2016	Measurement study	30	Adult	Abdominal, lumbo-pelvic region	Australia	Not stated/unclear	Healthy
124	Quantifying acromiohumeral distance in overhead athletes with glenohumeral internal rotation loss and the influence of a stretching program	Maenhout, A. Van Eessel, V. Van Dyck, L. Vanraes, A. Cools, A.	American Journal of Sports Medicine	2012	Cohort study	62	Adult	MSK – upper extremity	Belgium	Research setting - university/ hospital/military	Sports injury - shoulder ROM deficit
125	A novel externally applied neuromuscular stimulator for the treatment of stress urinary incontinence in women--"a pilot study	Maher, R. M. Caulfield, B.	Neuromodulation	2013	Cohort study	9	Adult	Abdominal, lumbo-pelvic region	United States of America	Not stated/unclear	Urinary incontinence
126	How Do Pelvic Floor Muscle Contractions Elicited by 2 Different Delivery Methods of Neuromuscular Electrical Stimulation Compare with Volitional	Maher, RM. Hayes, DM.	Journal of Women's Health Physical Therapy	2018	Randomized cross over trial	6	Adult	Abdominal, lumbo-pelvic region	United States of America	Research setting - university/ hospital/military	Healthy

	Contractions in Supine and Standing in Nulliparous Continent Women?										
127	Assessment of cam morphology of the hip with ultra sound imaging by physical therapists is reliable and valid	Mandema, L. Tak, I. Mooij, B. Groeneweg, R. Bakker, E. van Veldhoven, P.	Physical Therapy in Sport	2018	Measurement study	62 hips	Adult	MSK – lower extremity	Netherlands	Physiotherapy clinic	Healthy
128	Using real-time ultrasound imaging as adjunct teaching tools to enhance physical therapist students' ability and confidence to perform traction of the knee joint	Markowski, A. Watkins, M. K. Burnett, T. Ho, M. Ling, M.	Musculoskeletal Science and Practice	2018	Randomized controlled trial	86	Adult	n/a	United States of America	Research setting - university/ hospital/military	n/a
129	Asymmetrical abdominal muscle morphometry is present in injury free adolescent cricket pace bowlers: A prospective observational study	Martin, C Olivier, B Benjamin, N	Physical Therapy in Sport	2017	Cohort study	28	Pediatric	Abdominal, lumbo-pelvic region	South Africa	School	Healthy athletes
130	Biomechanics of the median nerve during stretching as assessed by ultrasonography	Martinez-Paya, J. J. Rios-Diaz, J. Del Bano-Aledo, M. E. Garcia-Martinez, D. De Groot-Ferrando, A. Merono-Gallut, J.	Journal of Applied Biomechanics	2015	Cross sectional study	22	Both	Neurology	United States of America	Research setting - university/ hospital/military	Healthy
131	A survey of diagnostic ultrasound within the physiotherapy profession for the design of future training tools	McKiernan, S. Chiarelli, P. Warren-Forward, H.	Radiography	2011	Descriptive study	99	Adult	n/a	Australia	Research setting - university/ hospital/military	n/a
132	A comparison between workshop and DVD methods of training for physiotherapists in diagnostic ultrasound	McKiernan, S. Chiarelli, P. Warren-Forward, H.	Radiography	2012	Non-randomized controlled trial	180	Adult	n/a	Australia	Research setting - university/ hospital/military	n/a
133	Professional issues in the use of	McKiernan, S. Chiarelli, P.	Radiography	2013	Qualitative	16	Adult	n/a	Australia	Research setting - university/	n/a

	diagnostic ultrasound biofeedback in physiotherapy of the female pelvic floor	Warren-Forward, H.								hospital/military	
134	Pelvic floor muscle training in women with stress urinary incontinence causes hypertrophy of the urethral sphincters and reduces bladder neck mobility during coughing	McLean, L. Varette, K. Gentilcore-Saulnier, E. Harvey, M. A. Baker, K. Sauerbrei, E.	Neurourology & Urodynamics	2013	Randomized controlled trial	40	Adult	Abdominal, lumbo-pelvic region	Canada	Research setting - university/ hospital/military	Urinary incontinence
135	Establishing Immediate Reliability of Sonographic Measurements of the Transversus Abdominis in Asymptomatic Adults Performing Upright Loaded Functional Tasks in a Clinical Context Without Delayed Recorded Measurement	McPherson, S. Watson, T. Pate, L.	Journal of Ultrasound in Medicine	2016	Measurement study	12	Adult	Abdominal, lumbo-pelvic region	United States of America	Research setting - university/ hospital/military	Healthy
136	Ultrasound assessment of lower limb muscle mass in response to resistance training in COPD	Menon, M. K. Houchen, L. Harrison, S. Singh, S. J. Morgan, M. D. Steiner, M. C.	Respiratory Research	2012	Case control study	64	Adult	MSK – lower extremity	United Kingdom	Hospital - outpatient department/unit/ clinic	Chronic obstructive pulmonary disease
137	Excursion of the sciatic nerve during nerve mobilization exercises: an in vivo cross-sectional study using dynamic ultrasound imaging	Coppieters, MW Andersen, LS Johansen, R Giskegjerde, PK Hoivik, M Vestre, S Nee, RJ	Journal of Orthopaedic and Sports Physical Therapy	2015	Cross sectional study	15	Adult	Neurology	Norway	Research setting - university/ hospital/military	Healthy
138	Proprioceptive StabilizerTM training of the abdominal wall muscles in healthy subjects: a quasi-experimental study	Morales, C. R. Sanz, D. R. Reguera, M. C. Martinez, S. F. Gonzalez, P. T. Pascual, B. M.	Revista da Associacao Medica Brasileira	2018	Non-controlled trial	41	Adult	Abdominal, lumbo-pelvic region	Spain	Not stated/unclear	Healthy
139	Test-retest and intrarater reliability of 2-dimensional ultrasound measurements of distance between	Mota, P. Pascoal, A. G. Sancho, F. Bo, K.	Journal of Orthopaedic and Sports Physical Therapy	2012	Measurement study	24	Both	Abdominal, lumbo-pelvic region	Norway	Physiotherapy clinic	Healthy

	rectus abdominis in women										
140	Reliability of the inter-rectus distance measured by palpation. Comparison of palpation and ultrasound measurements	Mota, P. Pascoal, A. G. Sancho, F. Carita, A. I. Bo, K.	Manual Therapy	2013	Measurement study	20	Both	Abdominal, lumbo-pelvic region	Portugal	Physiotherapy clinic	Healthy
141	The Immediate Effects on Inter-rectus Distance of Abdominal Crunch and Drawing-in Exercises During Pregnancy and the Postpartum Period	Mota, P Pascoal, A.G. Carita, A.I. Bo, K	Journal of Orthopaedic and Sports Physical Therapy	2015	Cross sectional study	84	Adult	Abdominal, lumbo-pelvic region	Portugal	Not stated/unclear	Pregnancy
142	Assessing muscle function of the male pelvic floor using real-time ultrasound	Nahon, I. Waddington, G. Adams, R. Dorey, G.	Journal of the Association of Chartered Physiotherapists in Women's Health	2012	Measurement study	28	Adult	Abdominal, lumbo-pelvic region	Australia	Not stated/unclear	Prostate cancer
143	The effects of a multisensory dynamic balance training on the thickness of lower limb muscles in ultrasonography in children with spastic diplegic cerebral palsy	Nam, S. M. Kim, W. H. Yun, C. K.	Journal of Physical Therapy Science	2017	Randomized controlled trial	15	Both	MSK – lower extremity	Korea	Hospital - outpatient department/unit/ clinic	Cerebral palsy
144	The Role of Preoperative Puborectal Muscle Function Assessed by Transperineal Ultrasound in Urinary Continence Outcomes at 3, 6, and 12 Months After Robotic-Assisted Radical Prostatectomy	Neumann, P. B. O'Callaghan, M.	International Neurourology Journal	2018	Cohort study	358	Adult	Abdominal, lumbo-pelvic region	Australia	Research setting - university/ hospital/military	Prostate cancer
145	Evaluation of a pilot programme on diagnostic thoracic ultrasound curriculum for acute care physiotherapists	Ntoumenopoulos , G. Ong, H. K. Toh, H. C. Saclolo, R. P. Sewa, W. D.	Australasian Journal of Ultrasound in Medicine	2017	Non-controlled trial	12	Adult	n/a	Singapore	Research setting - university/ hospital/military	n/a
146	Impact of an intensive education programme of diagnostic lung and	Ntoumenopoulos , G. Parry, S. M. Neindre, A. L.	Australasian Journal of Ultrasound in Medicine	2018	Non-controlled trial	32	Adult	n/a	Australia was the place where the research took	Research setting - university/ hospital/military	n/a

	lower limb ultrasound on physiotherapist knowledge: A pilot study								place but participant physiotherapists came from many countries		
147	Evaluating pelvic floor muscle contractility using two-dimensional transperineal ultrasonography in patients with pelvic organ prolapse	Ouchi, M. Kitta, T. Suzuki, S. Shinohara, N. Kato, K.	Neurourology & Urodynamics	2019	Non-controlled trial	31	Adult	Abdominal, lumbo-pelvic region	Japan	Hospital - outpatient department/unit/ clinic	Pelvic organ prolapse
148	The Variation of Cross-Sectional Area of the Sciatic Nerve in Flexion-Distraction Technique: A Cross-Sectional Study	Pagnez, Mam Correa, La Almeida, Rs Meziat-Filho, Na Mathieson, S Ricard, F Nogueira, Lac	Journal of Manipulative and Physiological Therapeutics	2019	Cross sectional study	30	Adult	Neurology	Brazil	Not stated/unclear	Healthy
149	Lumbopelvic dysfunction and stress urinary incontinence: a case report applying rehabilitative ultrasound imaging	Painter, E. E. Ogle, M. D. Teyhen, D. S.	Journal of Orthopaedic and Sports Physical Therapy	2007	Case report	1	Adult	Abdominal, lumbo-pelvic region	United States of America	Military - outpatient department/unit/ clinic	Urinary incontinence
150	Repeatability and Minimal Detectable Change in Longitudinal Median Nerve Excursion Measures During Upper Limb Neurodynamic Techniques in a Mixed Population: A Pilot Study Using Musculoskeletal Ultrasound Imaging	Paquette, P. Lamontagne, M. Higgins, J. Gagnon, D. H.	Ultrasound in Medicine & Biology	2015	Measurement study	18	Adult	Neurology	Canada	Research setting - university/ hospital/military	Carpal tunnel
151	Reliability of sonographic assessment of tendinopathy in tennis elbow	Poltawski, L. Ali, S. Jayaram, V. Watson, T.	Skeletal Radiology	2012	Measurement study	38 elbows from 19 people	Adult	MSK – upper extremity	United Kingdom	Research setting - university/ hospital/military	Lateral epicondylagia
152	Microcurrent Therapy in the Management of Chronic Tennis Elbow: Pilot Studies to Optimize Parameters	Poltawski, L Johnson, M Watson, T	Physiotherapy Research International	2012	Quasi-experimental study	62	Adult	MSK – upper extremity	United Kingdom	Research setting - university/ hospital/military	Lateral epicondylagia
153	Use of ultrasound imaging by physiotherapists: a	Potter, C.L. Cairn, M.C. Stokes, M.	Manual Therapy	2012	Descriptive study	46	Adult	n/a	United Kingdom	Not stated/unclear	n/a

	pilot study to survey use, skills and training										
154	Between-Day Repeatability and Symmetry of Multifidus Cross-Sectional Area Measured Using Ultrasound Imaging	Pressler, J. F. Heiss, D. G. Buford, J. A. Chidley, J. V.	Journal of Orthopaedic and Sports Physical Therapy	2006	Measurement study	30	Adult	Abdominal, lumbo-pelvic region	United States of America	Research setting - university/ hospital/military	Healthy
155	Immediate effects of lumbar spine manipulation on the resting and contraction thickness of transversus abdominis in asymptomatic individuals	Puentedura, E. J. Landers, M. R. Hurt, K. Meissner, M. Mills, J. Young, D.	Journal of Orthopaedic and Sports Physical Therapy	2011	Randomized controlled trial	35	Adult	Abdominal, lumbo-pelvic region	United States of America	Research setting - university/ hospital/military	Healthy
156	Observed changes in lateral abdominal muscle thickness after spinal manipulation: a case series using rehabilitative ultrasound imaging	Raney, N. H. Teyhen, D. S. Childs, J. D.	Journal of Orthopaedic and Sports Physical Therapy	2007	Case series	9	Adult	Abdominal, lumbo-pelvic region	United States of America	Research setting - university/ hospital/military	Low back pain
157	Measurement of glenohumeral joint translation using real-time ultrasound imaging: A physiotherapist and sonographer intra-rater and inter-rater reliability study	Rathi, S. Taylor, N. F. Gee, J. Green, R. A.	Manual Therapy	2016	Measurement study	12	Adult	MSK – upper extremity	Australia	Research setting - university/ hospital/military	Healthy
158	Correlation Between Upper Limb Volume and Arterial and Venous Blood Flow Velocity in Lymphedema Secondary to Breast Cancer Treatment	Rezende, M. S. Marsengo, A. L. Apolinario, A. Ferreira, V. T. K. Guirro, E. C. O.	Journal of Manipulative and Physiological Therapeutics	2017	Cross sectional study	30	Adult	MSK – upper extremity	Brazil	Research setting - university/ hospital/military	Breast cancer
159	Evaluation of supraspinatus strengthening exercises based on fiber bundle architectural changes	Sachdeva, R. Farthing, J. P. Kim, S. Y.	Scandinavian Journal of Medicine and Science in Sports	2017	Randomized controlled trial	34	Adult	MSK – upper extremity	Canada	Research setting - university/ hospital/military	Healthy
160	Abdominal exercises affect inter-rectus distance in postpartum	Sancho, M. F. Pascoal, A. G. Mota, P. Bo, K.	Physiotherapy	2015	Cross sectional study	38	Adult	Abdominal, lumbo-pelvic region	Portugal	Physiotherapy clinic	Post-partum women

	women: a two-dimensional ultrasound study										
161	Rehabilitative ultrasound imaging of the supraspinatus muscle: Intra- and interrater reliability of thickness and cross-sectional area	Schneebeli, A. Egloff, M. Giampietro, A. Clijsen, R. Barbero, M.	Journal of Bodywork and Movement Therapies	2014	Measurement study	25	Adult	MSK – upper extremity	Switzerland	Research setting - university/ hospital/military	Healthy
162	The opinion and experiences of Dutch orthopedic surgeons and radiologists about diagnostic musculoskeletal ultrasound imaging in primary care: A survey	Scholten-Peeters, G. G. M. Franken, N. Beumer, A. Verhagen, A. P.	Manual Therapy	2014	Descriptive study	213	Not reported	n/a	Netherlands	Hospital - outpatient department/unit/ clinic	n/a
163	The reliability of rehabilitative ultrasound imaging measurements of the lumbar multifidi recorded by physical therapist students with minimal training	Schrank, EC Abraham, K Wilson, MJ Myers, WV King, MG	Journal of Physical Therapy Education	2011	Measurement study	20	Adult	n/a	United States of America	Research setting - university/ hospital/military	n/a
164	The Scapular Assistance Test Results in Changes in Scapular Position and Subacromial Space but Not Rotator Cuff Strength in Subacromial Impingement	Seitz, AL. McClure, PW. Finucane, S Ketchum, JM. Walsworth, MK. Douglas Boardman Iii, N. Michener, LA.	Journal of Orthopaedic and Sports Physical Therapy	2012	Case control study	42	Adult	MSK – upper extremity	United States of America	Physiotherapy clinic	Sub-acromial impingement syndrome
165	Reliability of ultrasound thickness measurement of the abdominal muscles during clinical isometric endurance tests	ShahAli, S Arab, AM Talebian, S Ebrahimi, E Bahmani, A Karimi, N Nabavi, H	Journal of Bodywork and Movement Therapies	2015	Measurement study	19	Adult	Abdominal, lumbo-pelvic region	Iran	Physiotherapy clinic	Low back pain
166	The effect of core stability and general exercise on abdominal muscle thickness in non-specific chronic low back pain using ultrasound imaging	Shamsi, M. Sarrafzadeh, J. Jamshidi, A. Zarabi, V. Pourahmadi, M. R.	Physiotherapy Theory and Practice	2016	Quasi-experimental study	48	Adult	Abdominal, lumbo-pelvic region	Iran	Research setting - university/ hospital/military	Chronic low back pain

