

Ultrasonographic Evaluation of the Early Healing Process After Achilles Tendon Repair

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Investigation performed at Yao Municipal Hospital, Yao, Japan

Background: Little is known about early healing of repaired Achilles tendons on imaging, particularly up to 6 months postoperatively, when patients generally return to participation in sports.

Purpose: To examine changes in repaired Achilles tendon healing with ultrasonography for up to 12 months after surgery.

Study Design: Case series; Level of evidence, 4.

Methods: Ultrasonographic images of 26 ruptured Achilles tendons were analyzed at 1, 2, 3, 4, 6, and 12 months after primary repair. The cross-sectional areas (CSAs) and intratendinous morphology of the repaired tendons were evaluated using the authors' own grading system (tendon repair scores), which assessed the anechoic tendon defect area, intratendinous hyperechoic area, continuity of intratendinous fibrillar appearance, and paratendinous edema.

Results: The mean ratios (%) of the CSA for the affected versus unaffected side of repaired Achilles tendons gradually increased postoperatively, reached a maximum (632%) at 6 months, and then decreased at 12 months. The mean tendon repair scores increased over time and reached a plateau at 6 months.

Conclusion: Ultrasonography is useful to observe the intratendinous morphology of repaired Achilles tendons and to provide useful information for patients who wish to return to sports. Clinical parameters such as strength, functional performance, and quality of healed repaired tendons should also be assessed before allowing patients to return to sports.

Keywords: Achilles tendon repair; ultrasonography; tendon morphology; early healing process

An Achilles tendon rupture (ATR) often occurs in middle-aged persons who participate in recreational sports.¹⁸ A recent meta-analysis has shown that 20% of patients with an ATR cannot return to their previous level of activity.²⁶ Furthermore, the playing time and performance of professional athletes who return to sports after an ATR are

significantly decreased.^{1,21} Therefore, an ATR is considered a career-threatening injury among elite athletes.

The treatment of acute ATRs is controversial, and the main choices are either surgical or nonsurgical.^{9,12,14,16,17,22,24,25} The rate of reruptures is lower after surgical than nonsurgical treatment, but the difference is not always significant.^{9,12,14,16,17,22,24,25} Early weightbearing and mobilization exercises after an acute ATR are now generally thought to contribute to good outcomes.^{7,9}

Ultrasonography (US) and magnetic resonance imaging (MRI), as well as clinical tests such as the Thompson squeeze test, are useful for diagnosing ATRs. Several previous reports have indicated that US and MRI are useful for diagnosing ATRs, and other studies have used these modalities to evaluate the healing process of ATRs in vivo^{8,10} and in experimental animals.^{3,27} One prospective randomized trial compared the healing characteristics of Achilles tendons after surgical and nonsurgical repair using MRI and US¹¹ and concluded that the roles of these imaging modalities are limited by weak correlations with clinical findings. However, these tendons were evaluated by MRI or US from around 6 months after surgery, when patients are generally allowed to return to sports, and early changes on images of repaired ATRs were not assessed. The time when patients may return to sports is determined based on the

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experience of the surgeons, and an objective index has not been established.

The present study aimed to determine the healing quality of ATRs during the first 6 months after surgery and whether US is beneficial in assessing the point at which the quality of the repaired tendon is similar to that before the rupture.

METHODS

Participants

This study included 26 consecutive patients (mean age, 41.7 years [range, 17-67 years]; 18 male) who underwent primary Achilles tendon repair between 2012 and 2016. Patients with previous ATRs, functional impairments of the contralateral side, or diabetes mellitus were excluded. Diagnoses were based on a palpable tendon gap and a positive calf-squeeze test result²⁰ or on US if a tendon gap was not palpable. None of the patients developed postoperative complications such as infections, sural nerve disturbance, thrombophlebitis, or repeated ruptures. The institutional review board for human participant research at our institution approved the study, and all patients provided informed consent to participate in all aspects of the study before enrollment.

