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Original Article

Ultrasound evaluation of surgically repaired hand tendons during rehabilitation and its relation to clinical and functional assessment

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ABSTRACT

Objectives: This study aimed to evaluate the contribution of musculoskeletal ultrasound to the follow-up of surgically repaired hand tendons during rehabilitation programs and correlate ultrasound findings with the clinical outcome.

Patients and methods: In the prospective observational study, 40 patients (29 males, 11 females; mean age: 27.4±10.7 years; range, 15 to 55 years) who presented with postoperative hand tendon repair between January 2019 and March 2020 were randomized into two groups: Group 1 included 15 subjects with 16 repaired flexor tendons, whereas Group 2 consisted of 25 subjects with repaired extensor tendons. Afterward, the assessment was performed at the four, eight, and 12 weeks of rehabilitation utilizing the total active motion of injured fingers, Visual Analog Scale (VAS), grip strength, ultrasound, and hand assessment tool (HAT).

Results: The study's findings revealed a substantial improvement in pain based on the evaluation of grip strength, total active motion, VAS, and the affected hand's HAT score in both groups (p<0.001). In both groups, ultrasonographic evaluation of healing tendons revealed considerable enhancement in margination, defect size, thickness, echogenicity, and vascularity. A positive correlation was detected between VAS and healing tendon margination as well as the HAT score and handgrip margination in Group 1.

Conclusion: High-frequency ultrasound is an easily accessible modality in the follow-up and evaluation of tendon healing after surgical repair and during a rehabilitation program.

Keywords: Hand assessment tool, musculoskeletal ultrasound, rehabilitation of repaired hand tendons.

The human hand serves a unique function. It is an adaptive organ capable of sensation, prehension, communication, and expression. In addition, it contains highly complex and interconnected systems, such as nerves, skin, tendons, muscles, joints, bones, and vessels. These systems work together to make highly coordinated hand motions. This unit's malfunction may result in severe hand impairment.[1]

Hand injuries are quite pervasive, accounting for 5 to 10% of the visits to the emergency department as well as approximately 20% of overall treated injuries.[2] Tendon injuries are considered the second most prevalent kind of hand injury. They are frequently induced by penetrating injuries and may lead to serious functional loss if not treated.[3]

Management of hand tendon injuries is based on proper diagnosis, early surgical intervention, early application of a well-selected rehabilitation program, and close follow-up. Early physical therapy after surgical repair of hand tendons improves the gliding function of the healing tendons and increases tensile strength, resulting in improved functional outcome and a decrease in the period needed by the patient to return to work.[4]

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In the past, the postoperative evaluation of the tendon's healing was confined to functional evaluation as well as wound inspection. Early tendon changes, such as changes in the shape or perfusion modifications, repair site gapping, or bulkiness, in addition to postsurgical modifications to the synovial sheath as well as its adjacent neurovascular or subcutaneous structures, were challenging to be evaluated. High-frequency ultrasound is frequently utilized in the follow-up of tendon healing after surgical repair since it is a noninvasive, reproducible, and reasonably priced diagnostic tool.[5] Consequently, this study attempted to evaluate the contribution of musculoskeletal ultrasound in the follow-up of surgically repaired hand tendons during rehabilitation programs and relate the sonographic results with the postoperative clinical outcome.

PATIENTS AND METHODS

This prospective observational study recruited 40 subjects (29 males, 11 females; mean age: 27.4±10.7 years; range, 15 to 55 years) with postoperative tendon repair two weeks after the operation from the outpatient clinic of the Physical Medicine, Rheumatology, and Rehabilitation Department of Faculty of Medicine, Tanta University between January 2019 and March 2020. Patients with collagen disease, congenital hand deformities, bone fractures, nerve injuries, fingertip injuries, burn injuries, or thumb tendon repair were excluded from the study. Subjects were categorized into two cohorts according to the injured tendon. Group 1 included 15 patients with 16 repaired flexor tendons who underwent a modified Duran protocol of rehabilitation. They were instructed to use a custom fabricated dorsal protective splint, which put the wrist in 20° flexion, metacarpophalangeal joints in 40-50° flexion, and proximal interphalangeal joints (PIPs) in the neutral position.[6] Group 2 included 25 patients with repaired extensor tendons. They underwent a static immobilization with an early controlled mobilization rehabilitation program based on the injured zone; rehabilitation of zone I to IV injuries was done according to Brault,[7] while zone V to VIII injuries were treated according to Bulstrode et al.[8] All patients received pulsed electromagnetic field therapy for 1 h, six times a week over the site of injury. The treatment started one to two days after repair and continued for four weeks.[9] Some physical modalities, including a paraffin wax bath and ultrasound therapy, were added as needed to prevent complications, such as joint stiffness and adhesive scars, after complete wound healing.[10]

