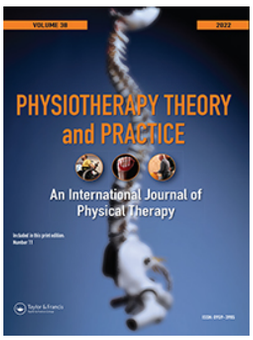

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Exploring the integration of diagnostic musculoskeletal ultrasound imaging into clinical practice by physical therapists

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ABSTRACT

Background: Musculoskeletal ultrasound (MSK-US) use for diagnostic purposes is expanding in physical therapy practice. Identifying and describing physical therapy-specific approaches to incorporating MSK-US into the evaluation process is needed. Musculoskeletal ultrasound extends the physical exam to allow clinicians to visualize anatomy and pathophysiology both statically and dynamically. Purpose: To document 1) weekly use of diagnostic MSK-US; and 2) clinical reasoning approach used in challenging patient cases by physical therapists (PTs) registered by Inteleos in musculoskeletal sonography (RMSK-certified).

Methods: Longitudinal, observational, cohort study using mixed methods for data collection and analysis. All 23 currently RMSK-certified PTs using MSK-US in clinical practice across the United States were contacted, and 16 participated. Data were collected using an online survey created with the Research Electronic Data Capture System. Participants documented MSK-US clinical use and significant cases using weekly, reflective, online journals for three months. Demographic data were summarized using descriptive statistics. Case data were analyzed thematically.

Results: Participating RMSK-certified PTs performed 1110 MSK-US examinations over 110 weeks. Clinicians averaged 7 (range 1–25) MSK-US examinations weekly, representing 28% of an average caseload. Examinations contributed significant anatomical/ pathological information 100% of the time. The most common joints scanned were the knee (n = 281), shoulder (n = 254), and wrist (n = 228). Case data revealed three themes: 1) augmenting the clinical evaluation to extend or narrow a diagnosis; 2) outcomes guiding action; and 3) lessons learned from clinical findings.

Conclusion: RMSK-certified PTs regularly used MSK-US to validate and refine their clinical diagnoses and treatment. Ultrasound imaging directly influenced patient care by informing the diagnostic process, guiding treatment, and appropriately identifying referrals.

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Introduction

Musculoskeletal ultrasound (MSK-US) is a valuable diagnostic tool because it can complement the physical examination by visually defining anatomy and pathophysiology (Jackson, Le, Kerkhof, and Corrado, 2021). The medical profession has embraced the potential of MSK-US across specialties and for a range of pathologies (Sconfienza et al., 2018). For example, a recent review of MSK-US use in geriatric care and rehabilitation listed many indications across diseases, injuries, and patient presentations (Can et al., 2017). Efficient clinical decision-making and improvements in patient outcomes and care have been demonstrated with the addition of diagnostic MSK-US (Smith and Finnoff, 2009).

In sports medicine the utilization of MSK-US has expanded exponentially due to its broad diagnostic capabilities that extend beyond the musculoskeletal system (Finnoff, 2016). Non-radiologist clinicians are rapidly incorporating MSK-US into clinical practice (Bureau and Ziegler, 2016). Physical therapist's (PTs) education and knowledge in musculoskeletal anatomy and physical examination skills positions them to incorporate diagnostic MSK-US into patient diagnosis and treatment approaches. The American Physical Therapy Association (APTA) research agenda and the Frontiers in Rehabilitation Science and Technology (FiRST) Council underscore that PTs can incorporate contemporary technology into practice to determine the effects of injury or disease (American Physical Therapy

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Association, 2020a; Goldstein et al., 2011). Physical therapists across the United States are first contact practitioners and can serve as primary care providers for musculoskeletal conditions (American Physical Therapy Association, 2021; Mabry et al., 2020). With increased autonomy and practice-based skills, PTs can diagnose a patient's presenting musculoskeletal complaints and if needed, appropriately refer to health care providers (American Physical Therapy Association, 2020b). If PTs incorporate MSK-US into their practice they might recognize benefits during the diagnostic process like other healthcare professionals.

Musculoskeletal ultrasound provides a missing visual dimension that PTs can employ to enhance diagnostic capabilities, improve patient care, and expedite referrals (Can et al., 2017; Whittaker et al., 2019). Musculoskeletal ultrasound can extend a clinical examination to visualize underlying trauma, disease, anatomical variations, soft tissue pathology, and dynamic motion (Paoletta et al., 2021). The diagnostic sensitivity and specificity of MSK-US for certain pathologies are comparable to magnetic resonance imaging (MRI) and computed tomography, minus the radiation risk and expense (Lento and Primack, 2008; Whittaker et al., 2019). Imaging by PTs, due to the ability for the clinician to visualize potential pathology can advance diagnostic accuracy leading to more efficient, effective, and economical interventions (Doria et al., 2015; Okoroha et al., 2019).

Despite the benefits of MSK-US, few American PTs incorporate this diagnostic tool into their personal scope of practice, defined as "activities for which a physical therapist is educated and competent to perform" (American Physical Therapy Association, 2020b). In contrast, diagnostic ultrasound has been adopted by European physiotherapists. Kooijman et al. (2020), reported that one in six Dutch physical therapy practices offer MSK-US. A potential reason for the slower adoption of MSK-US in the United States is that PTs are unaware of and/or untrained in its potential applications (Lesniak et al., 2014). Rundell, Maitland, Manske, and Beneck (2021) recently found that practicing PTs had less confidence in referring for MSK-US compared to other imaging methods including radiograph, bone scan, magnetic resonance imaging (MRI), and computed tomography (CT). Limited research has explored how PTs in the United States with expertise in MSK-US incorporate it into clinical practice as a diagnostic tool. The purposes of this study were to: 1) describe the weekly practice-based use (joints scanned, number of patients, contribution of information) of diagnostic MSK-US by PTs who were registered in musculoskeletal sonography (RMSK-certified); and 2) longitudinally document these clinicians' thought process, lessons learned, challenges, and treatment approaches in significant patient cases where they incorporated diagnostic MSK-US. We chose to study RMSK-certified PTs because they are early adopters of the MSK-US technology and have sought additional training to advance their diagnostic skills and expertise. To qualify to take the written RMSK certification exam offered by the Alliance for Physicians Certification and Advancement (APCA) organization which is governed by Inteleos, applicants must submit a third-party attestation documenting that the applicant has performed a minimum of 150 hands-on MSK-US studies on actual patients. In addition, a minimum of 30 MSK-US continuing education hours are recommended (Alliance for Physicians Certification and Advancement, 2020).

RMSK-certified PTs possess additional tools to assist with the clinical and decision-making process. Understanding how these RMSK-certified clinicians incorporate diagnostic MSK-US into clinical practice may provide insight for introducing this new technology into mainstream physical therapy practice. As MSK-US expands in physical therapy, profession-specific approaches to MSK-US use for diagnosis must be explored and identified.

Methods

A longitudinal, observational cohort study using mixed methods for data collection and analysis was conducted with physical therapist clinicians who were RMSK-certified. Institutional review board (IRB) approval was granted through Northeastern University (IRB #20-07-021).

Participants

Purposive sampling (Maxwell, 1996) was used to recruit study participants. Selection criteria included RMSK-certified PTs, practicing in the United States, and routinely using diagnostic MSK-US to supplement their clinical examination. Practitioners who are RMSK-certified were recruited because they possess advanced training, clinical reasoning, psychomotor skills, and professional behaviors that demonstrate the innovative use of MSK-US. A list of RMSK-certified PTs originated from the Academy of Orthopedic Physical Therapy (AOPT) database maintained by the APTA Imaging Special Interest Group president. Participants were excluded if they were not currently practicing or using MSK-US clinically. An international sample of PTs using MSK-US was not included because PTs from different countries have different entry-level training, scope of practice, licensure regulations, and practice patterns.

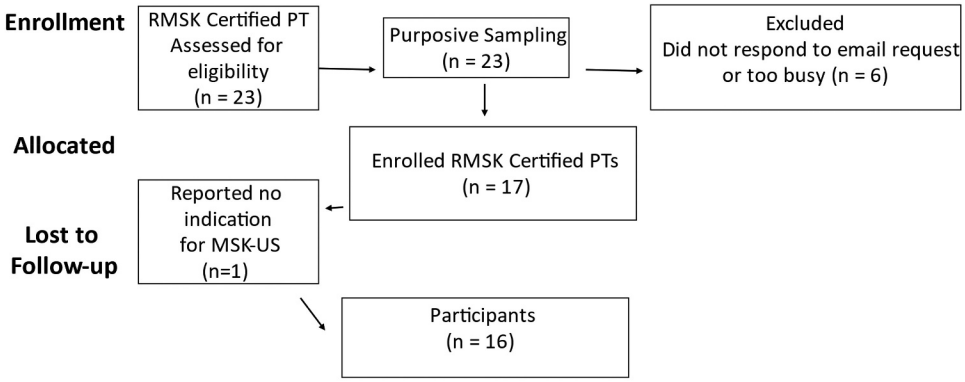

Figure 1. Participants flow. Registered in musculoskeletal ultrasound (RMSK), musculoskeletal ultrasound (MSK-US).

For this study, researchers sent a request to participate to all RMSK-certified PTs. Contact information for the participants, available through the AOPT database registry, and a Google search was used to generate e-mail invitations containing the recruitment script. At the time of the study, there were 23 RMSK-certified PTs in the United States. Of the 23 practitioners contacted, 16 RMSK-certified PTs currently using MSK-US for diagnostic purposes agreed to participate (Figure 1).

Instrumentation

An online survey was created by the researchers through the Research Electronic Data Capture System (REDCap™, version 9.3.2, Vanderbilt University, Nashville, TN). The researchers pilot-tested the survey process and questions with five MSK-US users for function, question logic, and the display of survey questions and answers in a web-based form. After the pilot test, the researchers modified survey questions to improve clarity, order, and reduce redundancy. These five pilot participants were not included as final study participants because they were not RMSK-certified.

Data Collection

Demographic characteristics

Using the RedCap™ online survey, data were collected on participant professional education level, clinical specialty, years in PT practice, and years as an RMSK-certified professional. Participants were also asked to report an average estimated weekly patient caseload. In addition, they were asked to rate using a five-point Likert scale (i.e. very often, often, sometimes, almost never, never) if they believed MSK-US contributed significant information to the clinical exam.

Weekly MSK-US usage

Data were collected weekly using a RedCap™ online survey for three months related to participant use of diagnostic MSK-US in clinical practice. Questions requested each participant to record if they used MSK-US, why they used it, how many exams were performed, and what body regions.

Weekly significant case- reflective questions

Each week, participants were asked to document and reflect on significant cases with whom they used MSK-US. A significant patient case was self-determined by each participant in response to a question asking them to: "reflect on how MSK-US contributed significantly to their learning during a patient encounter." Seven significant case reflective questions were collaboratively developed by the researchers based on existing literature and key concepts related to professional learning, development, and clinical reasoning in physical therapy (Embrey, Guthrie, White, and Dietz, 1996; Jensen et al., 2007; May and Dennis, 1991; Resnik and Jensen, 2003). The reflective significant case questions were provided to participants using the online REDCap™ system (Appendix). Weekly reminder notices with online links to the reflective questions were automatically generated. Completed reflective data were stored in a secure database using REDCap™.

