Hand-Held Portable Versus Conventional Cart-Based Ultrasound in Musculoskeletal Imaging

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Background: Portable ultrasound machines are now common, used for point-of-care applications and needle guidance for percutaneous procedures; however, the effectiveness of portable ultrasound in evaluation of the musculoskeletal system has not been fully assessed.

Purpose: To prospectively evaluate the use of portable hand-held ultrasound in comparison with conventional cart-based ultrasound in evaluation of the musculoskeletal system.

Study Design: Cohort study (diagnosis); Level of evidence, 2.

Methods: In this institutional review board–approved, prospective study, 100 consecutive patients with informed consent were imaged through use of both portable and cart-based ultrasound equipment using 12-5 MHz linear transducers. Agreement in ultrasound diagnosis was documented along with expected clinical changes in management if there was disagreement (definitely no, probably no, uncertain, probably yes, definitely yes). Imaging details of disagreement cases were recorded, and descriptive statistics were calculated.

Results: There were 42 male and 58 female patients (mean ± SD age, 53 ± 13 years) imaged over a time period of 20 months. Anatomic areas scanned were the shoulder (n = 30), elbow (n = 11), hand and wrist (n = 15), hip (n = 10), knee (n = 11), foot and ankle (n = 12), and others (n = 11). Scanning with conventional ultrasound revealed abnormality in 92% of patients. Agreement in diagnosis made between portable versus cart-based ultrasound was found in 65% of patients. In the 35% of patients with discordant results, the change in diagnosis resulted in no change in clinical management in 46%, probably no change in 29%, uncertain change in 14%, probable change in 11%, and definite change in 0%. The diagnoses changing management (4%; 4/100) included nondetection of a satellite nodule (n = 1), ganglion cyst (n = 1), hernia (n = 1), and underestimated tendon tear (n = 1).

Conclusion: When compared with conventional cart-based ultrasound, a musculoskeletal diagnosis using portable hand-held ultrasound was concordant or was discordant without clinical relevance in 96% (96/100) of patients. Knowledge of benefits and limitations of portable hand-held ultrasound will help determine areas where specific types of ultrasound equipment can be used.

Keywords: diagnostic ultrasound; musculoskeletal ultrasound; portable ultrasound; cart-based ultrasound

Ultrasound has been shown to be an effective imaging method in evaluation of the musculoskeletal system, such as tendons, muscles, ligaments, and joints. Accurate diagnosis is important because musculoskeletal disorders account for approximately $850 billion per year in health care costs and lost wages in the United States.[13] Conventional cart-based ultrasound equipment in this application has been used, producing detailed high-resolution images; however, the cost of such equipment (often >$100,000 US) and lack of portability can be significant limitations. The use of portable ultrasound units could overcome these limitations, given that hand-held portable ultrasound units cost approximately $2000 to $7000, and smaller hand-held devices could further improve accessibility. Without such barriers, hand-held ultrasound devices can potentially have a positive effect in medical education[5,11,13,14] and patient care, bringing ultrasound to classrooms, clinics, sidelines of the playing field, the battle ground,[13] rural locations, and countries with limited resources.[4,16]

Portable ultrasound machines are now common, used for point-of-care applications and needle guidance for percutaneous procedures.[2] More recently, ultrasound equipment has been developed that includes hand-held devices, where a transducer is connected to a tablet or phone to view images.[4] Such equipment has been used in several applications, such as trauma, cardiorespiratory assessment, and invasive procedures[4]; however, the effectiveness of portable ultrasound in evaluation of the musculoskeletal system has

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not been fully assessed.[7,9,10,12] Thus, the purpose of this study was to evaluate the use of a portable hand-held ultrasound device in the evaluation of the musculoskeletal system compared with conventional cart-based ultrasound. The hypothesis was that portable hand-held ultrasound would be as effective as conventional cart-based ultrasound.

METHODS

Institutional review board approval was obtained to prospectively evaluate 100 consecutive patients (single-center, evidence level 2 study) who underwent musculoskeletal ultrasound at an outpatient radiology clinic as part of routine patient care.[15] Written informed consent was obtained from all patients.