167	Musculoskeletal ultrasound imaging and clinical reasoning in the management of a patient with cervicogenic headache: a case report	Sillevis, R. Swanick, K.	Physiotherapy Theory and Practice	2019	Case report	1	Adult	MSK - spine, sternum, thorax	United States of America	Physiotherapy clinic	Cervicogenic headache
168	Ultrasound Imaging: Intraexaminer and Interexaminer Reliability for Multifidus Muscle Thickness Assessment in Adults Aged 60 to 85 Years Versus Younger Adults	Sions, JM Velasco, TO. Teyhen, DS. Hicks, GE	Journal of Orthopaedic and Sports Physical Therapy	2014	Measurement study	61	Adult	Abdominal, lumbo-pelvic region	United States of America	Research setting - university/ hospital/military	Older healthy adults
169	Comparison of lateral abdominal muscle thickness between weightlifters and matched controls	Sitilertpisan, P. Pirunsan, U. Puangmali, A. Ratanapinunchai, J. Kiatwattanacharoen, S. Neamin, H. Laskin, J. J.	Physical Therapy in Sport	2011	Case control study	32	Both	Abdominal, lumbo-pelvic region	Thailand	Research setting - university/ hospital/military	Healthy athletes
170	Relationships among lateral abdominal muscles, gender, body mass index, and hand dominance	Springer, B. A. Mielcarek, B. J. Nesfield, T. K. Teyhen, D. S.	Journal of Orthopaedic and Sports Physical Therapy	2006	Descriptive study	32	Adult	Abdominal, lumbo-pelvic region	United States of America	Research setting - university/ hospital/military	Healthy
171	Physiotherapist inter-rater reliability of the Haemophilia Early Arthropathy Detection with Ultrasound protocol	Stephensen, D. Classey, S. Harbidge, H. Patel, V. Taylor, S. Wells, A.	Haemophilia	2018	Measurement study	63 joints(21 elbows, 21knees, 21ankles) were examined in 21 patients	Adult	MSK – upper extremity and lower extremity	United Kingdom	Hospital - outpatient department/unit/ clinic	Hemophilia
172	A rehabilitative ultrasound imaging investigation of lateral abdominal muscle thickness in healthy aging adults	Stetts, D. M. Freund, J. E. Allison, S. C. Carpenter, G.	Journal of Geriatric Physical Therapy	2009	Cross sectional study	12	Adult	Abdominal, lumbo-pelvic region	United States of America	Research setting - university/ hospital/military	Healthy
173	The association between pelvic floor muscle function and pelvic girdle pain - A matched case	Stuge, B Saetre, K Braekken, IH	Manual Therapy	2012	Case control study	98	Adult	Abdominal, lumbo-pelvic region	Norway	Not stated/unclear	Pelvic girdle pain

	control 3D ultrasound study										
174	The automatic pelvic floor muscle response to the active straight leg raise in cases with pelvic girdle pain and matched controls	Stuge, B Saetre, K Braekken, IH	Manual Therapy	2013	Case control study	98	Adult	Abdominal, lumbo-pelvic region	Norway	Not stated/unclear	Pelvic girdle pain
175	Relationship between ultrasonography and electromyography measurement of abdominal muscles when activated with and without pelvis floor muscles contraction	Tahan, N. Arab, A. M. Arzani, P Rahimi, F.	Minerva Medica	2013	Non-controlled trial	30	Adult	Abdominal, lumbo-pelvic region	Iran	Research setting - university/ hospital/military	Healthy
176	In vivo measurements of humeral movement during posterior glenohumeral mobilizations	Talbott,; NR, Witt, D. W.	Journal of Manual and Manipulative Therapy	2016	Measurement study	28	Adult	MSK – upper extremity	United States of America	Research setting - university/ hospital/military	Healthy
177	Reliability and validity of thickness measurements of the supraspinatus muscle of the shoulder: an ultrasonography study	Temes, W. C. Temes Clifton, A. Hilton, V. Girard, L. Strait, N. Karduna, A.	Journal of Sport Rehabilitation	2014	Measurement study	15	Adult	MSK – upper extremity	United States of America	Physiotherapy clinic	Healthy
178	Changes in lateral abdominal muscle thickness during the abdominal drawing-in maneuver in those with lumbopelvic pain	Teyhen, D. S. Bluemle, L. N. Dolbeer, J. A. Baker, S. E. Molloy, J. M. Whittaker, J. L. Childs, J. D.	Journal of Orthopaedic and Sports Physical Therapy	2009	Case control study	15	Adult	Abdominal, lumbo-pelvic region	United States of America	Research setting - university/ hospital/military	Lumbopelvic pain
179	The use of ultrasound imaging of the abdominal drawing-in maneuver in subjects with low back pain	Teyhen, D. S. Miltenberger, C. E. Deiters, H. M. Del Toro, Y. M. Pulliam, J. N. Childs, J. D. Boyles, R. E. Flynn, T. W.	Journal of Orthopaedic and Sports Physical Therapy	2005	Randomized controlled trial	30	Adult	Abdominal, lumbo-pelvic region	United States of America	Research setting - university/ hospital/military	Low back pain
180	Changes in deep abdominal muscle thickness during common trunk-strengthening	Teyhen, D. S. Rieger, J. L. Westrick, R. B. Miller, A. C. Molloy, J. M. Childs, J. D	Journal of Orthopaedic and Sports Physical Therapy	2007	Cross sectional study	120	Adult	Abdominal, lumbo-pelvic region	United States of America	Research setting - university/ hospital/military	Healthy

	exercises using ultrasound imaging										
181	Low back and hip pain in a postpartum runner: Applying ultrasound imaging and running analysis	Thein-Nissenbaum, J. M. Thompson, E. F. Chumanov, E. S. Heiderscheit, B.	Journal of Orthopaedic and Sports Physical Therapy	2012	Case report	1	Adult	Abdominal, lumbo-pelvic region	United States of America	Physiotherapy clinic	Low back pain and hip pain
182	Effect of pelvic floor and transversus abdominis muscle contraction on inter-rectus distance in postpartum women: a cross-sectional experimental study	Theodorsen, N. M. Strand, L. I. Bo, K.	Physiotherapy	2019	Cross sectional study	38	Adult	Abdominal, lumbo-pelvic region	Norway	Physiotherapy clinic	Diastasis rectus abdominus
183	Pelvic floor ultrasound imaging: are physiotherapists interchangeable in the assessment of levator hiatal biometry?	Thibault-Gagnon, S. Gentilcore-Saulnier, E. Auchincloss, C. McLean, L.	Physiotherapy Canada	2014	Measurement study	14	Adult	Abdominal, lumbo-pelvic region	Canada	Research setting - university/ hospital/military	Healthy
184	Levator plate movement during voluntary pelvic floor muscle contraction in subjects with incontinence and prolapse: A cross-sectional study and review	Thompson, J. A. O'Sullivan, P. B.	International Urogynecology Journal	2003	Observational Study	104	Adult	Abdominal, lumbo-pelvic region	Australia	Physiotherapy clinic	Urinary incontinence and prolapse
185	Inter-professional agreement of ultrasound-based diagnoses in patients with shoulder pain between physical therapists and radiologists in the Netherlands	Thoomes-de Graaf, M. Scholten-Peeters, G. G. M. Duijn, E. Karel, Y. H. J. M. van den Borne, M. P. J. Beumer, A. Ottenheijm, R. P. G. Dinant, G. J. Tetteroo, E. Lucas, C. Koes, B. W. Verhagen, A. P.	Manual Therapy	2014	Measurement study	65	Adult	MSK – upper extremity	Netherlands	Physiotherapy clinic	Shoulder pain
186	Bedside ultrasound is a practical and reliable measurement tool	Tillquist, M. Kutsogiannis, D. J. Wischmeyer, P.	Journal of Parenteral and Enteral Nutrition	2014	Measurement study	78	Adult	MSK – lower extremity	Multiple sites in Canada, US, Belgium and France	Research setting - university/ hospital/military	Healthy

	for assessing quadriceps muscle layer thickness	E. Kummerlen, C. Leung, R. Stollery, D. Karvellas, C. J. Preiser, J. C. Bird, N. Kozar, R. Heyland, D. K.									
187	Bedside ultrasound is a practical measurement tool for assessing muscle mass	Toledo, D. O. Silva, Dcle Santos, D. M. D. Freitas, B. J. Dib, R. Cordioli, R. L. Figueiredo, E. J. A. Piovacari, S. M. F. Silva, J. M., Jr.	Revista Brasileira de terapia intensiva	2017	Measurement study	2	Adult	MSK – lower extremity	Brazil	Research setting - university/ hospital/military	Healthy
188	Do stages of menopause affect the outcomes of pelvic floor muscle training?	Tosun, O.C. Mutlu, E.K. Tosun, G Ergenoglu, A.M. Yeniel, A. O. Malkoc, M Askar, N Itil, I.M.	Menopause	2015	Cohort study	103	Adult	Abdominal, lumbo-pelvic region	Turkey	Hospital - outpatient department/unit/ clinic	Urinary incontinence
189	Reliability and validity of an ultrasound-based imaging method for measuring interspinous process distance in the lumbar spine using two different index points	Tozawa, R. Katoh, M. Aramaki, H. Kumamoto, T. Fujinawa, O.	Journal of Physical Therapy Science	2015	Measurement study	10	Adult	MSK - spine, sternum, thorax	Japan	Not stated/unclear	Healthy
190	Suprascapular Neuropathy After Distal Clavicle Resection and Coracoclavicular Ligament Reconstruction: A Residents Case Problem	Tragord, BS. Bui-Mansfield, LT. Croy, T Shaffer, SW.	Journal of Orthopaedic and Sports Physical Therapy	2015	Case report	1	Adult	Neurology	United States of America	Physiotherapy clinic	Subscapularis nerve injury
191	Persistence of improvements in postural strategies following motor control training in people with recurrent low back pain	Tsao, H. Hodges, P. W.	Journal of Electromyograph y & Kinesiology	2008	Cohort study	9	Adult	Abdominal, lumbo-pelvic region	Australia	Not stated/unclear	Low back pain

192	Non-invasive Treatment of Postpartum Diastasis Recti Abdominis: A Pilot Study	Tuttle, L J. Fasching, J Keller, A Patel, M Saville, C Schlaff, R Walker, A Mason, M Gombatto, SP.	Journal of Women's Health Physical Therapy	2018	Randomized controlled trial	30	Adult	Abdominal, lumbo-pelvic region	United States of America	Not stated/unclear	Diastasis rectus abdominus
193	Effect of scapular stabilization during cross-body stretch on the hardness of infraspinatus, teres minor, and deltoid muscles: An ultrasonic shear wave elastography study	Umehara, J. Hasegawa, S. Nakamura, M. Nishishita, S. Umegaki, H. Tanaka, H. Fujita, K. Kusano, K. Ichihashi, N.	Musculoskeletal Science and Practice	2017	Randomized controlled trial	20	Adult	MSK – upper extremity	Japan	Not stated/unclear	Healthy
194	Shoulder horizontal abduction stretching effectively increases shear elastic modulus of pectoralis minor muscle	Umehara, J. Nakamura, M. Fujita, K. Kusano, K. Nishishita, S. Araki, K. Tanaka, H. Yanase, K. Ichihashi, N.	Journal of Shoulder and Elbow Surgery	2017	Randomized controlled trial	18	Adult	MSK - spine, sternum, thorax	Japan	Research setting - university/ hospital/military	Healthy
195	Thigh Ultrasound Monitoring Identifies Decreases in Quadriceps Femoris Thickness as a Frequent Observation in Critically Ill Children	Valla, F. V. Young, D. K. Rabilloud, M. Periasami, U. John, M. Baudin, F. Vuillerot, C. Portefaix, A. White, D. Ridout, J. A. Meyer, R. Gaillard Le Roux, B. Javouhey, E. Pathan, N.	Pediatric Critical Care Medicine	2017	Measurement study	73	Pediatric	MSK – lower extremity	France and United Kingdom	Hospital – inpatient	Critically ill children
196	Clinical Improvements Are Not Explained by Changes in Tendon Structure on Ultrasound Tissue Characterization After an Exercise Program for Patellar Tendinopathy	van Ark, M. Rio, E. Cook, J. van den Akker-Scheek, I. Gaida, J. E. Zwerver, J. Docking, S.	American Journal of Physical Medicine & Rehabilitation	2018	Randomized controlled trial	29	Both	MSK – lower extremity	Australia	Research setting - university/ hospital/military	Sports injury - patellar tendinopathy
197	Quantifying acromiohumeral distance in elite	Vanderstukken, F. Maenhout, A.	Brazilian journal of physical therapy	2019	Case control study	50	Adult	MSK – upper extremity	Belgium	Amateur and semi-professional athletes teams	Healthy athletes

	male field hockey players compared to a non-athletic population	Spanhove, V. Jansen, N. Mertens, T. Cools, A. M.									
198	Abdominal muscle contraction thickness and function after specific and general exercises: a randomized controlled trial in chronic low back pain patients	Vasseljen, O. Fladmark, A. M.	Manual Therapy	2010	Randomized controlled trial	109	Adult	Abdominal, lumbo-pelvic region	Norway	Not stated/unclear	Chronic low back pain
199	Dance, balance and core muscle performance measures are improved following a 9- week core stabilization training program among competitive collegiate dancers	Watson, T Graning, J McPherson, S Carter, E Edwards, J Melcher, I Burgess, T	International Journal of Sports Physical Therapy	2017	Cohort study	24	Adult	Abdominal, lumbo-pelvic region	United States of America	Research setting - university/ hospital/military	Healthy athletes
200	What does normal tendon structure look like? New insights into tissue characterization in the Achilles tendon	Wezenbeek, E. Mahieu, N. Willems, T. M. Van Tiggelen, D. De Muynck, M. De Clercq, D. Witvrouw, E.	Scandinavian Journal of Medicine and Science in Sports	2017	Descriptive study	70	Adult	MSK – lower extremity	Belgium	Research setting - university/ hospital/military	Healthy
201	Impact of the FIFA 11+ on the structure of select muscles in adolescent female soccer players	Whittaker, J. L. Emery, C. A.	Physical Therapy in Sport	2015	Cohort study	23	Pediatric	Abdominal, lumbo-pelvic region and MSK – lower extremity	Canada	Research setting - university/ hospital/military	Healthy athletes
202	Comparison of the sonographic features of the abdominal wall muscles and connective tissues in individuals with and without lumbopelvic pain	Whittaker, J. L. Warner, M. B. Stokes, M.	Journal of Orthopaedic and Sports Physical Therapy	2013	Case control study	50	Adult	Abdominal, lumbo-pelvic region	United Kingdom and Canada	Physiotherapy clinic	Lumbopelvic pain
203	Ultrasound imaging transducer motion during clinical maneuvers: respiration, active straight leg raise test and abdominal drawing in	Whittaker, J. L. Warner, M. B. Stokes, M. J.	Ultrasound in Medicine & Biology	2010	Observational study	12	Adult	Abdominal, lumbo-pelvic region	United Kingdom	Not stated/unclear	Healthy
204	Induced transducer orientation during ultrasound imaging: effects on	Whittaker, J. L. Warner, M. B. Stokes, M. J.	Ultrasound in Medicine & Biology	2009	Observational Study	8	Adult	Abdominal, lumbo-pelvic region	United Kingdom	Not stated/unclear	Healthy

	abdominal muscle thickness and bladder position										
205	Sonographic Measures of the Gluteus Medius, Gluteus Minimus, and Vastus Medialis Muscles	Whittaker, J.L. Emery, C.A.	Journal of Orthopaedic and Sports Physical Therapy	2014	Measurement study	29	Pediatric	MSK – lower extremity	Canada	Not stated/unclear	Healthy athletes
206	The effect of shoulder position on inferior glenohumeral mobilization	Witt, D. W. Talbott, N. R.	Journal of Hand Therapy	2018	Cross sectional study	23	Adult	MSK – upper extremity	United States of America	Research setting - university/ hospital/military	Healthy
207	In-vivo measurements of force and humeral movement during inferior glenohumeral mobilizations	Witt, D. W. Talbott, N. R.	Manual Therapy	2016	Measurement study	23	Adult	MSK – upper extremity	United States of America	Research setting - university/ hospital/military	Healthy
208	Reliability of 2 ultrasonic imaging analysis methods in quantifying lumbar multifidus thickness	Wong, A. Y. L. Parent, E. Kawchuk, G.	Journal of Orthopaedic and Sports Physical Therapy	2013	Measurement study	27	Adult	Abdominal, lumbo-pelvic region	Canada	Not stated/unclear	Low back pain
209	Lumbar multifidus muscle thickness does not predict patients with low back pain who improve with trunk stabilization exercises	Zielinski, K. A. Henry, S. M. Ouellette-Morton, R. H. DeSarno, M. J.	Archives of Physical Medicine and Rehabilitation	2013	Cohort study	25	Adult	Abdominal, lumbo-pelvic region	United States of America	Physiotherapy clinic	Low back pain

*PT – physiotherapy, MSK – musculoskeletal, n/a = not applicable

CHAPTER 3

Scoping review of curricula and pedagogical approaches for physiotherapist performed point of care ultrasonography

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Scoping review of curricula and pedagogical approaches for physiotherapist performed point of care ultrasonography

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TITLE

Scoping review of curricula and pedagogical approaches for physiotherapist performed point of care ultrasonography

ABSTRACT

Purpose: This study collates and maps physiotherapy pre- and post-licensure curricula and pedagogical approaches for point of care ultrasonography (POCUS).

