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Diagnostic performance of high-resolution ultrasound in pre- and postoperative evaluation of the hand tendons injuries

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Abstract

Background: Hand tendon injuries are recognized clinical entities that are frequently seen. Clinical examinations usually warrant radiological correlative studies for confirmation and as a postoperative screening test. Here is a prospective observational cohort study enrolling 30 patients who were diagnosed clinically to have hand tendon injuries either pre- or postoperative; their ages were ranging from 5 to 64 years with a mean ± SD of 31.43 ± 12.19 years; 23 male patients (76.7%) and 7 female patients (23.3%) were evaluated by high-resolution ultrasound examination and a correlative evaluation was done by either intra-operative assessment or MRI study as gold standards.

Results: High-resolution ultrasound (HRUS) findings were binned into seventeen cases (56%) that had tendon tears, of which 10 cases (33.3%) had a complete tear and 7 cases (23.3%) had a partial tear. Postoperative tendon integrity was present in 13 cases (43.3%), a tendon callus was found in 2 cases (6.66%), and a postoperative abnormal motion on the dynamic study was present in 15 cases (50%). Intra-tendinous foreign bodies were detected in two cases (6.66%), a gap between the torn ends was found in 10 cases (33.3%), and re-tear (rupture) of the repaired tendons was present in four cases (13.3%). Coexistent nerve injuries were seen in two cases (6.66%); for the forementioned findings, HRUS had gained high accuracy measures as correlated to the gold standards (100% sensitivity and 100% specificity).

Conclusion: High-resolution ultrasound serves as a highly accurate potential diagnostic modality for preoperative evaluation of hand tendon injuries and the postoperative follow-up.

Keywords: High-resolution, Ultrasound-hand, Tendon, Injuries

Background

Hand tendon injury is a well-recognized surgical entity. Extensor tendons injuries are usually seen in predisposed cases with rheumatoid tenosynovitis, whereas flexor tendon tears are usually encountered with penetrating injuries and cut wounds [1, 2].

Few diagnostic imaging modalities had been implemented for assessment of the hand tendons including the plain radiography for assessment of the bony and articular units and for detection of radio-dense foreign bodies but with a lack of direct visualization of the tendon structure. MRI can serve as a diagnostic tool for assessment of the hand tendons through the use of special extremity coils, but its use may be limited in the patients who had undergone orthopedic surgeries and who had contraindications for MRI examination. High-resolution ultrasound (HRUS) of the musculoskeletal system has gained increasing popularity being simple, non-invasive, and cheap. Moreover, the current use of higher frequency and the small-sized musculoskeletal dedicated

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probes (ultra-high frequency probes) has led to an improvement in the spatial resolution and the image quality. Additionally, the dynamic examination can greatly help in the determination of the type and location of the tendon tears as well as the presence of postoperative peritendinous adhesions [3–6].

Preoperative assessment of the torn tendons is highly recommended for reconstructive surgery planning and determination of the type of tendon tear whether a partial or a complete one, and thus, it is considered of utmost importance, especially when the tear is perfectly allocated with the cutaneous demarcation of the retracted torn ends and measuring the intervening gap [6–8].

Postoperatively, HRUS plays an important role in the determination of the integrity of the repaired tendons and in the detection of limited mobility due to adhesions or re-tears by the use of dynamic tests (through the active and the passive tendon mobilization), which can determine whether the affected tendon is re-torn or just having peritendinous adhesions; both conditions are clinical mimics that may necessitate further imaging workup [9–11]. This work aimed to evaluate the usefulness of performing high-resolution ultrasound in the diagnosis and management of pre- and postoperative hand tendon injuries in correlation to the operative and MRI findings.

Methods

Subjects

A prospective observational cohort study was carried out in our institute and enrolled 30 patients who were recruited from the ER department and plastic surgery outpatient clinic, during the period from December 2018 to November 2019. The patients were diagnosed clinically to have hand tendon injuries either pre- or postoperative; the mean of their ages (± SD) was 31.43 (±12.19 years), of which 23 patients (76.7%) were males, and 7 patients (23.3%) were females (Table 1).