Ultrasound imaging was performed by 1 fellowship-trained musculoskeletal radiologist (J.A.J.; 23 years of experience in musculoskeletal ultrasound). Ultrasound imaging was first performed by use of a portable hand-held ultrasound device (Philips Lumify 12-5 MHz transducer; Nvidia 5 × 8.8-inch tablet) directed by the imaging requisition and patient history, and the resulting diagnosis was recorded. This was immediately followed with ultrasound imaging using a conventional cart-based ultrasound unit (Philips Epiq 7G 12-5 MHz transducer), and a resulting diagnosis was also recorded. The 12-5 MHz transducer was chosen rather than a higher frequency transducer to allow direct comparison with the portable hand-held ultrasound unit (only a 12-5 MHz linear transducer was available for the portable ultrasound unit). Additionally, when gray-scale abnormality was detected, color Doppler rather than power Doppler was used on the cart-based ultrasound unit, as power Doppler was not available on the portable hand-held ultrasound unit. Ultrasound examinations were focused to the area of concern, except for the shoulder, which received a comprehensive evaluation.

Diagnoses from the portable hand-held and conventional cart-based ultrasound units were later reviewed by the radiologist who performed the ultrasound imaging in consensus with a board-certified orthopaedic surgeon (M.T.F.). Agreement between the portable and conventional ultrasound diagnoses was determined by consensus along with expected changes in clinical management if disagreement was present (definitely no, probably no, uncertain, probably yes, definitely yes).

TABLE 1
Primary Abnormalities Found on Conventional Cart-Based Ultrasound Evaluation

Abnormality	No. of Cases
Tendon abnormality	49
Mass or cyst	17
Joint degeneration	7
Bursal abnormality	6
Hernia (groin, abdominal wall)	5
Joint effusion	4
Plantar fasciopathy	3
Ulnar collateral ligament injury (first metacarpophalangeal)	3
Inflammation or infection	3
Nerve abnormality	2
Dupuytren contracture	1

Descriptive statistics including mean, standard deviation, range, and percentage were used to evaluate the data of the consensus reading. Correlation was also made with magnetic resonance imaging (MRI) and surgical results if available, which were completed in some patients as part of routine clinical care. The decision to obtain MRI or pursue surgery was based on clinical judgment and may have been influenced by the conventional cart-based ultrasound imaging findings as part of routine patient care.

RESULTS

Demographics

The study group of 100 patients consisted of 42 male and 58 female patients with a mean ± SD age of 53 ± 13 years (range, 25-83 years). Anatomic areas scanned included shoulder (n = 30 patients), elbow (n = 11 patients), hand and wrist (n = 15 patients), hip (n = 10 patients), knee (n = 11 patients), foot and ankle (n = 12 patients), and others (n = 11 patients; neck, chest wall, abdominal wall, groin), imaged over a time period of 20 months. The time interval from the completion of patient scanning to retrospective consensus review of results was 6 months.

Ultrasound Results

Scanning with the conventional cart-based ultrasound machine revealed abnormality in 92% (92/100) of patients

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Ethical approval for this study was obtained from the University of Michigan Medical School Institutional Review Board (study No. HUM0013683).

