Effect of the Copenhagen Achilles Rupture Treatment Algorithm (CARTA) on Calf Muscle Volume and Tendon Elongation After Acute Achilles Tendon Rupture

A Predefined Secondary Analysis of the First 60 Patients in a Randomized Controlled Trial

Kristoffer Weisskirchner Barfod,*† MD, PhD, Anders Brøgger Overgård,† MD, Maria Swennergren Hansen,‡ PT, MSc, PhD, Ibrahim El Haddouchi,† MD, Marianne Toft,§ MD, PhD, and Per Hölmich,† MD, DMSc
Investigation performed at the Copenhagen University Hospital, Amager-Hvidovre, Denmark

Background: Surgical treatment of acute Achilles tendon rupture (ATR) lowers the risk of rerupture and may reduce calf atrophy and elongation of the Achilles tendon. The Copenhagen Achilles Rupture Treatment Algorithm (CARTA) was developed to provide individualized treatment selection based on ultrasonographic evaluation of the rupture.

Purpose: In a randomized setup, the present study aimed to investigate whether treatment selection using the CARTA could reduce atrophy and tendon elongation compared with (1) patients treated surgically and (2) patients treated nonsurgically.

Study Design: Randomized controlled trial; Level of evidence, 2.

Methods: A total of 60 patients with an acute ATR were randomly assigned to receive treatment based on the CARTA (intervention), surgical treatment (control), or nonsurgical treatment (control) in a 1 to 1 to 1 ratio. After 1 year, magnetic resonance imaging of both calves was performed, and muscle volume and Achilles tendon length were measured. Results were presented as the ratio between the affected and the unaffected limbs (ie, limb symmetry index; %).

Results: A total of 156 patients were assessed for eligibility, 60 patients were randomized, and 54 patients provided data for the study—19 patients received treatment based on the CARTA (intervention group), 17 patients received nonsurgical treatment (control), and 18 patients received surgical treatment (control). No statistically significant differences were found between the intervention group and the 2 control groups regarding muscle volume and tendon length. No statistically significant differences were found between patients treated surgically and patients treated nonsurgically. Comparison between the affected and the unaffected limb showed statistically significant muscle atrophy (24%-30%) and tendon elongation (soleus, 59%-76%; gastrocnemius, 8%-14%) in the affected limb in all 3 groups.

Conclusion: Individualized treatment of acute ATR using an ultrasonographic selection algorithm did not reduce calf muscle atrophy or tendon elongation when compared with surgical and nonsurgical treatment. Surgical treatment did not reduce calf muscle atrophy or tendon elongation compared with nonsurgical treatment.

Keywords: Achilles tendon; magnetic resonance imaging; muscle volume; rupture; surgical treatment; tendon elongation

Acute Achilles tendon rupture (ATR) leads to loss of function and reduced calf strength even years after the injury.[4,9,11,13,16,17] The reduced calf strength has been associated with loss of muscle mass in the triceps surae and elongation of the Achilles tendon, which is why the goal of

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treatment in recent years has focused on reducing these.[2,15,20] Treatment of ATR can be surgical or nonsurgical.[2,6,15] The choice of treatment has shown little impact on self-reported and clinically assessed function. Still, surgical treatment substantially lowers the risk of rerupture and has been claimed to reduce calf atrophy and elongation of the Achilles tendon compared with nonsurgical treatment.[2,6,9,18,19]

The Copenhagen Achilles Rupture Treatment Algorithm (CARTA) was developed to provide individualized treatment selection based on ultrasonographic evaluation of the rupture.[1,8] The protocol for the randomized controlled trial is available via open access in our previous study.[8]

The aim of the present study was, in a randomized setup, to investigate whether treatment selection according to the CARTA influences muscle volume of the triceps surae and the deep calf flexors and reduces elongation of the Achilles tendon 1 year after rupture in comparison with (1) patients treated surgically and (2) patients treated nonsurgically. We hypothesized that treatment selection according to the CARTA would reduce atrophy of the triceps surae muscle, reduce hypertrophy of the deep calf flexors, and reduce elongation of the Achilles tendon when compared with patients treated nonsurgically per default and result in equal muscle volume and tendon length as in patients treated surgically per default.