Data Analysis

Demographic data on the 16 participants (70% response rate) were summarized using descriptive statistics. To summarize weekly MSK-US usage of the potential 192 weeks of data (16 participants multiplied by 12 weeks) 110 weeks of complete data were analyzed. Of the 82 weeks that were excluded, 34 weeks were

excluded due to participant noncompliance with data entry for unknown reasons, 47 weeks due to participants being out of office (i.e. vacation and administrative work), and one week due to MSK-US not being indicated. To accommodate for vacation, administration time, job changes, and COVID, only the weeks that participants reported seeing patients were counted.

Our research team was comprised of 6 individuals, 5 who are PTs and one who is a student research assistant. Two researchers have research doctorates and extensive research experience and 4 researchers have clinical doctorates in physical therapy. Five researchers work in academic institutions and 3 work between 8–15 hours per week in the clinic treating clients with MSK concerns. The principal investigator for the project is a skilled qualitative researcher, does not use MSK-US, trained the entire team on qualitative data collection and interview techniques, and led the data analysis efforts. Four of the researchers are experienced in the use of MSK-US for diagnostic purposes and have taught MSK-US in their respective academic settings with students. None of the researchers were RMSK-certified.

Seventy-two significant patient case reflections were completed by the 16 participants. The case information resulted in a written transcript. To analyze the case data, the researchers employed a constant-comparative method for case analysis (Morse, 2015). During content analysis, the raw data from the cases were organized manually by the researchers into patterns using codes developed that grouped data with similar meanings (Morse, 2015). Then, the resulting patterns were collapsed into major categories that best summarized the data at a higher level (Miles and Huberman, 1994; Thomas, 2006). The researchers met virtually to discuss the predominant patterns and codes that were developed. Triangulation was used by the researchers to maintain the consistency and trustworthiness of the qualitative data. Denzin (2012) described three forms of triangulation: 1) investigator triangulation where multiple researchers participate in the study; 2) data triangulation involves repeated data collection over time, space, and persons; and 3) methodological triangulation which uses multiple methods for data collection. This study used these three forms of triangulation. Three of the 5 researchers, represented diverse geographic locations and academic institutions served as a strategy of interpretative rigor in which developing patterns, codes, and themes within the data could be discussed and debated (Denzin, 2012).

The researchers discussed biases that might impact data collection and analysis through the process of reflexivity (Kitto, Chesters, and Grbich, 2008). For the current study, researchers discussed how they possessed a wide range of familiarity with MSK-US. Four researchers used ultrasound for teaching, clinical, or research purposes. One researcher did not use MSK-US. Thus, the research team had a balanced perspective which increased validity during the analysis process (Kitto, Chesters, and Grbich, 2008).

Results

Demographics

Sixteen participants completed the REDCap™ demographic survey. The participants averaged 18 years in PT practice (range 5–36 years) and 4 years of RMSK-certification (range 1–9). Other demographic variables such as education level, and American Board of Physical Therapy Specialties (ABPTS) certifications are listed in Table 1. The estimated average weekly total patient caseload was 32 (range 15–55 patients). Of the 16 participants, 12 (75%) very often, and 4 (25%) often indicated that MSK-US contributed significant information to the clinical exam.

One hundred and ten weeks of data revealed that the participants performed 1110 total MSK-US examinations. On average, 7 weeks of data were reported per participant, and the average number of weekly MSK-US exams was 7 (range 1–25), representing 28% of the participants' caseload (Table 2). The most common joints scanned (total number for sample) were the knee (n = 281), shoulder (n = 254), hand/wrist (n = 228), and ankle/foot (n = 175) (Table 3).

Qualitative Data

Analysis of the reflective significant case data resulted in three major themes: 1) augmenting the clinical evaluation to extend or narrow a diagnosis; 2) outcomes that guide action; and 3) lessons learned from clinical findings. Each theme is defined below, and participant quotes are provided from specific cases to illustrate each point. A reflective case count by theme with subthemes is reported in Table 4. The number of reflective quotes per participant by theme can be found in Table 5.

Theme one, augmenting the clinical evaluation to extend or narrow a diagnosis, described practitioners' thinking related to indications for using MSK-US. Practitioners used MSK-US to extend or narrow a patient diagnosis. As defined by the researchers, during the qualitative data analysis process, extending a diagnosis refers to looking for other causes of a patient's symptoms, while narrowing refers to

Table 1. Sample demographics. N = 16.

Participant #	Years in PT practice	Years RMSK-certified by Intelos	Education Level Terminal degree Post Graduate Education	Additional ABPTS * Board Certification
1	23	7	MSPT	Sports
2	35	9	t-DPT	
3	12	5	t-DPT	Clinical Electrophysiology
4	13	1	t-DPT	Orthopedics
5	8	2	DPT Fellowship in MSK-US	Clinical Electrophysiology
6	15	8	t-DPT	Clinical Electrophysiology
7	11	7	DPT Residency in Orthopedics	Orthopedics
8	36	1	t-DPT	Orthopedics
9	12	5	t-DPT	Clinical Electrophysiology
10	17	6	t-DPT	Orthopedics
11	32	4	t-DPT	
12	9	4	DPT, DSc Fellowship in Orthopedics	Orthopedics
13	32	1	MSPT	
14	5	1	DPT	Clinical Electrophysiology
15	7	1	DPT Fellowship in MSK-US	
16	14	2	DPT Residency in Electrophysiology Fellowship in MSK-US	

Physical therapy (PT), musculoskeletal ultrasound (MSK-US), American Physical Therapy Association (APTA), registered in musculoskeletal ultrasound (RMSK); transitional doctorate of physical therapy (t-DPT), doctor of physical therapy (DPT), masters of science in physical therapy (MSPT), doctor of science (DSc). American Board of Physical Therapy Specialties (ABPTS)

Table 2. Musculoskeletal ultrasound (MSK-US) frequency .N = 16.

Participants	Estimated average weekly caseload	Weeks of clinical data reported	Average MSK-US exams per week reported	Percentage MSK-US use per reported case load
1	15	3	2	13%
2	30	10	13	43%
3	25	1	1	4%
4	45	10	2	4%
5	35	12	25	71%
6	20	10	18	90%
7	50	8	3	6%
8	15	3	1	6%
9	30	12	22	73%
10	45	8	2	4%
11	15	12	9	60%
12	20	3	6	30%
13	15	8	2	13%
14	50	1	1	2%
15	30	8	4	13%
16	40	1	4	10%

Musculoskeletal ultrasound (MSK-US).

Table 3. Frequency of body areas imaged ordered head to toe N (%).

Total MSK-US studies performed	1110
TMJ (temporomandibular joint)	2
Cervical Spine/Neck	3
Shoulder Upper arm	254 (22.9%)
Elbow Forearm	105 (9.5%)
Wrist/Hand	228 (20.5%)
Thoracic Spine Ribs	3
Chest/ Diaphragm	0
Abdomen	3
Spine/Low back	7
Pelvis	1 (0%)
Hip/ Thigh	48 (4.3%)
Knee	281 (25.3%)
Ankle Foot	175 (15.8%)

Musculoskeletal ultrasound (MSK-US),

eliminating other potential causes for a patient's diagnosis. An example of extending the diagnosis and guiding the treatment is illustrated by participant 12, case #23:

> *"The patient presented with lateral elbow pain and a mix of joint and soft tissue pain. The pain limited the patient's ability to grip and move his elbow through full extension."*

Ultrasound was indicated for expanding the differential diagnosis due to the patient's presentation with pain and multiple signs and symptoms, resulting in inconclusive objective findings. The participant reported that:

Table 4. Reflective significant case themes, subthemes, and frequency. N = 72.

Theme	Subtheme	Case frequency (%)
1) Augmenting the clinical evaluation to extend or narrow the diagnosis	• Ultrasound used to explore patient complaint of pain	14 (19.4%)
	• Ultrasound used to assist with clinical decision making	10 (13.9%)
	• Ultrasound used to look for structural changes to explain patient symptom presentation	48 (66.7%)
2) Outcomes that guide action.	• Ultrasound used to guide treatment changes	54 (75%)*
		16 (22.2%)
	• Ultrasound used to guide treatment changes resulting in a referral	12 (16.7%)
	• Ultrasound use resulted in no change in treatment.	6 (8.3%)
	• Not enough data reported by the clinician.	
3) Lessons learned from clinical findings.	• Reflection by clinician to realize ultrasound use helped them to clarify a diagnosis	46 (63.9%)
	• Reflection by clinician who replied that ultrasound was used by them to hunting for alternative explanation of a diagnosis	10 (13.9%)
	• Reflection by clinician who realized that ultrasound use resulted in unexpected exam results	9(12.5%)
	• Not enough data reported by clinician.	7(9.7%)

The 16 referrals were included in the 54 treatment changes category.

"MSK-US revealed synovial thickening with hyperemia on doppler. These findings helped explain the pathological reason for his symptoms. I think this patient may have been assumed to have lateral epicondylitis and was prescribed an [exercise] dosing strategy that may have caused some discomfort. Knowing the correct diagnosis led to a more targeted intervention. I think in the future, I'll be more cautious before prescribing [exercise] dosing exercises. Perhaps [I'll be] more thoughtful with my differential."

Table 5. Number of participant reflective quotes by theme.

Participant	Theme 1 Augmenting the clinical evaluation to extend or narrow the diagnosis	Theme 2 Outcomes that guide action.	Theme 3 Lessons learned from clinical findings
1	1	1	1
2	10	10	10
3	1	1	1
4	12	12	12
5	8	8	8
6	4	4	4
7	3	3	3
8	1	1	1
9	1	1	1
10	8	8	8
11	3	3	3
12	1	1	1
13	11	11	11
14	0	0	0
15	7	7	7
16	1	1	1

Another way our participants used MSK-US was to narrow and subsequently refine a diagnosis. For example, participant 10 case #16 indicated that the patient presented with:

"typical [shoulder] impingement in abduction plane." MSK-US was used *"to determine the presence of bursitis, rotator cuff tendinosis, or tear."*

After viewing the anatomy, participant 10 noted:

"The patient had an interstitial tear in the right shoulder. At the greater tuberosity, I saw a dark hypoechoic region in the supraspinatus that indicated that the tear is most likely old and not acute. These findings will help steer my plan of care in a more conservative direction."

Theme two, outcomes that guide action, includes MSK-US findings that resulted in either a change in diagnosis or treatment, confirmation of diagnosis or treatment, or referral for a condition determined out of the PT's scope of practice. An example of using MSK-US to change a diagnosis is illustrated with participant 16, case #40. In this case, an RMSK-certified PT was consulted after physical therapy treatment had been initiated for a tensor fascia latae strain. Participant 16 indicated:

"I saw a teenager with the onset of pain after a sports-related injury. The patient was positive for pain and limited range of motion. The patient also had complaints of weakness and difficulty performing activities of daily living. The ultrasound findings showed an anterior superior iliac spine avulsion fracture with apophysitis. If these findings had been detected initially, then we would have avoided prescribing advanced exercises during his rehabilitation process."