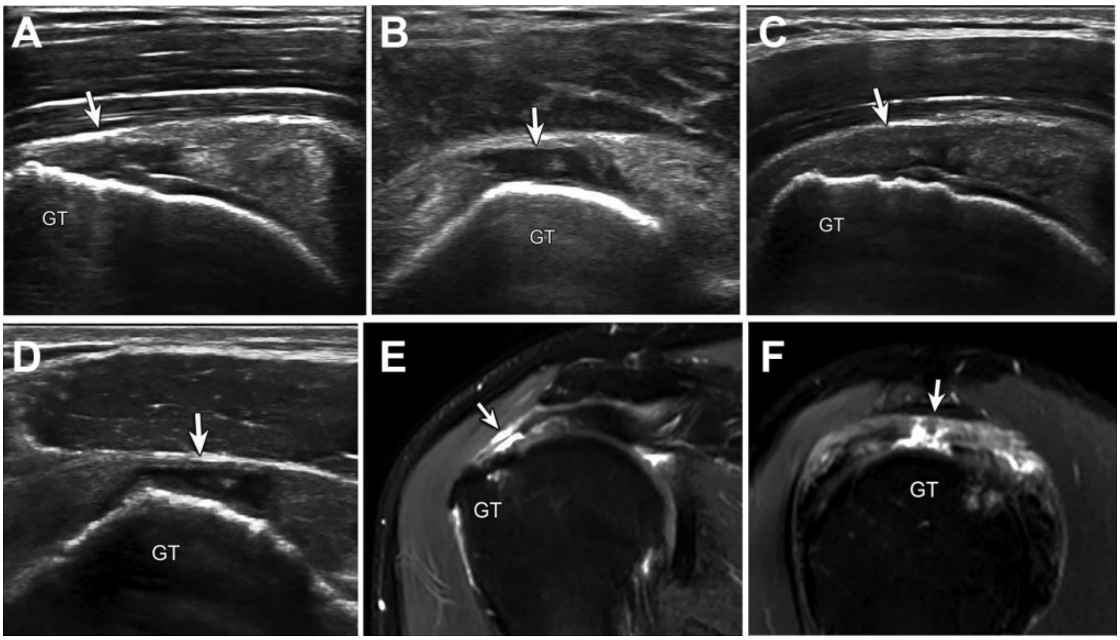

Figure 1. Findings for a 48-year-old man with full-thickness supraspinatus tear (concordant diagnoses). Images reveal tendon defect (arrows) shown on (A, B) portable hand-held ultrasound, (C, D) conventional cart-based ultrasound, and (E, F) magnetic resonance imaging. (A, C, E) Long axis of tendon. (B, D, F) Short axis of tendon. GT, greater tuberosity.

TABLE 2
Patients With Disagreement in Diagnosis Comparing Hand-Held Portable Versus Conventional Cart-Based Ultrasound and the Effect on Clinical Management

Influence on Clinical Management	No. (%) of Patients	Anatomic Area (No. of Patients)
Definitely no	16 (46)	Shoulder (5), elbow (4), wrist/hand (1), hip (1), knee (1), foot/ankle (2), other (2)
Probably no	10 (29)	Shoulder (6), elbow (1), wrist/hand (1), other (2)
Uncertain	5 (14)	Shoulder (1), elbow (1), wrist/hand (2), other (1)
Probably yes	4 (11)	Wrist/hand (2), hip (1), other (1)
Definitely yes	0 (0)	None

(Table 1). Comparison of portable hand-held and cart-based ultrasound findings showed that results were concordant in 65% (65/100) (Figure 1) and discordant in 35% (35/100) of patients. In the 35 patients with discordant results (Table 2), the discrepancy in diagnosis resulted in no change in clinical management in 46% (16/35) (Figure 2 and Table 3), probably no change in 29% (10/35) (Table 4), uncertain change in 14% (5/35) (Table 5), probable change in 11% (4/35) (Figure 3 and Table 6), and definite change in 0% (0/35) of patients. The diagnoses changing management included the following (Table 6): nondetection of a satellite nodule of 2 mm associated with a superficial mass (1 patient), incorrect interpretation of a 5-mm ganglion cyst as a possible solid mass (1 patient) (Figure 3), overlooked direct inguinal and femoral hernias (1 patient), and misdiagnosis of partial gluteus medius tendon tear as tendinosis (1 patient). Overall, the results from portable hand-held ultrasound were concordant or discordant without clinical relevance in 96% (96/100) of patients compared with those from conventional cart-based ultrasound.

Regarding conventional color Doppler evaluation, 11 patients showed a discrepancy where increased flow or hyperemia was present with conventional cart-based ultrasound and not detected with the portable hand-held ultrasound. These cases of discrepancy included the following anatomic areas: elbow (n = 6), Achilles tendon (n = 2), groin (n = 1), shoulder (n = 1), and shin (n = 1). They included abnormalities in the tendons (n = 7), masses or lymph nodes (n = 3), and a bursa (n = 1).

Tendon abnormality was diagnosed with conventional cart-based ultrasound in 49% of patients (49/100); discrepancies were found in 12 patients when portable ultrasound was used: tendinosis was misdiagnosed as normal tendon (n = 3), underestimated (n = 1), and overestimated (n = 1); tendon tears were overlooked (n = 2), underestimated (n = 2), and overestimated (n = 3). Overall, only 1 of these discrepancies would have caused a probable change in the clinical outcome, which involved the gluteus medius tendon.