Operative Procedure

All ATRs were repaired during open procedures via a posteromedial longitudinal incision. Ruptured tendons were apposed using a core Kessler stitch with a No. 2 nonabsorbable braided suture⁵ supplemented with 3-0 Vicryl (Ethicon) circumferential sutures. The paratenon was closed with 3-0 Vicryl sutures, and then the skin was closed with interrupted fine nylon mattress sutures (Ethicon). The limb was postoperatively immobilized in a full equinus cast.

Rehabilitation

All patients followed a standardized rehabilitation protocol (Table 1) under the supervision of experienced physical therapists. The postoperative plaster was replaced with an original footplate orthosis (Anzu) 14 days after surgery (Figure 1), and weightbearing was encouraged, with crutches if necessary. Five footplates (1 cm thick) were attached to the bottom of the orthosis (Figure 1) and removed one by one every week to increase ankle dorsiflexion. The orthosis was removed at 8 weeks after surgery, and walking was permitted without the orthosis. Bilateral or unilateral heel-raise exercises were started at 2 months. At 3 to 6 months, running and sport-specific training were allowed after considering US findings.

Clinical Evaluation

Subjective outcomes at 6 and 12 months after surgery were assessed using the Achilles tendon Total Rupture Score

TABLE 1
Rehabilitation Program

Weeks 2-8	<ul style="list-style-type: none"> • Treatment: wear footplate orthosis and use crutches if needed • Exercise program: visit a physical therapist once a week and perform home exercises daily <ul style="list-style-type: none"> • Ankle range of motion • Sitting heel raise • Gait training
Weeks >8-12	<ul style="list-style-type: none"> • Exercise program: visit a physical therapist once a week and perform home exercises daily <ul style="list-style-type: none"> • Ankle range of motion • Sitting heel raise • Standing heel raise (2 legs) • Gait training • Leg extension and leg curl
Weeks >12-16	<ul style="list-style-type: none"> • Exercise program: visit a physical therapist once a week and perform home exercises daily <ul style="list-style-type: none"> • Standing heel raise (1 leg) • Leg extension and leg curl • Jogging
Weeks >16	<ul style="list-style-type: none"> • Exercise program: visit a physical therapist as needed and perform home exercises daily <ul style="list-style-type: none"> • Exercise with increases in weight and intensity as tolerated • Side jumps and 2-legged jumps if possible • Gradual return to sports (depending on patient's ability)

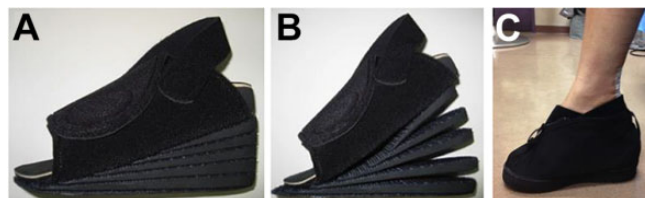


Figure 1. Original footplate orthosis. (A, B) Sole plates that are 1 cm thick can be removed in 5 stages to enable the gradual adjustment of ankle dorsiflexion angles. (C) The orthosis immediately after fitting.

(ATRS).¹⁵ The ATRS evaluates patient symptoms and tendon function based on a 10-item injury-specific score, with a maximum of 100 (10 points per item) indicating full recovery. We also conducted the Tegner activity scale before and 12 months after surgery. Range of motion was measured using a standard goniometer at 6 and 12 months after surgery. Ankle plantar flexion was measured with the patient in a seated supine position with the knee flexed 30° and the gastrocnemius relaxed. We determined range of motion as the affected side minus the unaffected side (side-to-side difference). Calf muscle endurance was evaluated using single-leg standing heel raises at 3, 4, 5, 6, 9, and 12 months after surgery.⁴ The number of standing unilateral heel raises 2 cm above the floor was counted (Figure 2). The test was stopped when the patient felt unable to continue.