METHODS

This study was performed as a predefined secondary analysis in a 3-armed parallel trial with patients individually randomized in a 1 to 1 to 1 ratio to 1 of the following groups: treatment selection based on the CARTA (intervention); nonsurgical treatment (control); or surgical treatment (control). A total of 300 patients were included in the main trial. The trial was designed and executed according to the CONSORT (Consolidated Standards of Reporting Trials) guidelines (ClinicalTrials NCT03525964), and the study protocol received institutional review board approval. This satellite study is briefly described in the protocol paper for the main trial.[8]

No changes were made to the study design in the period between the study design and the completion of data collection. After data collection, it was realized that the amount of data was too vast to publish in a single article. Before data analysis, we decided to divide the results into 2 separate publications describing (1) the gait pattern measured in the human movement analysis laboratory (published previously[7]) and (2) the muscle volume and tendon elongation measured using magnetic resonance imaging (MRI) (presented in this article). Because of the redefinition of reporting of the trial, no primary outcome is presented in the present article, and as such, the results are explorative rather than confirmative.

Randomization

The patients were randomly allocated to 1 of the 3 groups in a 1 to 1 to 1 ratio at time of treatment allocation by an independent physical therapist responsible for including patients in the trial. Randomization was performed in blocks of 12 patients through a web-based database (facilitated by Procordo ApS). A statistician with no other contact with the trial generated the random allocation sequence. Only the database manager at Procordo ApS had access to the allocation sequence during the trial.

Blinding

Blinding of the patient and the treating health care personnel was not possible because of the nature of the intervention. The follow-up was blinded by careful instruction of the patient placing a piece of tape over the Achilles tendon region on the injured leg. The MRI technician was blinded to the intervention, but the affected leg and surgical intervention could be observed on the scans. Data were blinded while the statistical analyses were performed.

Participants

Patients were included at Copenhagen University Hospital Hvidovre, Denmark, between June 2018 and September 2019. Patients were eligible for inclusion if they were aged 18 to 65 years, they had a complete rupture of the Achilles tendon when they arrived at the emergency department and received initial treatment with split plaster cast in maximal plantar flexion within 24 hours of their injury. The patients had to be included within 4 days of rupture, attend rehabilitation and postexaminations, be able to speak and understand Danish, and provide informed consent. Patients were excluded if the rupture was either at the insertion on the calcaneus or at the musculotendinous junction of the triceps surae; if there was a previous rupture of the

*Address correspondence to Kristoffer Weisskirchner Barfod, MD, PhD, Department of Orthopedic Surgery, Sports Orthopedic Research Center–Copenhagen, Arthroscopic Center, Copenhagen University Hospital, Amager-Hvidovre, Kettegård Allé 30, Copenhagen, Hvidovre 2650, Denmark (email: kbarfod@dadlnet.dk).

†Department of Orthopedic Surgery, Sports Orthopedic Research Center–Copenhagen (SORC-C), Copenhagen University Hospital Amager-Hvidovre, Denmark.

‡Department of Physical and Occupational Therapy, Physical Medicine & Rehabilitation Research–Copenhagen (PMR-C), Copenhagen University Hospital Amager-Hvidovre, Denmark.

§Department of Orthopedic Surgery, Viborg Regional Hospital, Viborg, Denmark.

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Ethical approval for this study was obtained from the National Committee on Health Research Ethics (ref No. 1-10-72-428-17).

Registration: NCT03525964 (ClinicalTrials.gov identifier).