With regard to calcifications, in 2 of the 6 affected patients, visibility was difficult when using the hand-held portable ultrasound unit compared with the conventional ultrasound unit in the rotator cuff (1 patient) and plantar aponeurosis (1 patient). In both patients, the lesser visibility did not change the patients' clinical management because the calcifications were not completely overlooked.

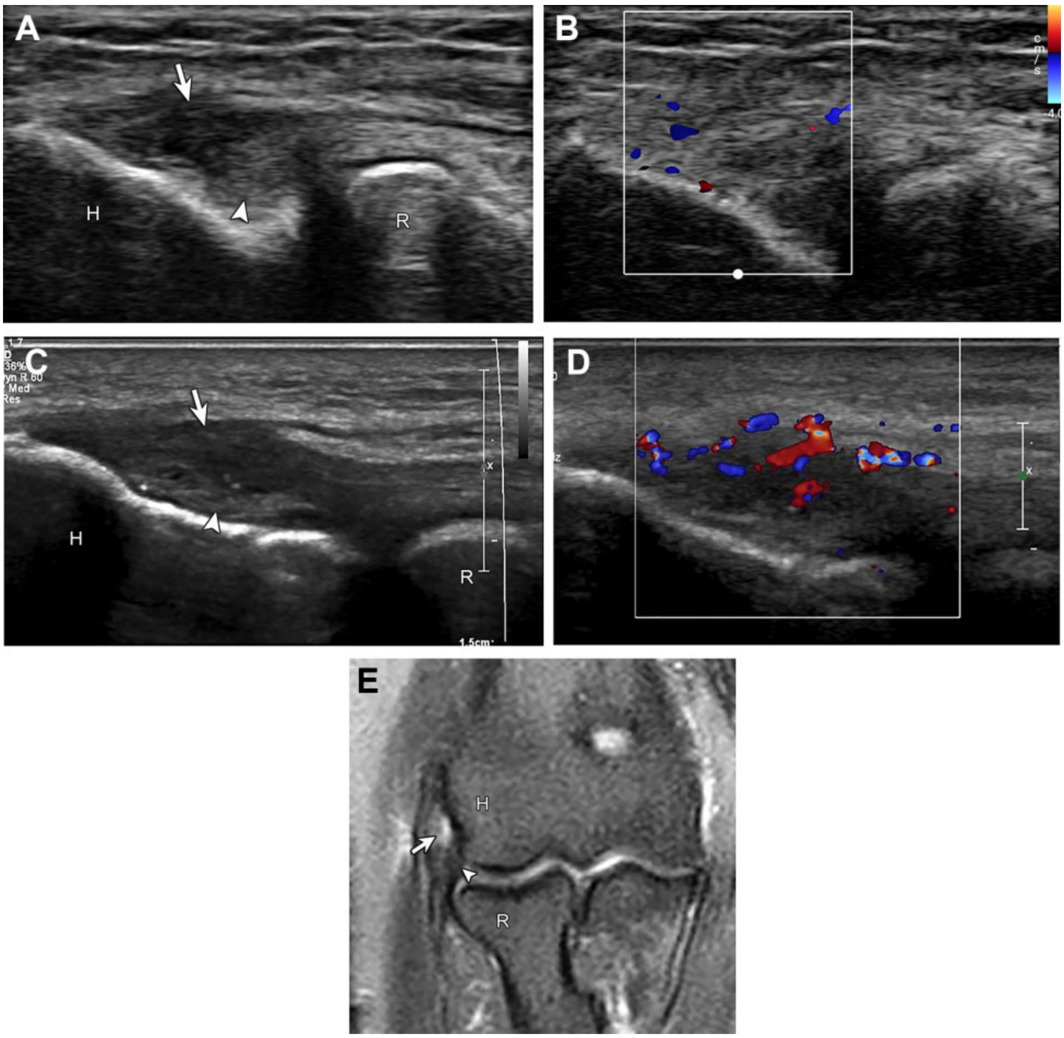

Figure 2. Findings for a 53-year-old man with common extensor tendinosis (discordant results due to differences in color Doppler information with no change in clinical management). Images reveal severe tendinosis (arrows) shown on (A, B) portable hand-held and (C, D) conventional cart-based ultrasound, appearing as increased signal on (E) intermediate-weighted fat saturation magnetic resonance image. Note increased flow on color Doppler image of (D) conventional ultrasound compared with (B) the portable unit. H, humerus; R, radial head; arrowhead, radial collateral ligament.

