Achilles tendon repair: ecostructural adaptations of the tendon and medial gastrocnemius following surgery

Reparación del tendón de Aquiles: adaptaciones ecoestructurales del tendón y del gastrocnemio medial después de la cirugía

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Abstract

Introduction: Surgical repair of the Achilles tendon (AT) may lead to reduced triceps surae function and strength due to morphological adaptations in the tendon and/or the medial gastrocnemius (MG). However, evidence describing these structural changes after AT repair remains limited.
Objective: to determine the differences in the echo-architecture of the MG and AT between the operated (OL) and non-operated leg (NOL) in individuals 6-18 months post-AT surgery.
Methodology: Ten participants (age: 42±12 years, weight: 84±8 kg, height: 176±8 cm) with AT repair 6-18 months post-surgery were evaluated. Ultrasound imaging was utilized to assess the pennation angle, MG thickness, and AT cross-sectional area in both the OL and NOL. Triceps surae strength was measured with the single-leg heel raise test (SHRT), and ankle function with the Foot and Ankle Outcome Score (FAOS-CL). Comparisons between OL and NOL were conducted using a significance level of $p<0.05$.
Results: The mean follow-up duration was 14.0 ±3.4 months. AT cross-sectional area (CSA) exhibited significant differences, being greater in the OL (1.4 [1.1-1.6] cm^2) compared to the NOL (0.6 [0.6-0.7] cm^2, $p<0.0001$). MG thickness was significantly lower in the OL (1.7 [1.7-2.0] cm) compared to the NOL (1.9 [1.7-2.1] cm). While the MG-pennation angle and the SHRT showed no differences. The FAOS-CL revealed lower scores in quality of life (61 points), sports (82 points), and symptoms (86 points) domains.
Conclusions: In the evaluated cohort, both the AT cross-sectional area and the MG thickness show architectural changes in the OL at 14 months after AT repair.

Keywords

Muscle eco-architecture; Achilles tendon repair; medial gastrocnemius; ultrasound.

Resumen

Introducción: La reparación quirúrgica del tendón de Aquiles (TA) puede generar una reducción en la función y fuerza del tríceps sural debido a adaptaciones morfológicas en el tendón y/o en el gastrocnemio medial (GM). Sin embargo, la evidencia que describe estos cambios estructurales después de la reparación del TA sigue siendo limitada.
Objetivo: Determinar las diferencias en la ecoarquitectura del GM y del TA entre la pierna operada (PO) y la no operada (PNO) en individuos evaluados entre 6 y 18 meses después de la cirugía del TA.
Metodología: Se evaluaron diez participantes (edad: 42 ± 12 años; peso: 84 ± 8 kg; estatura: 176 ± 8 cm) sometidos a reparación del TA entre 6 y 18 meses postcirugía. Se utilizó ultrasonografía para analizar el ángulo de penación, el espesor del GM y el área de sección transversal (AST) del TA en ambas extremidades (PO y PNO). La fuerza del tríceps sural se cuantificó mediante la prueba de elevación de talón con una sola pierna (SHRT), y la funcionalidad del tobillo mediante el Foot and Ankle Outcome Score (FAOS-CL). Las comparaciones entre PO y PNO se realizaron con un nivel de significancia de $p<0,05$.
Resultados: El seguimiento promedio fue de 14,0 ± 3,4 meses. El AST del TA presentó diferencias significativas, siendo mayor en la extremidad operada (OL) (1,4 [1,1–1,6] cm^2) en comparación con la extremidad no operada (NOL) (0,6 [0,6–0,7] cm^2; $p<0,0001$). El grosor del GM fue significativamente menor en la PO (1,7 [1,7–2,0] cm) en comparación con la PNO (1,9 [1,7–2,1] cm). Mientras que el ángulo de penación del GM y la SHRT no mostraron diferencias. El FAOS-CL mostró puntajes más bajos en los dominios de calidad de vida (61 puntos), deporte (82 puntos) y síntomas (86 puntos).
Conclusiones: En la cohorte evaluada, tanto el AST del TA como el grosor del GM evidenciaron cambios arquitectónicos en la PO a los 14 meses tras la reparación del tendón de Aquiles.

Palabras clave

Ecoarquitectura muscular; reparación del tendón de Aquiles; gastrocnemio medial; ultrasonido.