Inclusion criteria

Patients who had presented with recent hand tendon injuries to the ER and plastic surgery departments, those who underwent surgical repair of their injured tendons as a postoperative screening for tendon repair, and especially, those who had nonsatisfactory results (after clinical assessment and postoperative physiotherapy) to detect the possible underlying problem

Table 1 The gender distribution

	Count	%
Gender		
Male	23	76.7
Female	7	23.3

Exclusion criteria

Patients who had chronic hand and wrist conditions not related to tendon injuries (like rheumatoid arthritis, hand contracture, and neuropathies) and patients who had not the willingness to participate in the study were also excluded.

The protocol was reviewed and approved by the local ethics committee.

Our patients were subjected to the following:

1 Clinical assessment through the following:
   (a) *Relevant history taking*
   (b) *Clinical examination* was done by the clinician in order to triage the patients and for assessment of the degree and the type of tendon injuries, as a preoperative screening as well as postoperative evaluation of the repaired tendons to suggest a possible underlying cause of the nonsatisfactory results.
2 Examination by high-resolution ultrasound

Focused-hand ultrasound examination was done using Toshiba Aplio 500, General Electric Logic P7, General Electric Logic S8, and General Electric Voluson E6; all examinations were done by a linear probe of 7.5–12 MHz frequency with the application of a thick layer coupling gel. The examiner should hold the transducer near its footprint and spread the other fingers out to stabilize the transducer on the skin surface. The patients were asked to rest their hand on the trolley or their lap in a comfortable position (Fig. 1).

- The optimal technique involved adjusting the gain, depth, and focus to attain the best resolution image. It was also necessary to modify the angle of the probe to avoid the anisotropy artifact.
- In a sitting position, the affected hand and fingers were fully exposed, and the probe was moved longitudinally and transversely along the affected tendon to perform multiplanar scans without flexion or extension of the wrists in all cases. A comparison with the normal side was done if there was a need.
- *At rest*, the tendons were evaluated for evidence of tears, rupture, and postoperative complications.
- A partial rupture was defined as a tendon with a partial loss (> 50%) of its fibrillar pattern or with one or more areas of discontinuous hypoechogenicity at the site of the injury.
- A complete rupture was defined as a complete loss of the fibrillar pattern, and the gap between the torn

Fig. 1 Demonstration of an example of the examination steps (**a**) where the linear probe was positioned to obtain a longitudinal static scan for the extensor tendons of the middle finger (**b**) for a longitudinal static scan of the flexor tendons of the same digit (**c**) for dynamic evaluation of the flexor tendons with passive flexion of the middle finger by the operator

ends of the tendon could be filled with fluid or later on by granulation tissue.

- *Tendon callus* is identified by HRUS as pseudo mass formation showing a bulging contoured hypoechoic lesion with possible intra-tendinous echogenic surgical sutures\staples within the repaired tendon.
- *Dynamic examinations* were done, where the finger was moved passively to observe the free gliding motion of the tendons (Fig. 1c).
- HRUS examination had shown whether the tendons (of the immobile finger) were intact (but not gliding) or ruptured. Furthermore, in case of a rupture, determining the exact location of the proximal stump could precisely navigate the onward surgery as well.

The *examination duration* was variable depending on the extent of the injury and how many tendons were involved; however, at 15–30 min, the exam duration was roughly estimated as the usual time for the straightforward examination.

The *examination was done* under the supervision of an expert musculoskeletal ultrasound operator.

Follow-up examination of some transient postoperative ultrasound findings was done to determine whether they were persistent and significant findings or just transient reactive (postoperative) response.

3. *Intra-operative evaluation* of the injured tendons was done for the type and the degree of tendon injury and presence of tendon callus, and if there were peritendinous adhesions (done in 25 patients), the operative findings were reported by the surgeon and had been correlated to the HRUS findings.
4 *MRI examination* (done for 5 patients) was done for cases that were not a candidate for surgical interventions or those who had refused surgery. MRI examination was done on high field-strength scanners using Philips scanners Achieva or Intera (1.5 T) using the conventional MRI sequences including T1-weighted, T2-weighted, and STIR images in axial, coronal, and sagittal planes with the use of an arm coil; if finger MRI was requested a dedicated examination should be performed in "superman" position, with a maximum FOV of 120 mm and maximum thickness of 3 mm [12]. The image interpretation was done by an expert radiologist who was blinded from the HRUS findings to avoid diagnostic bias.
5 *Statistical methods and data analysis*

Data were coded and entered using the statistical package SPSS (Statistical Package for the Social Sciences) version 26 (IBM Corp., Armonk, NY, USA). Data was summarized using frequency (count) and relative frequency (percentage) for categorical data. Standard diagnostic indices including sensitivity, specificity, positive predictive value (PPV), negative predictive value (NPV), and diagnostic efficacy were calculated. For comparing categorical data, chi-square (χ^2) test was performed. Exact test was used instead when the expected frequency is less than 5. A *P* value less than 0.05 was considered statistically significant [13, 14].