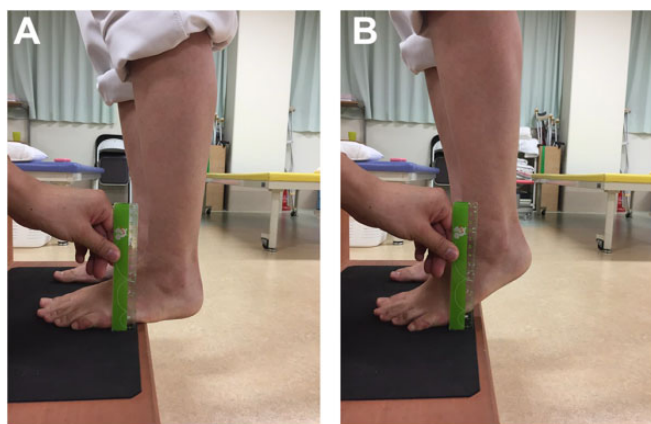


Figure 2. Standing single-leg heel-raise test: height of heel raise and number of repetitions.

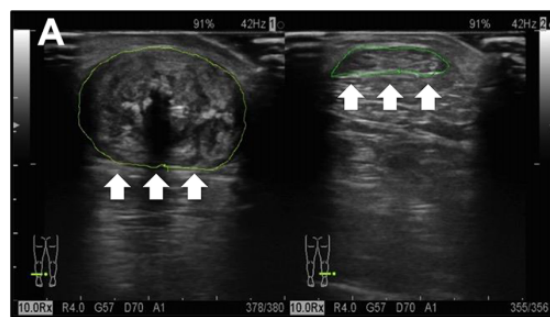
Ultrasonography

Patients were prospectively evaluated at 1, 2, 3, 4, 6, and 12 months after surgery by 2 experienced ultrasonographers using a real-time US scanner (ProSound F75; Hitachi) with an 8- to 18-MHz linear array probe (UST-5415; Hitachi). The appropriate imaging parameters for the high resolution of tendons, including optimal focusing, were set before imaging. Longitudinal and axial images of affected and unaffected tendons were acquired, and the maximal sagittal dimension was recorded on both sides in the axial plane.

The US findings were evaluated based on the cross-sectional area (CSA) and intratendinous morphology of the repaired tendon. The CSA ratio of the tendon at the rupture site in the axial plane was calculated as the ratio of the affected to the unaffected side (Figure 3). The intratendinous morphology of the repaired tendon was evaluated using our grading system with reference to the modified Moller grading system.¹¹ We measured anechoic areas of tendon defects as discontinuous, fibrillar echo texture (Figure 4A), intratendinous hyperechoic areas exhibiting scar tissue of the repair (Figure 4B), continuity of an intratendinous fibrillar appearance with collagen fiber alignment along the long axis of the repaired tendon (Figure 4C), and peritendinous reactions (Figure 4D). Residual anechoic tendon defects were recorded as 0% to <1%, 1% to <50%, and 50% to 100%. The intratendinous hyperechoic area at the rupture site was categorized as 0% to <25%, 25% to <50%, 50% to <75%, and 75% to 100%. The continuity of an intratendinous fibrillar echo texture was categorized as complete, incomplete, or absent. Peritendinous reactions such as local edema and/or effusions were categorized as present or absent. Points were allotted for each parameter, with a maximum of 10 points indicating a repaired tendon (Table 2). All scores were summed and evaluated.

Measurement Reliability

Two observers (K.H. and T.M.) independently measured the CSAs of 20 repaired tendons to assess interobserver



$$\text{CSA ratio} = \frac{\text{CSA (affected side)}}{\text{CSA (unaffected side)}} \times 100 (\%)$$

Figure 3. Measurement of the cross-sectional area (CSA) ratio. (A) Ultrasonographic image in the axial plane shows affected (left) and unaffected (right) tendons. The Achilles tendon is outlined. (B) The CSA ratio is the ratio of the affected to the unaffected side.

agreement (intraclass correlation coefficient [ICC], 0.92), and 1 observer (K.H.) measured these parameters twice at an interval of 1 week to assess intraobserver agreement (ICC, 0.90).

Statistical Analysis

Data were statistically analyzed using SPSS statistical software (version 21.0; IBM) and statistical package R (version 3.0.2; R Development Core Team [http://www.r-project.org]) for all analyses. Statistical significance was assessed at $P < .05$. The postoperative time course of CSAs and tendon repair scores at 5 time points was analyzed using generalized linear mixed models.