A full history was taken from all patients, and the pain was evaluated by the Visual Analog Scale (VAS) at the second, 4^{th}, 8^{th}, and 12^{th} weeks of the rehabilitation program.[11] Total active motion (TAM) of the injured fingers was evaluated by a goniometer (JE MEDIGUARD, Stainless Steel Goniometer Jullundur Enterprise, Delhi, India) at the 8^{th} and 12^{th} weeks according to the Strickland classification using the following equation:

$$\frac{(\text{PIP} + \text{DIP})\ \text{flexion} - (\text{PIP} + \text{DIP})\ \text{extension deficit} \times 100 = \%\ \text{of normal active PIP+DIP}}{175}$$

motion.[12]

Grip strength of the affected hands was evaluated at the 8^{th} and 12^{th} weeks using a modified sphygmomanometer technique. Percentage decrease of handgrip compared to the normal hand was calculated.[13] The hand assessment tool (HAT), a consistent and internally valid tool for evaluating the limitations of the activity for subjects who had hand or wrist injuries, was evaluated at the 8^{th} and 12^{th} weeks. Seven factors, firm grip, extension, fine hand skills, neuritic symptoms, pain, gross grip, and aesthetics, were assessed by 14 questions. Each question answered was scored, and a total score was obtained using the equation [(sum of n responses)/n)-1] ×25; n refers to the number of items.[14]

All patients underwent ultrasonographic evaluation at the 4^{th}, 8^{th}, and 12^{th} weeks using Samsung Medison (UGEO H60; Samsung Medison UGEO H60, South Korea) using linear array transducers with frequencies ranging between 9 and 13 Hz. The patients were seated facing the examiner, and the transducer was placed directly on the patient's skin with gel. The longitudinal and the transverse planes were scanned to pinpoint the location of the tendon repair. The influence of anisotropy artifact was avoided by positioning the transducer perpendicular to the tendon. The equivalent site on the contralateral undamaged finger was found utilizing bone markers.

Ultrasound measurement definitions were made according to the study of Bűhler et al.[15] The defect size was the length (mm) between the observable margins of the hypoechoic area of the healing tendon as well as the neighboring normoechoic tendon. The tendon thickness was the linear measurement (mm) recorded in the transverse view at the midpoint of tendon repair on the injured digit and also at the corresponding site on the uninjured hand. The vascularity was evaluated utilizing the power Doppler mode in the transverse plane. The signals were scored as follows: Grade 0= no signal detected, Grade 1= slight vascularity with a transverse area ≤30%, Grade 2= intermediate vascularity ≤60%, and Grade 3= severe vascularity <60%. Echogenicity was rated according to the reflectivity of the transverse area using the following scale: Grade 0= normal tendon, Grade 1= an estimated decrease in reflectivity of 25%, Grade 2= decreased reflectivity between 25 and 50%, Grade 3= decreased reflectivity of 50 to 75%, and Grade 4= decreased reflectivity between 75 and 100%. Tissue margination was graded using the following scale: Grade 1= clearly outlined margins, Grade 2= relatively less definition between margins, Grade 3= uneven margins, and Grade 4= merged boundaries.