As a result of the MSK-US exam, the clinician changed the diagnosis and treatment direction with referral to a specialist.

Another example, that illustrates the theme "outcomes that guide action" was the use of MSK-US to explore a symptom of pain. Participant 6, in case #3

received a patient with a diagnosis of medial meniscus tear. However, the participant indicated:

> *"the patient presented with marked effusion and pain over the pes anserine complex."* Through the use of MSK-US the participant noted that *"The medial meniscus looked fine, well there was a longitudinal tear, but without surrounding reactivity and there was no effusion in the popliteal cyst. There was major fluid accumulation but minimal hyperemia around the sartorius and gracilis tendons. The patient was referred to a sports orthopedic physician for possible platelet rich plasma injection."*

The result of the MSK-US exam allowed our participant to explore a patient's complain of pain, assist with clinician decision-making, understand the patient symptom presentation, and refer appropriately to a physician.

An example of confirmation of diagnosis and treatment is seen with participant 7, case #51. As participant 7 noted:

> *"I incorporated MSK-US with the physical exam and radiographic findings and determined that the rotator cuff tear was not high grade in nature. Based on this information, I held off referring the patient to an orthopedic physician. Shoulder 'impingement' is a wide-ranging diagnosis . . . from full-thickness cuff tear to bursitis. I used MSK-US to grade the pathology."*

Physical therapists in our sample also used MSK-US to rule out sinister pathology. An example where a participant ruled out a sinister pathology is participant 2, case #9, a 92-year-old man with an odd elbow lump. The PT documented that the lump was:

> *"not painful but was in the way [of elbow range of motion]."* The MSK-US revealed a *"distal, bicipital tendon bursitis versus the hypothesized metabolically active neoplasm."*

The use of MSK-US enabled the PT to rule out pathology and continue with the established plan of rehabilitative care.

Theme three, lessons learned from clinical findings, refers to the participant's reflective thinking about the MSK-US exam and how the findings can enable them to clarify, hunt for, and explore unexpected results that may impact future action. For example, participant 6, case #37 had a patient referred for posterior tibialis tendinopathy. The MSK-US exam revealed an unexpected result. The participant noted:

> *"Patient presented with medial ankle/foot pain upon walking and running. Inconclusive clinical exam, X-rays, and inability to reproduce/elicit symptoms. Ultrasound findings revealed partial muscle herniation of the abductor hallucis muscle and tenosynovitis of the flexor digitorum longus and flexor hallucis longus intersection."*

The MSK-US data was subsequently integrated into the clinician's decision-making process. As a result of the data collected using MSK-US, the clinician concluded:

> "This is a rare pathology which you normally do not expect in medial ankle pain presentation. For clinicians performing MSK-US, close attention to aggravating factors and subjective complaints is required."

The PT referred the patient to a specialist because they saw a problem that was unrelated to the original diagnosis, an unexpected and different pathology.

The theme of "lessons learned from clinician findings" is also illustrated by participant 11 in case #49. The patient was referred for verification of a right elbow hemarthrosis to determine appropriate levels of clotting replacement. Upon examination, using MSK-US, the clinician identified an extensive intramuscular hematoma to the flexor compartment of the forearm as well as evidence of a significant avulsion of the medial epicondyle. The participant stated:

> *"Ultrasound can be used quickly to uncover or rule out other pain causality, The moral of the story is to sonographically investigate the patient's area of concern and maintain a healthy check on one's diagnostic bias and selective inattention."*

Discussion

This study had two purposes; the first was to describe the weekly practice-based use (i.e. number of patients, joints scanned, and contribution of significant information) of MSK-US by PTs who are RMSK-certified. Based on our findings the RMSK-certified PTs in our sample judicially incorporated MSK-US in almost one-third of their weekly cases for diagnostic purposes. In addition, MSK-US contributed significant information to the clinical exam either very often or often. Musculoskeletal ultrasound diagnostic use has expanded in medical practice (Sharpe et al., 2012). It is routinely used in: sports medicine (Baloch et al., 2018; Finnoff, 2016; Hall et al., 2021; Jackson, Le, Kerkhof, and Corrado, 2021; Lesniak et al., 2014); musculoskeletal medicine (Lento and Primack, 2008; Okoroha et al., 2019; Sconfienza et al., 2018; Smith and Finnoff, 2009); hematology (Doria et al., 2015); and rheumatology (Xue, Luo, Zhao, and Jiao, 2020) as an important diagnostic tool.

In United States based physical therapy practice, case studies have documented clinician MSK-US use to explore: causes of pain (Burzynski et al., 2021; Mechelli, Probaski, and Boissonnault, 2008); and lung function (Leech, Bissett, Kot, and Ntoumenopoulos, 2015). Based on these studies in medicine and physical therapy, and in support of our findings, MSK-US has the

potential to contribute profession-specific information to a patient diagnosis. In addition, recent advancements in MSK-US technology including improved image resolution, increased portability, and reduced cost have made the tool accessible to more clinicians (Lento and Primack, 2008).

We examined the daily clinical application of MKS-US in physical therapy by body region. The most frequently scanned joints recorded in our study were comparable to those found in other studies and parallel the 2018 European Society of Musculoskeletal Radiology consensus paper on evidence-based indication for MSK-US diagnostic studies by region and pathology (Sconfienza et al., 2018). While the frequency of joints scanned could reflect patient populations, we believe that MSK-US adds important clinical information for these specific joints. The knee, ankle, shoulder, and wrist are among the most treated body parts across all settings of physical therapy (Klauser et al., 2012). One explanation for the frequency is that these joints are superficially located, anatomical structures that are hard to differentiate on clinical exam, and the function of these joints lend themselves to dynamic evaluation (Klauser et al., 2012). Musculoskeletal ultrasound provides anatomical insight related to specific pathology and verifies the integrity of complex anatomical structures (Jackson, Le, Kerkhof, and Corrado, 2021). Physical therapists are uniquely positioned to incorporate MSK-US into patient care due to their education in musculoskeletal anatomy and physical examination coupled with the profession's focus on physical health, movement, and function (American Physical Therapy Association, 2004). However, better preparation and mentorship are needed in two areas: for PT students to incorporate MSK-US effectively into future clinical practice (Hayward et al., 2022) and to increase confidence for using the tool for practicing PTs (Rundell, Maitland, Manske, and Beneck, 2021).

The second purpose of this study was to describe thought processes, lessons learned, challenges, and changes in treatment in significant patient cases in which the participants incorporated MSK-US. The reflective data provided additional insight into indications and applications for MSK-US use. Participants recorded 72 significant cases, which were summarized into three major themes that described the context in which MSK-US was used, how findings impacted clinicians' approach to clinical care, and self-directed learning through reflection.

As noted in theme one our participants used MSK-US to supplement a physical therapy clinical examination and to explore what structures could be causing pain, view structural changes that might explain a patient's presentation, and to understand inconclusive physical examinations that required differentiation between possible pathologies. The additional information provided by an MSK-US exam led the clinician to consider additional pathology. These findings are supported by Xue, Luo, Zhao, and Jiao (2020) who documented how physicians in China used MSK-US to differentiate between the anatomical features of two diagnoses-gout and rheumatoid arthritis. The authors concluded that MSK-US clarified a diagnosis because each disease possessed unique anatomical features that could be identified with ultrasound.

Ultrasound can be used by PTs to identify alternative hypotheses that could explain a patient's pain or physical presentation. Other clinicians use MSK-US to evaluate the structural integrity of the anatomy both statically and dynamically to narrow a diagnosis. Evidence supports that MSK-US can be as reliable as MRI to assist the decision-making process involved in narrowing a diagnosis such as: rotator cuff pathology (Farooqi et al., 2021; Sconfienza et al., 2018); patellar tendon pathology; ligament pathology; and nerve entrapments (Klauser et al., 2012). Another benefit of MSK-US compared to MRI is that it results in immediate findings which can inform treatment while avoiding wait time and costs associated with ordering advanced diagnostic imaging (MRI) (Farooqi et al., 2021). In these examples, MSK-US was used to identify possible hypotheses to explain the patient's pain or physical presentation. A common error in clinical reasoning is considering too few hypotheses (Jones, 1992). Incorporation of diagnostic MSK-US enables a clinician to treat pathology in addition to symptomology because one can visualize and identify the involved tissue (Klauser et al., 2012). Theme two described the benefit of MSK-US for patient management and outcomes. Gathering additional information using MSK-US can guide a clinician's action with respect to: treatment changes, referrals, and confirmation of clinical findings with no change to treatment or diagnosis. Because a MSK-US exam produces immediate findings, clinicians can implement real-time changes to the plan of care, provide appropriate treatments, and 'informed' referrals. Physical therapist administered MSK-US exams may decrease the need for duplicate services, which may result in improved patient care, and allocation of resources (Baloch et al., 2018; Bureau and Ziegler, 2016). Images provided objective data utilized by our participants to evaluate soft tissue, extend a diagnosis beyond an obvious presentation, and consult with physicians. Collaborative reasoning results in a collegial approach to establishing treatment goals, implementation, and progression (Higgs, Jones, Loftus, and Christensen, 2008).

Patients often present with nonspecific symptoms that do not indicate pathology. However, differentiating between innocent symptoms and serious disease can present a challenge for all health care providers, including physical therapists. Several case studies in the physical therapy literature have documented the utility of MSK-US to assist with differentiating possible sinister pathology resulting in appropriate medical referrals (Burzynski et al., 2021; Habibollahi, Lozano-Calderon, and Chang, 2022; Leech, Bissett, Kot, and Ntoumenopoulos, 2015; Mechelli, Probaski, and Boissonnault, 2008; Ramanayake and Basnayake, 2018). Musculoskeletal ultrasound can add information useful for expediting the identification of either a benign or possible sinister pathology. In one of our case examples, a physician sent a patient to physical therapy for back pain. Based on the PT's evaluation, the patient returned to the physician for an ultrasound. The diagnostic MSK-US differentiated between back pain and an abdominal aortic aneurysm, which resulted in a rapid diagnosis and reduced possibility of morbidity and mortality due to the patient having an aneurysm. If the PT had performed the ultrasound, time could have been saved and the patient would have immediately been referred to the emergency room. With more expertise and training in the use of MSK-US, PTs may assume a primary role in managing musculoskeletal conditions, validating diagnoses, and referring to appropriate health care providers.

Theme three illustrated the reflective thinking demonstrated by the participants about diagnostic MSK-US use and how exam findings can impact future action. In physical therapy, metacognition is the act of reflecting on clinical decision-making and identifying areas for improvement (Embrey, Guthrie, White, and Dietz, 1996; Martin, Siosteen, and Shepard, 1999; May and Dennis, 1991; Mostrom, 2007; Resnik and Jensen, 2003). For our participants, lessons learned from clinical findings involved using MSK-US to clarify, hunt for, or explore unexpected results. These actions were engaged because some aspect of the case was complicated, i.e., unusual presentation/complaint, multiple issues that required analysis, the patient's condition was not improving, need to refer, or treatment without having to refer out. For example, as described previously, participant 6 in case #37, had a patient referred for posterior tibialis tendinopathy but the MSK-US exam revealed a partial muscle herniation of the abductor hallucis muscle and tenosynovitis of the flexor digitorum longus and flexor hallucis longus intersection. Participant 6 reflected on the opportunity to learn more by visualizing the unexpected results, which allowed for clarification. In this instance, the PT identified a rare pathology using MSK-US and reflected on how future evaluations could be improved, thereby expanding his hypothesis.