RESULTS

The mean ATRS score at 6 and 12 months was 85.6 (range, 62-97) and 95.4 (range, 83-100), respectively. The mean Tegner activity score before injury and 12 months after surgery was 5.9 and 5.4, respectively. Side-to-side differences in dorsiflexion were -2.1° (range, 0° to -10°) and -1.4° (range, 0° to -5°), respectively, and those in plantar flexion were -3.1° (range, 0° to -10°) and -0.9° (range, 0° to -5°), respectively, at 6 and 12 months. The mean time that elapsed before the patients could complete 25 heel raises was 4.5 months (range, 3-9 months).

The ratios of the CSA of repaired Achilles tendons versus the unaffected side at 1, 2, 3, 4, 6, and 12 months were 339% (range, 10%-600%), 496% (range, 160%-740%), 568% (range, 200%-870%), 610% (range, 270%-930%), 632% (range, 430%-970%), and 507% (range, 350%-780%), respectively (Figure 5). The CSAs were significantly larger at 6 months than at 1 and 2 months and were significantly smaller at 12 months than at 6 months.

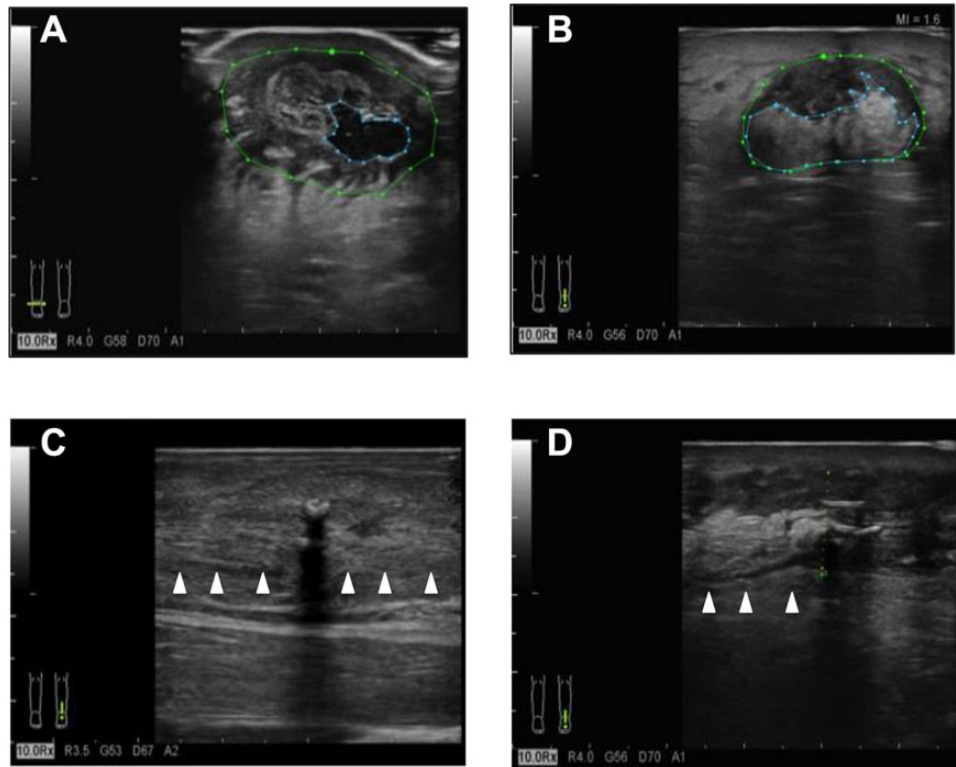


Figure 4. Intratendinous morphology of a repaired tendon on axial and longitudinal ultrasound images. (A) A residual anechoic tendon defect (black lesion outlined in blue) in the axial plane. (B) An intratendinous hyperechoic area at the rupture site (brighter than adjacent tissue outlined in blue) in the axial plane. (C) Continuity of the intratendinous fibrillar appearance (layered hyperechoic line; white arrowhead) in the longitudinal plane. (D) Peritendinous edema appearing as soft tissue swelling, resembling cobblestones, adjacent to the repaired tendon (white arrowhead) in the longitudinal plane.