Statistical analysis

Data were analyzed utilizing the IBM SPSS version 20.0 software (IBM Corp., Armonk, NY, USA). In addition, qualitative data were expressed in the form of percentages and numbers, whereas normally distributed variables were analyzed utilizing the paired t-test to make a comparison between two periods. Quantitative variables with normal distribution were analyzed with analysis of variance with repeated measurements to compare between more than two stages or periods, whereas pairwise comparisons were made by the Bonferroni-adjusted post hoc test. Furthermore, Wilcoxon signed-rank test was utilized for abnormally distributed quantitative variables to make a comparison between two periods. The Friedman test was adopted for quantitative variables with nonnormal distribution. Dunn's post hoc test was utilized for pairwise comparisons. The Pearson coefficient was adopted to test the correlation between two quantitative variables with normal distribution. The Spearman coefficient was utilized to evaluate the correlation between two nonnormally distributed quantitative variables. A p value of <0.05 was considered statistically significant.

RESULTS

The demographic variables are described in Table 1. The little finger was the most injured finger in Group 1 (31.25%), whereas the index finger was the most common in Group 2 (40%). All cases of flexor tendon injuries in Group 1 were in zone II, while extensor tendon injuries in Group 2 were between zone V and VIII.

The findings demonstrated substantial improvement in pain evaluated according to the VAS after the 4th, 8th and 12 weeks of the rehabilitation program compared to the second week and after the 8th and 12th weeks compared to the fourth week in both groups (p<0.001).

Data revealed a substantial improvement in the TAM of afflicted fingers, grip strength, and HAT score

TABLE 1
Distribution of the studied cases according to demographic data, side of injury, and injured finger

	Group 1 (n=15)				Group 2 (n=25)			
	n	%	Mean±SD	Min-Max	n	%	Mean±SD	Min-Max
Age (year)			26.8±8.8	16.0-48.0			29.4±12.5	15.0-55.0
Sex								
Male	10	66.7			19	76.0		
Female	5	33.3			6	24.0		
Occupation								
Student	4	26.7			7	28.0		
Manual worker	6	40.0			14	56.0		
Housewife	5	33.3			4	16.0		
Side of injury								
Right	11	73.3			15	60.0		
Left	4	26.7			10	40.0		
Injured finger								
Little	5	31.25			3	12.0		
Ring	4	25.0			4	16.0		
Middle	4	25.0			8	32.0		
Index	3	18.75			10	40.0		

SD: Standard deviation.

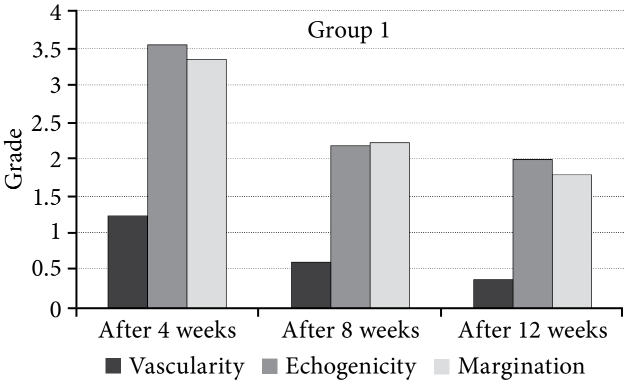

Figure 1. Assessment of vascularity, echogenicity and margination of healing tendon by ultrasound at 4^{th}, 8^{th} and 12^{th} weeks of rehabilitation program in Group 1.

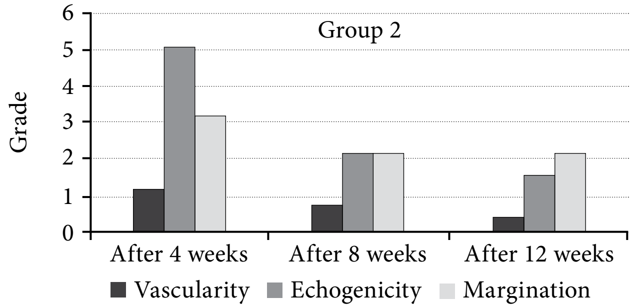

Figure 2. Assessment of vascularity, echogenicity and margination of healing tendon by ultrasound at 4^{th}, 8^{th} and 12^{th} weeks of rehabilitation program in group 2.

of the affected hand after 12 weeks of the rehabilitation program compared to the eighth week in the two cohorts (p<0.001).