Method: We used a standardized scoping review methodology and reporting framework. A total of 18,217 titles and abstracts, and 1,372 full text citations were screened, with 209 studies classified as physiotherapist performed POCUS.

Results: Of the 209 studies, 15 evaluated pre- and post-licensure curricula and pedagogical approaches. Seventy-two to 98% of pre-licensure programs reported including theoretical knowledge of POCUS and 44–45% reported practical teaching or competency assessment. In post-licensure studies of POCUS, 0–61% of physiotherapists reported training for POCUS. All studies of post-licensure pedagogical approaches included an assessment of theoretical knowledge of POCUS, but only one study included a practical assessment of competency. There was considerable variability in POCUS methods and duration of pedagogical approaches. Except for one study, all pedagogical approaches reported improvement in theoretical knowledge.

Conclusion: Progress in physiotherapy-specific, standardized, competency-based curricula and pedagogical approaches in POCUS has been limited, with minimal research available, and considerable variability both pre- and post-licensure. These findings could be used to advocate for the inclusion of POCUS in pre- and post-licensure physiotherapy

curriculum, and suggest a need for clear guidelines from regulatory colleges and licensing bodies, and a common terminology for physiotherapist performed POCUS. Future directions for research include a systematic review of the psychometric properties of physiotherapist performed POCUS within and across anatomical areas, an assessment of value of different forms of training, and an evaluation of the impact of physiotherapist performed POCUS on patient outcomes.

Key Words: physical therapists; physical therapy modalities; point of care systems; teaching; ultrasonography.

Contributors: K.S., A.K.C., M.R.M., and P.S. conceived and designed this review. K.S. and A.N. extracted and reviewed the data for accuracy. K.S. analyzed and completed the data analysis and drafted the manuscript. All authors read and approved the final manuscript.

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INTRODUCTION

With advances in technology and research, new modalities and treatments are emerging in physiotherapy practice and research. For curricular and pedagogical approaches to remain aligned with these advances, pre-licensure physiotherapy programs must adapt to ensure safe and efficacious entry-level standards. Post-licensure continuing development courses must also integrate new practices into course offerings to provide educational opportunities that reflect the evolving needs of the profession. Advances in education also provide the foundation for regulatory colleges and licensing bodies to protect the public with the provision of governance frameworks and guidance on quality assurance processes.

Point of care ultrasonography (POCUS) is a relatively recent application of sonography.[1] With appropriate training, physiotherapists can perform POCUS for the evaluation of a specific organ, pathology, or procedure within their area of practice.[2,3] However, POCUS is operator dependent, and several authors suggest there may be a risk of misdiagnosis if it is used improperly or by untrained users.[2-4] The first international meeting on physiotherapist performed diagnostic imaging, termed rehabilitative ultrasound, occurred in 2006.[5] At this time, rehabilitative and diagnostic imaging by physiotherapists was in its infancy and the need to establish training standards for physiotherapists was recognized as a priority.[5] Standards for training are needed to ensure competency, diagnostic accuracy, and patient safety.[3] Educational curricula, professional governance, and local institutional protocols should be in place to advance the scope of the physiotherapy profession in POCUS and to ensure proper clinical implementation.[3]

A narrative review identified three areas of POCUS in physiotherapy practice (diagnostic, rehabilitative, interventional) and outlined a range of clinical purposes.[1] A recent scoping review found 82% of studies on physiotherapist performed POCUS were published in the last 10 years, confirming POCUS as an emerging area of practice. Most studies reported on establishing psychometric properties of physiotherapist performed POCUS. Only 35% of included studies reported on the training that the physiotherapist received to perform POCUS (K. Strike et al., unpublished data, June 2021).

Despite its emergence, most pre-licensure physiotherapy programs do not provide theoretical and practical education on POCUS.[1] Currently there are no internationally accepted curricula or minimum competency requirements for physiotherapist performed POCUS.[1] Physiotherapists can access training programs such as the Berwin Institute of Diagnostic Medical Ultrasound and the American Registry for Diagnostic Medical Sonography.[1] However, these programs do not provide physiotherapy-specific education and may not meet local regulatory requirements.[1]

Whittaker and colleagues proposed a competency-based education framework for POCUS as a foundation for the development and evaluation of POCUS courses for physiotherapists.[1] Strike and colleagues developed a post-licensure POCUS training program for physiotherapists in hemophilia.[6,7] However, information on pedagogical approaches pre- and post-licensure for physiotherapist performed POCUS remains sparse.

To better understand current methods and make recommendations for education, a greater appreciation of the literature on the curricular and pedagogical approaches for physiotherapist performed POCUS is required. Scoping reviews explore broad questions in emerging areas of practice.[8] Scoping reviews methodologically map existing literature and summarize the main sources and types of evidence available on a specific topic.[8] The primary objective was to collate and map physiotherapy pre- and post-licensure curricula and pedagogical approaches for POCUS.

METHODS

Research questions

1. What curricular and pedagogical approaches have been used in pre-licensure physiotherapy degree programs to teach POCUS?
2. What curricular and pedagogical approaches have been used in post-licensure physiotherapy continuing education courses to teach POCUS?
3. How were the pre- and post-licensure curricular and pedagogical approaches assessed? What were the results?

Study selection

This study protocol was developed a priori and followed the standardized scoping review methodology by Arksey & O'Malley and Levac and colleagues.[8,9] The Preferred Reporting Items for Systematic Reviews and Meta-analyses Extension for Scoping Reviews (PRIMSA-ScR) was used as a framework for reporting.[10] Search strategies were developed in consultation with a health research librarian. The following databases were searched from January 1, 1980—November 10, 2019: OVID Medline, CINAHL, AMED, and EMBASE. Search strategies are included in online Appendices 1–4.

Following the database search, citations were imported into EndNote X8 to remove duplicates, and exported to Covidence (2020 Veritas Health Innovation, Melbourne, Australia). For the selection of studies on physiotherapist performed POCUS, two reviewers performed a calibration exercise using a purposeful selection of 40 citations to evaluate reviewer agreement using Cohen's kappa statistic. A value of greater than 0.80 was required. This calibration exercise resulted in a Cohen's kappa of 0.886, indicating a strong level of agreement between the reviewers.[11] The two reviewers independently reviewed all titles, abstracts, and full-text citations. Conflicts were resolved by discussion. If consensus could not be reached, conflicts were resolved with a third reviewer. Inclusion criteria were original research on POCUS in which the imaging was performed by a physiotherapist, or if the ultrasound operator was trained to use POCUS by a physiotherapist. Studies were excluded if they were non-English language, review articles, studies of therapeutic ultrasound, or grey literature. Studies that were classified as physiotherapist performed POCUS were then assessed by one reviewer for reporting on curriculum and pedagogical approaches.

Data extraction

The data extracted from each study included citation, study design, country, anatomical area of POCUS, sample size, and characteristics of curricula or pedagogical approaches for POCUS including methods of assessment and results.

Data synthesis and analysis

Descriptive statistics were applied to the numerical data. The descriptive numerical summary included sample size, study design, country, type and duration of pedagogical approach, and anatomical area of POCUS. Thematic analysis consisted of identifying similarities and differences in how curricula and pedagogical training approaches were assessed, and the results of these approaches.

RESULTS

Our database search identified 19,455 citations. Following the removal of duplicates, 18,217 titles and abstracts were screened, and 1,372 full text articles were assessed, resulting in 209 studies of physiotherapist performed POCUS. Of the 209 studies, 15 evaluated POCUS curricula and pedagogical approaches. Refer to the PRISMA diagram (Figure 1).

Characteristics of included studies

The 15 studies were published in 11 different journals with 1,930 (median = 49) participants enrolled. Most studies were descriptive surveys (*n* = 7; 46.7%), followed by three randomized controlled trials (20%), two non-controlled trials (13.3%), one non-randomized controlled trial, one qualitative study, and one measurement study. Eighty-six per cent (*n* = 13) of the studies were published from 2010–2019. Four studies were completed in Australia, three in Spain, and two in both the United Kingdom (UK) and the United States of America (USA). A single study was completed in both Singapore and New Zealand. One study was a collaboration between Australia and New Zealand and one study involved multiple countries. For details of included studies, refer to Appendix 5.

Pre-licensure physiotherapy degree programs

Curricular and pedagogical approaches

Two studies surveyed pre-licensure physiotherapy degree programs about their curricular approaches.[12,13] Chipchase and colleagues used a semi-structured interview to survey 13 faculty members representing all 18 entry-level physiotherapy programs in New Zealand and Australia on current curricula for electrophysical agents including POCUS.[12] POCUS for biofeedback was included in theory in 13 (72.2%) programs; however, only 8 (44%) included practical teaching. The most common reason given for this discrepancy was that POCUS was not common in clinical practice.[12] Thirty-nine per cent of respondents indicated that POCUS was not an entry-level competency.[12] Boissonnault and colleagues surveyed faculty from 155 physiotherapy programs in the USA.[13] Of the respondents, 152 (98.1%) included imaging in their programs. The average amount of teaching time for imaging theory, clinical applications, and skills was 24.4 hours (range 2–75 hours). Sixty-eight (45%) programs assessed student competency. On a scale of 1–5 (1 = not competent, 5 = competent), respondents rated entry-level competency for the utilization of ultrasound at 1.77.[13]

Assessment of pedagogical approaches and results

Four studies evaluated pre-licensure pedagogical approaches for POCUS.[14-17] Two studies assessed competence in palpation and ultrasound imaging of the knee and the lumbopelvic region using e-learning strategies in addition to traditional classroom teaching.[15,16] One study investigated mobile learning, or m-learning, as an adjunct to traditional classroom teaching on palpation and ultrasound imaging of the shoulder.[14] One study assessed if a six-hour training program was sufficient for students to reliably perform measurements of the lumbar multifidus using POCUS.[17] As shown in Table 1, all four studies assessing pedagogical approaches demonstrated that the curriculum resulted in improvement in practical skills and theoretical knowledge. The e-learning and m-learning groups scored significantly higher than the control groups on global objective standardized clinical evaluation scores.[14-16] There were no differences in theoretical knowledge between groups. The two reliability studies demonstrated discordant results. Cantarero-Villanueva and colleagues demonstrated inferior interrater reliability between novice and expert examiners, while Schrank and colleagues demonstrated that interrater and intrarater reliability was high between the expert and novice raters and the three novice raters.[15,17]

Post-licensure physiotherapy courses

Curricular and pedagogical approaches

Six studies investigated post-licensure curricular and pedagogical approaches.[18-23] Five studies were descriptive studies that surveyed physiotherapists in Australia, New Zealand, and the UK; one was a qualitative study from Australia. [18-23] Four descriptive surveys investigated POCUS in physiotherapy practice, and one survey was specific to thoracic ultrasound. The qualitative study targeted POCUS for biofeedback of the pelvic floor. [18-23] Three studies used random sampling and reported a range of POCUS usage in practice from 11.6% to 67% (median 24%).[20,22,23] In the study of thoracic ultrasound, 31% reported using POCUS in practice.[19]

Methods and duration of training were highly variable. McKiernan and colleagues found 61% of respondents reported training; of these, 67% reported that the training was for "several hours."[23] Jedrzejczak and Chipchase reported that 26.7% had attended training with the majority of courses being a half day or less.[22] Potter and colleagues reported that 52% of respondents received formal training ranging from 5–8 hours with 41–50% including practical sessions.[21] Informal training ranged from 0–4 hours.[21] Ellis and colleagues reported 43% of users of POCUS had received formal training, 48% received informal training, and 10% had not received any training but were using POCUS.[20] In the survey of thoracic ultrasound, 44% of respondents had undertaken training, 8% progressed beyond the introductory course to complete a formal assessment of competency, and 3% reported using POCUS without training.[19] In the focus group study of pelvic floor physiotherapists, none of the respondents reported participating in a formal course, most had participated in informal training and some reported no training at all.[18]

Formal training emphasized theory including ultrasound physics, safety, standardization of measurements, and practical sessions.[19-21] Informal approaches included self-directed training, training provided by the supplier of the ultrasound machine, attendance at a university lecture, and clinical observation with radiologists, gynecologists, or specialist physiotherapists. [18-23] Physiotherapists in all six studies identified the need for more training. Preferred methods included formal physiotherapy-specific courses, workshops, DVDs, practical hands-on sessions, e-learning, and clinical supervision.[18,19,21,231]

Assessment of pedagogical approaches and results

Three studies evaluated pedagogical approaches post-licensure.[24-26] Two studies investigated a one-day course for physiotherapists, one focused on thoracic ultrasound, and the other focused on the lung, diaphragm, and lower limb muscles.[24,25] The third study compared a one-day workshop with a self-paced DVD for POCUS of the abdominal muscles, multifidus, and pelvic floor.[26] As shown in Table 2, all three studies included pre- and post-intervention knowledge assessments. One study included a practical examination of scanning competence for a limited number of participants.[24]

The course on thoracic ultrasound resulted in improvement in theoretical knowledge and proficiency in the practical evaluation.[24] In contrast, participants in the course for ultrasound of the lung, diaphragm, and lower limb muscles did not demonstrate improvement in knowledge.[25] There were statistically significant increases in post-assessment knowledge scores for both the one-day workshop and the DVD; however, there was no significant difference between the two interventions.[26] Participants in both of the one-day training course studies felt that there was insufficient time in practical sessions.[24,25]

DISCUSSION

This scoping review systematically mapped physiotherapy pre- and post-licensure curricula and pedagogical approaches for POCUS. While 15 studies were published between 2005–2019, progress in the development of a physiotherapy-specific, standardized, competency-based curricula remains in the early stages. The majority of studies reported assessment of theoretical knowledge; however, there was limited practical teaching and evaluation. There was considerable variability in POCUS uses, methods, and duration of pedagogical approaches.

With the exception of one, all studies reported improvement in theoretical knowledge of POCUS regardless of pedagogical approach.[14-17,24-26] The study that did not report improvement in knowledge evaluated the impact of a one-day training program on POCUS of the lung, diaphragm, and lower limb muscles.[25] In contrast with the other studies that focused on one anatomical area, this study taught POCUS in three anatomical areas, which may have increased the complexity of the content. Also, language barriers may have impacted the findings, as the physiotherapists were from 14 different countries and the course was provided in English.[25]

Effective use of POCUS is dependent on operator skill and training.[3,27-29] As a key stakeholder, the Canadian Association of Radiologists (CAR) published a position statement on POCUS by non-radiologists to provide guidance on scope and training standards.[27-29] The CAR cautions that inappropriate use of musculoskeletal POCUS by untrained physicians may result in patient harm via incorrect diagnoses and subsequent interventions. [27-29] CAR's position states that health care professionals performing POCUS must receive training equivalent to a qualified imaging specialist within their area of practice.[27] This review confirmed that there is currently no accepted standard of training for the use of POCUS by physiotherapists in any area of practice. The variation in formal and informal training and competency assessment may lead to variable skills in image acquisition, optimization, and interpretation. This review also found that physiotherapists are using POCUS in clinical practice without training.[18-20] The lack of training may impact the credibility of the physiotherapy profession and patient safety, highlighting concerns for regulatory colleges, licensing bodies, and medical colleagues.