In review of the medical records, 14% of patients (14/100) had additional MRI evaluation where correlation confirmed the cart-based conventional ultrasound diagnosis. Of these, 2 patients had surgery that confirmed the diagnosis of complex ganglion cyst and lipoma. In the 7 patients with joint degeneration on ultrasound, radiographs were present in 5 cases. In the 3 patients with inflammation or infection, additional clinical history, clinical evaluation, and laboratory values confirmed the diagnoses of rheumatoid arthritis, psoriasis, and abscess, respectively.

DISCUSSION

Although the use of portable hand-held ultrasound has been described in general ultrasound applications, its use in routine musculoskeletal applications has not been fully assessed. Our study showed that the results from portable hand-held ultrasound were concordant or were discordant without clinical relevance in 96% (96/100) of patients compared with conventional cart-based ultrasound.

Portable ultrasound was first developed for military purposes to identify and diagnose serious injuries in the battlefield.[13] In clinical situations, portable ultrasound may be of benefit when the transport of a patient to the ultrasound department is not possible or the heavy conventional ultrasound machine is less accessible to the patient. Such point-of-care ultrasound applications may also include the emergency department and the outpatient clinic, where an urgent diagnosis may be important.[1,6] The lower cost of such portable devices (approximately $2000-$7000) compared with conventional machines (often >$100,000) creates another opportunity, especially for less economically

TABLE 3
Discrepancies in the Diagnosis: No Definite Change in Management

Anatomic Area	Diagnosis on Portable Ultrasound	Additional or Changed Diagnosis on Conventional Cart-Based Ultrasound
Shoulder	Postoperative changes and no cuff tear	Supraspinatus and infraspinatus muscle fatty infiltration (additional diagnosis)
Shoulder	Subacromial-subdeltoid bursal thickening and impingement	Mild supraspinatus tendinosis (additional diagnosis)
Shoulder	Subacromial-subdeltoid bursal thickening, tear, subluxation of the long head of the biceps brachii tendon	Tendinosis of subscapularis and supraspinatus (additional diagnosis)
Shoulder	Partial bursal-sided tear of the supraspinatus tendon, fatty muscle infiltration	Tendinosis of the subscapularis tendon (additional diagnosis)
Shoulder	Mild supraspinatus tendinosis, bursal thickening, joint effusion	Moderate supraspinatus tendinosis (changed diagnosis)
Elbow	Severe common extensor tendinosis and partial tearing	Flow on color Doppler imaging (additional diagnosis)
Elbow	Moderate common extensor tendinosis	Flow on color Doppler imaging (additional diagnosis)
Elbow	Moderate common extensor tendinosis, interstitial tear	Flow on color Doppler imaging (additional diagnosis)
Elbow	Olecranon bursal distention	Flow on color Doppler imaging (additional diagnosis)
Thumb	Carpometacarpal osteoarthritis, remote injury of radial collateral ligament	Ganglion cyst (additional diagnosis)
Abdominal wall	Soft tissue nodule	Postoperative changes (changed diagnosis)
Hamstring	Moderate to severe tendinosis of conjoined semitendinosus and biceps femoris tendons	Mild to moderate tendinosis (changed diagnosis)
Knee	Joint effusion, osteoarthritis, abnormal lateral collateral ligament	Synovial proliferation (additional diagnosis)
Calf	Gastrocnemius and plantaris tear	Normal plantaris (changed diagnosis)
Achilles tendon	Severe tendinosis, interstitial tear	Flow on color Doppler imaging, peritendinitis (additional diagnosis)
Heel	Plantar fasciopathy	Calcification (additional diagnosis)