There was a considerable decline in defect size after the 8^{th} and 12^{th} weeks of the rehabilitation program compared to the fourth week as well as after the 12^{th} week compared to the eighth week in both groups.

There was a marked decline in thickness after the 8^{th} and 12^{th} weeks of the rehabilitation program compared to the fourth week as well as after the 12^{th} week compared to the eighth week in both cohorts. Furthermore, there was a substantial alleviation in thickness of healing tendons after the 4^{th}, 8^{th} and 12^{th} weeks of the rehabilitation program than in the normal hand in both cohorts.

There was a substantial decline in vascularity after the 8^{th} and 12^{th} weeks of the rehabilitation program compared to the fourth week in Group 1, while in Group 2, there was a significant decrease in vascularity after the 12^{th} week of the rehabilitation program compared to the fourth week. There was a significant improvement in echogenicity after the 8^{th} and 12^{th} weeks of the rehabilitation program compared to the fourth week, and after the 12^{th} week compared to the eighth week in both cohorts.

There was a marked enhancement in margination after the 8^{th} and 12^{th} weeks of the rehabilitation program compared to the fourth week in Group 1, while in Group 2, there was a substantial enhancement in margination after the 8^{th} and 12^{th} weeks of the rehabilitation program compared to the fourth week and after the 12^{th} week compared to the eighth week (Figures 1, 2, 3 and 4).

A positive relationship was revealed between healing tendon margination assessed by ultrasound and the VAS score in Group 1, while there was no significant correlation between ultrasound findings and the VAS score in Group 2. Furthermore, both

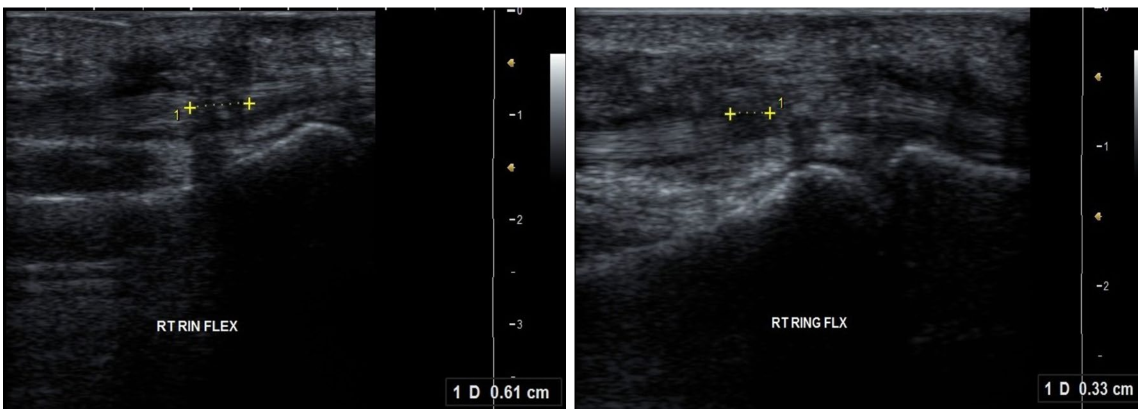

Figure 3. Defect size in cut FDP of right ring finger after 4^{th} and 12^{th} weeks of surgical repair respectively in Group 1.

FDP: Flexor digitorum profundus; RT: Right.