Introduction

The Achilles tendon (AT) is one of the tendons in the human body with a high incidence of injuries (Magnan et al., 2014). Rupture of the AT is among the most severe, often occurring during sports activities involving sudden accelerations and decelerations (McCormack & Bovard, 2015), leading to structural deficiencies and loss of lower limb functionality (Ganestam et al., 2016). Patients undergoing surgical AT repair may experience reduced plantar flexor muscle strength one-year post-surgery, with 20% failing to return to their previous physical activity level, thereby limiting their quality of life (Zellers et al., 2020).

Currently, there is no consensus regarding the loads to which the AT is exposed during rehabilitation. Decision-making for progression is generally based on temporal criteria, without considering potential differences in the mechanical properties and echo-architecture of the triceps surae (Brorsson et al., 2017; Shim et al., 2014). This is particularly relevant given that 30% of patients continue to experience muscle weakness, predominantly affecting the medial gastrocnemius (MG), which is associated with a decrease in both fiber length and cross-sectional area (Zellers et al., 2019). However, the existing evidence remains scarce.

Over the past two decades, Real-Time Ultrasound Imaging for physical therapists (RUSI) has emerged as a valid, reliable, and low-cost tool, enabling the quantification and individualization of the recovery process for patients with AT reconstruction (Whittaker et al., 2019). According to the literature, important factors to assess in individuals who have undergone AT repair surgery include muscle thickness, pennation angle, and cross-sectional area (Fenech et al., 2024; Hullfish et al., 2019; Peng et al., 2017). These parameters are crucial for understanding potential morphological and mechanical changes following injury and repair. For instance, a study by Peng et al. (2017) highlighted a smaller muscle thickness (1.7 vs 1.9 cm) and a larger pennation angle (31.2 vs 28.9°) in the MG of the operated leg compared to the contralateral side six months after AT repair. These measurements not only reflect possible structural alterations caused by surgery but also allow for the evaluation of progress during rehabilitation and the functional levels of the affected lower limb (Peng et al., 2017). However, there is limited evidence regarding ultrasound changes between 6 months and one-year post-AT surgery and their impact on the MG muscle, which could limit the understanding of its morphological and functional evolution during recovery.

In clinical practice, one of the most reliable assessment tests for measuring the muscular work performed by the triceps surae is the single-leg heel raise test (SHRT), performed in a vertical position while supporting full body weight (Silbernagel et al., 2010). This test is a commonly used functional assessment to evaluate the strength and integrity of the calf muscles, particularly the work developed by the gastrocnemius, soleus, and AT. Due to its utility, it is frequently employed in rehabilitation to monitor progress after surgical AT repair, evaluating both muscle strength and function (Dams et al., 2019; Spennacchio et al., 2016). In this context, a study using the SHRT showed significant differences in asymmetry indices when comparing the operated leg with the non-operated leg at 6 and 12 months post-AT surgery, demonstrating a progressive reduction in asymmetry percentages between both limbs (Silbernagel et al., 2010).

Additionally, the self-reported functional assessment scale (FAOS-CL) represents another clinical tool to evaluate ankle health and functionality across five domains: pain, symptoms, activities of daily living, sport, and quality of life (Pellegrini et al., 2020). For example, Westin et al. (2018) reported low scores in the quality-of-life area when comparing patients who experienced a second AT rupture versus those with only one episode, generating a prolonged psychological impact due to the severity of the injury. However, there is limited literature on the functional changes that could be indicated by data collected through the SHRT and FAOS-CL in individuals who have undergone AT surgery.

Based on the above, the objective of this study was to determine the differences in the echo-architecture of the MG and AT between the operated leg (OL) and the non-operated leg (NOL) in individuals 6 to 18 months post-AT surgery. Secondarily, the study aimed to characterize postoperative functional status by assessing functional performance (SHRT) and patient-reported outcomes (FAOS-CL).

Method

This cross-sectional study evaluated 10 individuals (age: 42±12 years, weight: 84±8 kg, height: 176±8 cm). Inclusion criteria were i. age range between 18 and 60 years, and ii. Individuals who underwent minimally invasive AT repair (PARS-Dresden technique) (Pellegrini et al., 2019) within a 6–18-month post-operative period. Exclusion criteria included: i. individuals who had undergone re-operation on the same AT, ii. bilateral rupture, and iii. individuals with associated metabolic diseases. All participants signed an informed consent form previously approved by the ethics committee of the Universidad de los Andes (code: CEC2021004), in accordance with the stipulations of the Declaration of Helsinki.