Results

Clinically, the patients were presenting postoperatively in 21 cases (70%) and preoperatively in 9 cases (30%).

Flexor tendons injury was present in 19 cases (63.3%), while the extensor tendons injury was present in 11 cases (36.7%). Thickened skin was seen in 26 cases (86.6%) and edema was present in 18 cases (62.1 %) (Table 2).

In correlation to the gold standards (operative data and the MRI findings), HRUS findings (Table 3 and Figs. 2, 3, 4, 5, 6, and 7) were correlated and binned into 17 cases (56%) that had tendon tears of which 10 cases

Table 2 The clinical findings with the demonstration of the number and percent of the affected cases

Clinical data in the examined cases	No. of cases	Valid percent (%)
Flexor surface injury	19	63.3
Extensor surface injury	11	63.7
Preoperative cases	9	30
Postoperative cases	21	70
Thickened skin	26	86.7
Edema	18	62.1

(33.3%) had a complete tear (Fig. 2) and 7 cases (23.3%) had partial tears. Postoperative tendon integrity was present in 13 cases (43.3%), a tendon callus (Figs. 3 and 6) was detected in two cases (6.66%), and postoperative abnormal motion on dynamic examination was present in 15 cases (50%) (Fig. 8). Intra-tendinous foreign bodies were detected in two cases (6.66%) (Fig. 4), a gap between the torn ends was present in 10 cases (33.3%) who had retracted torn tendon ends (Fig. 5), and re-tear (re-rupture) of the repaired tendons was present in four cases (13.3%). Coexistent nerve injury was only present in two cases (6.66%) (Fig. 7).

The HRUS findings were correlated to the intra-operative findings and to the MRI findings in non-operated cases regarding the tendon injuries and the tendon integrity as well with P value < 0.001 and the tested sensitivity was 100% (95% CI, 80.49 to 100.00%) (Tables 4 and 5).

Discussion

Next to hand fractures, the hand tendon injuries are considered the most common hand injuries with open and penetrating injuries specifically reported as the commonest type of injuries rather than dull avulsions and disrupted pulley system [2].

Hand tendon injuries are considered serious injuries especially if involving the flexor tendons and need to be carefully evaluated and skillfully managed by reconstructive hand surgeries, so a meticulous imaging workup should be employed for this purpose including the HRUS or MRI examination; the former has the advantage of being cheaper and could be complemented by dynamic maneuvers; additionally, a side to side comparison to the contralateral unaffected hand could be performed [15, 16].

In concordance with Hall study [17] which had included a sample of population in an age group close to our study population, there was male gender predominance in both studies and this could be attributed to the more frequent male involvement in the manual occupations.

Hand tendons tears were present in 56.7% of our cases, of which 33.3% had a complete tear while 23.33% had a partial tear; this was matching Lee et al.'s study that had reported a predominance of the full thickness tears in their cases by ultrasonography and had been confirmed during surgery [18].

Regarding the type of tendon affection, our study had shown more affection of the flexor tendons (63.3%) (Fig. 4), mismatching the Hall study, where the extensor tendon injuries were more frequently seen [17].

In another study by Lee et al., among 24 patients, the most commonly affected tendon was the extensor pollicis longus tendon, being found in 11 of their patients, where the thumb was the most commonly affected

Table 3 The HRUS findings in the study population as correlated to the gold standard

Findings	No. of cases by HRUS	No. of cases by gold standard[a]
Tendon injury	17	17
Postoperative tendon integrity	13	13
Partial rupture	7	7
Complete rupture	10	10
Gap between the torn tendon ends	10	10
Postoperative abnormal motion in the dynamic study	15	15
Re-rupture	4	4
Foreign body	2	2
Tendon callus	2	2
Associated nerve injury and sonographic Tinel's sign	2	2

[a]The gold standard was the operative data or MRI images for those who were nonsurgical candidates or refusing surgery