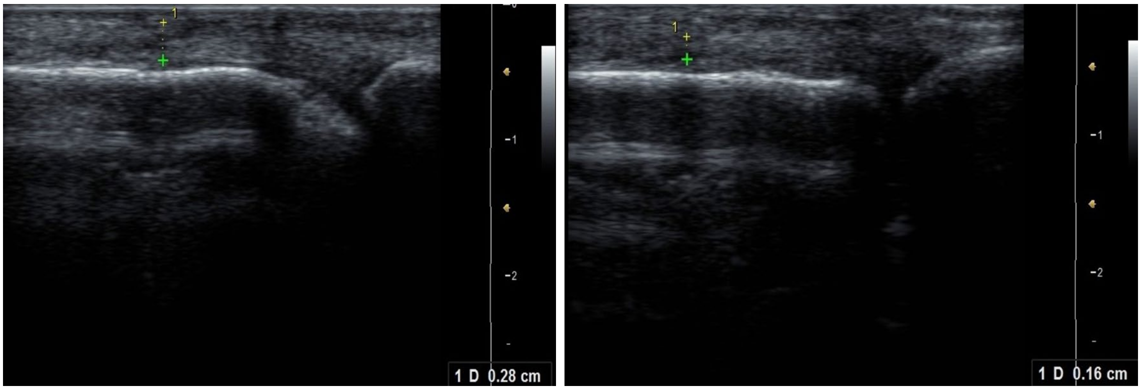

Figure 4. Thickness of cut EDC in left index finger after 4th and 12th weeks of surgical repair respectively in Group 2.
EDC: Extensor digitorum communis.

TABLE 2
Correlations between the VAS, TAM, hand grip, and HAT score with ultrasound findings

	Change in VAS in Group 1 (4 to 12 weeks)		Change in TAM in Group 1 (8 to 12 w)		Change in Hand grip in Group 1 (8 to 12 w)		Change in HAT score in Group 1 (8 to 12 w)	
Change in US findings in Group 1	r_s	*p*	r	*p*	r	*p*	r_s	*p*
Decrease in defect size	0.110	0.696	0.431	0.095	0.106	0.706	0.304	0.271
Decrease in thickness in mm	-0.372	0.172	-0.013	0.961	0.062	0.825	0.056	0.842
Change in vascularity	0.222	0.426	-0.456	0.076	0.100	0.722	-0.212	0.449
Decrease in echogenicity	0.160	0.568	0.340	0.197	0.296	0.285	-0.078	0.782
Decrease in margination	0.610*	0.016*	0.191	0.478	0.530*	0.042*	0.828*	<0.001*
	Change in VAS in Group 2 (4 to 12 weeks)		Change in TAM in Group 2 (8 to 12 w)		Change in Hand grip in Group 2 (8 to 12 w)		Change in HAT score in Group 2 (8 to 12 w)	
Change in US findings in Group 2	r_s	*p*	r	*p*	r	*p*	r_s	*p*
Decrease in defect size	-0.135	0.520	0.187	0.371	0.008	0.969	-0.138	0.511
Decrease in thickness in mm	0.134	0.522	0.232	0.265	-0.366	0.072	-0.093	0.660
Change in vascularity	-0.101	0.631	-0.137	0.513	-0.246	0.235	0.155	0.461
Decrease in echogenicity	-0.038	0.858	-0.137	0.512	-0.267	0.196	0.231	0.266
Decrease in margination	0.224	0.283	0.216	0.300	0.439*	0.028*	0.086	0.683

VAS: Visual Analog Scale; TAM: Total active motion; HAT: Hand assessment tool; US: Ultrasound; r_s: Spearman coefficient; r: Pearson coefficient; * Statistically significant at $p \leq 0.05$.

groups had a positive association between margination of the healing tendon, assessed by ultrasound, and hand grip and HAT score (Table 2, Figures 5, 6, and 7).

DISCUSSION

After hand tendon repair, rehabilitation enhances tendon excursion, accelerates morphological healing of the wounded tendons, and decreases adhesion formation. This results in improved functional outcomes following hand tendon surgical repair and minimizes possible complications.[16] In this study, a significant improvement was observed in pain assessed by the VAS after the 4th, 8th, and 12th weeks of the rehabilitation program compared to the second week and after the 8th and 12th weeks compared to the fourth week in both groups. These results are by the application of early motion protocols that decrease the possibility