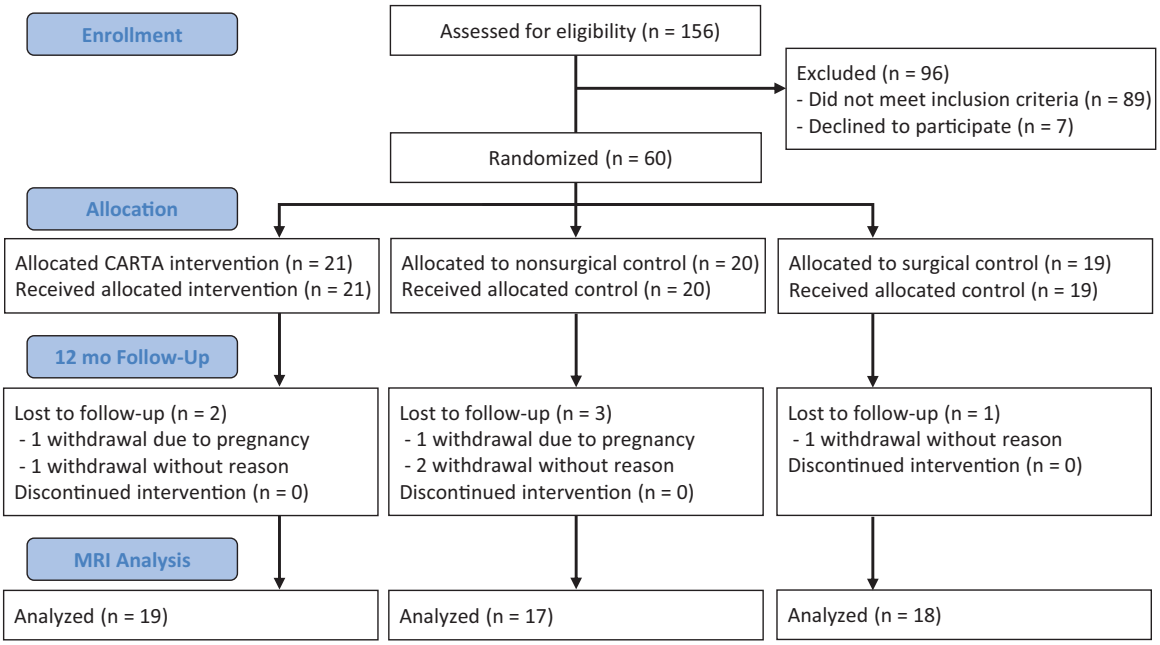

Figure 1. CONSORT flow diagram of patient enrollment. CARTA, Copenhagen Achilles Rupture Treatment Algorithm; CONSORT, Consolidated Standards of Reporting Trials; MRI, magnetic resonance imaging.

Achilles tendon in either leg; if treated with fluoroquinolones or corticosteroids within the last 6 months; if being medically treated for diabetes; if other conditions before the injury resulted in reduced function on either leg; if there were contraindications for surgery; or if the patient had an American Society of Anesthesiologists score $\geq$3.

Of the 156 patients initially assessed for eligibility, 60 patients were randomized, and 54 provided data for the study—19 patients received treatment based on the CARTA (intervention group), 17 patients received nonsurgical treatment (control), and 18 patients received surgical treatment (control) (Figure 1).

Study Groups

In the intervention group, treatment selection was performed according to the CARTA. The development and execution of the CARTA has been previously described.[1,8] The CARTA is an ultrasonographic selection algorithm in 2 steps. First, the overlap of the tendon ends was evaluated. If a transverse picture could be identified with a cross-sectional area of tendon fibers constituting <25% of the cross-sectional area of the healthy tendon, the rupture was evaluated as "not overlapping" and the patient was prescribed surgery. If tendon fibers constituted >25% of the cross-sectional area, the second criterion was applied, and elongation of the ruptured tendon was measured with the Copenhagen Achilles Length Measure.[1,3] If elongation >7% was found, the patient was prescribed surgery. Patients with >25% overlapping tendon fibers and <7% elongation were prescribed the nonsurgical treatment. For patients treated according to CARTA the nonsurgical intervention was the same as for the nonsurgical control group, and the surgical intervention was the same as for the surgical control group. If a transverse picture could be identified with a cross-sectional area of tendon fibers constituting <25% Standard rehabilitation was prescribed for all patients regardless of group—a detailed description of this is found in the protocol paper.[8]