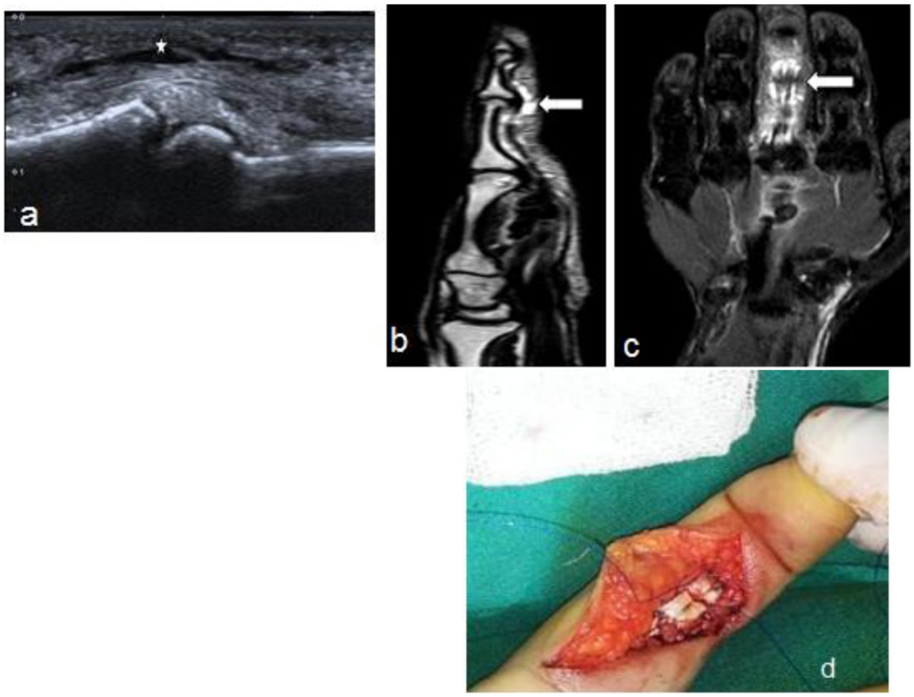

Fig. 2 Ultrasound (**a**), sagittal T2-weighted (**b**), coronal (**c**), and STIR MRI (**d**) photography images on the volar aspect of the middle finger at the site of tendon injury demonstrating the empty tendon sheath (white star, **a**) with the corresponding high signal intensities in the sagittal and coronal MRI images (side open arrows, **b** and **c**) denoting a complete rupture (**d**) photography of intra-operative tendon repair

finger [18]; we do not have an explanation for such difference between the three studies; however, there were no selection criteria for our patients regarding the type of the tendon affection.

By HRUS, our results had revealed that the tendon tears were the predominating features among injuries (17 cases; 56%) followed by the abnormal mobility (15 cases; 50%), and then a gap between the torn tendon ends (10 cases; 33.3%); post-reconstructive tendon integrity was present in 13 cases (44%), while re-tear (re-rupture) had existed in four cases (13.3%). A tendon callus was present in only two cases (6.66%) (Figs. 3 and 6); these findings were *greatly matching* Lee et al.'s study, where they had found that among the sonographic

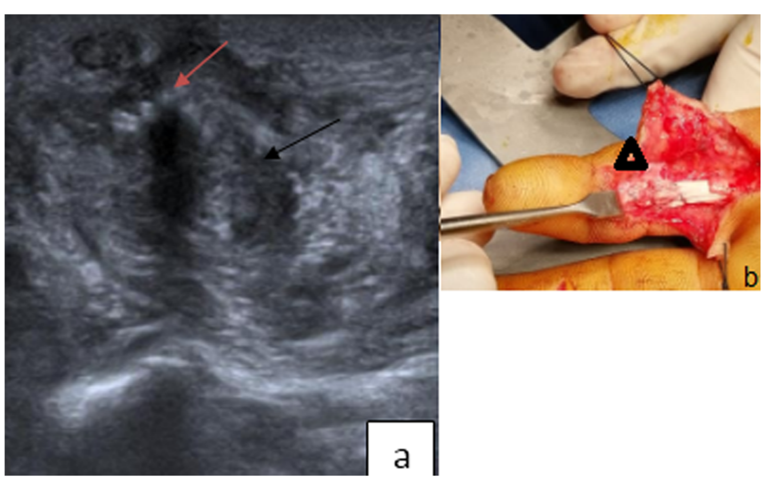

Fig. 3 a B-mode ultrasound photography images of the repaired (postoperative case) tendon showing a heterogeneous hypoechoic tendon callus at the site of the tendon repair (black arrow) with the echogenic suture material seen in the vicinity of the callus (red arrow). **b** Intra-operative photography showing the pseudo mass appearance of the tendon callus (black arrowhead)