TABLE 4
Discrepancies in the Diagnosis: Probably No Change in Management

Anatomic Area	Diagnosis on Portable Ultrasound	Additional or Changed Diagnosis on Conventional Cart-Based Ultrasound
Shoulder	Tendinosis supraspinatus tendon	Interstitial tear of supraspinatus tendon (changed diagnosis)
Shoulder	Focal full-thickness tear of supraspinatus tendon	Overestimated tear size on portable ultrasound (changed diagnosis)
Shoulder	Full-thickness tear of subscapularis, partial-thickness tear of supraspinatus	Partial-thickness tear of subscapularis, full-thickness tear of supraspinatus (changed diagnosis)
Shoulder	Solid mass	Flow on color Doppler imaging (additional diagnosis)
Shoulder	Calcification	Possible small tendon cleft (additional diagnosis)
Shoulder	Biceps tendon split tear, subluxation, bursal thickening	Partial-thickness tear of subscapularis tendon (additional diagnosis)
Elbow	Moderate common extensor tendinosis, partial-thickness tear	Flow on color Doppler imaging (additional diagnosis), no tear (changed diagnosis)
Thumb	Remote injury of ulnar collateral ligament, no Stener lesion	Partial-thickness tear of ulnar collateral ligament, nondisplaced avulsion fragment (additional diagnosis)
Abdominal wall	Lipoma	Size underestimated on portable ultrasound (changed diagnosis)
Leg	Soft tissue mass	Flow on color Doppler imaging (additional diagnosis)

developed regions.[2,4] Portable ultrasound has also been described in the field of medical education.[5,11,13,14] Common applications for portable ultrasound include evaluation for cardiac or abdominal abnormality.[5,14] The use of portable ultrasound in the musculoskeletal system has been described for foreign body removal[7,9] and rib fracture assessment.[12] One study evaluated 10 shoulders and concluded that abnormality could be identified[10]; however, a comprehensive evaluation of routine musculoskeletal applications has not been previously assessed.

Our study showed the utility of portable hand-held ultrasound in the evaluation of common musculoskeletal applications that is typical of an outpatient clinic. In our study population, evaluation for tendon abnormality was the most common application (49%, or 49/100). Of these 49 patients, the results were concordant in 76% (37/49) when both portable and conventional ultrasound equipment were used. In the remaining 12 patients, the most common discrepancy was a change in severity of tendinosis, either increasing or decreasing; however, the diagnosis provided

TABLE 5
Discrepancies in the Diagnosis: Uncertain About Change in Management

Anatomic Area	Diagnosis on Portable Ultrasound	Additional or Changed Diagnosis on Conventional Cart-Based Ultrasound
Shoulder	Mild tendinosis, calcifications in subscapularis	Calcifications in infraspinatus tendon (additional diagnosis)
Elbow	Moderate common extensor tendinosis, interstitial tear	Flow on color Doppler imaging (additional diagnosis)
Finger	Probably ganglion cyst	Definite ganglion cyst (changed diagnosis)
Thumb	Carpometacarpal osteoarthritis	Small cyst (additional diagnosis)
Groin	Direct hernia	Femoral hernia (additional diagnosis)

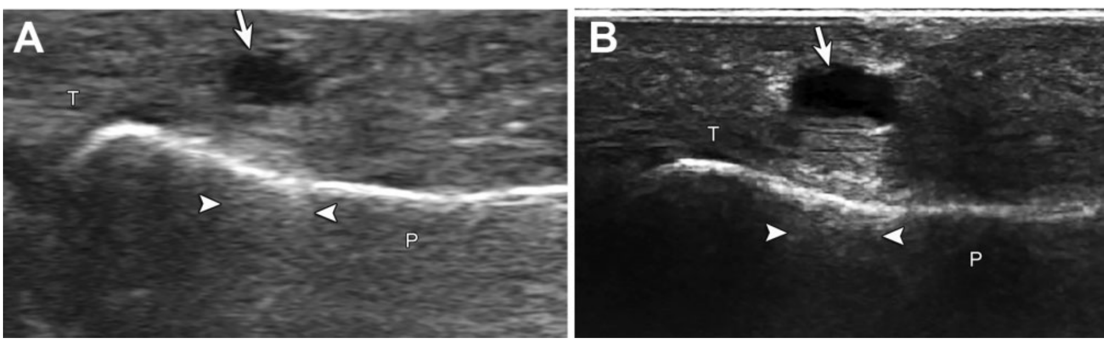

Figure 3. Findings for a 35-year-old woman with ganglion cyst (discordant results with probable change in clinical management). (A) Image made on the portable hand-held unit reveals focal abnormality (arrow) appearing hypoechoic, raising concern for solid mass. (B) On the image from the conventional cart-based unit, the abnormality appears anechoic consistent with cyst. Note increased conspicuity of the posterior increased through transmission (arrowheads) in A compared with B. P, proximal phalanx; T, flexor tendon.