Scholten-Peeters and colleagues surveyed orthopedic surgeons and radiologists in the Netherlands and reported no additional value of physiotherapist performed POCUS in primary care.[30] Although this is a single study, and further research is needed, perceived disadvantages of physiotherapist performed POCUS in primary care were false-positive or false-negative results, lack of experience, insufficient education, and the inability to relate the outcomes of POCUS with other forms of diagnostic imaging.[30] Along with the position statement from the CAR, this study suggests that in order for the physiotherapy profession to gain credibility and support from key stakeholders, increased attention should be paid to education and competency-based training.

Variability in training may also impact the psychometric properties of POCUS. Acceptable intrarater and interrater reliability of physiotherapist performed POCUS has been documented in the assessment of the acromion-greater tuberosity distance, supraspinatus, transverse abdominus, lumbar multifidis, quadriceps, and the lung.[31-35] However, studies have also reported suboptimal interrater reliability when compared to more experienced POCUS users, and fair inter-professional agreement with radiologists.[36-38] Thoomes-de Graaf and colleagues investigated the inter-professional agreement between physiotherapists and radiologists in patients with shoulder pain, and found physiotherapists with more experience and training showed moderate agreement compared to only slight agreement in physiotherapists with less training, indicating the need for further education.[37]

Physiotherapists are using POCUS under different terminology and language such as rehabilitative ultrasound or real-time ultrasound.[1,22] The lack of consistent definitions and terminology may also contribute to challenges in professional credibility and advancing education. This variability may be due to physiotherapists adopting different language in order to meet institutional or regulatory requirements, or to avoid perceived infringement on the scope of practice of other health care disciplines.[1] To move forward, it will be important to engage key stakeholders and clinicians who are using and contributing to the research base to agree on the internationally accepted definitions, terminology, and scope of physiotherapy diagnostic ultrasound.

This scoping review identifies potential next steps. First, educators could use these findings to advocate for the inclusion of POCUS in pre- and post-licensure physiotherapy curricula. Development of physiotherapy specific pedagogical approaches should include both theoretical and practical assessments with an established procedure to ensure ongoing quality assurance. Training should be methodological and evaluative, and should include a component of experiential learning. Content of theoretical and practical teaching should be guided by local regulatory colleges, and physiotherapy scope of practice, as both vary around the world. Competency-based education is one form of pedagogy that has been reported in advanced practice physiotherapy and pelvic floor physiotherapy, and has been proposed as a possible educational framework for POCUS.[1,7,39,40] Secondly, researchers could use the findings to identify research priorities moving forward. Next steps could include: a systematic review and meta-analysis on the reliability and validity of physiotherapist performed POCUS within and across diagnoses; an assessment of the value of training including the impact of different forms of education, experience, and pedagogy on the psychometric properties of POCUS; and an evaluation of the impact of physiotherapist performed POCUS on patient outcomes. Lastly, adoption of internationally accepted definitions for POCUS will promote collaboration and research agendas. Ideally, these definitions would aim to align with position statements on the use of POCUS from other stakeholders in the field.

LIMITATIONS

Database searching resulted in over 19,000 studies, and therefore non-English language, review articles, and grey literature were excluded for feasibility. All but one study reported improvement in theoretical knowledge of POCUS regardless of the methods used. However, the heterogeneity in pedagogical approaches make it difficult to provide recommendations regarding the effectiveness of one training method over another. The majority of the included studies were completed in Australia, Spain, USA, and the UK, which may affect generalizability to educational and professional systems around the world.

CONCLUSION

This scoping review identified 15 studies from 2005–2019 and found considerable variability in pre- and post-licensure curricular and pedagogical approaches for physiotherapist performed POCUS. Progress in the development of a physiotherapy specific, standardized, competency-based curricula has been limited, with minimal research available, and remains in the early stages.

KEY MESSAGES

What is already known on this topic

Physiotherapist performed POCUS is emerging in clinical practice, education, and research. However, there are no internationally accepted curricula or minimum competency requirements. Very little is known about the outcomes of different pedagogical approaches on theoretical knowledge and practical scanning competence.

What this study adds

Progress in the development of a physiotherapy-specific, standardized education curricula and pedagogical approaches for POCUS has been limited. This scoping review demonstrated considerable variability in pre- and post-licensure curricular and pedagogical approaches. These findings suggest that there is a need for clear guidelines from regulatory colleges and licensing bodies, physiotherapy-specific curricula and pedagogical frameworks, and a common terminology for physiotherapist performed POCUS.

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TABLES AND FIGURES

Figure 1: Preferred Reporting Items for Systematic Reviews and Meta-analyses (PRIMSA) flow diagram of process used to select included studies.

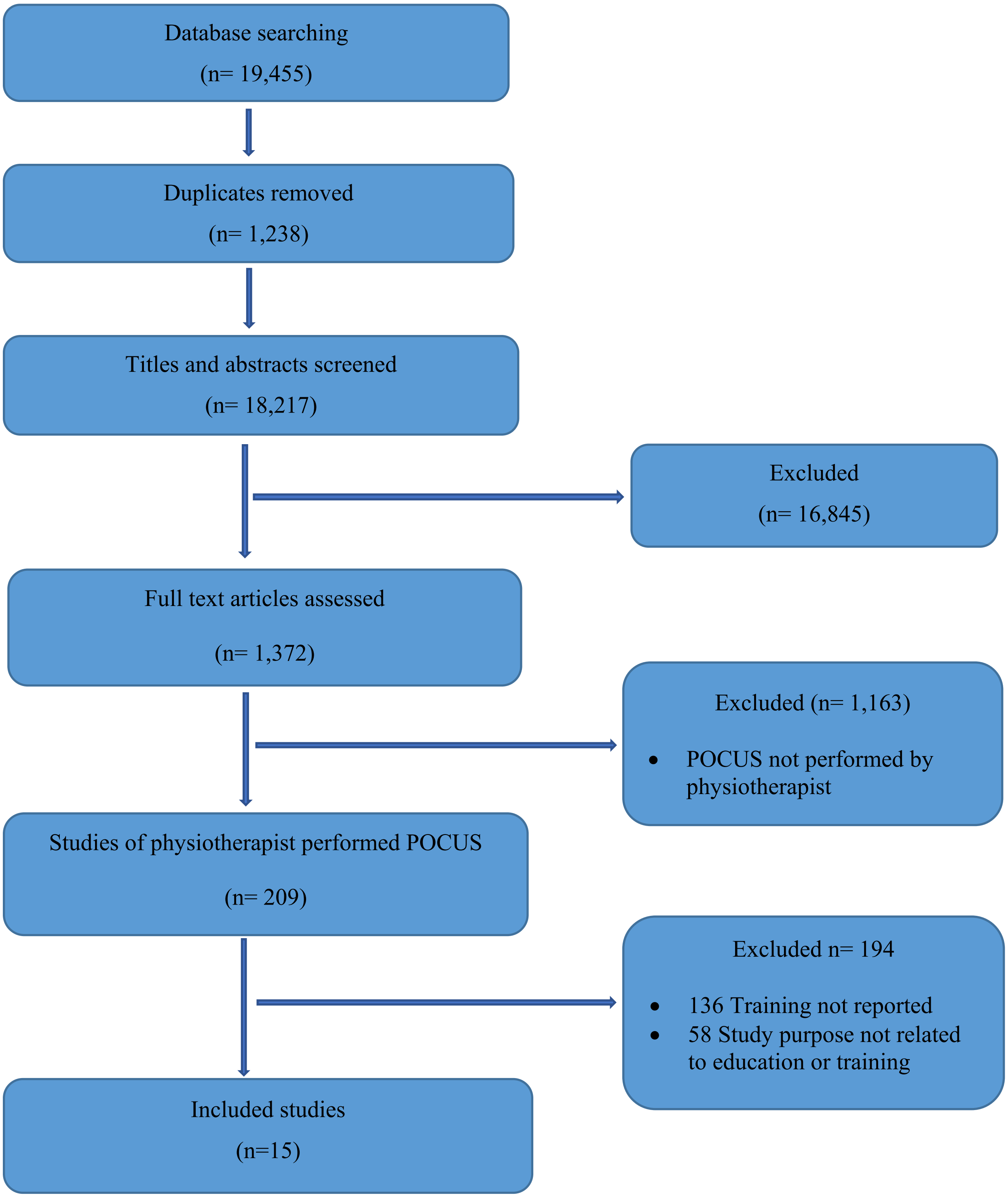

Table 1: Pre-licensure Physiotherapy Degree Programs

Pedagogical Approach	Citation	Anatomical area	Duration	Assessment	Results
E-learning (n=2)	Arroyo-Morales, M.[2]	Knee	4 classroom hours 3 weeks self-study	1. Palpation, ultrasound skills via SOCE 2. Theoretical knowledge via MCQ 3. Time to generate reliable image and to localize specific structure with palpation 4. Quality of the intervention on 5-point Likert scale	1. E-learning group scored significantly higher on global SOCE scores 2. No intergroup difference in knowledge 3. E-learning group required less time for palpation, more time to obtain image 4. Both groups reported satisfaction with the intervention

	Cantarero-Villanueva, I.[3]	Lumbo-pelvic region	6 classroom hours 20 self-study hours	1. Palpation, ultrasound skills via OSCE 2. Reproducibility in measurement of multifidus cross sectional area 3. Quality of the intervention on 5-point Likert scale	1. E-learning group scored significantly higher on OSCE 2. ICC for control and e-learning groups as compared to reference measurement was 0.61, 0.65 3. No difference between groups on quality of the intervention
Mobile learning (n=1)	Fernandez-Lao, C.[4]	Shoulder	6 classroom hours 20 self-study hours	1. Palpation, ultrasound skills via OSCE 2. Theoretical knowledge via MCQ	1. M-learning group scored significantly higher on Global OSCE scores

				3. Time to generate reliable image and to localize specific structure with palpation 4. Quality of the intervention on 5-point Likert scale 5. M-learning group assessed satisfaction on 11-point numeric rating scale	2. No intergroup difference in knowledge 3. No difference between groups in time to generate image and palpation 4. M-learning reported higher ratings on items: teacher was competent, lessons were interesting, able to learn a lot, size of groups were optimal, teacher-student interaction adequate 5. M-learning satisfaction was high

Six-hour program (n=1)	Schrank, E.C.[5]	Lumbar multifidus at L2-L3, L4-L5	6 hours: 2 hours education in ultrasound imaging, 4 hours practice time	1. Interrater, intrarater reliability via ICC and SEM	1. Interrater reliability for all raters at L2-L3, L4-L5 was high (ICC = 0.827 and 0.936) 2. Interrater reliability for novice raters was good at L2-L3 (ICC = 0.760), high at L4-L5 (ICC = 0.905) 3. Reliable intrarater measurements at L2-L3 and L4-L5 4. SEM showed stability of the measurements

SOCE: structured objective clinical evaluation; MCQ: multiple choice questions; OSCE: objective structured clinical evaluation; ICC: intraclass correlation coefficient; SEM: standard error of measurement

Table 2: Post-licensure Physiotherapy Courses

Pedagogical Approach (n)	**Citation**	**Anatomical area**	**Duration**	**Assessment**	**Results**
One day course (n=2)	Ntoumenopoulos, G.[6]	Thoracic	6.5 hours: 2.5 hours didactic lectures, 4 hours practical training	1. Pre-, post-knowledge MCQ 2. Practical examination for 6 participants 3. Evaluation of course satisfaction 4. 4-6 week follow-up survey	1. MCQ increased from 73.3 +/− 15.5% to 86.5 +/− 5.5% (mean, SD) 2. Median practical examination score: 15.5/16 3. All participants felt course would impact their clinical practice. 42% reported insufficient time in practical session

					4. 67% performed 1-3 scans in practice. Most frequent barrier was time constraints
	Ntoumenopoulos, G.[7]	Lung, diaphragm, lower limb muscles	6.5 hours: 2.5 hours didactic lectures, 4 hours practical training	1. Pre-, post-knowledge MCQ 2. Evaluation of course satisfaction	1. Pre- and post-knowledge scores: 63% and 62% 2. 83% felt pre-reading was appropriate, 48% reported insufficient time in practical training. All sessions were rated as good or excellent
Workshop and DVD	McKiernan, S.[8]	Abdominal muscles, multifidus, pelvic floor	Workshop : One day DVD: 2 months	1. Pre-, post-assessment of knowledge and perception of training	1. Significant increase in post-assessment scores in both groups, no

				using true/false, open ended and MCQ	difference between groups All participants reported training was good Workshop: areas of improvement: more supervision in practice sessions, more time identifying anatomy on ultrasound DVD: areas of improvement: more annotation on images in motion, more difficult

					examples, summary sheet of operational points

MCQ: multiple choice questions; SD: standard deviation.

APPENDICES

Appendix 1: Search Strategy OVID Medline: 1980 – November 10, 2019

1. exp Physical Therapists/
2. exp Physical Therapy Modalities/
3. exp Physical Therapy Specialty/
4. physiotherap*.mp.
5. physical therap*.mp.
6. 1 or 2 or 3 or 4 or 5
7. exp Ultrasonography/
8. dg.fs
9. ultraso*.mp.
10. sonography.mp.
11. 7 or 8 or 9 or 10
12. 6 and 11
13. point of care.mp or exp Point-of-Care Systems/
14. sports medicine.mp or exp Sports Medicine/
15. orthopedics.mp or exp Orthopedics/
16. respiratory*.mp or exp Respiratory System/
17. chest physi*.mp
18. atelectasis.mp or exp Pulmonary Atelectasis/
19. rotator cuff*.mp or exp Rotator Cuff/
20. pelvic*.mp or exp Pelvic Floor/

21. h?emophilia*.mp
22. exp Hemophilia A/
23. exp Hemophilia B/
24. neuropathy.mp
25. acupuncture.mp or exp Acupuncture/
26. rheumatology.mp or exp Rheumatology/
27. exercise therap*.mp or exp Exercise Therapy/
28. therapeutic exercise.mp
29. musculoskeletal*.mp or exp Musculoskeletal System/
30. exp Musculoskeletal Diseases/
31. exp Musculoskeletal injur
32. 14 or 15 or 16 or 17 or 18 or 19 or 20 or 21 or 22 or 23 or 24 or 25 or 26 or 27 or 28
33. 29 and 11 and 13
34. 30 or 12
35. Limit 31 to (English language and yr="1980-Current")

Appendix 2: Search Strategy CINAHL: 1980 – November 10, 2019

1. physical therapists/
2. exp physical therapy/
3. exp physiotherapy, evidence database/
4. physical therapy practice, evidence-based/
5. exp research, physical therapy

6. physiotherap*.mp.
7. physical therap*.mp.
8. 1 or 2 or 3 or 4 or 5 or 6 or 7
9. exp ultrasonography
10. ultraso*.mp.
11. sonography.mp.
12. 9 or 10 or 11
13. 8 and 12
14. exp “point of care testing” or “point of care”.mp
15. sports medicine.mp or exp sports medicine/
16. orthopedics.mp or exp orthopedics/
17. respiratory*.mp
18. chest physi*.mp or exp chest physical therapy
19. atelectasis.mp or exp pulmonary atelectasis/
20. rotator cuff*.mp or exp rotator cuff/
21. exp rotator cuff injuries/
22. pelvic*.mp or exp pelvic floor muscles/
23. h?emophilia*.mp or exp hemophilia/
24. exp Hemophilia B/
25. neuropathy.mp
26. acupuncture.mp or exp Acupuncture/
27. rheumatology.mp or exp Rheumatology/

28. exercise therapy.mp or exp therapeutic exercise/
29. musculoskeletal.mp or exp musculoskeletal system/
30. 15 or 16 or 17 or 18 or 19 or 20 or 21 or 22 or 23 or 24 or 25 or 26 or 27 or 28 or 29
31. 30 and 12 and 14
32. 31 or 13
33. Limit 32 to (English language and yr=”1980-Current”)

Appendix 3: Search Strategy for AMED: 1980 – November 10, 2019

1. exp physiotherapists/
2. exp physical therapy modalities/
3. exp physical therapy specialty/
4. physiotherap*.mp.
5. physical therap*.mp.
6. 1 or 2 or 3 or 4 or 5
7. exp Ultrasonography/
8. ultraso*.mp.
9. sonography.mp.
10. 7 or 8 or 9
11. 6 and 10
12. point of care.mp
13. sports medicine.mp or exp Sports Medicine/
14. orthopedics.mp or exp Orthopedics/