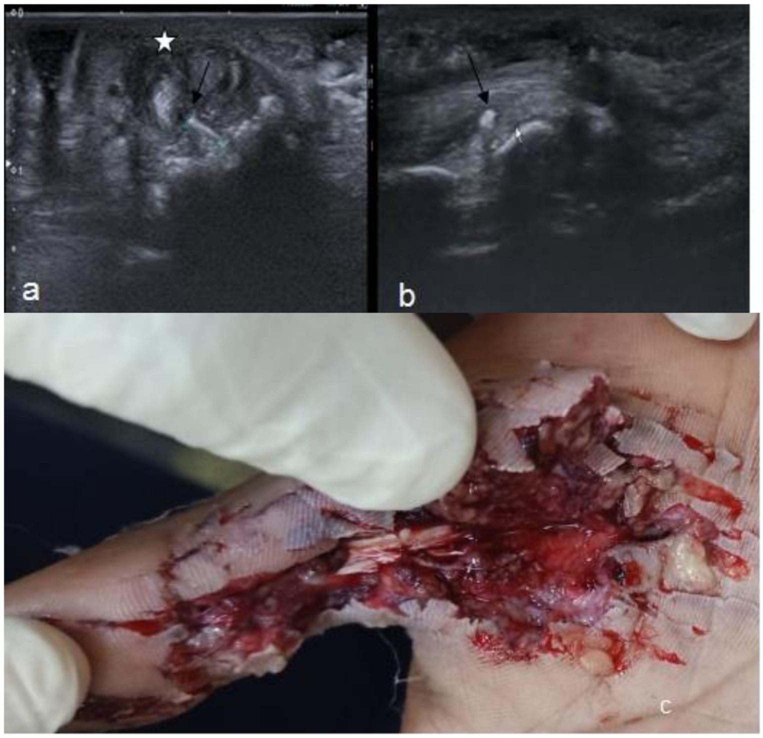

Fig. 4 Ultrasound images (**a** short axis section and **b** long axis section) at the site of flexor tendon injury in the thumb demonstrating the swollen disrupted tendon (white star, **a**) with an echogenic foreign body inside possibly woody in nature (black arrows, **a** and **b**); this was confirmed intra-operatively (**c**) preoperative photography for the injured thumb showing cutaneous maceration with exposed tendons down to the thumb base

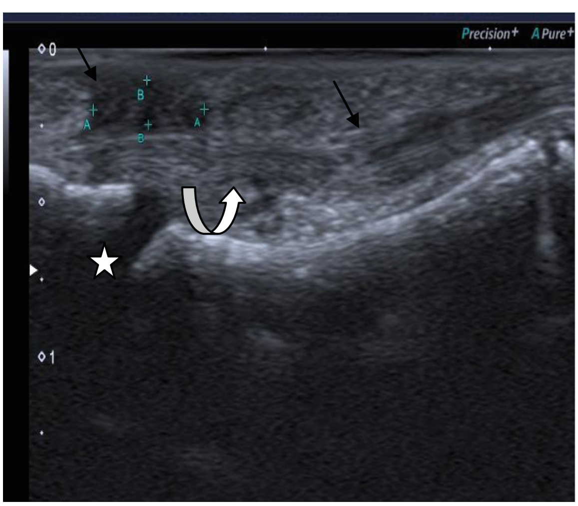

Fig. 5 Ultrasound image on the dorsum of the hand at the site of tendon injury demonstrating the cortical disruption of the metacarpal bone (white star) with an extensor tendon tear showing buckled retracted ends (black arrows) with an intervening granulation tissue filled gap (curved white arrow)

findings of tendon injuries, a tendon tear was the salient ultrasound finding, being noticed in 23 of 24 cases followed by the gapping tendons (18 cases), and then the abnormal motion (14 cases). The decreased echogenicity of the tendon was seen in 11 of 24 cases. Out of all (24 cases), only nine cases had a tendon callus, while tenosynovitis was present in seven cases [18].