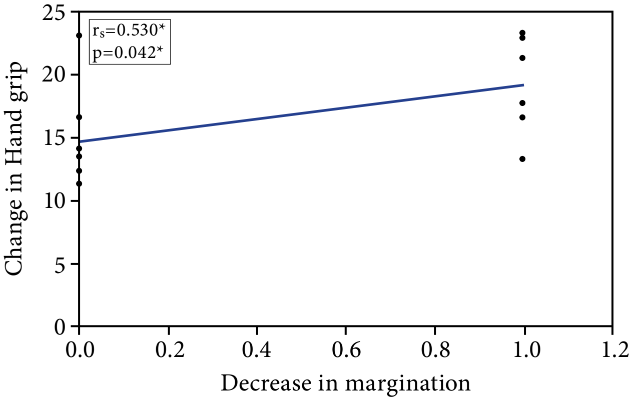

Figure 5. Correlation between hand grip and decrease in margination in Group 1.

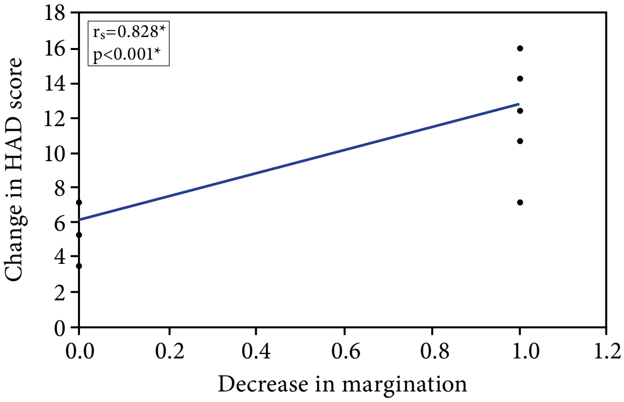

Figure 6. Correlation between change in HAT score and decrease in margination in Group 1.
HAT: Hand assessment tool.

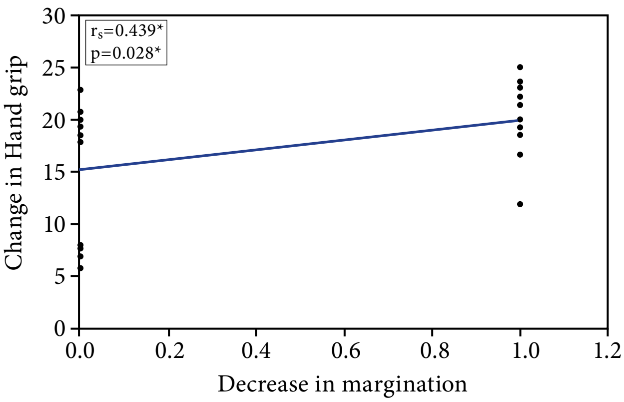

Figure 7. Correlation between change in hand grip and decrease in margination in Group 2.
HAT: Hand assessment tool.

of stiffness and adhesions and pulsed electromagnetic field therapy, which helped resolve edema and enhance tendon repair, thus decreasing postoperative pain. Moreover, some physical modalities were added, such as a paraffin wax bath and ultrasound therapy, which helped decrease pain, joint stiffness, and adhesive scars.

The TAM of the injured finger improved after the 12th week compared to the eighth week in both groups. This finding is compatible with those of Rrecaj et al.,[17] who used the Strickland classification to assess the range of motion of injured flexor tendons after using a Duran rehabilitation protocol. They found that the range of motion of the damaged flexor tendons improved after the 12th week of the rehabilitation program in comparison to the eighth week. This is explained by an improvement in pain assessed by VAS and the application of more advanced exercises in the rehabilitation protocol, which results in an improved TAM of the affected fingers.

We found that grip strength of the affected hand significantly improved after the 12th week in both groups. This is explained by the application of strengthening and resisted exercises after the eighth week of the rehabilitation program in both groups, which led to improved grip strength in the affected hand.