15. respiratory*.mp or exp respiratory muscles/
16. chest physiotherapy.mp or exp chest physiotherapy/
17. atelectasis.mp or exp atelectasis/
18. rotator cuff*.mp or exp Rotator Cuff/
19. pelvic*.mp or exp Pelvic Floor/
20. h?emophilia*.mp exp Hemophilia/
21. neuropathy.mp
22. acupuncture.mp or exp Acupuncture/
23. rheumatology.mp or exp rheumatic disease/
24. exercise therapy.mp or exp Exercise Therapy/
25. musculoskeletal.mp or exp Musculoskeletal System/
26. 13 or 14 or 15 or 16 or 17 or 18 or 19 or 20 or 21 or 22 or 23 or 24 or 25
27. 26 and 10 and 12
28. 27 or 11
29. Limit 28 to (English language and yr="1980-Current")

Appendix 4: Search Strategy for EMBASE: 1980 – November 10, 2019

1. exp physiotherapist/
2. exp physiotherapy/
3. exp physiotherapy practice/
4. physiotherap*.mp.
5. physical therap*.mp.
6. 1 or 2 or 3 or 4 or 5

7. exp ultrasound/
8. exp echography/
9. ultraso*.mp.
10. sonography.mp.
11. 7 or 8 or 9 or 10
12. 6 and 11
13. exp “point of care testing” or “point of care”.mp
14. sports medicine.mp or exp sports medicine/
15. orthopedics.mp or exp orthopedics/
16. respiratory*.mp
17. chest physi*.mp
18. atelectasis.mp or exp atelectasis/
19. rotator cuff*.mp or exp rotator cuff injury/
20. pelvic*.mp or exp pelvic floor muscle training/
21. h?emophilia*.mp
22. exp hemophilia A/
23. exp Hemophilia B/
24. neuropathy.mp or exp neuropathy/
25. acupuncture.mp or exp Acupuncture/
26. rheumatology.mp or exp Rheumatology/
27. exercise therapy.mp or exp kinesiotherapy/
28. musculoskeletal.mp or exp musculoskeletal system/

29. 15 or 16 or 17 or 18 or 19 or 20 or 21 or 22 or 23 or 24 or 25 or 26 or 27 or 28 or 29
30. 29 and 11 and 13
31. 30 or 12
32. Limit 31 to (English language and yr=”1980-Current”)

Appendix 5: Details of Included Studies

Title	Authors	Year	Journal	Study design	Sample Size	Country
A blended learning approach to palpation and ultrasound imaging skills through supplementation of traditional classroom teaching with an e-learning package[16]	Arroyo-Morales M, Cantarero-Villanueva I, Fernandez-Lao C, Guirao-Pineyro M, Castro-Martin E, Diaz-Rodriguez L.	2012	Manual Therapy	Randomized controlled trial	46	Spain
Diagnostic and procedural imaging curricula in	Boissonnault WG, White DM, Carney S,	2014	Journal of Orthopaedic and	Descriptive study	Faculty from 155 PT programs	United States of America

physical therapist professional degree programs[13]	Malin B, Smith W.		Sports Physical Therapy			
Evaluation of e-learning as an adjunctive method for the acquisition of skills in bony landmark palpation and muscular ultrasound examination in the lumbopelvic region: a controlled study[15]	Cantarero-Villanueva I, Fernandez-Lao C. Galiano-Castillo N, Castro-Martin E, Diaz-Rodriguez L, Arroyo-Morales M.	2012	Journal of Manipulative and Physiological Therapeutics	Randomized controlled trial	50	Spain

A survey of electrophysical agents' curricula in entry-level physiotherapy programs in Australia and New Zealand[12]	Chipchase LS, Williams MT, Robertson VJ.	2005	New Zealand Journal of Physiotherapy	Descriptive study	13 participants representing all 18 entry level physiotherapy programs in Australia and New Zealand	Australia, New Zealand
Exploring the clinical use of ultrasound imaging: A survey of physiotherapists in New Zealand[20]	Ellis R, De Jong R, Bassett S, Helsby J, Stokes M, Cairns M.	2018	Musculoskeletal Science and Practice	Descriptive study	415	New Zealand

The effectiveness of a mobile application for the development of palpation and ultrasound imaging skills to supplement the traditional learning of physiotherapy students[14]	Fernandez-Lao C, Cantarero-Villanueva I, Galiano-Castillo N, Caro-Moran E, Diaz-Rodriguez L, Arroyo-Morales M.	2016	BMC Medical Education	Randomized controlled trial	49	Spain
Diagnostic thoracic ultrasound imaging – An exploration of respiratory	Hayward S, Smith M, Innes S.	2019	Ultrasound	Descriptive study	133	United Kingdom

physiotherapists' interest and use in clinical practice: A national survey[19]						
The availability and usage frequency of real time ultrasound by physiotherapists in South Australia: an observational study[22]	Jedrzejczak A, Chipchase LS.	2008	Physiotherapy Research International	Descriptive study	664	Australia
A survey of diagnostic ultrasound within	McKiernan S, Chiarelli P,	2011	Radiography	Descriptive study	99	Australia

the physiotherapy profession for the design of future training tools[23]	Warren-Forward H.					
A comparison between workshop and DVD methods of training for physiotherapists in diagnostic ultrasound[26]	McKiernan S, Chiarelli P, Warren-Forward H.	2012	Radiography	Non randomized controlled trial	180	Australia
Professional issues in the use of diagnostic ultrasound	McKiernan S, Chiarelli P, Warren-Forward H.	2013	Radiography	Qualitative study	16	Australia

biofeedback in physiotherapy of the female pelvic floor[18]						
Impact of an intensive education programme of diagnostic lung and lower limb ultrasound on physiotherapist knowledge: A pilot study[25]	Ntoumenopoulos G, Parry SM, Neindre AL.	2018	Australasian Journal of Ultrasound in Medicine	Non-controlled trial	32	Physiotherapists from Australia, South Africa, Singapore, Chile, Canada, Iran, New Zealand, Switzerland, Brazil, Nigeria, East Africa, West Africa, Pakistan,

						and United Arab Emirates
Evaluation of a pilot programme on diagnostic thoracic ultrasound curriculum for acute care physiotherapists[24]	Ntoumenopoulos G, Ong HK, Toh HC, Saclolo RP, Sewa WD.	2017	Australasian Journal of Ultrasound in Medicine	Non-controlled trial	12	Singapore
Use of ultrasound imaging by physiotherapists: a pilot study to survey use, skills and training[21]	Potter CL, Cairn MC, Stokes M.	2012	Manual Therapy	Descriptive study	46	United Kingdom

The reliability of rehabilitative ultrasound imaging measurements of the lumbar multifidi recorded by physical therapist students with minimal training[17]	Schrank EC, Abraham K, Wilson MJ, Myers WV, King MG.	2011	Journal of Physical Therapy Education	Measurement study	20	United States of America

CHAPTER 4

Point of care ultrasonography in patients with hemophilia and acute hemarthrosis: a physiotherapist and sonographer inter-professional agreement pilot study

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Point of care ultrasonography in patients with hemophilia and acute hemarthrosis: a physiotherapist and sonographer inter-professional agreement pilot study

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TITLE:

Point of care ultrasonography in patients with hemophilia and acute hemarthrosis: a physiotherapist and sonographer inter-professional agreement pilot study

ABSTRACT:

Introduction: Hemophilia treatment centers around the world are increasingly adopting point of care ultrasonography (POCUS) for the assessment of acute hemarthrosis and to monitor joint health. POCUS is in large part administered by physiotherapists in most comprehensive care teams. Appropriate implementation of hemophilia-specific POCUS requires an educational foundation and training to ensure competency and optimal outcomes. Inter-professional agreement and evaluation of image quality are important measures of competency and acceptable use of POCUS.

Aims: To determine the level of agreement between the physiotherapist and sonographer-performed POCUS scans and to compare the quality of the ultrasound images obtained by physiotherapists to those obtained by the sonographer.

Methods: This single blind, prospective, pilot study recruited patients with hemophilia A and B who presented to clinic with a suspected acute hemarthrosis of the elbow, knee, or ankle and consented to participate. POCUS scans were performed by one trained physiotherapist and one sonographer in the hemophilia ambulatory clinic at patient presentation, one-week follow-up, and two-week follow-up. The physiotherapist participated in formal training consisting of 12 hours of online didactic modules and a two-day, 12-hour practical module with instructor led hands-on training. For the primary objective, the outcome of interest was the binary decision on the presence or absence of blood within the joint. For the secondary objective, image quality was evaluated by the radiologist post hoc and rated as optimal, acceptable, or sub-optimal.

Results: Thirteen participants with hemophilia consented to the study. The results indicated an excellent level of agreement (k=0.80) with an observed agreement of 91.7%, a specific positive agreement of 94.1%, and a specific negative agreement of 85.7% for the detection of blood within the joint space. The quality of the ultrasound images obtained by the physiotherapist were rated by the radiologist as optimal (84.6%) and acceptable (15.4%). None of the images were rated as sub-optimal.

Conclusions: Optimal image quality and a high level of agreement between the physiotherapist and sonographer-performed POCUS for the assessment of acute hemarthrosis in people with hemophilia A and B was observed. These results suggest that, with a short formal training program, physiotherapists can be proficient in the performance, acquisition, and interpretation of POCUS scans in patients with hemophilia.

INTRODUCTION:

Hemophilia is a hematological condition with orthopedic manifestations. People with hemophilia are prone to several complications. Hemarthrosis is the most frequent complication, accounting for 70-80% of all bleeding episodes (1). Although any joint may be affected, hinge joints, particularly the ankles, knees and elbows, are the most commonly involved (1). Blood within the joint space has detrimental effects on all joint structures and leads to the development of hemophilic arthropathy (2, 3). A single hemarthrosis is capable of causing the same long-term arthropathy as seen in recurrent hemorrhages (4, 5). Time between the initiation of joint bleeding symptoms and treatment with factor replacement therapy is crucial; however, some hemarthroses may present ambiguously. On initial presentation it may be difficult to assess if acute joint pain is due to a joint bleed or underlying arthropathy (6). Recent evidence suggests that the clinical examination alone is not sensitive to detect small amounts of blood within a joint (4, 6, 7). Therefore, each bleeding event requires early and complete bleed assessment and management to ensure the best possible outcomes for people with hemophilia.

Magnetic resonance imaging (MRI) is the gold standard for the detection of hemarthrosis, however it is expensive, often inaccessible, and may require sedation of children to ensure that the images are not compromised by patient movement (8). Computed tomography (CT) is another sensitive method; however, the benefits of CT may not outweigh the downside of ionizing radiation (8, 9). Ultrasound is time-efficient, non-ionizing, and relatively inexpensive (8, 10-12). Ultrasound can detect complex fluid suggestive of blood within the joints of patients who are clinically asymptomatic, leading to the recommendation that ultrasound be used in combination with the clinical exam to inform treatment decisions following hemarthrosis (7). However, clinical integration of ultrasound is limited by timely access to sonographers/radiologists with knowledge and experience in hemophilia. Further, treatment of hemarthrosis is time-sensitive, and same-day diagnostic imaging appointments are not always feasible. Point-of-care ultrasound (POCUS) is a modality that has the potential to address many of these challenges. POCUS is performed by a health care professional at the bedside or in the ambulatory clinic, in combination with the clinical examination to identify the presence or absence of a specific clinical finding (13). POCUS should be utilized when time saving for diagnosis or treatment is critical to patient care (13). However, POCUS is a highly user dependent modality, and there is a risk of misdiagnosis if it is used to aid clinical decision making by inexperienced or untrained health care professionals (14).

Proficiency with the clinical examination and an understanding of the role of POCUS are important competencies for physiotherapists (15). POCUS has been described within physiotherapy practice in orthopedics or sport injuries to detect atrophy, tendon, ligament or muscle injury, in rheumatology to assist clinical decisions, and as a potential tool for physiotherapists working in critical care (16-21). It is important that physiotherapists who are using POCUS have confidence in their interpretation and findings, as this could impact the credibility of the profession, patient safety, support from regulatory colleges and licensing bodies, and collaboration with medical colleagues. A survey of orthopedic surgeons and radiologists in the Netherlands reported no additional value of physiotherapist performed POCUS in primary care (22). This is a single study that assessed the subjective opinions of the survey respondents, perceived disadvantages of physiotherapists performed POCUS were false-positive or false-negative results, lack of experience, inadequate training, and the inability to correlate the reported findings on POCUS with other forms of imaging (22). Even though this study reported a low survey response rate and a potential for a response bias, the lack of trust radiologists and orthopedic surgeons reported for physiotherapist knowledge and performance of POCUS in primary care should be addressed through future studies (22). Rathi and colleagues investigated the inter-rater reliability of glenohumeral joint translation using POCUS (23). Although high intra-rater reliability (physiotherapist: ICC 0.86-0.98, expert sonographer: 0.85-0.96) was found, the inter-rater reliability was moderate to good for posterior measurements (ICC 0.50-0.75) and poor to moderate for anterior measurements (ICC 0.31-0.53). These results suggest that to improve inter-rater reliability with an expert sonographer, the physiotherapist may benefit from additional or a different form of training (23). Similar findings were reported by Thoomes-de Graaf and colleagues (24). Across four diagnostic categories, Thoomes-de Graaf et al. found a kappa coefficient of 0.36 between physiotherapists and radiologists on the use of diagnostic ultrasound in patients with shoulder pain (24). Although the level of agreement was low, this study reported that physiotherapists with more experience and training had a higher level of agreement with the radiologist than novice physiotherapists (24).

Training appears to be an important contributor to inter-rater reliability of physiotherapist performed POCUS. Mayer and colleagues found excellent inter-rater reliability (ICC ranged from 0.76-0.97) between a physiotherapist, physiotherapy students, and an expert physician sonographer following 8 hours of structured formal training as a group and a one-hour private practical training session with the expert sonographer (25). An inter-examiner agreement study of physiotherapists in the Netherlands found an acceptable level of overall agreement (61.7-93.6%) and specific positive agreement (43.9-91.4%) for detecting rotator cuff tears and other pathology (26). The Dutch physiotherapists in this study had obtained certification on basic musculoskeletal ultrasound skills and completed a six-hour training program specific to the study protocol with an expert in musculoskeletal sonography (26).

Physiotherapists in hemophilia treatment centers have extensive knowledge of anatomy, pathophysiology, and functional implications of a bleeding disorder on the musculoskeletal system. A global survey of hemophilia treatment centers found that the majority (70%) of POCUS scans were completed by physiotherapists (27). In this study, an inter-disciplinary panel of hematologists/oncologists, radiologists, and physiotherapists reported that physiotherapists are appropriate users for the acquisition and interpretation of POCUS scans in hemophilia treatment centers around the world (27). While several researchers have studied diagnostic ultrasound and the correlation with disease activity and hemophilic arthropathy, inter-professional agreement and an evaluation of image quality for physiotherapist performed POCUS in patients with acute hemarthrosis in patients with hemophilia has not been investigated (28-33). Inter-professional agreement and evaluation of image quality are important measures of competency and acceptable use of POCUS. Image quality provides evidence to support the diagnosis of a bleed and decreases the chance of artifact incorrectly demonstrating pathology. Given the role of the physiotherapists within hemophilia treatment centers in Canada, and the emergence of POCUS, the present pilot study aims to add novel research to this discussion.

Objectives:

1. To determine the level of agreement between physiotherapist and sonographer-performed POCUS to assess for the presence or absence of blood in acute hemarthrosis in people with hemophilia A and B.
2. To compare the quality of the ultrasound images obtained by the physiotherapist to those obtained by the sonographer.

METHODS:

Study Design: This study was a single blind, prospective, pilot study.