Contradicting Lee et al.'s study, the hypoechoic areas were seen only in four of our cases (13.33%) compared to 11 in theirs; our explanation for this mismatch is attributed to the timing of the postoperative scanning, where the immediate postoperative examination could reveal some transient ultrasound findings, as the presence of peritendinous hypoechoic thin rind of simple fluid (described as minimal simple tenosynovitis) had faded spontaneously after a few days on ultrasound follow-up examination and this was considered an acceptable postoperative reactive process; also, we had noticed that the presence of intra-tendinous hypoechoic areas but with no associated fiber discontinuity or abnormal mobility of the affected tendons had disappeared completely and spontaneously on follow-up examinations; thus, it was considered a reactive process or subsiding postoperative edema.

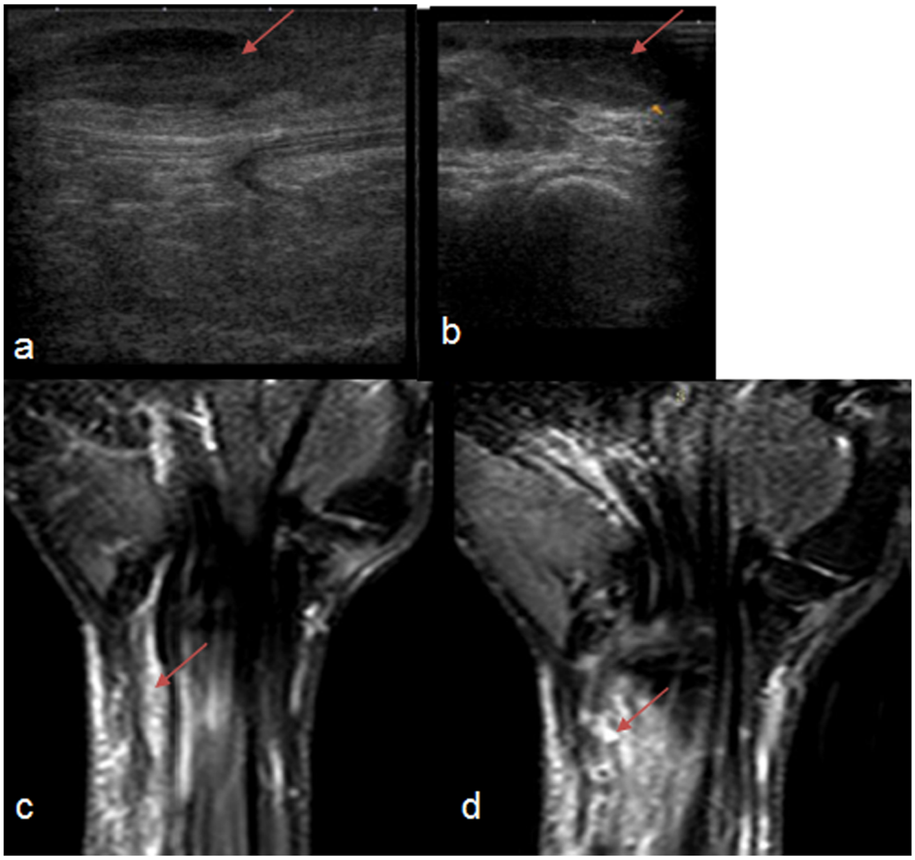

Fig. 6 Ultrasound (**a**, **b**) and coronal STIR MRI (**c**, **d**) images demonstrating the hypoechoic spindle-shaped pseudo mass lesion (red arrows, **a** and **b**) seen inside the tendon of the flexor carpi ulnaris muscle at the site of the tendon injury; **c**, **d** MRI images showing the corresponding high signal intensity at the same site and surrounding soft tissue edema

However, any persistent intra-tendinous hypoechoic areas, especially if associated with abnormal mobility or fiber discontinuity, were considered postoperative significant findings and could be a partial tear that might necessitate a follow-up examination.

Many works of the literature had reported superiority of the ultrasound examination in the assessment of hand tendon injuries especially in the postoperative evaluation and in the detection of tenosynovitis with a diagnostic capability that may exceed the computed tomography examinations and might emulate the MRI with contrast,