TABLE 6
Discrepancies in the Diagnosis: Probable Change in Management[a]

Anatomic Area	Diagnosis on Portable Ultrasound	Diagnosis on Conventional Cart-Based Ultrasound
Hand	Single solid mass	Solid mass with *satellite nodules*
Finger	Differential diagnosis of hyperechoic or anechoic cyst versus solid mass	*Ganglion cyst*
Groin	Iliopsoas bursitis	Iliopsoas bursitis *Additionally, direct inguinal hernia and femoral hernia*
Hip	Hydroxyapatite deposition disease of the medial gluteus tendon, tendinosis of the gluteus minimus tendon	Hydroxyapatite deposition disease of the medial gluteus tendon *Missed partial-thickness tear of the gluteus medius tendon*

[a]Probable changes in management are indicated with italics.

by the conventional ultrasound would have changed clinical management in only 1 patient (2%, or 1/49), in whom the gluteus medius was involved. Importantly, there were no changes in clinical outcome involving the shoulder, which was the most common joint included in our study (30%, or 30/100). A previous study evaluated 10 shoulder cases via portable ultrasound versus conventional ultrasound and could identify abnormality in 70% to 80% of the cases[10]; however, the authors did not investigate whether the incorrect diagnosis would have changed the clinical outcome. Previous studies have also not evaluated the use of portable ultrasound for other musculoskeletal applications beyond the shoulder; our study included a relatively uniform distribution of cases outside of the shoulder, evaluating the elbow (11/100), wrist and hand (15/100), hip (10/100), knee (11/100), ankle and foot (12/100), and other miscellaneous applications, such as the neck, chest wall, abdominal wall, and groin (11/100).

In our study, there were 4 discrepant results that could have potentially changed the clinical management (see Table 3), which included 2 superficial (hand and finger) and 2 deep (groin and hip) pathologic findings. One case was an overlooked superficial satellite nodule measuring 2 mm adjacent to a solid mass of the palmar hand that could have potentially influenced the surgical management. The second case was a 5-mm ganglion cyst of the finger on conventional cart-based ultrasound where the portable ultrasound could not distinguish cyst versus solid, which may have resulted in an unnecessary biopsy or excision. The third case involved the hip and groin; trochanteric bursal distention was identified, but the direct inguinal and femoral hernias were overlooked with the portable ultrasound unit. In the fourth case, a partial tear of the gluteus medius tendon at the greater trochanter was misdiagnosed as tendinosis. The diagnosis of partial-thickness tear could have changed management from percutaneous tenotomy or fenestration to whole blood or platelet-rich plasma injection to minimize risk of complete tendon tearing.[3,8]

One limitation of the portable hand-held ultrasound unit was the low sensitivity of the color Doppler compared with cart-based ultrasound. Although we chose the low-flow setting, there were 11 patients in whom the portable ultrasound did not reveal internal blood flow in tendons ($n = 7$), masses ($n = 3$), and an olecranon bursa ($n = 1$); however, the additional finding of hyperemia when using the conventional cart-based ultrasound machine did not significantly change clinical management. Another limitation of the portable ultrasound equipment was difficulty in identifying small calcifications in the rotator cuff ($n = 1$) and plantar aponeurosis ($n = 1$), which also did not change clinical management.