Participants: A convenience sample of patients with hemophilia with a suspected acute hemarthrosis of the elbow, knee, or ankle were recruited from a single hemophilia treatment centre in Canada. The physiotherapist (K.S.) who performed the POCUS scan is a member of the Canadian Physiotherapists in Hemophilia Care and successfully completed the McMaster University Mohawk College POCUS Training Program for Acute Hemarthrosis and Synovitis and has 17 years of experience in hemophilia care. The training program includes 12 hours of online didactic modules and a two day, 12 hour practical training module with instructor led hands-on practice (34). The didactic modules include summative assessments, and the practical component includes an assessment of competency using a simulated performance environment. The assessments were created to model the Sonography National Competency Profile developed by Sonography Canada and the Sonography Canada Clinical Skills Assessment Tool for this specific application of POCUS (34). The sonographer (L.F.) who performed the ultrasound scan is a senior sonographer in the diagnostic imaging department at a large tertiary care hospital and has over 30 years of clinical experience in sonography. A single radiologist (N.S.) with 12 years of experience in ultrasound imaging and 10 years experience in pediatric imaging, provided oversight to the study and reviewed all POCUS scans and case report forms.

Study Procedures: The study procedure consisted of a POCUS performed by a physiotherapist and a sonographer. Refer to Appendix 1 for POCUS scanning procedure. The POCUS scans were performed in the hemophilia ambulatory clinic at patient presentation, one-week follow up, and two-week follow-up. The order of assessment was based on clinician availability. The sonographer was allowed to add additional images to the imaging protocol given their area of expertise, but the physiotherapist was instructed to acquire the images according to the scanning procedure. Ambiguous results were referred to the diagnostic imaging department for further formal investigation. Both the physiotherapist and the sonographer were blinded to each other's findings and to the results of previous scans. Methods of blinding included the use of a private clinic room and each clinician performing their assessment and documentation independently. Case report forms were placed in a sealed envelope. POCUS images were saved on the hard drive of the POCUS machine (GE Logiq) using an anonymous participant identification number.

Inclusion and Exclusion Criteria: Patients (age >1 year of age) with hemophilia A or B, with an acute hemarthrosis involving the elbow, knee, or ankle who presented to the clinic within five days of symptom onset were eligible to participate. Participants were excluded if there was an open wound over the scanning area, if an ultrasound scan of the hemarthrosis had already been completed, or if they were not able to read and understand English.

Outcome Assessment: Outcomes were assessed at presentation, one-week follow-up, and two- week follow up, resulting in a three-week study period. For the primary objective, the outcome of interest was the binary decision on the presence or absence of blood within the joint. As the technique and protocol in this study was specific to hemophilia, the criteria used to distinguish blood from effusion on ultrasound was blood presents as a complex fluid collection with mixed echogenicity and displaceable speckles on real time compression and effusion presents as simple anechoic fluid with the absence of echoes.(35) In the context of hemophilia with no symptoms suggestive of infection, complex effusions with mixed echogenicity can be assumed to represent hemarthrosis based on previous studies that have documented the accuracy of this approach using joint aspiration (35). The physiotherapist completed the scanning protocol and interpreted the findings to make the binary assessment. Since interpreting ultrasound falls outside the scope of the sonographer, the sonographer provided an impression on the presence or absence of blood on the case report form. The radiologist read the sonographer images and provided a final diagnosis. The radiologist also reviewed the images of the physiotherapist performed ultrasound. To compare the level of agreement, the radiologist's final diagnosis was compared to the physiotherapists' interpretation. Both the physiotherapist and the sonographer recorded inconclusive ultrasound findings as absence of blood within the joint.

For the secondary objective, criteria used to evaluate image quality were appropriate pre-sets, depth, field of view, focus, gains/time gain compensation, color and/or power Doppler, with suitable landmarks and annotation. Image quality was evaluated by the radiologist post hoc and rated as optimal, acceptable, or sub-optimal. Optimal was defined as good image quality with optimal ultrasound settings and correct annotation/documentation. Acceptable was defined as good image quality, with one image setting that should have been better optimized or a minor error in annotation/documentation that did not impact the interpretation of the POCUS scan. Sub-optimal was defined as poor image quality with more than one image setting not sufficiently optimized or an error in annotation/documentation that impacted the radiologists' interpretation of the POCUS scan.

Statistical Analysis: For the primary objective, the prevalence of positive findings was calculated. The inter-rater agreement of the binary assessment of the presence and absence of blood within the joint was assessed with the Kappa coefficient and 95% confidence intervals for the total sample and interpreted according to the categories by Landis and Koch (36). As this is a pilot study, we did not set an a priori threshold for agreement. Observed agreement, specific positive agreement and specific negative agreement were also calculated to provide the results in a clinically relevant format (37). For the secondary objective, the quality of the images were independently rated by the radiologist. Descriptive statistics including counts and percentages of optimal, acceptable, and sub-optimal for the physiotherapist and the sonographer performed POCUS scans were reported.

Ethics Approval: The proposed study received research ethics board approval from the Hamilton Integrated Research Ethics Board. All participants provided informed consent to participate in the study.

RESULTS:

Thirteen patients with hemophilia met the inclusion criteria and were recruited into the study. Two of the POCUS scans involved elbows (15.4%), five (38.5%) ankles, and six (46.2%) knees. The median age of participants was nine years (interquartile range: five years).

Level of agreement on the presence or absence of blood within the joint

As presented in Table 1, the Kappa coefficient was k= 0.80 (95% CI, 0.59 – 1.00). The prevalence of positive findings was 70.8%, observed agreement was 91.7%, the specific positive agreement was 94.1%, and the specific negative agreement was 85.7%. The sonographer was absent and unable to complete three POCUS scans, these scans were excluded from the level of agreement analysis.

Quality of Ultrasound Images

Post hoc analysis of the quality of the ultrasound images is shown in Table 2. The physiotherapist performed POCUS scans demonstrated that 84.6% of the images were rated by the radiologist as optimal, 15.4% were rated as acceptable, and none were rated as sub-optimal. For the sonographer performed POCUS scans, 88.9% of the images were rated as optimal, 11.1% were rated as acceptable, and none of the scans were rated as sub-optimal.

DISCUSSION:

Although pilot in design, this study adds to the emerging literature supporting the quality of physiotherapist-performed POCUS. The level of agreement between physiotherapist and sonographer is encouraging suggesting that a trained physiotherapist is able to acquire and interpret POCUS scans of acute hemarthrosis in patients with hemophilia A and B at the same level of expertise as an experienced sonographer (36). The specific positive agreement was greater than the specific negative agreement indicating better agreement when confirming the presence rather than the absence of blood within the joint. Clinically, these results indicate that if the physiotherapist performed and interpreted the POCUS scan as positive for presence of blood within the joint, the probability that the sonographer and radiologist would also confirm hemarthrosis is 94.1%. Encouraging results were also found for the absence of blood within the joint with the probability of absence of blood at 85.7%. While agreement was less for the absence of blood, the results were still high. Clinically, this supports physiotherapist consultation with radiology to determine whether further imaging is required if the POCUS scan indicates a lack of blood in the joint but other indicators such as patient symptomatology, mechanism of injury, inhibitor status, trough level, and underlying joint health, are all highly suggestive of hemarthrosis. The quality of the images obtained by the physiotherapist were optimal and comparable to the sonographer. This indicates that the trained physiotherapist was able to produce images that support the diagnosis on the presence or absence of a joint bleed with a low likelihood of imaging artifact incorrectly demonstrating or missing pathology.

In clinical practice, POCUS images are seldom stored for future review or comparison (38). This process has been questioned as it limits the possibility of performing quality assurance audits and does not acknowledge the importance of reviewing serial scans to assess for the evolution/resolution of pathology (38). To be consistent with this process and to maintain the independence of POCUS scans, the current study blinded the physiotherapist and the sonographer to the images and findings from previous scans. However, given the evolution of blood on ultrasound, the potential for underlying joint arthropathy in patients with hemophilia, and the role of normal physiologic fluid in synovial joints, it may be important for the POCUS operator to have access to previous POCUS scans. Having the ability to access previous images can facilitate analysis of the clinical evolution of pathology and physiologic fluid, which may have implications on the level of agreement between the trained physiotherapist and sonographer as there may be variations in agreement at different stages of recovery. Also, recording previous images may also decrease health care costs. If the POCUS scans are done with similar standards as diagnostic imaging, accessing stored images may avoid the need for repeat scans if clinical questions arise that may require consultation with radiology. These considerations may have implications for education and clinical practice and will be important areas for future study.

The current study had a number of strengths. The physiotherapist was trained to a set standard for this specific application of POCUS by an accredited academic institution. Both the physiotherapist and the sonographer were blinded and were provided with a standardized scanning protocol with the order of assessment randomized based on clinician availability. Both the physiotherapist and the sonographer used the same ultrasound machine and after each POCUS scan the machine was returned to the main screen to maintain blinding and the independence of scans. All 13 participants recruited into the study attended all study visits. Lastly, the study procedures were consistent with the traditional pathway in diagnostic imaging. The study was designed in this manner to ensure that the same quality and standard of care was provided in the clinic setting.

Although this is a pilot study, the main limitations of this study are the small sample size and inclusion of a single physiotherapist and sonographer, both of which may impact generalizability. While the results suggests that a short training program provided the physiotherapist with an appropriate level of education and training in the performance, acquisition, and interpretation of POCUS scans in patients with hemophilia, this needs to be replicated with physiotherapists and sonographers with varying levels of training and experience. It would be interesting to compare the competencies of sonographers with no musculoskeletal experience to physiotherapists who have completed POCUS training specific to the musculoskeletal system. Future inter-professional agreement studies should also consider including other members of the hemophilia comprehensive care team, such as physicians/hematologists and nurses, who may be using POCUS in clinical practice. In addition, with the decreasing annualized bleeding rates in people with hemophilia (39), a multi-centre trial would be needed to obtain a sufficient number of suspected bleeding episodes for a definitive study.

This study focused on hinge joints of the knee, ankle, and elbow. These joints account for the majority of hemarthrosis in patients with hemophilia and are easily accessible with relatively simple POCUS scanning protocols. Future research would need to look at the inter-professional agreement and image quality for more complex joints, such as the ball-and-socket joints (i.e., shoulder and hip). Although hemarthrosis could occur in patients with other musculoskeletal injuries, these results should only be applied to the assessment of hemarthrosis in patients with hemophilia (40-42). The protocol and training that the physiotherapist received in this study was specific to hemophilia and it is important to remember that one of the downsides of POCUS occurs when users extrapolate beyond their protocol and training (13). Therefore, generalizing the findings of this study to patients with other conditions should be done with caution. However, this study does demonstrate that within a relatively short period of formal training, that includes both didactic and practical curricula, physiotherapists can become proficient in POCUS. Given their background knowledge in anatomy and physiology, this study lends support for physiotherapists to be trained to use POCUS with different patient populations and conditions.

CONCLUSION:

Optimal image quality and an excellent level of agreement between the physiotherapist and sonographer-performed POCUS for the assessment of acute hemarthrosis in people with hemophilia A and B was observed. This pilot study found that a physiotherapist who received training in the McMaster University Mohawk College Training Program can perform and interpret POCUS scans for the assessment of acute hemarthrosis to a level that is comparable to an experienced sonographer. Further investigation is warranted.

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Conflict of Interest:

Anthony Chan is supported by Hamilton Health Sciences and the McMaster Children's Hospital/Hamilton Health Sciences Foundation Chair in Pediatric Thrombosis and Hemostasis.

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TABLES:

Table 1: Level of agreement on the presence or absence of blood within the joint

	Kappa coefficient	Agreement
Overall (n= 36)	k= 0.80 (95% CI, 0.59 – 1.00) p=0.000	Prevalence: 70.8% OA: 91.7% SPA: 94.1% SNA: 85.7%

k: Kappa coefficient; OA: observed agreement; SPA: specific positive agreement; SNA: specific negative agreement.

Table 2: Quality of Ultrasound Images

	Quality of Ultrasound Images		
	Optimal	Acceptable	Sub-optimal
Physiotherapist	84.6%	15.4%	0%
Sonographer	88.9%	11.1%	0%

Optimal: good image quality with optimal ultrasound settings and correct annotation/documentation.
Acceptable: good image quality, one image setting should have been better optimized or a minor error in annotation/documentation that did not impact POCUS interpretation.
Sub-optimal: poor image quality with more than one image setting not sufficiently optimized or an error in annotation/documentation that impacted POCUS interpretation.

APPENDICES:

Appendix 1: POCUS Scanning Procedure

<u>Elbow Protocol</u>

1. Have the patient roll sleeves (or wear a sleeveless shirt) to expose the posterior elbow
2. Position patient with the elbow in 90° flexion and the hand internally rotated, resting the palm on a small table slightly above the height of the bed/stretcher
3. Orient the transducer in the longitudinal axis of the posterior humerus at the level of the olecranon articulation (**Figure 1**).
4. Obtain an image (**Figure 2**) of the posterior joint recess
    a. Display the overlying triceps tendon long axis
    b. Display the olecranon process on the right of the image with the distal humerus on the left
    c. Interrogation scan medially/laterally to visualize full joint recess in the sagittal plane and superiorly and inferiorly in the transverse plane
    d. Apply compression
    e. If fluid positive turn on power Doppler
    f. If fluid negative perform real time ROM to assess for fluid with video loop
5. Label the image "RT/LT ELBOW POST SAG"

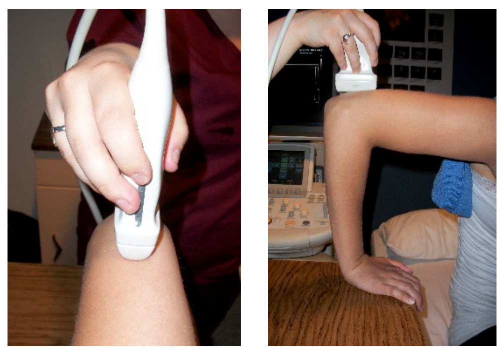

Figure 1: Patient position and transducer orientation for posterior elbow joint recess

Figure 2: Right elbow, posterior joint recess in long axis with overlying Triceps tendon

<u>Knee Protocol</u>

1. Have the patient roll pant leg (or wear shorts) to expose the anterior knee and lower thigh
2. Position patient supine with knee slightly flexed, approximately 45° and place a rolled towel or sponge beneath the knee to support the position.
3. Orient the transducer (**Figure 3**) in the long axis of the anterior suprapatellar region
4. Obtain an image (**Figure 4**) of the suprapatellar anterior joint recess
    a. Display the overlying quadriceps tendon and insertion into patella base
    b. Display the patella at the right side of the image
    c. Interrogation scan medially (**Figure 5 and 6)** and laterally (**Figure 7 and 8)** to visualize full joint recess in the sagittal plane and superiorly and inferiorly in the transverse plane
    d. Apply compression
    e. If fluid positive turn on power Doppler
    f. If fluid negative perform real time ROM to assess for fluid with video loop with patient sitting on the edge of the bed.
5. Label the image "RT/LT KNEE ANT SAG"

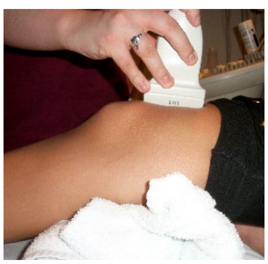

Figure 3 (left)

Figure 4 (right)

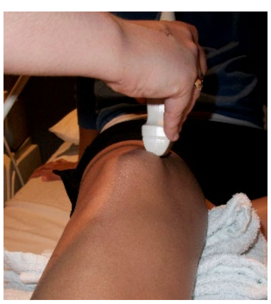

Figure 5 (far left), **Figure 6** (middle left), **Figure 7** (middle right), **Figure 8** (far right)

Ankle (Tibiotalar) Protocol

1. Have the patient roll pant leg just above the ankle and remove sock and shoe
2. Position the patient sitting or supine with knee flexed and foot flat on the bed, forming an angle of approximately 20-30° across the ankle
3. Orient the transducer in the longitudinal axis over the distal tibia in line with the first metatarsal bone (**Figure 9**) palpating the large anterior tibialis tendon if necessary
4. Obtain an image (**Figure 10**) of the anterior joint recess
    a. Display distal tibia on the left of the image, talus on the right, and the long axis of the overlying anterior tibialis tendon
    b. Interrogation scan medially/laterally to visualize full joint recess in the sagittal plane and superiorly and inferiorly in the transverse plane
    c. Apply compression
    d. If fluid positive turn on power Doppler
    e. If fluid negative perform real time ROM to assess for fluid with video loop
5. Label the image "RT/LT ANKLE ANTERIOR SAG."
6. **Figure 9**: Patient position and transducer orientation for anterior tibiotalar joint recess
7. **Figure 10**: Right tibiotalar joint, anterior joint recess in sagittal plane with overlying anterior tibialis tendon

Figure 9: Patient position and transducer orientation for anterior tibiotalar recess

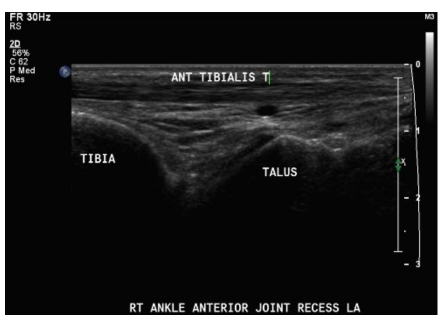

Figure 10: Right tibiotalar joint, anterior joint recess in sagittal plane with overlying anterior tibialis tendon

<u>Summary of Required Images:</u>

If positive for blood in the joint:

1. Still image of effusion in the sagittal plane
2. Still image of the effusion in the transverse plane
3. Video loop of real time ROM

If negative for blood in the joint:

1. Still image of joint recess in the sagittal plane
2. Video loop of real time ROM

CHAPTER 5

Thesis Discussion and Conclusion

Diagnostic ultrasound is used in a variety of clinical settings due to its low cost, accessibility, sensitivity, and lack of ionizing radiation.[1] Physiotherapist-performed POCUS is a relatively recent application of diagnostic ultrasonography in physiotherapy clinical practice, education, and research. Despite first being introduced to the physiotherapy profession over 40 years ago, physiotherapist-performed POCUS is still in its early stages. To advance the scope of the profession, the overall goal of this thesis was to add to the evolving literature on physiotherapist-performed POCUS. In the following sections the main findings of each manuscript will be summarized followed by recommendations and implications of this program of research on physiotherapy clinical practice, education, research, and policy. The strengths and limitations of this work are also presented. Results can be used by clinicians, researchers, physiotherapy regulatory colleges and licensing bodies, educators, and institutional leaders, to facilitate discussion on terminology, curriculum and training, and clinical implementation of physiotherapist-performed POCUS. Directions for future research are provided.