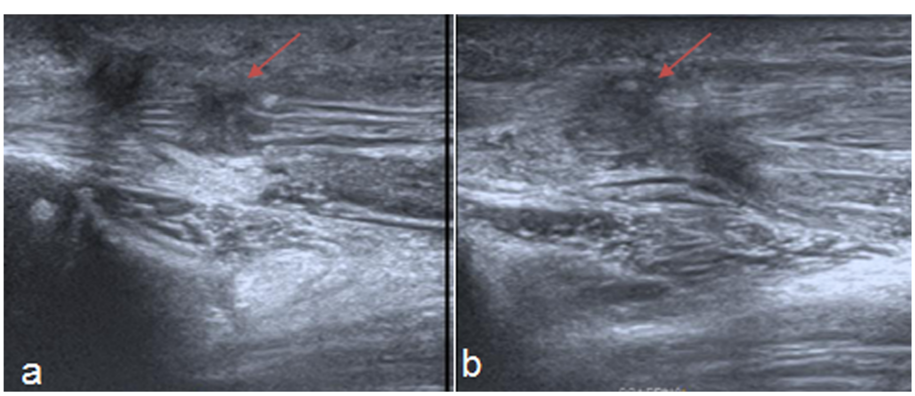

Fig. 7 Ultrasound images (**a**, **b**) at different long axis planes demonstrating the hypoechoic lesion (red arrows) seen between the torn ends of the ulnar nerve (neural stumps); sonographic Tinel's sign was elicited on probing

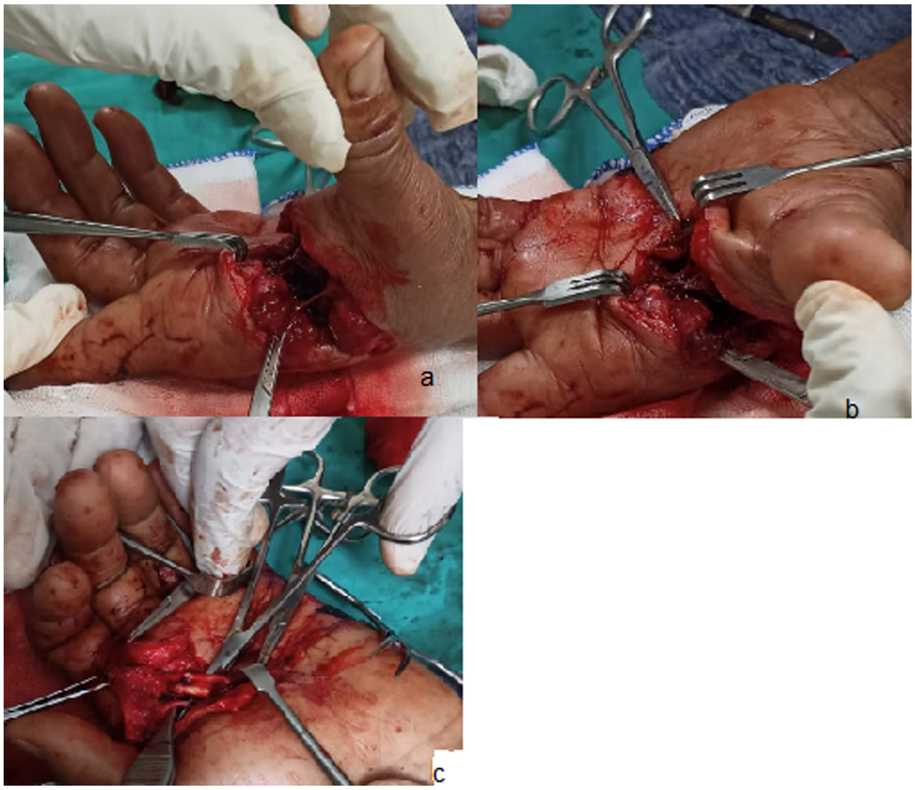

Fig. 8 Operative images (**a**, **b**) for a repaired tendon that failed to attain the normal range of motion after surgical repair and physiotherapy; HRUS was done and revealed an intact tendon with abnormal motions on dynamic scan likely due to peritendinous adhesions **a** showing the incision before the flexor tendons exploration and **b** showing the intact (repaired) tendon after adhesiolysis

as it can alleviate the metallic artifacts that are frequently encountered in postoperative orthopedic patients [19–21].

In a consensus study based on a Delphi process done by the European Society of Musculoskeletal Radiology (ESSR), experts of musculoskeletal imaging had recommended US as the first-choice technique for assessment of hand and finger injuries, including the intrinsic muscles and bones when the other imaging modalities could not be used and for foreign body detection [22, 23]; moreover, the consensus has been recently updated in the image-guided interventions as well [24].