In the nonsurgical control group, per default, all patients were treated with a circular below-the-knee cast for 3 weeks with the ankle in maximal unforced plantar flexion. Crutches were mandatory, and weightbearing not permitted. After 3 weeks, the cast was replaced with an Aircast walker boot (DJO Global) with 3 wedges producing 20° of plantar flexion.[12] Standard rehabilitation was used.[8]

In the surgical control group, per default, all patients were operated within 14 days of the rupture. The procedure was performed under local or regional anesthesia with the patient in the prone position. A 5-cm incision was made medially to the rupture site. The paratenon was kept intact by stump dissection and incised with a transverse incision at the rupture. The tendon stumps were drawn through the incision, and 2 modified Kessler sutures with FiberWire® suture size 2, (Arthrex, Naples, Florida), were used to catch healthy tendon fibers through the paratenon 3 to 4 cm proximally and distally to the rupture site. The paratenon was then closed with a resorbable suture before maximally tightening the modified Kessler sutures. Preoperative dicloxacillin 2 g was administered. Please refer to the protocol paper for a full surgical technique description.[8] A circular below-the-knee cast was administered for 3 weeks with the ankle fixated at maximal unforced plantar flexion. Standard rehabilitation was also used.[8]

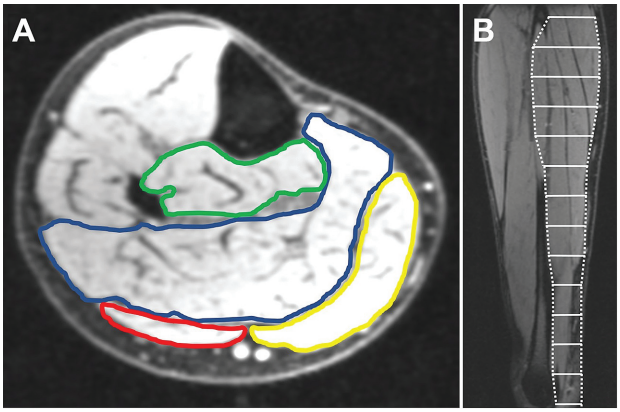

Figure 2. Schematic illustration of how the muscle volumes were calculated. (A) The cross-sectional area was measured manually for every 20 mm of the calf using the closed polygon function in OsiriX Lite. Red indicates the lateral head of the gastrocnemius; yellow indicates the medial head of the gastrocnemius; blue indicates the soleus; and green indicates the deep plantar flexor complex. (B) The sum of cones with irregular tops in 20-mm steps was added to the full volume.

Outcomes and Data Collection

The study outcomes were muscle volume and tendon elongation 1 year after rupture. Volumetric measurements were made using MRI. In all participants, measurements consisted of (1) the lateral head of the gastrocnemius muscle, (2) the medial head of the gastrocnemius muscle, (3) the soleus muscle, and (4) the deep plantar flexor complex (flexor hallucis longus, flexor digitorum longus, and tibialis posterior). The muscle volumes were calculated as the sum of cones with irregular tops in steps of 20 mm using the formula $h/3 \times [A_1 + \sqrt{(A_1 \times A_2)} + A_2]$, where h is the height of the cone and A_1 and A_2 are the cross-sectional area of the bottom and top of the cone, respectively.[9] The cross-sectional areas were measured manually for every 20 mm from the distal to proximal position using the closed polygon function in OsiriX Lite 12.0 (Pixmeo SARL, Geneva) (Figure 2). The first and most distal slice was defined by the axial slice intersecting the most cranial aspect of the talus. The length of the coil defined the proximal border of the measured volume as the most proximal 20-mm interval slice available. The same number of slices with 20 mm intervals was measured on both legs. MRI was performed on a 1.5-T MRI system (Magnetom Avanto; Siemens), a 3-dimesional (3D) gradient echo sequence (Siemens DESS package) with 1-mm axial slices and 1-mm interslice distance. Both calves were scanned from the most inferior point of the calcaneus and as far proximal as our 50-cm field of view allowed. Patients were scanned in a supine position with the ankle joint fixed at 90° with the aid of a custom-made orthosis.