In physical therapy, failure to consider enough hypotheses is a common error (type 2) in clinical reasoning (Jones, 1992). Many of our participants' reflective cases demonstrated the need to avoid errors in clinical reasoning. When our participants identified a mistake, reflected on it, they learned and grew as a professional (Schon, 1987). Research on the development of expertise in physical therapy has illuminated that a distinguishing factor of expert clinicians is engagement in self-assessment (Jensen et al., 2007; Schon, 1987) and metacognition (i.e. thinking about practice) which advances their clinical reasoning skills (May and Dennis, 1991; Mostrom, 2007; Pintrich, 2002). Our RMSK-certified participants, who possessed advanced training in MSK-US, documented their reflective thinking about cases they found significant to their learning and required MSK-US to explore and clarify unexpected results.

Transformative learning occurs in a learner (clinician) with the capacity to distinguish thinking (regarding a diagnosis), reflect on the adequacy of this thought process (diagnosis), and adopt a revised perspective (Mezirow, 1991). A catalyst for transformative learning occurs when the individual (therapist) encounters "murkiness" such as when a patient presentation is poorly defined or does not align with what is expected (original diagnosis) (Schon, 1987). Our data revealed that participants incorporated visual informational provided by MSK-US to confirm clinical decision-making. In addition, the participants demonstrated awareness through critical reflection on the underlying assumptions held about a particular diagnosis and chose to use MSK-US to confirm or refute their assumptions. The MSK-US tool enabled our participants to integrate additional data to validate, narrow, or extend a diagnosis. This type of thinking aligns with hypothetico-deductive reasoning (Edwards et al., 2004).

In physical therapy practice, learning new skills can be daunting and perplexing. The learning process can be augmented by incorporating reflection on experience to provide learners with a mechanism for exploring and making sense of the unexpected. Reflection on experience is one form self-directed professional development (Schon, 1987).

Limitations

Study participants were limited to 16 RMSK-certified PT clinician experts who use MSK-US in clinical practice for diagnostic purposes. In addition, the reflective data set was small and represents only 72 significant cases. As such, our sample may not be representative of all clinicians and students throughout the United States who

use MSK-US, which may limit the generalizability of these findings. It is unknown whether the opinions and experiences of the 7 experts who chose not to participate or could not participate would be similar to the 16 who participated in the study.

Conclusions

As demonstrated by the study participants, MSK-US can be an important tool to guide clinical reasoning, elaborate on the specific physiologic conditions of an injury, and complement the diagnostic process. Clinicians use MSK-US to validate and refine their clinical diagnoses. Integration of MSK-US into PTs' evaluation of musculoskeletal disorders provides vital diagnostic data that can supplement the clinical exam and guide clinical decision-making. Our research demonstrated that RMSK-certified PTs used MSK-US imaging to extend, narrow, or validate a patient's diagnosis. The imaging findings further influenced patient care by guiding treatment to include supporting or changing a treatment plan or identifying the need for medical referral, which may include identifying sinister pathology and expediting care. Consistent with clinicians in other medical fields, our participant's most frequently scanned joints were the shoulder, knee, ankle, and wrist. As MSK-US technology grows in use, researchers in physical therapy need to continue to explore understanding when and how the tool can be used effectively and competently by physical therapists.

Disclosure statement

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Appendix – Significant Case Reflective Questions

(1) Do you believe that any of patient cases that performed ultrasound on were significant to your learning?
(2) Please provide a brief description of your patient presentation.
(3) What was your clinical indication for using ultrasound imaging for your patient?
(4) How did your ultrasound finding impact your actions or patient outcomes?
(5) Describe your decision-making process with this patient.
(6) Were there any inconsistencies with either your diagnosis and or the referral diagnosis and your diagnosis post ultrasound imaging examination? Please describe.
(7) Describe. What about this case made you feel it was significant (atypical, learning)? Brought it to your attention? Please explain

Elements of Learning and Integration of Diagnostic Musculoskeletal Ultrasound Imaging Into Practice: Physical Therapists' Educational Journeys

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Introduction. Physical therapists (PTs) have the autonomy and expertise to assume a more significant role in the primary care of musculoskeletal conditions, validate diagnoses, and serve as a referral source to appropriate health care providers. Ultrasound diagnostic imaging has been identified as a high-priority area to advance science and innovation in physical therapy. Yet, few PTs are certified to incorporate musculoskeletal ultrasound (MSK-US) as a diagnostic tool into their personal scope of practice. Diagnostic MSK-US has unique benefits compared with other imaging modalities, and recent technological advances have reduced its cost and improved portability. However, no research exists describing the learning experiences and decision-making process of PTs who use MSK-US for diagnostic purposes. In addition, the educational process for learning MSK-US is not standardized. The study's purpose was to describe the learning and practice-based use of MSK-US by PTs registered in musculoskeletal sonography (RMSK).

Methods. Using purposive sampling, we attempted to recruit all 21 RMSK-certified PTs currently using diagnostic ultrasound in clinical practice across the United States. Sixteen PTs participated in the study. We employed a qualitative, multiple case study, phenomenological approach. Data were collected using an online demographic survey and one-on-one, semi-structured interviews.

Results. Sixteen interviews were conducted with RMSK-certified PTs. Data synthesis resulted in 5 elements: 1) self-directed learning; 2) educational process; 3) honing the skill and the role of mentorship; 4) diagnostic information; and 5) clinical application.

Discussion and Conclusion. Participants identified elements critical for post-entry level, life-long, applied learning and integrating diagnostic MSK-US into clinical practice. The participant learning process was self-directed and incorporated various materials and methods to improve diagnostic skills. Participants honed their skills through repetition and one-on-one mentorship. Supportive employment settings were integral for creating environments conducive to learning and integrating MSK-US into clinical practice. Our participants perceived that ultrasound imaging provided them with the missing visual dimension used to improve diagnostic capabilities, supporting the benefits of direct access.

Key Words: Musculoskeletal ultrasound imaging, Expertise, Diagnosis, Metacognition, Self-directed learning.

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INTRODUCTION

Twenty-six years ago, the American Physical Therapy Association (APTA) House of Delegates officially stated that physical therapists (PTs) are primary care providers.[1] More recent versions of this position were expanded to include primary care and direct access.[2] Currently, patients have direct access to PTs across the nation.[3] Physical therapists are assuming a more significant role as primary care providers for musculoskeletal conditions.[4] The reasons for the role change include efficient and effective patient care, as well as comparable patient safety compared with physician-initiated PT care.[4] With increased autonomy and expertise, PTs use their practice-based skills to diagnose a patient's presenting complaint, validate the diagnosis of a referring provider, and refer to health care providers where appropriate. The APTA research agenda underscores that contemporary technology can be used to determine the effects of injury or disease by PTs.[5] Diagnostic musculoskeletal ultrasound (MSK-US) is an example of contemporary technology that allows PTs to image tissues directly. The APTA Frontiers in Rehabilitation, Science, and Technology (FiRST) council has identified ultrasound imaging as a high-priority area to advance science and innovation in physical therapy. The FiRST council recommended that the profession incorporate ultrasound into practice, education, and research.[6]

These factors have contributed to a recent change in the profession's perception of the importance of diagnostic ultrasound imaging in physical therapy concerning the clinical

decision-making process.[6,7] Musculoskeletal ultrasound is part of PTs' professional and legislative scope of practice.[8,9] Musculoskeletal ultrasound is most often used for rehabilitation (eg, evaluation of soft tissue function and biofeedback—retraining of muscles); diagnostic (eg, evaluation of injury or disease), interventional (eg, guidance of needles for injections of medication), and research purposes.[10]

Few studies exist that quantify either the current state of MSK-US use by PTs in the United States or the education of Doctor of Physical Therapy (DPT) students in this technology. A survey conducted in 2014 on the status of diagnostic imaging curricula in DPT professional degree programs revealed that 98.1% (209 programs) introduce 5 imaging modalities: radiography, magnetic resonance imaging (MRI), computed tomography (CT), bone scans, and ultrasound. Despite an increased emphasis on including ultrasound imaging education in entry-level DPT programs in the United States, no standard exists with respect to when content is introduced, what content is included, and how students are assessed.[11] In addition, no consensus exists regarding how and to what extent to teach ultrasound, and what resources to provide faculty to assist them to teach imaging in DPT curricula.[11]

A recent 2021 survey conducted on PTs practicing in the United States described their attitudes, knowledge, and behaviors regarding diagnostic imaging.[12] Results indicated that 90% of requested images were for the musculoskeletal system, and PTs were most comfortable ordering plain radiographs and MRI over ultrasound and other imaging modalities. Participants indicated that the median number of hours of entry-level imaging training was estimated at 5 and that the education provided varied between DPT programs.[12] These attitudes and beliefs have contributed to the need to understand how to increase confidence in PTs for incorporating MSK-US as a diagnostic tool into their personal scope of practice, defined as "activities for which a physical therapist is educated and competent to perform."[13]

Musculoskeletal ultrasound is a focused area of ultrasound imaging. Registration in musculoskeletal sonography (RMSK) is a certification available to PTs through Inteleos.[14] Inteleos is a globally recognized medical certification organization that predominately trains physicians to become RMSK-certified. Inteleos is the only certification organization that provides RMSK certification for PTs. Being RMSK-certified enables a PT to be reimbursed, depending on the state and insurer type, for providing ultrasound for diagnostic purposes. Although there is no formal educational process for becoming RMSK-certified, RMSK certification offered through Inteleos requires that a clinician: 1) documents 150 MSK-US patient cases using a log sheet to demonstrate experience in the use of MSK for diagnosis; 2) completes 30 hours of continuing education training in the use of ultrasound; and 3) pass an online national specialty examination in ultrasound technology use offered under the Inteleos umbrella. Currently, only 21 PTs in the United States hold the RMSK certification. These 21 PTs have specialized training and certification in using ultrasound for diagnostic decision making in physical therapy.

Purpose

Early adopters, such as these 21 RMSK-certified PTs, can provide unique perspectives related to the educational, decision-making, and clinical experiences critical for introducing new techniques into mainstream practice and developing skill in clinical practice. Thus, the purpose of this study was to describe the learning processes and practice-based use of MSK-US by PTs who possessed RMSK certification. The information gathered from these therapists may identify the elements of learning needed to become proficient in MSK-US use.

REVIEW OF THE LITERATURE

Physical therapists are uniquely positioned to incorporate MSK-US into patient care due to their education in musculoskeletal anatomy and physical examination. Coupled with the profession's focus on physical health, movement, and function, the potential exists to develop innovative practice frameworks for MSK-US in physical therapy.[7]

Diagnostically, MSK-US has unique benefits compared with other imaging modalities, and recent technological advances have reduced costs and improved portability. The diagnostic sensitivity and specificity of MSK-US are comparable with MRI and CT without the radiation risk.[15,16] Evidence supports that MSK-US can be integrated into a clinical evaluation to visualize morphology, soft tissue pathology, and dynamic motion.[17]

Despite the enormous potential of MSK-US, surveys of PT faculty[18] and students[19] in the United States found that student competence was rated lowest for ultrasound imaging compared with radiography, MRI, CT, or bone scan.[18] Similarly, Rundell et al[12] recently found that practicing PTs had less confidence in referring for MSK-US compared with other imaging methods.