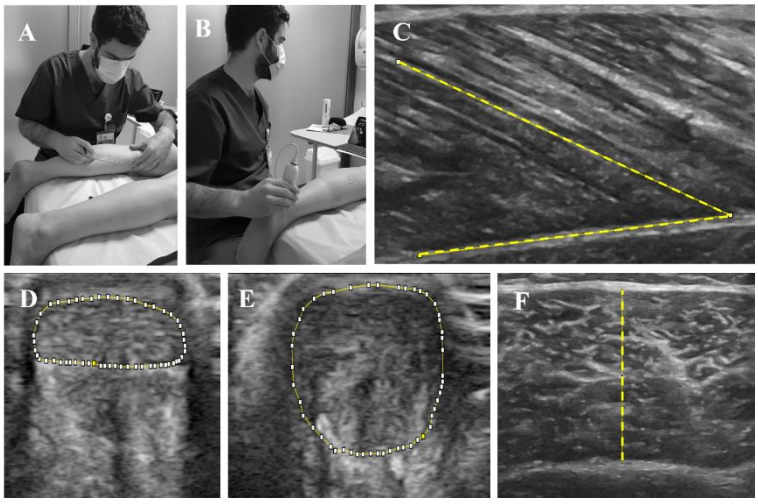
Measurement Protocol

Initially, each participant completed the self-reported FAOS-CL (Pellegrini et al., 2020) scale and was classified according to their physical activity level (1. Sedentary, 2. Low, 3. Active, 4. Competitive) based on the article published by Grimby et al., 2015). Subsequently, echo-structural evaluations of both legs (OL and NOL) were performed in a static prone position, with the foot off the examination table and the ankle in a neutral position (Figure 1). Before measurements, a line was drawn at 30% of the distance between the medial malleolus of the tibia and the medial femoral condyle to locate the MG region (Kubo et al., 2003). Then, a point 4 cm proximal to the calcaneal tuberosity was marked (Liu et al., 2018), as tendon pathologies often occur in this area. Thus, when performing transverse and longitudinal image evaluations, the marked points represented the specific regions where the probe should be located.

During image acquisition, three variables of interest were considered: pennation angle (AP) along the longitudinal axis of muscle fibers, MG muscle thickness, and AT cross-sectional area (CSA) (Figure 1), with the latter two evaluated in a transverse view. Measurements always began with the left leg, followed by the right, regardless of the operated side. Data were collected by a single evaluator using a Philips Lumify™ ultrasound scanner (Philips Healthcare, Amsterdam, The Netherlands), equipped with a L12-4 MHz broadband linear transducer with 128 elements. Images were obtained in B-mode at a frequency of 10 MHz, with automatic focus adjustment, considering 60 dB gain, 3.5 cm depth for MG, and 3 cm for AT. Three images per cut were recorded and subsequently processed using the open-access software Image J (Bethesda, ML, USA, https://imagej.nih.gov/ij/).

Additionally, the SHRT was performed on a platform inclined 10° from the floor surface. Prior instructions regarding test execution were provided. Before the SHRT, participants performed an 8-minute warm-up on a treadmill (Life Fitness, Activate model, 3HP magna drive motor, USA) at a self-selected speed. For the SHRT, participants performed repeated single-leg heel raises while standing on one limb with the knee fully extended and the contralateral limb flexed to 90°. The task was continued until volitional fatigue. The primary outcome was the total number of completed repetitions, defined as the number of ankle elevation cycles (plantarflexion–dorsiflexion).

Figure 1. Ultrasound evaluation of both the operated and non-operated leg of a patient.



Note. A and B show the position adopted by the evaluator and the volunteer. C represents the estimation of the pennation angle between the direction of the medial gastrocnemius fibers and its deep aponeurosis. D and E illustrate the cross-sectional area of the Achilles tendon, non-operated versus operated leg, respectively. F shows the muscle thickness of the medial gastrocnemius. The last four images were processed and extracted from Image J ® software.

Statistical Analysis

Demographic data and FAOS-CL scale scores were presented as mean and standard deviation. The main variables of interest (MG muscle thickness, pennation angle, AT CSA, and SHRT) were assessed for distribution using the Shapiro-Wilk test. Since these variables did not follow a normal distribution, they were represented by the median and interquartile ranges (25-75%). Subsequently, the Wilcoxon Signed-Rank Test for paired samples was used to compare between OL versus NOL. All analyses were performed using GraphPad Prism software (v10, San Diego, California, USA) with two tails, considering statistical significance at a p-value less than 0.05.