The tendon length was measured on sagittal MRI individually for the 3 parts of the Achilles tendon: (1) the free length of the Achilles tendon from the calcaneal bone to the distal tip of the soleus muscle; (2) the length from the calcaneal bone to the distal tip of the medial head of the gastrocnemius muscle; and (3) the length from the calcaneal bone to the distal tip of the lateral head of the gastrocnemius muscle. The distal landmark representing the insertion of the Achilles tendon on the calcaneal bone was defined as the most proximal point where the calcaneus and the Achilles tendon were in contact, disregarding a thin bursa when present (Figure 3D). The proximal landmarks were defined as the most distal visible muscle fibers' insertion into the myotendinous junction (Figure 3, A-C). The tendons were measured in 3D diagonally between landmarks with the ruler tool in OsiriX Lite 12.0.

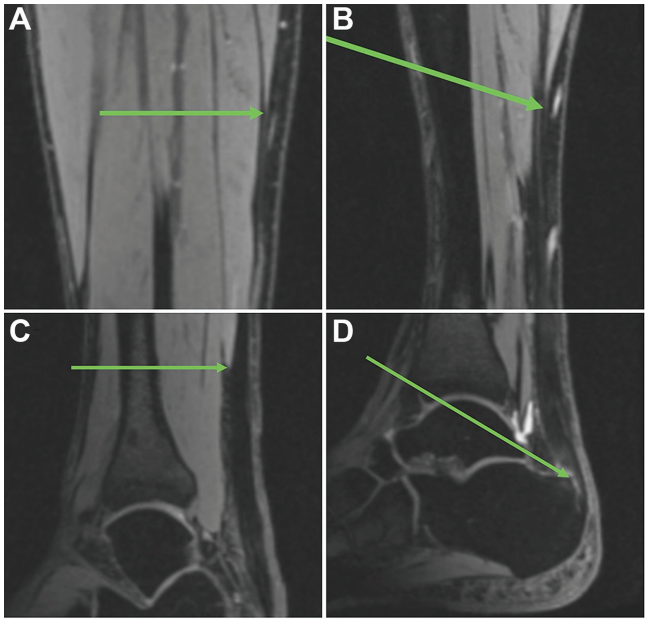

Figure 3. Illustration of the anatomic landmarks (green arrows) used for measuring tendon elongation. (A) The tip of the head of the medial gastrocnemius muscle. (B) The tip of the head of the lateral gastrocnemius muscle. (C) The tip of the head of the soleus muscle. (D) The calcaneal bone where the calcaneus and the Achilles tendon were in contact.

The results for the volumetric measurements and measures of tendon length at 1 year after tendon rupture were reported as absolute values for the affected and unaffected limbs and the limb symmetry index (LSI). The LSI, expressed as a percentage, is the ratio between the affected and unaffected limb ($LSI = [Affected/Unaffected] \times 100$). In addition, descriptive baseline characteristics (sex, age, height, and body mass index) were collected for the patients in the 3 study groups.

Statistical Analysis

The sample size of the present satellite study was set to 60 patients based on logistical and economic considerations.[8] No power calculation was performed.