Kitis et al.[18] reported that the affected hand's average grip strength was 81% of the normal hand after 12 weeks in patients who used a controlled passive movement rehabilitation protocol for flexor tendons. Grip strength was estimated utilizing a Jamar dynamometer. In the majority of other studies that assessed grip strength after six months or one year, it is shown to improve during the first six months and then reach a plateau at one year, as illustrated by Libberecht et al.[12,13,19]

On evaluating the functional outcome of the patients using the HAT score, we found that the HAT score significantly decreased after the 12th week compared to the eighth week. This can be explained by the improved TAM of the injured finger, grip strength of the affected hand, and pain assessed by the VAS, leading to improvement in hand functions and thus a decreased HAT score.

With regard to ultrasound assessment, we found that the defect size of the healing tendon was significantly decreased after the 12th week compared to the fourth and eighth weeks in both groups, which is explained by the natural healing process that consists of three stages; inflammatory, proliferative, and remodeling.[20]

In comparison to the normal hand, we found that the thickness of the healing tendons was significantly increased, which is consistent with the results of Bűhler et al.,[14] who reported that values of the tendon thickness in the surgically repaired tendon at the mid-repair site was between 94 and 369% of subjects with uninjured contralateral tendons. Furthermore, there was a dramatic decline in tendon thickness after the 12th week when compared to the fourth and eighth weeks in both groups. These findings can be explained by the healing process. For instance, in the proliferative phase, there is a quick fibroblast proliferation resulting in the secretion of proteoglycans, collagen, and other extracellular matrix components. High cellularity and the formation of vascular network in the healing tendon make its thickness higher than normal tendon thickness; then, in the remodeling period, which starts six to eight weeks following injury, there is a decline in cellularity as well as diminished matrix synthesis, decreasing tendon thickness.[21]

Vascularity of healing tendons was significantly decreased after the 12th week compared to the fourth week in both groups due to the natural healing process as a significant blood vessel network is formed in the proliferative stage. The remodeling peroid then begins, during which tenocyte and tendon vascularity drop.[22]

We found that the echogenicity of the healing tendon was significantly improved after the 12th week compared to the fourth and eighth weeks in both groups. This finding agrees with Puippe et al.,[23] who illustrated that echogenicity changes during the healing course throughout the healing process towards further hyperechogenic formations inside the suture sites. They explained their findings by phases of tendon healing; during the early proliferative as well as inflammatory phases, tendons were preponderantly hypoechogenic, which can be attributed to the elevated blood vessels and edema content, whereas during the remodeling phase, the elevation in the fibers of organized collagen results in elevated echogenicity within the tendon.

Regarding the correlation data, a positive relationship was proven between the VAS score and healing tendon margination assessed by ultrasound in Group 1, while there was no substantial association between all ultrasound findings and the VAS score in Group 2. Furthermore, a positive relationship was revealed between the HAT score and healing tendon's margination on ultrasound and hand grip in both groups. Our results can be explained by the well-defined tendon margins that may indicate a good healing process, resulting in good clinical and functional outcomes.

Tendon repair comprises three stages: an inflammatory phase, a reparative phase, and a remodeling phase. These stages are correlated with a number of growth factors that tend to be the most active in chronological order.[21] Bone-tendon and tendon-tendon repair is enhanced by endogenous growth factors.[22] The purpose of imaging in this scenario is to provide a noninvasive method of determining various stages of healing and assessing the effects of primary repair or healing therapies. The sequence of events that lead to tendon deterioration, tearing, and subsequent bone-tendon healing after repair are elucidated by ultrasound.[24]

The main limitation of the study is the small sample size. Further studies are recommended on a larger scale of patients.

In conclusion, high-frequency ultrasound is an easily accessible modality in the follow-up and evaluation of tendon healing after surgical repair and during a rehabilitation program.

Ethics Committee Approval: The study protocol was approved by the Tanta University, Faculty of Medicine Ethics Committee (date: 22/11/2018, no: 32684/11/8). The study was conducted in accordance with the principles of the Declaration of Helsinki.

Patient Consent for Publication: A written informed consent was obtained from each patient.

Data Sharing Statement: The data that support the findings of this study are available from the corresponding author upon reasonable request.

Author Contributions: Data collection and writing manuscript: N.H.; Review and general supervision: N.E.; Supervision, data analysis/interpretation: A.E.; Idea, design, clinical supervision and data analysis: M.A.

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