Summary of Findings from Each Manuscript

Chapter 2: Physiotherapist-performed Point of Care Ultrasonography (POCUS): A Scoping Review of 209 Studies

This is the first known scoping review of physiotherapist-performed POCUS that included all areas of practice. Over 19,000 studies were identified via database searching and 209 studies were included in this review. The majority of the included studies were completed in the last 10 years, which confirmed physiotherapist-performed POCUS as an emerging area. The studies were published in 81 different peer reviewed journals and included studies from 27 different countries. Over 90% of the studies were completed in adult subjects and most were completed in a research setting. This comprehensive review illustrated the wide range of anatomical areas and disease conditions in which physiotherapists are using POCUS. Most studies imaged the abdominal and lumbo-pelvic regions followed by musculoskeletal imaging of the upper extremity, lower extremity, and the spine, sternum, and thorax. In terms of study design, the largest single body of literature on physiotherapist-performed POCUS in this review were measurement studies. Most of the measurement studies assessed the reliability of physiotherapist-performed POCUS of the musculoskeletal or abdominal lumbo-pelvic region in healthy adult subjects. Overall, this manuscript provided an improved understanding of the breadth of existing literature on physiotherapist-performed POCUS. The findings of this scoping review can be used to inform clinical practice, policy, and directions for future research.

Chapter 3: Scoping review of curricula and pedagogical approaches for physiotherapist-performed point of care ultrasonography

The objective of this manuscript was to collate and map physiotherapy pre- and post-licensure curricula and pedagogical approaches for POCUS. Fifteen studies were included. The included studies were published in 11 different journals, 86% were reported between 2010-2019 and the majority of the studies were descriptive surveys. The review found considerable variability in pre- and post-licensure curricular and pedagogical approaches. Methods and duration of training were inconsistent. Most studies reported assessment of theoretical knowledge; however, there was limited practical teaching and evaluation. Several studies reported that physiotherapists were using POCUS in practice without training. This review confirmed that there is currently no accepted standard of training for the use of POCUS by physiotherapists in any area of practice. This scoping review concluded that progress in the development of physiotherapy-specific, standardized education curricula and pedagogical approaches for physiotherapist-performed POCUS has been limited and remains in the early stages of development. The findings of this review suggest that there is a need for physiotherapy specific curricula and pedagogical frameworks with clear guidelines from regulatory colleges and licensing bodies.

Chapter 4: Point of care ultrasonography in patients with hemophilia and acute hemarthrosis: a physiotherapist and sonographer inter-professional agreement pilot study

The final chapter of this thesis adds to the emerging literature on the quality of physiotherapist-performed POCUS. To the best of our knowledge, this is the first known inter-professional agreement study between a physiotherapist and a sonographer in patients with hemophilia A and B. POCUS scans of the elbow, knee, or ankle in patients with hemophilia were acquired by a trained physiotherapist and an experienced sonographer in the study. Thirteen patients (hemophilia A = 84.6%, hemophilia B = 15.4%) with varying severities (severe with inhibitors = 23.1%, severe = 53.8%, moderate = 15.4%, mild = 7.7%) were included in the study. The results indicated a high level of agreement between the physiotherapist and the sonographer for the detection of blood within the joint space. The physiotherapist and sonographer both demonstrated optimal image quality. This pilot study suggests that after a short formal training program that included both didactic and practical pedagogies, a physiotherapist was able to acquire and interpret POCUS scans to a comparable level of proficiency as an experienced sonographer for this specific application of diagnostic ultrasound. Overall, the findings of this study support the notion that a trained physiotherapist can become proficient in the acquisition and interpretation of POCUS images and can be used as a model in other areas of physiotherapy practice.

Implications and Recommendations

Clinical Practice

This research helps to inform the physiotherapy community and provides details on where, with whom, and for what purpose physiotherapists are using POCUS. Although this work highlighted considerable heterogeneity in the peer-reviewed literature on physiotherapist-performed POCUS, consolidating the evidence is an important next step and the findings add substantive information to the evidence base. By demonstrating the breadth and depth of physiotherapist-performed POCUS and highlighting the diverse practice areas and patient populations in which physiotherapists are using POCUS, the findings from this review provide a strong foundation for the profession to advocate for formal integration of POCUS into physiotherapy scope of practice.

This thesis identified that physiotherapists are using several different terms to describe diagnostic ultrasonography in practice. Current language includes rehabilitative ultrasound, diagnostic ultrasound, interventional ultrasound, real-time ultrasound, or bedside ultrasound.[2-5] The Canadian Association of Radiology (CAR) provides guidance on appropriate use of POCUS and suggests that all ultrasound in which an image is produced is diagnostic and referring to ultrasound as something other than a diagnostic modality does not properly describe is use in practice.[1] The heterogeneity in terminology calls attention to a potential knowledge gap that may present challenges for educators and regulatory/institutional authorities as the scope and use of physiotherapist-performed POCUS is not clear. Establishing a common language for physiotherapist-performed POCUS may assist with clinical implementation and acceptance of physiotherapist-performed POCUS within the physiotherapy profession and the diagnostic imaging community.[6]

POCUS is intended to answer a specific clinical question and should be used in conjunction with a physical examination.[1] Health care professionals should ensure that they have adequate training and experience for the specific application of the modality in their clinical practice.[1] As shown in Chapter 3, there is considerable variability in methods and duration of training for physiotherapist-performed POCUS. Physiotherapists are using POCUS in clinical practice, and educators and physiotherapy regulators may need to pay increased attention to education and training. Adequate training, competency assessment and ongoing quality assurance processes are important for the safe and appropriate use of POCUS in physiotherapy clinical practice.[1,7]

Inter-professional agreement and assessment of image quality are important measures of competency and appropriate use of POCUS. Clinically, the results from the inter-professional agreement study (Chapter 4) provide support to physiotherapists who have completed training on POCUS to use the imaging modality in practice. The results of this pilot study advance the field of physiotherapy and diagnostic imaging by demonstrating that a trained physiotherapist can produce high quality images that support the diagnosis or absence of hemarthrosis in patients with hemophilia. Although it is important to exercise caution when extrapolating the findings from this pilot study to other patient populations or conditions, this research supports the notion that physiotherapists can be trained to use POCUS in clinical practice.

Education

As presented in Chapter 2, physiotherapists are using POCUS in many different areas of clinical practice and with diverse patient populations. It is also accepted that POCUS is operator dependent and there may be a risk of misdiagnosis if it is used improperly or by untrained users.[7-9] Standards for training are needed to ensure competency, diagnostic accuracy, and patient safety.[7] As POCUS is a novel technology in physiotherapy clinical practice and research, it is important to understand how physiotherapists are being trained to use POCUS.[7]

Although, not included in the manuscript presented in Chapter 2, further analysis found that only 35% of the studies reported on the training that the physiotherapist received to perform POCUS. To further investigate education and training, the scoping review in Chapter 3 collated and mapped the current status of curricula and pedagogical approaches for physiotherapist-performed POCUS. The review showed considerable variability in pre- and post-licensure curricular and pedagogical approaches. Most studies reported assessment of theoretical knowledge; however, there was limited practical teaching and evaluation.

The variability and the limited amount of hands-on practical teaching and assessment may lead to inconsistent application of POCUS and may result in sub-optimal or inappropriate use.[10] Although the scoping review in Chapter 3 found improvement in theoretical knowledge of POCUS regardless of the pedagogical approach used, the variability in educational methods has implications for quality assurance and effectiveness as comparisons between pedagogical approaches and ability to recommend one training method over another is limited. As a user dependent imaging modality, the lack of practical teaching and evaluation may result in gaps in manipulative imaging skills including the ability to generate and optimize an image, and the ability to critically appraise the imaging findings and apply them to clinical practice.

By providing increased granularity and analysis of the literature, Chapter 3 adds valuable knowledge to the evidence base on physiotherapist-performed POCUS. Consolidating the literature is an important step towards practice change. Highlighting the need for the development of education and training standards in this program of work provides a foundation for physiotherapy clinicians and educators to address an education – practice gap, to begin to build curriculum and training standards, and to advocate for clear guidelines from regulatory colleges and licensing bodies on the use of POCUS in practice.

Chapter 3 suggests that to aid POCUS implementation into physiotherapy practice and gain credibility and support from key stakeholders in diagnostic imaging, increased attention should be paid to competency-based education and training. However, currently there are no mandated minimum standards of training to guide competency requirements for physiotherapy performed POCUS. In contrast to core areas of practice, emerging areas of physiotherapy practice without defined competencies rely on the physiotherapist to seek out their own educational opportunities and to self-monitor competence to an acceptable standard.[10] Locally available training and self-monitoring can be a challenge as there is no standard against which physiotherapists can compare their own performance and use of POCUS in clinical practice.[10] Additionally, measuring competency is a complex task and expertise can be self-proclaimed.[11-13] Attendance and participation in an educational event does not provide an assurance of professional competency.[11]

This thesis suggests that it is time to standardize curricula and training approaches for entry level and practicing physiotherapists to protect the public, enhance collaboration with colleagues, and promote the physiotherapy profession. Several key stakeholders in radiology including the CAR and the International Federation for Emergency Medicine have published position statements on the use of POCUS in practice and suggest that training should be optimized through a combination of didactic and practical pedagogies.[1,14] Competency-based education has been proposed as a potential educational framework for physiotherapist-performed POCUS.[2,15,16] Competency-based education is defined by Frank et al. as a distinct educational approach with predefined graduate abilities.[17] Competency-based education promotes the progression of competence that is aligned with professional, societal and patient needs.[17,18] It is centred on the learner and emphasizes the process of learning over duration of training with the pace of learning tied to the acquisition of competency.[17] Students progress along a series of defined competencies towards the standardized outcome of the training program.[17] Competency-based education must be accompanied by vigorous, multi-faceted assessments and evaluations to ensure that competence has been attained.[10,18]

Competency is a continuum rather than a binary outcome and there needs to be a recognized process for ongoing quality assurance and development of expertise.[19] Advantages of competency-based education include the ability to organize the curriculum around the competencies needed to best serve patients, greater transparency and consistency of standards, greater focus on observable and measurable rather than time-based outcomes, and greater engagement of learners.[17,18,20] Limitations of a competency-based approach include lack of trained faculty, challenges differentiating between competencies required for entry-level, post graduate and clinical specialist roles, and competency assessments tend to focus on skills that are easily measured rather than more intangible aspects of practice such as critical thinking, decision making and self-appraisal.[18-20]

Competency-based education has the potential to address the limitations in practical teaching and evaluation found in Chapter 3 by ensuring hands-on training approaches are integrated into curricular and outcome assessment before competency can be assessed. Competency-based education can respond to changing needs of the health care system, can adapt to new ultrasound technologies, and be applied in a variety of health care settings. Competency-based education frameworks have been proposed in advanced practice physiotherapy and pelvic floor physiotherapy.[10,21] Recently, Whittaker et al. proposed a competency-based education framework for POCUS to provide a foundation for the development and evaluation of POCUS courses for physiotherapists.[2]

Outcomes for training will vary depending on the level of training of the operator (pre-licensure vs. post-licensure) and the context/patient population in which physiotherapist-performed POCUS is to be used.[2] Pre-licensure outcomes should include foundations of ultrasound physics, basic knowledge on the manipulation of ultrasound knobs and system controls for optimal image acquisition, ultrasound safety and maintenance, and an overview of common applications of POCUS in physiotherapy practice.[2,7,15,22] Very simple POCUS skills and applications including differentiating bone, muscle, cartilage, or effusion in joints of the appendicular skeleton would be appropriate for pre-licensure curriculum. Post-licensure outcomes should vary across patient populations and should be specific to the area of practice in which POCUS will be used. Post-licensure outcomes should focus on image interpretation and optimization, and disease specific sonographic protocols. Specific competencies should be aligned with each protocol and the POCUS user should be able to demonstrate critical appraisal and an ability to incorporate the POCUS findings into clinical decision making.[2,7,15]

One example of competency-based training is the McMaster University and Mohawk College Medical Radiation Sciences POCUS Training Program. The goal of this partnership was to develop a post-licensure academic training and certification program for physiotherapists in hemophilia care on the application of POCUS for the assessment of acute hemarthrosis.[15] The training program was built in consultation with radiology and educators in sonography. The training program included principles of competency-based education including didactic, hands-on training, and supervised scans, to ensure an appropriate level of education and training in the performance, acquisition, and interpretation of POCUS images.[15] Course assessments included an evaluation of theoretical knowledge via multiple choice questions following each theoretical module, and practical skills were assessed in a simulated performance environment. All assessments were aligned with a selection of appropriate competencies from the Sonography National Competency Profile developed by Sonography Canada and the practical examination measured performance for this specific application of POCUS using the Sonography Canada Clinical Skills Assessment Tool.[15] This program can serve as a model for future competency-based POCUS educational initiatives.

The fourth chapter of this thesis advances the field of physiotherapy and diagnostic imaging by demonstrating that a trained physiotherapist can produce high quality images that support the presence or absence of hemarthrosis in patients with hemophilia. The findings also support the curricular approach of the McMaster

University/Mohawk College POCUS Training Program for Acute Hemarthrosis and Synovitis; this can inform others in the development of similar training and educational programs in POCUS. With the continued expansion of POCUS in physiotherapy professional practice and research, competency-based education will be an important area of future study.