TABLE 2
Achilles Tendon Repair Scoring

Parameter	Points
Anechoic tendon defect area	
Absent	2
0%-<50%	1
50%-100%	0
Intratendinous hyperechoic area	
0%-<25%	3
25%-<50%	2
50%-<75%	1
75%-100%	0
Continuity of intratendinous fibrillar pattern	
Complete	3
Incomplete	1
Absent	0
Peritendinous edema	
Absent	2
Present	0
Total	10

Tendon repair scores (up to 10 points) at 1, 2, 3, 4, 6, and 12 months were 3.5 (range, 1-5), 5.2 (range, 3-8), 6.8 (range, 4-9), 8.2 (range, 6-10), 9.2 (range, 7-10), and 10 points, respectively (Figure 6). Tendon repair scores increased over

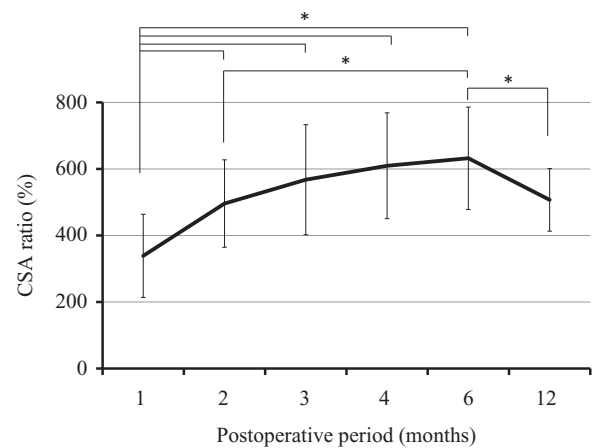


Figure 5. Changes in the cross-sectional area (CSA) ratio over time. *Significantly different: $P < .05$.

time, and all patients achieved 10 points for each category at 12 months. Tendon repair scores did not significantly differ between 6 and 12 months. Figure 7 shows details of the scores for intratendinous hyperechoic areas and a fibrillar appearance of the repaired tendon. The score for the

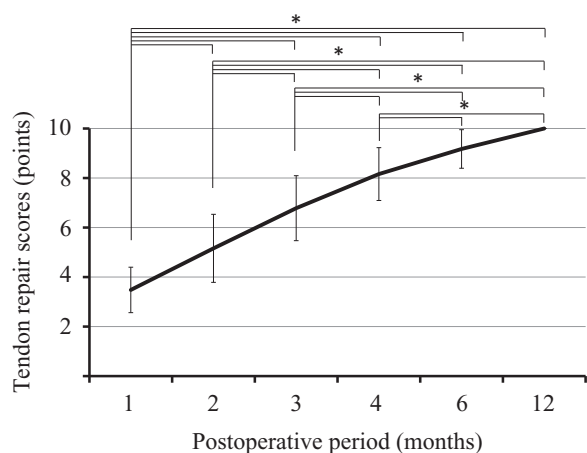


Figure 6. Sequential changes in tendon repair scores over time. *Significantly different: $P < .05$.

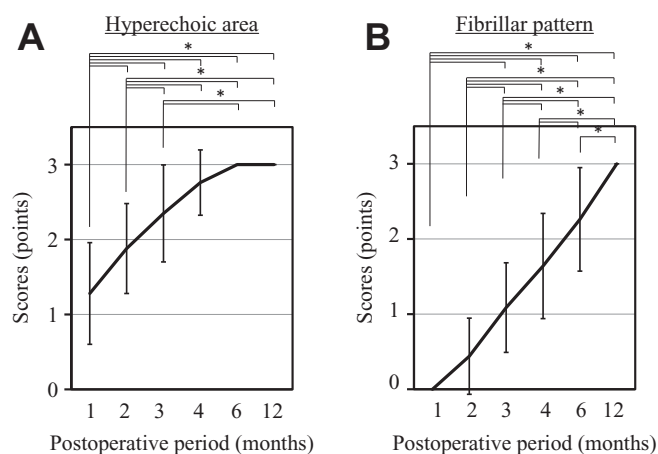


Figure 7. Sequential changes in details of the scores for intratendinous hyperechoic areas and a fibrillar appearance of the repaired tendon. *Significantly different: $P < .05$.

intratendinous hyperechoic area of the repaired tendon with scar tissue was increased and reached a plateau within 4 months. The score for the fibrillar appearance of the repaired tendon with collagen fiber alignment along its long axis gradually increased until 12 months.