Surveys conducted in the United Kingdom, Australia, and New Zealand demonstrate that no internationally accepted training or competencies exist for MSK-US in PT practice.[16] Since the first published article on ultrasound imaging by PTs in the UK in 1980, attempts have been made to define and standardize its use and delivery.[16] However, considerable variability persists, including inconsistencies in terminology associated with PT use of ultrasound due, in part, to the various ways it is used across the profession.[16] Inconsistencies in the use of diagnostic MSK-US may reflect debate over the fundamental concept of diagnosis within the profession of physical therapy.

Evolution of a diagnostic framework for physical therapy has been described as a prerequisite to justify practice[20] that would include diagnostic imaging. Professional debate in the United States regarding physical therapy diagnosis and categorization of patient presentations is ongoing. Three decades ago, it was suggested that PTs consider patient problems with a different lens, outside the standard classification systems.[21] Physical therapy scholars have concluded that PTs' treatment choices were influenced by more than a pathological label and there was considerable professional uncertainty regarding physical therapy diagnosis and treatment.[22,23] From a physical therapy framework, a diagnosis is "the process of determining mechanisms by which the patient's physical health condition arises."[23] Musculoskeletal imaging by PTs can emulate the use by other professions to improve diagnostic accuracy leading to more efficient, effective, and cost-effective interventions.[24,25]

Since 2011, several articles have been written about MSK-US's potential role in physical therapy clinical care, education, and research.[24-31] Use of MSK-US in clinical practice is limited to a few clinicians. Recent advancements in technology and affordable devices make this the ideal time to promote MSK-US use through educational resources targeted for current and future practice. Physical therapists can adapt to changes in available technology and educators can prepare our profession to incorporate MSK-US effectively into clinical practice.

Research is needed to understand how experienced clinicians use MSK-US, which will bridge gaps related to the scope of practice and MSK-US specialized education needs.[16,32] The development of clinical reasoning skills is essential for physical therapy practice. Yet, limited information exists about the distinct knowledge, skills, and professional behaviors used in applying MSK-US for patient care and how to develop these skills in students and practicing PTs. Previous research that examined expert practice in physical therapy documented that a distinguishing factor of expert clinicians is that they continually engage in self-assessment[33] and metacognition—thinking about practice—that advances their clinical reasoning skills.[34-38] Physical therapist

use of MSK-US in clinical practice is in its early stages and the profession needs to develop a curriculum informed by experienced clinicians to educate students and practicing PTs about MSK-US in diagnosis.

Subjects

Purposive sampling[39] was used to recruit participants for the study. Criteria for selection included PTs who were RMSK-certified and currently using MSK-US for diagnostic purposes in clinical practice across the United States. We only queried the participants on their clinical usage of MSK-US. Participants were excluded if they were not currently practicing or using MSK-US in the clinic. We chose not to include an international sample of PTs using MSK-US because PTs from different countries have dissimilar entry-level training, scope of practice, licensure regulations, and practice patterns.

For this study, researchers sent a request to participate to all 21 PTs who were RMSK-certified from the Academy of Orthopedic Physical Therapy (AOPT) database that is kept by the APTA Imaging Special Interest Group president. Achieving RMSK certification, like gaining specialty American Board of Physical Therapy Specialist certification in other areas of physical therapy, is considered a step toward gaining expertise in the use of MSK-US. Certified practitioners were recruited because they are experienced in the learning processes, critical thinking, psychomotor skills, and professional behaviors that demonstrate successful use of MSK-US.

METHODS

Research Design

The investigators used a qualitative, multiple case study research method with a phenomenological approach.[40] Data were collected using an online demographic questionnaire and one-on-one, semi-structured interviews. Institutional Review Board approval was granted through XX University (IRB #20-07-021).

Instrumentation

Demographics were collected via an online survey created by the researchers through the Research Electronic Data Capture System (REDCap, version 9.3.2; Vanderbilt University, Nashville, TN). Demographic data were collected on participants' age, gender, professional education level, clinical specialty, patient load, and education related to diagnostic imaging. Four Likert scale questions asked participants to report on their use of MSK-US related to the diagnostic process (Appendix 1, Supplemental Digital Content 1, http://links.lww.com/JOPTE/A162).

Interview questions and probes were designed through a collaborative effort by the research team to explore participants' perceptions and experiences regarding MSK-US. The research team pilot-tested the survey link with 5 MSK-US users for function, question logic, and display of survey questions and answers in a web-based form. The interview questions were also pilot-tested before data collection with the same sample of 5 MSK-US users for face validity. After the pilot test, the researchers changed demographic and interview questions to improve clarity, order, and reduce redundancy. The pilot participants were not included in the final study because they were not RMSK-certified.

The final semi-structured interview (Appendix 2, Supplemental Digital Content 1, http://links.lww.com/JOPTE/A162) contained 14 open-ended questions in 4 general categories: 1) personal scope of practice journey to becoming an MSK-US user; 2) education pursued; barriers and facilitators for gaining skill in MSK-US; 3) mapping of the application of diagnostic ultrasound into clinical practice; and 4) vision for future use of MSK-US in physical therapy practice.

Data Collection

Contact information for the participants, available through the AOPT database registry and a Google search, was used to generate email invitations containing the recruitment script. Those interested in participating responded via email or phone. Nonresponders received another email or phone call after 1 week. Once participants agreed to be interviewed, they were enrolled in the study and sent the demographic intake form link via email.

After the demographic survey data were completed, the interview questions and instructions for the study were sent to the participant. As each clinician was enrolled, they were assigned an interviewer. Each researcher interviewed 3 to 4 participants. Interviews lasted between 45 and 60 minutes and were conducted remotely over the internet using Zoom (San Jose, CA), which features an automatically generated transcript file. After each interview, the researcher reviewed the transcript for accuracy. Once the transcript was cleaned, it was sent to the interviewee for a member check.[39]

Our research team comprised 6 individuals, all of whom are PTs. Three individuals have research doctorates and extensive research experience and 3 individuals have clinical doctorates in physical therapy. All researchers work in academic institutions and 2 work between 8 and 15 hours per week in the clinic, treating clients with MSK concerns. The principal investigator is a skilled qualitative researcher, does not use MSK-US, trained the entire team on qualitative data collection and interview techniques, and led the data collection and analysis efforts. Four of the researchers are experienced in the use of MSK-US for diagnostic purposes. Five researchers have taught MSK-US in their respective academic settings with students. None of the researchers were RMSK-certified.

Data Analysis

The researchers employed a constant-comparative method for within-case and cross-case analyses.[41] During content analysis, the raw data from the interview transcripts were organized manually by the researchers into patterns using codes developed that grouped data with similar meaning.[41] Then, the resulting patterns were collapsed into major categories that best summarized the data at a higher level.[42,43] The researchers met virtually to discuss the predominant patterns and codes developed.

The researchers took several steps to ensure trustworthiness in the qualitative data. Triangulation was used to maintain consistency and trustworthiness.[44] Denzin[44] describes 3 forms of triangulation: investigator triangulation, where multiple researchers participate in the study; data triangulation involves repeated data collection over time, space, and persons; and methodological triangulation, which uses multiple methods for data collection. This study used the 3 forms of triangulation. Six researchers, with diverse geographic locations and academic institutions, engaged in the data analysis for this project, serving as a strategy of interpretative rigor in which developing patterns, codes, and themes within the data could be discussed and debated.[45] Data sources included interview transcripts and the demographic survey data. The semi-structured nature of the interviews enabled the researchers to clarify comments and questions that arose during an interview. The structure of the coding and analysis process served as an additional strategy to ensure procedural rigor. Participant review of results was used as a form of participant triangulation and uses "member checking." Participant checking concurs with the recommendation by Morse[41] for prolonged engagement to enable a rich description of themes.

The practice of reflexivity requires that a researcher acknowledge personal experiences and biases that might affect data collection and analysis.[46] The researchers had a wide range of familiarity with MSK-US. Four of the

Table 1. Sample Demographics (*N* = 16)

Participant Number	Years in PT Practice	Years RMSK-Certified by Inteleos	Average Patient Caseload Per Week	No. of Patients on Which MSK-US Was Used Weekly	Education Level: 1) Terminal Degree; 2) Postgraduate Education	Additional ABPTS Board Certification
1	23	7	15	10	MSPT	Sports
2	35	9	30	20	t-DPT	
3	12	5	25	25	t-DPT	Clinical Electrophysiology
4	13	1	45	3	t-DPT	Orthopedics
5	8	2	40	15	DPT Fellowship in MSK-US	Clinical Electrophysiology
6	15	8	20	18	t-DPT	Clinical Electrophysiology
7	11	7	50	5	DPT Residency in Orthopedics	Orthopedics
8	33	2	15	7	t-DPT	Orthopedics
9	10	3	55	1	DPT	Orthopedics
10	17	6	45	8	t-DPT	Orthopedics
11	32	4	15	5	t-DPT	
12	9	4	15	10	DPT, DSc Fellowship in Orthopedics	Orthopedics
13	32	1	15	4	MSPT	
14	5	1	50	2	DPT	Clinical Electrophysiology
15	7	1	30	6	DPT Fellowship in MSK-US	
16	14	2	45	15	DPT Residency in Electrophysiology Fellowship in MSK-US	

Abbreviations: ABPTS = American Board of Physical Therapy Specialties; APTA = American Physical Therapy Association; DPT = doctor of physical therapy; DSc = doctor of science; MSK-US = musculoskeletal ultrasound; MSPT = masters of science in physical therapy; PT = physical therapy; RMSK = registered in musculoskeletal ultrasound; t-DPT = transitional doctorate of physical therapy.

authors used ultrasound for teaching, clinical, or research purposes. One author did not use ultrasound for any purposes. Thus, the research team had a balanced perspective, which increased validity during the analysis process.[46]

Roles of the Funding Source

The APTA Academy of Education supported this research but had no role in the design, conduct, or reporting of the results. External grant funds were used to compensate subjects for their participation and researchers for their efforts on study.

RESULTS

Demographics

Of the 21 participants approached, 16 (80% response rate) completed both the REDCap survey and the one-on-one interview. Demographic data on the sample of 16 participants were summarized manually using descriptive statistics (Table 1). Seventy-five percent of the sample identified as male, 62.5% identified as White, and the average age was 43.4 years (range, 31–74 years). The average total number of patients seen weekly was 32 (range, 15–55 patients). Clinicians used MSK-US, on average, with 10 patients per week (range, 1–25) or 31% of total caseload. Our participants consistently indicated that they experienced a reduction in the number of patients seen when their clinics were closed during the COVID pandemic. Data collection for our study occurred when the participants' clinics were open. The average number of patient visits was reported to be reduced due to the COVID pandemic. We did not request patient volume numbers before COVID.