Intra-tendinous foreign bodies were found in two of our cases by ultrasound examination, and this was considered an important finding, as the retained foreign bodies (Fig. 4) can induce inflammatory reaction and superadded soft tissue infections might supervene [25]. However, within the repaired tendons, the surgical materials (sutures and staples) could be seen (Fig. 3) and should be carefully interpreted to avoid unnecessary interventions.

Like MRI, HRUS can depict an avulsed bony fragment attached to the injured tendon with fairly good visualization of the irregular bony cortex of the parent

Table 4 The relation between HRUS and gold standard in detection of injury

	Gold standard				*P* value
	Tendon Injury		Intact tendon		
	Count	%	Count	%	
HRUS					
Injury	17	100	0	0	< 0.001
Intact	0	0	13	100	

Table 5 The accuracy of HRUS in detection of injury

Statistic	Value	95% CI
Sensitivity	100.00%	80.49 to 100.00%
Specificity	100.00%	75.29 to 100.00%
Positive predictive value	100.00%	
Negative predictive value	100.00%	
Accuracy	100.00%	88.43 to 100.00%

bone, allowing the differentiation from a dystrophic intra-tendinous calcification in long-standing tendon injuries [6].

The role of the dynamic ultrasound examination for torn tendons had been emphasized by many studies over the static examination, especially in the tendon tears, where the retracted torn ends are being more appreciated and the limitation of the tendon movement could be obviously seen [26], and this was supported by our results (Table 3).

Being in close anatomical proximity, nerves may be involved in traumatic affection of the hand tendons; this was found in two of our cases (6.66%), in agreement with Rajesh Kumar et al.; the ultrasound had a great diagnostic value in the evaluation of the nerve injury as regards the extent and the level of the lesion as much as a twofold confirmation of the clinical examination and the nerve conduction studies. By HRUS examination, the torn nerve may show a discontinuity along its trunk with a hypoechoic mass-like area (stumps) (Fig. 7) which might be seen. As a result of the inflammatory changes, marked tenderness and neurogenic (electric) pain could be elicited by probing this lesion; a finding that is known as sonographic Tinel's sign (Table 3) [16, 27].

A recent study by Albano et al. has emphasized the promising role of the HRUS and the ultra-HRUS (frequencies 22–70 MHz) in delineating the anatomical details and the ultrastructural changes of the very superficial nerves, pulley systems, retinacula, and the tendons [28].

We agreed that HRUS examination of the hand tendon injuries had proved a high diagnostic value (Tables 4 and 5), especially, in postoperative tendon repair and cases of retained foreign bodies; moreover, its availability, its relatively low-cost, and the high spatial resolution of the obtained images could provide wide popularity for its use.

Some limitations were met in this work: First is the use of two gold standards (operative and MRI evaluation); however, this was justified that not all of our patients were candidates for surgery or accepting it; thus, we used the MRI examinations as a complementary study that support our HRUS findings. The second was the concept that ultrasound is an operator-dependent technique and this is usually compensated by frequent practice under the supervision of the experienced seniors and the second-look examination if there was a need for this. The third one was being a single-center study with a relatively small sample size for the recruited patients, so the statistical analysis was not so robust. And the last one is the lack of the long-term follow-up examinations (about 1-year duration study) for most of the repaired lesions; thus, we recommend a long-term follow-up for postoperative cases in the future researches.

Conclusion

High-resolution ultrasound serves as a highly accurate potential diagnostic modality for preoperative evaluation of the hand tendon injuries and the postoperative follow-up.

Abbreviations

ER: Emergency room; HRUS: High-resolution ultrasound; MRI: Magnetic resonance imaging

Acknowledgements

Not applicable.

Authors' contributions

AAB, the corresponding author, had contributed by doing ultrasound examinations and the interpretation of the corresponding correlative image studies available in the research work. ABH had shared in the ultrasound examinations for the patients and in the manuscript editing and reference collection. HMA had the role of clinical assessment of the patients and the operative intervention correlation for the patients in the study and the follow-up. HMS had introduced the idea of the current study and helped in the image selection and in the editing of the manuscript and reference collection. All authors have read and approved the manuscript.

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Availability of data and materials

All data are available on a software system owned by each of the authors and the corresponding author has the authority to respond if there is any query.

Ethics approval and consent to participate

The protocol was reviewed and approved by the local ethics committee of the Radiology Department, Kasr Alainy Hospital, Cairo University. The reference number was not applicable.

Consent for publication

All patients had given their written consents for publication of this work.

Competing interests

All authors had no competing interests.

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