Research

The scoping review in Chapter 2 demonstrated that measurement studies comprise the single largest body of literature on physiotherapist-performed POCUS. This is a promising finding as it is important to understand the psychometric properties of physiotherapist-performed POCUS to determine whether the measures derived from the ultrasound images can be used as primary outcomes for research. Continuing to investigate the reliability and validity of POCUS in different patient populations and areas of practice will be important to build credibility for the profession and engage key stakeholders in diagnostic imaging.[23]

The review also found considerable heterogeneity in study reporting which presented challenges for data synthesis but provided further support for the need to consolidate the literature. This work provides valuable information towards understanding and advancing POCUS in physiotherapy research and practice. Similar heterogeneity was found in a scoping review of physiotherapy performed thoracic ultrasound.[6] These limitations in study reporting may pose challenges for knowledge translation.[2,3] In order for research on physiotherapist-performed POCUS to inform clinical practice and identify knowledge gaps, it will be important to improve study reporting.[6]

The EQUATOR (Enhancing the Quality and Transparency of Health Research) Network is an international initiative that aims to improve reporting of study methodology and results through the use of evidence-based guidelines.[24] The EQUATOR network provides free online access to peer-reviewed publications and checklists for reporting randomized controlled trials (CONSORT Statement), systematic reviews and/or meta-analyses (PRISMA Statement), observations studies (STROBE Statement), and diagnostic accuracy studies (STARD Statement).[24] Several physiotherapy journals including Physiotherapy Canada, Physical Therapy, Physiotherapy, and the Brazilian Journal of Physical Therapy, require submitted manuscripts to follow the appropriate EQUATOR Network reporting guidelines. Despite these and other physiotherapy journals requiring the use of reporting guidelines, a meta-analysis of high impact journals found that a small minority of authors used reporting guidelines and when they were used only half used the guidelines appropriately.[25] This thesis provides useful feedback to physiotherapists and researchers on the current limitations in study reporting found for physiotherapist-performed POCUS. To help clinicians critically appraise, interpret, and apply research to clinical practice, it will be important for more journals to require the use of reporting guidelines. There is need for a system to ensure that the guidelines have been used correctly.[24]

For studies using ultrasound it is also important to ensure adequate reporting of the imaging nomenclature, settings, equipment, and procedures.[26] The European League Against Rheumatism has proposed a reporting checklist for the use of ultrasound in rheumatic and musculoskeletal diseases research.[26] This checklist is available on the EQUATOR network. The checklist was designed to be used in conjunction with other existing study design reporting guidelines and aims to improve the transparency and comprehensiveness of reporting in ultrasound research.[26]

Of the 209 studies included in Chapter 2, only one was a qualitative study. Given the preponderance of quantitative studies on physiotherapist-performed POCUS, researchers need to consider utilizing qualitative methodologies to further advance the knowledge base. Qualitative studies can provide greater insight into the practice environment and patient/provider experience for physiotherapist performed POCUS. Questions that are best suited to qualitative studies include how POCUS is best implemented into clinical practice and why some physiotherapists successfully implement POCUS and others do not.[27] It will also be important to obtain a qualitative perspective on how patients and physiotherapists experience POCUS and how its use influences patient engagement, clinical decision making, and physiotherapy assessment and treatment.[27]

Policy

This program of research highlights several implications and recommendations for policy. Chapter 2 demonstrated the need for a common terminology and for guidance from regulatory authorities to assist with professional oversight and appropriate use of POCUS. Pre- and post-licensure educational programs should work together with regulatory colleges and licensing bodies to provide governance frameworks concerning novel modalities in clinical practice. Educational programs also assist with advancing the scope of the profession by delivering education and training to an accepted standard and by providing guidance on appropriate clinical implementation. Therefore, the findings from Chapter 3 contribute valuable information to the discussion on physiotherapist-performed POCUS.

Integrating evidence into health policy is a complex task. Several strategies have been proposed to address the evidence-policy gap including establishing connections with policy makers, key stakeholders, and other relevant organizations to build networks and/or communities of practice, following an evidence-based approach when establishing recommendations and priorities, and building a plan for implementation.[28,29] Communities of practice are networks of individuals who share research, experience, and drive innovation and knowledge in an area of common interest.[28,30] Communities of practice can occur in person or via virtual platforms such as webinars, blogs, or online discussions.[30] Virtual communities of practice can implement both synchronous and asynchronous activities which may allow for enhanced participation by reducing barriers of geography, the time and cost of travel, or work demands.[30] Communities of practice support interactions between key stakeholders and encourages the participation of both novice and expert members.[31] Communities of practice focus on learning, networking, and building frameworks that facilitate the dissemination and implementation of knowledge.[31]

The program of research presented in this thesis demonstrated the extent of physiotherapist-performed POCUS globally. This work suggests that imaging professionals (radiologists, sonographers), educators, researchers, institutional leaders, clinicians, and patients, are key stakeholders in this discussion. The creation of a community of practice for physiotherapist performed POCUS is an important next step. Although, several different strategies have used to design and implement communities of practice, there is minimal consensus on the optimal method.[30,32] Ideally, communities of practice locally, and at a national level, could work with other groups around the world to create a network of health care professionals, educators, researchers, and policy makers to support scope of practice and the transfer of evidence into practice and health policy. Each community of practice should have a leader, a facilitator/knowledge broker, and a core group of members who regularly interact to advance knowledge in a specific area.[32] The facilitator/knowledge broker can be an individual or an organization who works to provide a link between researchers and end-users.[33] Hurtubise et al., studied the role of a knowledge broker in a pediatric physiotherapy virtual community of practice and found that knowledge brokers promoted a respectful learning environment, built capacity within the group, and created links between research and practice.[33] To advance the field of POCUS, the first step will be to purposefully identify and recruit leaders, knowledge brokers and core members.[33] Following this it will be important to develop the purpose, goals, and outcomes of the group. Funding and administrative support can be potential challenges to creating a community of practice so it will be important to seek out sponsorship or funding grants.[28]

Inter-disciplinary collaborations are an effective method to address complex issues and reach common goals in the health care system.[28] Through networks and communities of practice, research priorities and barriers to physiotherapist-performed POCUS could be identified. To move ahead in this area, a coordinated approach to physiotherapist-performed POCUS is needed. Although it is valuable to have local leaders in physiotherapist-performed POCUS, it will be important to move away from independent activity and different recommendations for policy, education, and practice in different jurisdictions. Briggs et al, suggest that siloed networks or organizations are less effective as there may be variability in resources, goals, and stakeholder interest across the health care continuum in different regions.[28] Working collaboratively with local leaders, a community of practice has the potential for a greater sphere of influence, more effective communication, and may facilitate the development of a comprehensive road map for education and implementation.[28]

Synthesizing the evidence in Chapters 2 and 3, provide an important starting point for this discussion. Researchers, clinicians, and policy makers need to acknowledge that physiotherapists are using POCUS in practice, and it is time to develop physiotherapist specific governance and oversight. Restrictive policies and relying on physicians to provide medical directives may limit the professions' ability to demonstrate the importance, expertise, and impact that physiotherapist-performed POCUS may have on patient outcomes and the health care system.

Strengths and Limitations

The systematic and methodological rigor of this novel research has been outlined in Chapters 2, 3, and 4. Given the similarities in methodology, the strengths and limitations of Chapter 2 and 3 are presented in Table 1. The strengths and limitations from Chapter 4 are well documented and have been summarized in Table 2.

Table 1: Strengths and Limitations of Chapters 2 and 3

	Strengths	Limitations
1.	Comprehensive search strategy that was developed, piloted, and peer-reviewed by a health research librarian	Over 19,000 studies were identified through database searching
2.	Followed the Preferred Reporting Items for Systematic Reviews and Meta-Analysis Extension for Scoping Reviews (PRISMA-ScR) reporting guidelines	Non-English language, review articles, and grey literature were excluded for feasibility
3.	Search strategies included as appendices in publication	16 missing studies
4.	Utilization of a referencing management software program (EndNote X8) and an internet-based review software (Covidence 2020 Veritas Health Innovation)	Only included studies where it clearly stated that the POCUS was performed by a physiotherapist or if the ultrasound operator was trained to use POCUS by a physiotherapist
5.	Completion of an a priori calibration exercise, k= 0.886 indicating a strong level of agreement	
6.	Two reviewers completed all phases of screening	

Table 2: Strengths and Limitations of Chapter 4

	Strengths	Limitations
1.	Physiotherapist underwent training for this specific application of POCUS at an accredited academic institution	Small sample size and the inclusion of a single physiotherapist and sonographer in the inter-professional agreement study
2.	Both the physiotherapist and the sonographer were blinded and	Limited to hemarthrosis of the elbow, knee, and ankle

	performed the POCUS scan according to a standardized scanning protocol using the same ultrasound machine in the clinic setting	
3.	High participant retention rate	Training for POCUS was specific to hemophilia
4.	Study procedures followed clinic processes and compared physiotherapist-performed POCUS to the traditional pathway in diagnostic imaging	

The methodological rigor implemented in this thesis minimized the likelihood of selection bias and allows for replication and future updates. The systematic and thorough approach to the review methodology ensured a comprehensive search of the literature and integrity of the data. A high level of consistency in the study selection process and data extraction summarized a very heterogenous body of literature and demonstrated the range and extent of physiotherapist-performed POCUS which can be used to inform future research. The fidelity to study methodology in each manuscript helps provide confidence in the findings which may help strengthen the credibility of the physiotherapy profession in the field of diagnostic imaging.[1] The strong retention rate indicates that participants were engaged in the study and valued the addition of POCUS to the assessment of hemarthrosis. As patients are key stakeholders, this may be an important finding for knowledge translation and clinical implementation.

Limiting to English language and excluding review articles and grey literature may limit generalizability. Studies were included if it was clearly stated that POCUS was performed by a physiotherapist or if the ultrasound operator was trained to use POCUS by a physiotherapist. This conservative approach along with the heterogeneity of the included studies and the limitations in study reporting, may have resulted in misclassification or missed studies. This approach may have minimized the likelihood that a citation was included in error but may also have resulted in the under-reporting of physiotherapist performed POCUS.

Screening the large number of citations obtained from database searching was time consuming and increased the duration of the data screening process. Recommendations for future updates include engaging a larger team of reviewers, revisiting the subject headings with a health research librarian to determine if more specific subject headings can be used, or if the search strategy can be modified to include fewer keyword synonyms for disease conditions and areas of practice. Also, over 80% of the studies were completed since 2010 therefore, future updates could limit the search to this date which may help maintain the breadth and depth of the review and produce a feasible number of search results.

In Chapter 4, the inclusion of a single physiotherapist and sonographer may limit the generalizability of the findings to physiotherapists with varying levels of experience and training or to other health care professionals, such as physicians and nurses, involved in the treatment of patients with hemophilia. Also, the sonographer had over 30 years of experience in musculoskeletal sonography, which may impact the application of the findings to the broader sonography and physiotherapy communities. Future studies should compare the competencies of sonographers with no musculoskeletal sonography experience to trained physiotherapists with the same years of experience in their respective professions. The physiotherapist received training that was specific to hemophilia and focused on the six joints that are easily accessible with ultrasound and are most affected by hemarthrosis (elbow, knee, and ankle). This may limit the generalizability of the results to more complex ball and socket joints, such as the hip and shoulder, and to physiotherapists working with other patient populations.

Other lessons can be learned from this pilot study. Given that it is expected that patients with hemophilia who are on prophylaxis regimens will have 2-5 bleeding episodes and 0.5 joint bleeds per year and the small sample size in this single centre study, larger, multi-centered efficacy and effectiveness studies are required.[34,35] The lack of attrition and the fidelity to the study procedures enhances data integrity and provides a realistic examination of blinding assessment processes, patient flow, and retention.[34] This information can be used to inform the methodology and may enhance the success of future studies.

Future Directions

The literature on physiotherapist-performed POCUS continues to grow each year, however gaps remain. With the goal of clinical implementation and best practices, further research is needed to continue to progress the scope of the profession and to support education and training in POCUS.

The scoping review presented in Chapter 2 demonstrated the breadth and depth of physiotherapist-performed POCUS. Although this review added substantive research to the emerging evidence on physiotherapist-performed POCUS, future research is needed to explore the patient and provider experience when POCUS is added to their clinical examination and/or physiotherapy intervention. It will be important to determine if there are barriers to clinical implementation from the provider perspective and if there are certain patient populations or interventions that are unsuitable for POCUS in a clinic setting. It will also be important to assess the importance of interprofessional collaboration with radiologists and sonographers as there may be a perceived infringement on scope of practice. Understanding the barriers and facilitators to physiotherapist performed POCUS will be a meaningful aspect of knowledge translation.[36] As mentioned above, qualitative research methods are ideally suited for these research questions.

As physiotherapists are using POCUS to help supplement the clinical examination and to enhance the quality and effectiveness of an intervention, it will be important to investigate the impact of POCUS on patient outcomes and experiences. Particularly, does the integration of POCUS into the physiotherapy profession, improve the safety, diagnostic accuracy, or performance of rehabilitative programs. Given the heterogeneity of the included studies, lack of a common terminology for physiotherapist-performed POCUS, and the limitations in study reporting, it will be important to consider these limitations as opportunities for future research. The creation of a community of practice via internationally accepted language for POCUS and improved reporting of study methodology, will assist with the further consolidation of the literature in this field and will help to engage key stakeholders to advance the scope of the profession in diagnostic imaging.

The scoping review presented in Chapter 3 demonstrated that progress in the development of a physiotherapy-specific, standardized, competency-based curriculum has been limited. Also, the heterogeneity in pedagogical approaches limited the ability to identify the most effective training method and to determine the ideal duration of training. To progress further in education, pedagogical approaches, and curriculum development, further research is needed to assess the value of training. As POCUS is a user dependent imaging modality and there is a potential for patient harm if it is used inappropriately or by untrained users, it will be important to determine if training (1) minimizes errors to ensure patient safety, (2) improves the reliability and validity of the measurements, (3) improves the sensitivity and specificity of the diagnosis, (4) improves competency in the acquisition and interpretation of POCUS images, and (5) enhances collaboration and engagement with key stakeholders in diagnostic imaging which may help to advance the scope of the profession.

Competency-based education has been proposed as a potential educational model for physiotherapy performed POCUS and should be a focus of future research. It will be important to investigate how best to integrate POCUS into pre- and post licensure curriculum. This could be done by introducing basic theoretical knowledge, fundamental practical skills, and the wide variety of applications of POCUS in the physiotherapy profession in pre-licensure curriculum. Post-licensure courses could then focus on didactic and practical training specific to the patient population or disease condition in which POCUS will be used. Focusing post-licensure curriculum on a specific application of POCUS may improve assessments of competency and help establish quality assurance processes, as the content can be clinically relevant and could be linked to existing ultrasonography standards that govern traditional imaging specialists. As post-licensure competencies and outcomes vary across conditions and anatomical structures, it will be important for POCUS users to limit use to the applications in which they have been trained and assessed.[7] This will be an important area of future study.

Building on the findings from the inter-professional agreement study presented in Chapter 4, further research is also required to explore (1) if storing POCUS images for future comparison impacts quality assurance processes and/or patient management as storing POCUS images is not current practice[37], (2) if the evolution of pathology influences interprofessional agreement, (3) the impact of physiotherapist-performed POCUS on health care costs, (4) if the McMaster University/Mohawk College POCUS Training Program can be extended to patients with other musculoskeletal injuries that could present with hemarthrosis, (5) the inter-professional agreement of more complex joints such as the hip or knee, and (6) the impact of varying levels of training and experience in POCUS. This pilot study provides a foundation for a multi-centre trial. A definitive trial will be an important next step to further investigate the safety and effectiveness of physiotherapist-performed POCUS in patients with hemophilia A and B.

To initiate practice change, it will be important to create multi-faceted interventions targeted at clinicians, educators, and policy makers.[23] This may include identifying key opinion leaders working collaboratively to form a community of practice, creating clinical practice guidelines for clinicians wishing to incorporate POCUS into clinical practice, and developing regulatory frameworks to guide appropriate use from physiotherapy professional colleges and licensing bodies.[23] It will be important to investigate facilitators and barriers to knowledge use and to tailor the physiotherapist-performed POCUS to the local environment.[36] Ensuring ongoing and iterative evaluation of the knowledge translation process will be important to ensure that all stakeholders are well informed and continuing to advance high quality research and clinical implementation of physiotherapist-performed POCUS.[36]

Conclusions

This dissertation included both knowledge synthesis and knowledge creation and added substantive evidence to the evolving literature on physiotherapist-performed POCUS. By consolidating the literature on physiotherapist-performed POCUS this dissertation helps to advance the scope of the profession in the field of diagnostic ultrasonography across all areas of practice. This thesis addressed several important gaps in the literature and highlighted that increased attention needs to be paid to education and training, creation of common terminology for physiotherapist-performed POCUS and improved reporting of study methodology. This thesis also suggests that following a short formal training program a physiotherapist can be trained to an optimal level of performance, interpretation, and quality, when compared to an expert sonographer. Future investigation including the impact of physiotherapist-performed POCUS on patient outcomes is warranted. This foundational work can be used to engage physician colleagues, researchers, physiotherapy regulatory colleges, educators, and other key stakeholders in POCUS to provide support for the incorporation of POCUS into physiotherapy scope of practice.

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