Four questions used a Likert scale ranging from "never" scored as a 0 to "very often" scored as a 5; MSK-US was used very often or often by 12 participants to confirm a referral diagnosis. Ten participants indicated that they changed their physical therapy diagnosis either "very often" or "often" based on the MSK-US. Six participants indicated that "very often" or "often" MSK-US resulted in a physician referral. All participants practiced in orthopedic fields, including outpatient, sports medicine, performing arts, research, and consulting.

The educational experiences pursued by our participants are summarized in Table 2. No uniform educational plan exists related to either learning MSK-US or preparing for the RMSK certification exam. Fifteen of 16 participants learned how to use MSK-US by attending structured courses such as a professional conference and continuing education classes. Other

self-directed learning methods included reading journal articles, textbooks, and watching online videos and webinars. With respect to mentorship, 12 of 16 participants had access to one-on-one mentorship. One person had mentorship provided by a sonographer, 6 relied on PTs, and 5 were mentored by medical doctors.

Qualitative Data

Analysis of the interview data resulted in 5 major themes: 1) self-directed learning; 2) educational process; 3) honing the skill and the role of mentorship; 4) diagnostic information; and 5) clinical application. Table 3 contains additional illustrative participant quotes to support the themes. Based on our findings, a model was created to organize the thematic data into 5 elements describing our participants' journey to becoming proficient in the use of MSK-US for diagnostic purposes (Figure 1).

Theme 1 demonstrated that acquiring skill required self-motivation that included initiative, dedication, and a passion for self-directed learning of MSK-US. As participant 16 stated: "I know that I should learn a little more in the field of diagnostics, because when you know the root cause of pathology, then your physical therapy treatment is very effective." Hours of practice were required using a variety of methods and materials to learn how to use MSK-US for diagnosis. The following quote from participant 2 supports these statements: "I am obsessed with learning MSK-US. That obsession has motivated me and I've put in hours and hours of practice to learn it."

Theme 2 concerned the self-initiated educational processes to become skilled in MSK-US use. Participants understood that the complexity of learning how to use MSK-US required skills in many domains such as anatomy, pathology, ability to read and understand images, and ultrasound machine operation. The educational process was typically initiated with formal didactic instruction (continuing education or professional conference) as participant 9 stated: "…a structured course on the foundations [so] that you have a protocol. Those [elements] are like your home base as you start there." However, the need for skills in multiple domains was exemplified in the following participant 11's quote: "it was imperative for me to learn the basics, in terms of not only the physics, the anatomy, and knowing how to do [use the knobs on the] the screen from start to finish…"

Sustaining the educational process required a supportive supervisor and work environment, as well as access to the technology. Participant 4 stated: "It was helpful that we had an ultrasound machine in the office and my boss was really an advocate for MSK-US and she saw the benefits of it, so she pushed it forward and, so that was really fortunate for me."

Theme 3 illustrates that honing the skill required sustained, one-on-one mentorship due to the complexity of becoming proficient in MSK-US. Our participants benefited from a supportive environment that may include a community of learners also interested in learning how to use MSK-US, time for practice, access to an ultrasound machine, and one-on-one mentorship. Our participants indicated that mentorship was represented by a variety of people such as physicians, PTs, and sonographers. As participant 3 indicated: "I was personally mentored by a group of orthopedic surgeons. They called me the resident. An orthopedic surgeon helped me with the whole process. I struggled with the basics and revisited what I had learned. I learned from my mistakes and was guided by top surgeons."

Four participants did not identify a formal mentor who provided one-on-one sustained support. Lack of a formal mentor may indicate that these 4 participants did not believe the term "mentoring" captured their

Table 2. Educational Experience Related to Becoming RMSK-Certified (*N* = 16)

Participant Number	Clinical Mentor	Educational Experiences
1	Yes, PT	Conferences, continuing education classes, text books, and journal articles
2	Yes, sonographer	Conferences and continuing education classes
3	Yes, MD	Conferences, continuing education classes, text books, YouTube, and webinars
4	Yes, PT	Conferences and continuing education classes
5	Yes, PT	Conferences and continuing education classes
6	Yes, MD	Conferences and continuing education classes
7	Yes, PT	Home study and journal articles
8	No mentor	Conferences and continuing education classes
9	Yes, MD	Conferences and continuing education classes
10	No mentor	Conferences and continuing education classes
11	No mentor	Conferences and continuing education classes
12	Yes, MD	Conferences and continuing education classes
13	No mentor	Conferences and continuing education classes
14	Yes, MD	Conferences and continuing education classes
15	Yes, PT	Conferences and continuing education classes
16	Yes, PT	Continuing education classes, online videos, and text books

Abbreviations: MD = medical doctor; PT = physical therapist.

Table 3. Qualitative Themes, Subthemes, and Example Quotes

Qualitative Themes	Example Quotes
Theme 1. Self-directed learning	
Subtheme: Takes initiative Demonstrated self-motivation to devote time to learn how to use the musculoskeletal ultrasound.	"I then started to think that maybe it (MSK-US) could add to my clinical abilities, particularly from a rehabilitative standpoint…" Participant 1 "I am obsessed with learning MSK-US. That obsession has motivated me and I've put in hours and and hours of practice to learn it." Participant 2 "In 2014 I had a very painful ankle sprain that was initially diagnosed as simple. I needed to know the diagnosis. It turned out not to be simple but required a cast (split tear of the peroneus longus tendon with subluxation and complete retinaculum tear). This was the turning point for me. I diagnosed myself with ultrasound and the surgeon was impressed. It facilitated the whole management. 50/50 chance between cast versus ankle reconstruction surgery, not just Tylenol and ankle wrapping as was initially diagnosed. Afterward I decided it will be my mission to expand MSK-US awareness to other professionals (I took it personally)." Participant 3
Subtheme: Practice Repetition of the skill to learn how to use the modality.	"We [PTs] practice on each other, a lot like once we did that weekend with the formal training, we practiced with each other. We studied the material from the class, followed the videos, and then practiced on each other corrected each other." Participant 5 "Scanning, scanning, and scanning as much as possible. PTs are very hands on we're doers. I must have done 100 scans each week at that hospital and that helped me immensely, so I think a physical therapist finding a good clinic that allows them to do as much scanning as possible, build on that, that's vital." Participant 11 "The more practice to learn how normal tissue looks on a grey scale image. It was helpful to have my students or my coworkers sit as test subjects and practice scanning on them." Participant 14 "Along with the training we started practicing on our friends, colleagues, family members. Sonogram, when you see it (tissue) the first time it's only oceans and clouds, you see, so it needs a lot of personal training." Participant 16
Subtheme: Materials Use of reference materials, textbooks, anatomy and cadaver laboratories, online resources, technology, and practice time.	"European protocols, ESSR. That's I would say that's what I started first, because, those structures, those protocols for a joint region are very well written. And then the informal training was a lot of self-scanning, text articles, books." Participant 9 "Got the textbook by Jacobson that was vital for me. There was a lot of YouTube videos, courses online you can take that has educational didactic material you can watch and this helps with your knowledge of the ultrasound, and the images that you're viewing and the pathology." Participant 11 "Having X as a mentor and being able to listen to his tutorials on scanning each joint repeatedly with practice helped me get my skills. Reading the evidence in the journals and a student in-service were helpful." Participant 14
Theme 2: Educational process	"There were the CME courses continuing education. Some webinars that I've watched through the AIUM." Participant 4 "Exposure to even the same pathology but in different varieties of it would be useful…" Participant 7 "One of the things that I learned in my educational pathways is just learning the landmarks. Landmarks are vital and learning your ultrasound interfaces. Those are two optimal points in terms of helping learn about ultrasound and what I'm seeing on the screen. The last thing is always compare with the other side. Always compare with the non-symptomatic side." Participant 11 "The first step is to have an introduction lecture and DPT programs on imaging." Participant 14 "…it is operator dependent…you need hand eye coordination. You need to develop your skills and it is (in fact) motor learning. So, I'm lucky I have had both (didactic and practice). But I also embraced the difficulty and the natural progression of learning and embracing the initial awkwardness." Participant 15 "Know the foundation of it [MSKUS]. We learn anatomy in a different way as a physical therapist, and then when you become a diagnostician or when you become a sonographer you have to see the anatomy, not only in the

Table 3. Qualitative Themes, Subthemes, and Example Quotes *continued*

Qualitative Themes	Example Quotes
	proper textbook way, but dynamically when you examine the joints. You should know the difference when the muscles move or when the joints move. So that is something that you have to learn actively. You cannot just read the books or watch the videos." Participant 16
Subtheme: Sustaining the work environment	"We never really had a formal name it was really, we would get in you know I would get someone asked me - hey can you teach us, and I would broke those two guys, you know they get someone asked, and they brought me in. We put together a website at the time that's not even operational now we used for letting people know who we were and what we did. Then I learned through textbook reading, reading papers, clinical experience, and refining my own skills. I also connected with a sonographer from Georgetown where I was working at the time. I shadowed that clinician who used US. There were no good didactic courses for PTs it was new and early in the space, so we had to find our own way to educate ourselves and get proficient." Participant 1 "You increase your skills by being in the right environment. I was working with people that were trained surgeons." Participant 3 "Luckily, I got a chance at my company to enroll in the MSK-US training. They were offering the training for the RMSK certification in musculoskeletal ultrasound. In addition, training was offered for learning EMG conduction which is nerve conduction studies, and I enrolled in both." Participant 8 "I met some excellent doctors along the way, who have allowed me to cut my teeth in their office…. with orthopedic surgeons in diagnosing rotator cuff tears. We identified what type of tears, and then compared them to the findings in the operating room." Participant 10 "Hands-on seminars, which provided educational, ultrasound services for their staff, and of course people all over. I started off training under people. I was trained to learn the upper extremity and then the lower extremity. My second boss at the time, the owner at the clinic, was also training to be RMSK certified. So, I would get a little training from him. That training was more informal. I took a formal hands-on seminar course, which was a weekend course where you would learn protocols, anatomy, and to gauge how to go about performing a MSK-US case study from start to finish." Participant 11
Theme 3: Honing the skill and the role of mentorship	"As we were doing US on the patients, we also had our mentors. We used to do the patient case studies and send our images to the particular mentors. The mentors used to see the images and give us the feedback, how we are doing, what is going wrong, what we should be improving in our imaging." Participant 7 "That's where the mentorship comes in; I did not have a mentor. If you're trying to learn without a mentor along the way, that emotional cycle of change will keep you on the bottom. People get left out, people drop off, they get disenfranchised maybe think MSK-US is not for them. Having the mentor is part of the process, it helps you learn, facilitates that cycle of change, and allows you to develop and mature as you're learning the skill." Participant 10 "Having X as a mentor and being able to listen to his tutorials on scanning each joint repeatedly with practice help me get my skills." Participant 14
Theme 4: Diagnostic information	"So you just use ultrasound as something that helps us find that missing piece of the puzzle." Participant 9 "Oh, this is why and what's going on. And even at the back of the neck, and we do a study there to see a side-to-side comparison if it's a unilateral radiculopathy, is there any drop in paraspinal muscle mass between the right or the left. That's also a sign that maybe something's going on with the dorsal primary ramus or something like that or sign of atrophy. To determine if the lesion is more at the spine or more peripherally." Participant 11 "A patient tells me about his symptoms. And when I examine the patient, and I feel like we need more than just some range of motion examination, strength examination, or special tests. We need to dig deeper into the cause of the problem, then I feel that we should do the MSK-US on that particular patient. We need to get a very proper focused treatment for that particular condition to get the patient better faster. When I see the weak symptoms.