Results

Of the total sample evaluated (n=10), 90% were men (n=9) with a mean age of 42 years, and only one woman aged 28 years. Regarding the laterality of the operated leg, 7 individuals underwent surgery on the left side and 3 on the right side. The average follow-up time reported was 14.0 ±3.4 months. In terms of physical activity level, all participants engaged in some form of physical activity. Of these, 30% were categorized as sedentary (level 1), another 30% as low activity (level 2, i.e., < 4 hours per week), 30% as active (level 3, i.e., 3-4 times per week), and 10% as competitive (level 4) (Grimby et al., 2015). The demographic data of the evaluated individuals are presented in Table 1.

Table 1. Demographic characteristics of evaluated individuals (n=10)

	Mean	SD
Age (years)	42.0	(12.3)
Weight (kg)	84.4	(8.0)
Height (cm)	176.8	(8.8)
BMI (kg/m²)	27.0	(1.8)

SD: standard deviation.

Regarding echo-architecture, AT CSA and MG thickness differed significantly between limbs (Table 2). AT CSA was greater in the OL than in the NOL (1.4 [1.1-1.6] cm2 versus 0.6 [0.6-0.7] cm2, respectively), whereas MG thickness was significantly lower in the OL (1.7 [1.7-2.0] cm) compared to the NOL (1.9 [1.7-2.1] cm). In contrast, the SHRT showed no significant between-limb differences (p>0.05).

Table 2. Distribution of the median and interquartile range (25th–75th percentiles) for the evaluated variables: muscle thickness, pennation angle, Achilles tendon cross-sectional area (CSA), and single heel raise test (SHRT).

Variable	NOL (n=10)		OL (n=10)		
	Median	RI 25-75%	Median	RI 25-75%	p-value
MG Thickness (cm)	1.9	[1.7-2.1]	1.7	[1.7-2.0]	0.03
Pennation Angle (°)	25.5	[22.6-28.5]	27.4	[23.8-32.5]	0.08
CSA (cm²)	0.6	[0.6-0.7]	1.4	[1.1-1.6]	0.002
SHRT (number of repetitions)	26.0	[23.7-28.2]	25.0	[17.5-31.2]	0.34

NOL: non-operated leg. OL: operated leg. MG: Medial Gastrocnemius. CSA: Achilles Tendon cross-sectional area. SHRT: single heel raise test.

On the other hand, the FAOS-CL scale reported low average scores for quality of life (61.9±24.5 points), sports (82.0±16.3 points), and symptoms (86.1±15.3 points). In contrast, the areas of pain (92.2±6.4 points) and activities of daily living (97.8±2.7 points) described the highest scores.

Discussion

The present study aimed to determine differences in the echo-architecture of the MG and AT in individuals who underwent AT reconstruction. The primary findings reveal differences in the AT CSA 14 months post-surgery, with a larger area observed in the OL compared to the NOL. This suggests a structural alteration in the repaired AT that persists beyond one year post-surgery. This finding aligns with previous studies that associate increased AT thickening with the tissue repair and collagen fiber remodeling process during the initial phases of recovery (Hiramatsu et al., 2018; Kubo et al., 2003). These structural changes would extend throughout the remodeling phase of the repaired AT up to six months, during which a hyperechoic intratendinous area can be observed. This area tends to decrease by 12 months as a result of the reorganization and alignment of collagen fibers along the tendon axis (Hiramatsu et al., 2018). Nevertheless, the increase in the AT CSA observed in the OL compared to the NOL persists in the long term, as reported in the present study. This finding gains particular relevance when considering the low scores recorded in the FAOS-CL subscales for quality of life (61 points) and sport (82 points). Together, these observations highlight the importance of incorporating complementary structural monitoring into the functional assessment of patients following AT repair.

On the other hand, it is important to highlight that structural thickening of the AT and reduced MG muscle thickness on the OL do not necessarily result in greater asymmetry of plantarflexion force, as evidenced by the results of the SHRT, which showed no differences between the OL and NOL after one year. Nevertheless, it is important to note that only one variable was assessed during the SHRT (i.e., number of repetitions), which is a limitation of this test. However, this also raises questions about the relationship between the possible morphological adaptations of the AT and the progressive functional recovery. In this regard, it should be noted that the present study did not directly assess the neuromuscular activity of the triceps surae during the SHRT, which limits the interpretation of the findings from an electrophysiological perspective. In this regard, it is suggested that future studies address this limitation by incorporating surface electromyography, which would allow for a more comprehensive understanding of muscle activation strategies and their relationship to the structural adaptations observed during dynamic functional tasks (e.g., gait, running, jumping, among others) after AT repair. This recommendation is supported by evidence that changes in lower-limb kinematics are accompanied by systematic alterations in EMG activity during functional conditions and that foot-strike mechanics can meaningfully modulate gastrocnemius activation during running (Valencia et al., 2021; Valencia et al., 2020).