DISCUSSION

We used US to evaluate early healing of repaired ATRs during the first 12 months after surgery. The principal findings were that the CSA of the reconstructed tendon gradually increased postoperatively, reached a maximum at 6 months, and decreased at 12 months; that tendon repair scores did not significantly differ between 6 and 12 months; and that all patients achieved maximal scores at 12 months.

Normally, the CSA of tendon or ligament tissues increases after surgical repair until it reaches a plateau,

after which it decreases.² This could be because of low rupture strength of tendon tissue soon after surgery, causing decompensatory hypertrophy of the CSA until sufficient mechanical strength is regained, after which the CSA decreases.¹³ The CSA of grafts after anatomic triple-bundle anterior cruciate ligament reconstruction using autogenous hamstring tendons increases for up to 1 year postoperatively, decreases gradually thereafter, and reaches a plateau at around 3 years.⁶ In the present study, the CSA of repaired tendons increased over time, reached a maximum at 6 months, and then decreased at 12 months. These findings suggest that repaired tendons acquire sufficient mechanical strength by 6 months after surgical repair.

Tendon healing after surgical repair generally progresses through a short inflammatory phase of about 1 week, followed by a proliferative phase of a few weeks and a remodeling phase that persists for several months.²³ Macrophages and tendon fibroblasts proliferate and form scar tissue during the inflammatory and proliferative phases.¹⁹ Scar tissue appears as an intratendinous hyperechoic area because it comprises various types of cells and the extracellular matrix. During the remodeling phase, fibroblasts produce, deposit, orient, and cross-link fibrillar collagen.¹⁹ The fibrillar appearance on US is gradual, as fibrillar collagen is cross-linked and aligns along the long axis of the repaired tendon. The present study identified intratendinous hyperechoic areas that are considered to represent scar tissue soon after surgical repair. These hyperechoic areas gradually diminished and became replaced by isoechoic tissue, after which a fibrillar appearance became evident, suggesting that recovery was underway. By 6 months, the hyperechoic area had essentially disappeared, repaired tendons mostly assumed a fibrillar appearance, and tendon repair scores did not significantly change thereafter up to 12 months. Therefore, repaired Achilles tendons begin to plateau by about 6 months postoperatively.

This small-scale prospective study at a single institution has several limitations. Large, multicenter prospective studies will be required to validate our results. The accuracy of US is affected by the orientation and position of the transducer, as well as the positioning of regions of interest, which can result in measurement bias. Tendon tissue is highly anisotropic, and measurements can be affected by only a few degrees of difference in the position of the transducer. To overcome such bias, we evaluated tendon repair on images acquired in the longitudinal plane. The intratendinous morphology of repaired tendons was evaluated only using US. Correlations between the quality of a healed tendon and clinical parameters such as strength and functional performance should also be assessed to more accurately judge the timing of return to sports. However, this study provides useful information for return to sports because the morphology of repaired tendons can be visualized by US and objectively assessed. We plan to clarify the criteria of return to sports by assessing correlations between US findings and clinical parameters.

CONCLUSION

The US assessment of surgically repaired Achilles tendons showed a much larger CSA of the affected versus the unaffected side. The CSA reached a maximum at 6 months and decreased at 12 months postoperatively. The intratendinous status of the repaired tendon on US improved over time and reached a plateau at 6 months postoperatively.

US of repaired tendons is a convenient and inexpensive method of assessing whether normal internal structures that appear fibrillar and hyperechoic on images are restored. Therefore, we consider that US findings of the quality of healed repaired tendons could support clinical findings of parameters such as mechanical strength and functional performance before patients are advised that they are fit enough to return to sports.

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