Table 3. Qualitative Themes, Subthemes, and Example Quotes *continued*

Qualitative Themes	Example Quotes
	And when we feel that treatment is going all over. So where should we focus. At that time, RMSK really helps us." Participant 13
Subtheme: Confirmation of the correct diagnosis	"MSK-US integrates a piece of the overall puzzle of physical therapy in a consultation. I see MSK-US as an extension of my evaluation and treatment, you know and it's you know part of all of the tools and then I tell patients to let your eyes and your hands be your number one tool, but MSK-US is a very useful adjunct." Participant 1 "When you've exhausted with your efforts of doing the orthopedic manual testing and you've got it refined down to what you feel your diagnosis and your differentials are giving me a chance to help you further refine that down by by adding the component of looking at the tissue." Participant 2 "The benefits are that I can see the patient's problem and more. It's much more than just imaging. Using the US, I can get an accurate diagnosis. I can be accurate in my differential diagnosis. I also increase patient confidence. I can tell the patient to look at the screen and see evidence for their diagnosis. I can use this evidence for follow up. We can do a pre and post physical therapy treatment comparison. There is no radiation, so the US is safe, and it is fast. The patient does not have to be sent for a diagnostic test somewhere else. We can save the patient unnecessary treatments cost and inconvenience." Participant 3 I use MSK-US an adjunct to my exam process and clinical reasoning, I don't use it immediately but after getting an idea of what's going on with the patient's history and comprehensive physical exam and if I have a suspicion of something that's going on, especially if the patient hasn't seen a doctor and I if I think the image will help to either ruling in or rule out a specific problem. Participant 4 "Okay, we think is a shoulder tear, but there's something going on with the neck there as well. So, let's try to differentiate so the clinical process of using the ultrasound is to confirm, okay, it's definitely the shoulder because all the special tests and tests that we did on the shoulder were all positive, but he's also in a lot of pain. So, how can we confirm that is just a rotator cuff issue when it's just pain, right. So, that's the clinical process I go through in terms of using ultrasound just to be a help differentiate between multiple causes of what could be causing something." Participant 11 "MSK-US gives you an inside look at the integrity of the soft tissue (tendon, ligament) and the PT can advance a patient's program with that in mind. Often times a patient may present better during a physical exam despite poor tissue integrity. This allows the PT to advance the patient more appropriately." Participant 14 "I had patient with pain in the back of the knee, horrible pain. He had severe hemophilia, ankle effusions, but he liked to hike with his wife. The knee pain was bad and the knee swelled up. The couple wanted to know what's going on, "do I have blood to my joint?" I checked it out and it had a different presentation clinically. And then I looked at the structures and something was afoul and I thought my first best guess was a lateral gastroc strain at the proximal medial head. And yet (with MSKUS), it just wasn't and there's no hematoma in that area. It's a matter of looking at "where does it hurt?" I palpate and the patient went "ouch," I put the ultrasound short axis on longitudinal axis. I mean, no one's told me about THIS type of injury. I had XX to consult. He emails me back, this is a semimembranosis avulsion tear." Participant 15
Theme 5: Clinical application	"MSK-US gives you an inside look at the integrity of the soft tissue (tendon, ligament) and the PT can advance a patient's program with that in mind. Often times a patient may present better during a physical exam despite poor tissue integrity. MSK-US allows the PT to advance the patient more appropriately." Participant 1 "For the clinical reasoning process, I use ultrasound to evaluate thickening of ligaments or tendons or use it as a guide if somebody is tender to palpation. I might scan for the tissue involved if I feel lumps when I'm palpating, I might scan for a referral or follow-up. For example, if a wrist has a Baker cyst I use ultrasound for objective measurements." Participant 14 "As a physical therapist and as a consultant. I work half of the time in a physical therapy clinic and half of my time as a consultant, I work with a

Table 3. Qualitative Themes, Subthemes, and Example Quotes *continued*

Qualitative Themes	Example Quotes
	specialist. Doctors like a rheumatologists and neurologist, I do sonograms in their office, check the needles, the joints, and I sent them the reports. I can give an example of the type of people that I use sonograms with, it includes a young population. And the patients with sports related injuries, geriatrics, and rheumatology. The joint battle oh geez, you know, arthritis. So, it's a mix of everything." Participant 16
Subtheme: Patient education	"the patients feel part of the process, they can see what and how their body is moving on the screen…ultrasound is really helpful for communicating with your patient, elite athletes in the NBA, and other professional athletes. Much of it is reassurance and showing them and reassuring them and helping them in that way, seeing that have impact on patients help and how it helped clinically was the impetus to going further." Participant 1 "I also increase patient confidence. I can tell the patient to look at the screen and see evidence for their diagnosis. I can use this evidence for follow up. We can do a pre and post physical therapy treatment comparison. There is no radiation, so the US is safe, and it is fast. The patient does not have to be sent for a diagnostic test somewhere else. We can save the patient unnecessary treatments, cost, and inconvenience." Participant 3 "One of my biggest reasons why I love ultrasound is you get patients that come in, and they say they can't move the knee, the knee is done, they have arthritis, the doctor said their knee is bone on bone. Then you're doing the scan, the sunrise view's beautiful, everything's fine, no ligament damage, tendons are fine, and that's proof you can show to a patient." Participant 11 MSK-US is interactive for the patient and we can educate the patients with the images." Participant 12
Subtheme: Interprofessional education	"I work as a diagnostician and do scans for doctors whose patients I work with in PT, and with the local physicians at medical clinics and urgent care centers when they identify that a person needs to have MKS-US done." Participant 2 "I was in a unique setting because I was also board certified in clinical electrophysiology. So I was collaborating with physicians and surgeons and practicing clinical electrophysiology, doing EMG tests." Participant 6 "And then the second scenario is that US is a great tool as you can collaborate with other health care providers." Participant 9

Abbreviations: AIUM = American Institute of Ultrasound in Medicine; CME = continuing medical education; EMG = Electromyography; ESSR = European Society of Musculoskeletal Radiology; MSK-US = musculoskeletal ultrasound; NBA = National Basketball Association; PT = physical therapy; RMSK = registered in musculoskeletal ultrasound; t-DPT = transitional doctorate of physical therapy.

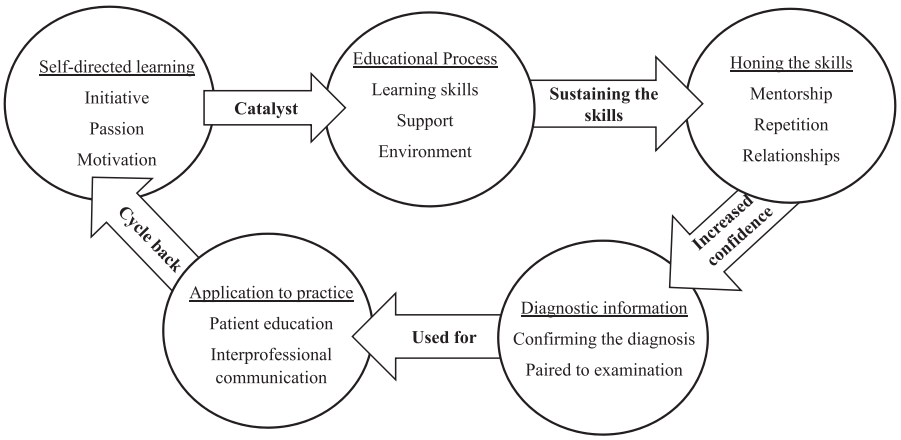
experiences. Three of these participants had been in the physical therapy field for 32–33 years and one participant for 17 years and learned to use the MSK-US technology on their own. Even without a formal mentor, these participants did find clinicians to informally guide their learning by providing intermittent coaching and/or sponsorship. Corroboration of this statement is provided by participant 10, who had been a PT for 17 years, who stated: "I met an orthopedic surgeon, who was pretty good at ultrasound, at a time when I was intermediately skilled. He took me under his wing a little bit and helped me get better, but outside of that, no mentor." Participant 8, who had been a PT for 33 years, indicated: "I learned through textbook reading, reading papers, clinical experience, and refining my own skills. I also connected with a sonographer from XX where I was working, and I spent some time shadowing. Back then, there were not good didactic courses for PTs, MSK-US was very new and we were very early in the space, so we found our own way to educate ourselves and get proficient."

Theme 4 illustrated the cyclical process of the feedback obtained from gathering diagnostic information by our subjects to support a differential diagnosis. As stated by participant 5: "Our decision making for the patient's PT management is based on clinical testing but once we do the MSK-US and see that there is something else, such as if a patient has a tendinosis and a partial tear, the MSK-US image changes our whole protocol." Theme 5 depicted how participants learned to use MSK-US in clinical practice, for referral, and to guide the plan of care for progressing or regressing treatment. MSK-US was also used by the participants to increase a patient's confidence in the diagnosis, and course of treatment, as illustrated by the following quote from participant 16: "When the patient sees the screen we educate them, because of this [visual information] everything has a purpose. Everything is done to get the patient better. And when the patient understands that, which is very clear and thorough with ultrasound, then the PT treatment is more effective and efficient. Patients attend physical therapy treatments and see improvement, because we do the ultrasound pre- and post-physical therapy."

DISCUSSION

The purpose of this research was to describe the learning and practice-based use of MSK-US by RMSK-certified PTs. This group used diagnostic imaging frequently for examination. Analysis of 16 clinician interviews elucidated 5 essential elements describing their professional journey to become proficient in MSK-US use for diagnostic purposes. The data from these clinician perspectives resulted in a model that contained 5 elements emerging from the thematic data (Figure 1). The elements were tightly integrated and described how a participant's learning and growth for using MSK-US was self-directed, influenced by the contextual surroundings,

Figure 1. Professional Journey to Proficiency in MSK-US



and guided by mentors in the clinical practice community who value MSK-US. Data collected through MSK-US was used to confirm a diagnosis, guide treatment, referral, and patient education. Figure 1 and elements represent a cycle that is iterative and continuous, which motivates a practitioner to continue to learn in a manner that is self-directed and collegial if they are part of a community of learners who value MSK-US.

Regarding element one, specifically, for our RMSK-certified participants, the first step in the development of skill relied on self-initiated and self-directed learning. Knowles[47] provided an early definition of self-directed learning, which describes how an individual diagnoses their learning needs, seeks learning experiences, locates essential resources, and evaluates their learning outcomes. Professionals in many fields are defined by their continual initiative for self-assessment[48,49] and metacognition or reflective self-awareness[50] that results in self-directed professional growth. Developing expertise involves more than accumulating skills and knowledge; it is the thinking about the action that results in growth. Reflection is a strategy used by professionals for thinking and acting either on (after) or during (while) practice.[48] Reflect-in-action or during novel or challenging experiences can lead professionals to develop habits of professional development that are self-directed.[48] The process of becoming a skilled clinician is a journey of personal awareness (metacognition) and discovery. Learning through experience is cyclical and dynamic, as well as subjective and personal. Our participants demonstrated initiative to learn MSK-US that was self-directed, dynamic, cyclical, and personal.

