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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.

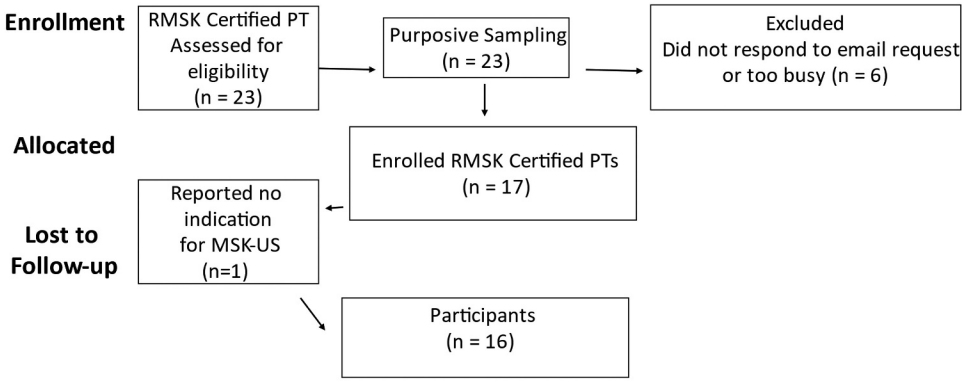

Figure 1. Participants flow. Registered in musculoskeletal ultrasound (RMSK), musculoskeletal ultrasound (MSK-US).

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.

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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