Another variable of interest was the MG muscle thickness; prior work has reported a reduction at six months post-surgery compared with the contralateral limb (Peng et al., 2017). In this context, we observed significantly lower MG thickness in the OL than in the NOL, indicating that residual atrophy of the MG muscle belly may persist despite a mean follow-up of 14 months. From a biomechanical perspective, persistent morphological deficits might generate an altered load transmission within the Achilles tendon–muscle unit, shifting the muscle away from its optimal sarcomere operating length and thereby reducing force-generating capacity (Peng et al., 2017). Supporting this interpretation, Heikkinen et al. (2017) reported a 13% reduction in MG volume in the OL at one year post-repair using magnetic resonance imaging, accompanied by impairments in heel-rise performance and plantarflexion force. Importantly, such architectural alterations may not be captured by all functional assessments; in the present study, the number of repetitions using SHRT did not detect significant between-limb differences.

Another key factor that may contribute to the significantly lower MG thickness in the OL compared to the NOL is the potential decrease in exercise adherence once patients have passed the acute and subacute phases of rehabilitation. Patients frequently reduce or discontinue specific triceps surae strengthening protocols after the initial supervised period, leading to persistent muscle volume deficits (Brorsson et al., 2015). This observation is particularly relevant given the low scores recorded on the FAOS-CL subscales for quality of life (61 points) and sport (82 points). These lower functional perceptions may reflect a lack of confidence or a perceived inability to resume previous activity levels, which often correlates with reduced motivation to maintain strengthening exercises long-term. Therefore, the structural asymmetry seen by ultrasound highlights the need for ongoing structural monitoring and strategies to promote exercise adherence throughout the recovery, as functional scores indicate that patients have not yet achieved their maximum physiological or psychological potential 14 months post-surgery.

Regarding the PA of the MG fibers, a non-significant tendency toward an increased PA was observed in the OL. In contrast, Peng et al. (2017) reported a significant increase in PA at 90% of maximal voluntary contraction in individuals less than six months post-surgery. According to these findings, such changes may be associated with alterations in MG fascicle architecture, which could reduce the mechanical efficiency of force transmission through the tendon, possibly as an adaptive mechanism during the early postoperative period. In this context, it may be interpreted that during the initial stages of rehabilitation (i.e., the first six months), patients may exhibit an increased PA as an adaptive response to muscle hypotrophy. Subsequently, during the intermediate phases, characterized by a greater hypertrophic stimulus, an increase in muscle thickness accompanied by a progressive decrease in PA would be expected, coinciding with the transition towards the return-to-sport phase. Conversely, the findings of the present study revealed similar PA values between the OL and NOL one year after AT reconstruction. This may be interpreted as a potential restoration of fascicle architecture, approaching the levels of mechanical efficiency observed in the healthy limb at this stage of recovery. Nevertheless, longitudinal studies are required to determine more precisely the timing and progression of these morphological adaptations.

A major limitation of this study is the small sample size (n =10), which reduces statistical power and increases susceptibility to inter-individual variability. Consequently, although a significant difference in MG thickness was observed, in the absence of corresponding differences in pennation angle, this finding should be interpreted with caution. Moreover, the possibility of Type II error for the remaining outcomes cannot be ruled out. Therefore, the present results should be regarded as preliminary and interpreted as evidence from a pilot study. Other limitations might be related to the ultrasound assessment was performed only once, at a specific point in each subject's recovery. Therefore, it is not possible to understand the behaviour during the entire rehabilitation process. In this regard, future research is recommended to conduct follow-up on these patients, especially during the first year post-AT surgery. Secondly, the number of participants might also affect the comparison of the PA between lower limbs, in which no significant differences were observed. Based on the aforementioned variables, it is suggested that future research consider a larger number of individuals who have undergone AT surgery and, at the same time, compare them with a control group (without a history of AT surgery), with the aim of identifying possible neuromotor adaptations that are also part of these patients' evolution.

Conclusions

Based on the evaluated sample, this study demonstrates that approximately one year after minimally invasive AT repair, structural alterations persist within the muscle–tendon unit. These changes are characterized by a significantly greater CSA and reduced MG thickness in the OL. In contrast, no significant differences were observed in the PA of the MG, which may suggest a partial or progressive restoration of muscle architectural organization over time. Collectively, these findings highlight the sensitivity of muscle–tendon ultrasonography for detecting residual structural adaptations and support its use as a complementary, non-invasive tool for longitudinal monitoring during post-surgical AT rehabilitation.

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