Self-directed learning was a catalyst for the educational processes in element 2 (Figure 1). Although not all PT MSK-US participants began the process with formal training or instruction, most recognized that introduction of MSK-US technology through didactic instruction was useful. However, the participants acknowledged that becoming skilled in the ultrasound tool was critical and required multiple information sources. Our participants diagnosed their learning requirements and realized the need to integrate multiple sources of materials—books, internet, laboratory courses, and protocols to understand the various elements that comprise the practice of MSK-US, as supported by Knowles.[47]

An environment that supports the development of MSK-US skills, such as possession of the technology, knowledgeable coworkers, access to mentors, and time for practice, was essential for sustaining and extending the learning and development of knowledge.

Self-directed learning is context-specific and nurtured by supportive environments.[51] For our participants, the workplace environment in the early stages of learning MSK-US, inclusive of a supportive supervisor, provided a vital space for developing meta-cognitive skills in the context of actual practice. Situated learning focuses on the relationship between learning and the social context in which learning occurs.[52] A learner acquires skill by engaging in a community, such as those interested in MSK-US, with a goal of mastery. In the early stages of skill development, participation enables the learner to be situated within a social context of learning with limited risks. With increasing confidence in a skill, the learner allows them to gain access to knowledge and understanding through growing involvement and community membership who value MSK-US.[52]

Element 3 of Figure 1 described continual knowledge development, which most our participants identified as requiring sustained, one-on-one mentorship. Mentorship is defined as a relationship that facilitates knowledge and perspective sharing between a mentor and a novice mentee.[53] Collaborative learning represents a unique combination of: a domain of knowledge; a community of people invested in the domain; and shared practice for developing skill in the domain.[52] A goal of the mentorship relationship is to promote professional development and self-actualization.[53] Self-directed adult learning can isolate learners if it is not situated within a collaborative learning community.[52] In health care, mentorship can assist the mentee in seeing the connection between theory and clinical practice.[54] Collegial, experiential, and reflective learning generated within a practice environment allows the mentee to analyze and discuss different approaches to their work and shape their current actions, beliefs, feelings, and values. Within a shared learning context, collaboration between mentors and mentees can result in the generation of new knowledge through common experience.[52,55]

The first 3 elements of Figure 1 document the self-directed educational journey of our participants who had chosen to develop skill in the use of MSK-US for diagnostic purposes. Our results are supported by the work of Jensen et al[56] on excellence and innovation in PT education. Jensen et al call for researchers to identify educational pathways of "people who seek excellence." Through our research we have attempted to understand what values are shared and the education required by RMSK-certified PTs to learn how to use MSK-US for diagnostic purposes.

Although these findings reflect a small sample of PT clinicians, we provide suggestions for the general physical therapy education community. The first is to introduce ultrasound technology and the advantages for patient care management early and longitudinally within the DPT curriculum. MSK-US can be used as an adjunct learning tool for students to gain fundamental knowledge of the technology, see the anatomy, and demonstrate clinical applications. For our participants, a catalyst for learning MSK-US was exposure to the tool. In both medical and physical therapy education, exposure to the use of ultrasound to teach anatomy increased student's motivation and confidence for using it.[57] MSK-US could also be incorporated in laboratories in, musculoskeletal, anatomy, clinical integration, and cardiopulmonary courses, for example. The data suggest that students may need to reach a minimal level of competence before they are able to benefit from the visual feedback offered by ultrasound.[58]

Further recommendations for general physical therapy education community are supported by Jensen and colleagues.[56] These authors recommend that key stakeholder groups, such as academic institutions, professional organizations, APTA fellowship, residencies, and specialties, be identified for

intentional partnership to accelerate the adoption of novel diagnostic approaches. Our work supports that the development of skill in MSK-US requires self-directed learning—which incorporates opportunities for intentional self-reflection either through journaling or through discussion on developing knowledge with a community of learners who value MSK-US. Other elements include a supportive environment that includes access to ultrasound technology, time for practice with the technology, and clinical mentorship to guide the learning and clinical application process. For example, mentorship in DPT programs on the use of MSK-US could be provided by intentionally pairing DPT students with clinicians experienced in this skill as part of the curriculum expectations during clinical rotations. For our sample of clinicians, continued skill refinement required ongoing professional development coursework that included specialty certification, residencies, and fellowships.

Element 4 (Figure 1) illustrated the thought process that arose during the observation and gathering of information by our participants to support or refute a differential diagnosis. Element 4 is supported by the first 3 elements of self-directed learning, which was a catalyst for the educational process, that was sustained by mentorship and increased participant confidence for using MSK-US during the diagnostic process. Transformative learning occurs in a learner (clinician) with the capacity to distinguish thinking (regarding a diagnosis), reflect on the adequacy of this thought process (diagnosis), and adopt a revised perspective.[59] A catalyst for transformative learning occurs when the individual (therapist) encounters "murkiness" such as when a patient presentation is poorly defined or does not align with what is expected (original diagnosis).[48,59] Our data revealed that participants incorporated visual information provided by MSK-US to confirm clinical decision making. In addition, the participants demonstrated awareness through critical reflection on the underlying assumptions held about a particular diagnosis and chose to dig deeper and look below the surface using MSK-US. The MSK-US tool enabled our participants to integrate another piece of the diagnostic puzzle to help them validate or extend a diagnosis using a reliable tool. This type of thinking is in line with hypothetico-deductive reasoning.[60]

In the clinical setting, findings from the history and physical examination are synthesized with MSK-US imaging for screening or diagnosis purposes. The value of ultrasonography for screening purposes is immediate, rapid, and noninvasive and provides information about many different physiologic systems.[61] An example of screening is illustrated by ultrasound imaging for a possible aortic aneurysm when a person presents to physical therapy with low back pain.[62] In this case report, a person with sudden onset of constant, deep, and boring low back pain was not relieved by changes in posture or time of day. PT examination of the lumbar spine, pelvis, and hip regions did not result in altered symptoms and minimal impairments detected. However, a strong nontender, palpable pulse was noted over the left lateral lumbar region, with the patient lying prone. These symptoms caused the PT to refer the patient for an abdominal ultrasound, which revealed a 10-cm-diameter abdominal aortic aneurysm.

Diagnostically, a series of focused ultrasonographic examinations can be used to efficiently diagnose or rule out certain conditions.[61] MSK-US has acceptable diagnostic accuracy for a wide spectrum of musculoskeletal conditions.[63] An example of MSK-US for differential diagnosis in physical therapy is case report of a soccer player who presented with anterior thigh pain felt during a soccer game that resulted in a popping sound, immediate pain upon decelerating, edema, and ecchymosis along the anterior mid-thigh. In this case, MSK-US was used to differentiate a contusion of the quadriceps femoris, avulsion fracture of the anterior inferior iliac spine, complete quadriceps femoris rupture, and other specific quadriceps femoris strain.[64] Current research of MSK-US focuses on screening and diagnostic capabilities, so data remain at the level of diagnosis rather than outcomes.[65]

There are parallels between the rapid rise of MSK-US and curriculum development for medical fields over the last 2 decades and the potential use of MSK-US by clinical PTs. Patient populations are similar and require a differential diagnosis process, and professions need to incorporate this new technology into training programs. As a result of the rapid increase in MSK-US by nonradiologist physicians, it has become a mandatory Accreditation Council for Graduate Medical Education requirement for physical medicine and rehabilitation residency training.[66] Programs require that residents have progressive responsibility in diagnosing conditions commonly encountered and include the use of MSK-US. However, barriers to teaching MSK-US in medical schools and residencies include insufficient expertise of instructors, poor access to equipment, and lack of a structured curriculum.[67]

Element 5 (Figure 1) concerns how MSK-US was used by the participants for referral, progressing or regressing treatment, and educational purposes. Our participants reported that images provided by the MSK-US tool were incorporated with their examination of the patient and a specific situation. The clinician action was contextual and reliant on a particular patient, provider, or clinical encounter. For our participants, the first 4 elements of Figure 1 described a process for them to gain confidence for incorporating diagnostic information gathered from MSK-US for use during clinical practice.

Our participants used images as a critical source of evidence in their decision-making process to analyze and make meaning of symptoms articulated by a patient or provider.[68] Images provided objective data that participants could use to evaluate soft tissue, extend a diagnosis beyond an obvious presentation, and consult with physicians. Collaborative reasoning results in a collegial approach to establishing treatment goals, implementation, and progression.[68]

Direct ordering of diagnostic imaging by PTs in nonmilitary settings is uncommon and payment data are limited. Insurance entities may require preauthorization and/or a physician referral. In addition, reimbursement is variable by geographic region and insurer.[9] For PTs to bill for MSK-US use, they must be RMSK-certified. However, even if RMSK-certified, it may not guarantee reimbursement by all insurances for all people, for MSK-US services related to scanning soft tissue (joints, muscles, nerves, tendons), and ultrasound-guided therapeutic procedures, such as dry needling.[9]

Finally, images were used to instill confidence in patients regarding a diagnosis, treatment progression, need for referral, and educational purposes. This type of strategy is referred to as interactive reasoning, which is influential in establishing and managing therapist–patient rapport.[60] As with experts in other fields, a cycle of reflective practice is completed by returning to the original starting point of self-directed learning as a process for continued development.

Limitations and Future Research

Study participants were limited to 16 RMSK-certified clinicians who use MSK-US in clinical practice. As such, they may not be representative of all clinicians and students throughout the United States who use MSK-US, which may limit the generalizability of these findings. It is not known whether the opinions and experiences of the 5 clinicians who chose not to participate or could not participate would be similar to the 16 who participated in the study. Also, this research was limited because it did not follow the clinicians longitudinally. Thus, more research is indicated to better understand and examine

the longitudinal development of MSK-US clinical reasoning in PTs.

In addition, research to explore the specifics related to the appropriate number of continuing education courses, hours of training, and specific training programs could be useful for delineating a clear educational path for RMSK-certification. Future research is needed in the development and implementation of pedagogical strategies for developing expertise in MSK-US and measurement of student outcomes and patient satisfaction. The small number of PT certified in RMSK will unlikely meet the clinical education and mentorship required to expand PT personal scope of practice in MSK-US imaging.

CONCLUSION

Our study described the learning processes and practice-based use of MSK-US by PTs, who possessed RMSK certification. The findings report on post-entry-level participants, which underscores the importance of life-long learning for both DPT student and clinicians. The information gathered from these individuals allowed us to identify 5 elements of learning (Figure 1) they used to become proficient in MSK-US. Our findings were consistent with previous research that described the development of professional skills. Our research describes how thinking, performing, and action by RMSK-certified PTs in the use of MSK-US involve habits of self-directed learning in physical examination skills. Ultrasound imaging provides a missing visual dimension that PTs can use to improve diagnostic capabilities and validate the benefits of direct access. Introduction of MSK-US in several places within DPT curriculum may increase student familiarity with the tool.

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