We acknowledge that our study has some limitations. We did not directly assess the image quality of the 2 different ultrasound techniques; however, the goal of our study was to evaluate the clinical effect of diagnosis discordance using a hand-held portable ultrasound unit. Second, imaging was performed by only 1 observer without assessment of interobserver or intraobserver variability. Also, this observer had significant experience in musculoskeletal ultrasound; a study with multiple observers with different experience would confirm generalization of our results. Another limitation is that the images were obtained with the hand-held portable examination performed first and interpreted in a nonrandomized fashion not blinded toward the type of ultrasound equipment used, which potentially introduced bias. No statistical analysis (including power analysis) was obtained. Also, the vast majority of patients did not have additional imaging or surgical findings to correlate with our results. An intrinsic limitation of the hand-held ultrasound machine is the lack of power Doppler and a linear transducer with the highest frequency of 12-5 MHz; similar settings and transducer frequency were used with the conventional cart-based ultrasound unit to allow direct comparison. Although we determined overall concordance, we were unable to determine concordances specific to each joint given the low sample size.

CONCLUSION

In evaluation of the musculoskeletal system, our study showed that the results from portable hand-held ultrasound were concordant or were discordant without clinical relevance in 96% (96/100) of patients compared with conventional cart-based ultrasound. The most common joint evaluated was the shoulder, which showed no clinically relevant discrepancies in diagnosis.

REFERENCES

1. Appropriate use criteria for handheld/pocket ultrasound devices. *Ann Emerg Med*. 2018;72(4):e31-e33.
2. CADTH Rapid Response Reports. *Portable Ultrasound Devices in the Pre-Hospital Setting: A Review of Clinical and Cost-Effectiveness and Guidelines*. Ottawa, ON: Canadian Agency for Drugs and Technologies in Health; 2015.
3. Chiavaras MM, Jacobson JA. Ultrasound-guided tendon fenestration. *Semin Musculoskelet Radiol*. 2013;17(1):85-90.
4. Epstein D, Petersiel N, Klein E, et al. Pocket-size point-of-care ultrasound in rural Uganda—a unique opportunity "to see", where no imaging facilities are available. *Travel Med Infect Dis*. 2018;23: 87-93.
5. Galusko V, Khanji MY, Bodger O, Weston C, Chambers J, Ionescu A. Hand-held ultrasound scanners in medical education: a systematic review. *J Cardiovasc Ultrasound*. 2017;25(3):75-83.
6. Guermazi A, Hayashi D, Jarraya M, et al. Sports injuries at the Rio de Janeiro 2016 Summer Olympics: use of diagnostic imaging services. *Radiology*. 2018;287(3):922-932.
7. Holleyman RJ, Husaini H, Rankin KS. Image guided surgery for removal of deep foreign bodies and soft tissue tumours using portable ultrasonography. *Ann R Coll Surg Engl*. 2019;101(2): 136-137.
8. Jacobson JA, Rubin J, Yablon CM, Kim SM, Kalume-Brigido M, Parameswaran A. Ultrasound-guided fenestration of tendons about the hip and pelvis: clinical outcomes. *J Ultrasound Med*. 2015;34(11): 2029-2035.
9. Kent MJ, Melton JT. Use of portable ultrasound for exploration and removal of superficial foreign bodies. *Ann R Coll Surg Engl*. 2009; 91(4):344-345.
10. Lau BC, Motamedi D, Luke A. Use of pocket-sized ultrasound device in the diagnosis of shoulder pathology. *Clin J Sport Med*. 2020;30(1): 20-24.
11. Maetani TH, Schwartz C, Ward RJ, Nissman DB. Enhancement of musculoskeletal radiology resident education with the use of an individual smart portable ultrasound device (iSPUD). *Acad Radiol*. 2018; 25(12):1659-1666.
12. Martin VT, Zeng L, Nzengue JC, Mao L, Huang J, Peng X. The use of a portable ultrasound system in the surgical assessment of rib fractures in an elderly patient. *Ann Med Surg (Lond)*. 2018;36: 96-98.
13. McGahan JP, Pozniak MA, Cronan J, et al. Handheld ultrasound: threat or opportunity? *Appl Radiol*. 2015;44(3):20-25.
14. Nielsen MB, Cantisani V, Sidhu PS, et al. The use of handheld ultrasound devices—an EFSUMB position paper. *Ultraschall Med*. 2019; 40(1):30-39.
15. Schweitzer ME. Evidence level. *J Magn Reson Imaging*. 2016; 43(3):543.
16. Shokoohi H, Raymond A, Fleming K, et al. Assessment of point-of-care ultrasound training for clinical educators in Malawi, Tanzania and Uganda. *Ultrasound Med Biol*. 2019;45(6): 1351-1357.