TABLE 1
Demographic Characteristics of the Participants (N = 54)[a]

Characteristic	CARTA (n = 19)	Nonsurgical (n = 17)	Surgical (n = 18)
Male sex	16 (84.2)	13 (76.5)	16 (88.9)
Age, y	40.2 ± 9.2	41.2 ± 10.5	44.3 ± 7.7
Height, cm	178 ± 8	178 ± 9	178 ± 7
BMI, kg/m^2	26.6 ± 4.5	26 ± 2.5	26.2 ± 3.6

[a]Data are reported as mean ± SD or n (%). BMI, body mass index; CARTA, Copenhagen Achilles Rupture Treatment Algorithm.

Between-group differences (CARTA vs nonsurgical treatment and CARTA vs surgical treatment) were investigated using the independent *t* test. A linear regression was fitted for each comparison to account for possible confounders. Confounders were sex, age, body mass index, and ATR preinjury; the confounding effect of the variables was evaluated in the model by including and removing the variable and evaluating the change between the treatment group estimates. Statistical tests were performed at the 2-sided 5% significance level. No interim analyses were planned; hence, no statistical testing was performed until all data were available for a 1-year analysis. Statistical analyses were performed using the Statistical Package for Social Sciences (SPSS; Version 25.0 for Windows; IBM).

RESULTS

The 54 study patients underwent MRI scans at a mean of 406 ± 38 days after the intervention. Descriptive characteristics according to the study groups are shown in Table 1.

No statistically significant differences were found between the intervention group and the 2 control groups regarding muscle volume and tendon length (Table 2). Comparison between the affected and unaffected limbs showed statistically significant muscle atrophy and tendon elongation in the affected limb in all 3 groups. The mean muscle atrophy of triceps surae and soleus ranged from 24% to 27% in the affected limb (Table 2). Achilles tendon elongation was significant within all groups when comparing the affected with the unaffected leg. The soleus tendon of the affected leg had a mean elongation of 3.3 cm (74%) in the group that received treatment based on the CARTA, 3.2 cm (76%) in the group given nonsurgical treatment, and 2.1 cm (59%) in the group that received surgical treatment (Table 2). The mean tendon elongation ranged from 1.6 cm (8%) to 2.7 cm (14%) for the medial and lateral gastrocnemius (Table 2).

In the group that received treatment based on the CARTA, 6 patients were treated nonsurgically and 13 surgically. Adding these to the patients who received nonsurgical and surgical treatments, 23 patients were treated nonsurgically and 31 surgically. Comparing all surgically and nonsurgically treated patients revealed no differences in regard to muscle volume and tendon elongation (Table 3).

DISCUSSION

Treatment selection using the CARTA did not reduce calf muscle atrophy or tendon elongation when compared with patients treated nonsurgically per default. It resulted in equally good outcomes compared with patients treated surgically per default. When interpreting the results, one should bear in mind that the study was performed as a predefined secondary analysis, and no power analysis was performed, which is why the setup was explorative by definition and the results were not conclusive.

No difference in calf muscle atrophy or tendon elongation was found between the 3 groups. This contrasts with previous literature where surgery has been shown to reduce atrophy and tendon elongation. In a study of 60 patients randomized to either a surgical or nonsurgical treatment group, a statistically significant reduction in atrophy of the soleus muscle of 7% and a statistically significant reduction in tendon elongation of the soleus tendon of 19 mm was found, resulting in up to 18% reduction in strength in the nonsurgically treated group compared with the surgically treated group.[9,13] The authors believed that the large tendon elongation in the nonsurgical group might be caused by an aggressive rehabilitation regime in combination with a lack of biomechanical strength.

Intuitively, it seems logical that a torn tendon with displaced tendon ends would benefit from surgical repair, increasing the biomechanical strength. Still, in real life, it has proven difficult to detect functional benefits from surgery. Except for the above mentioned study by Heikkinen et al,[9] numerous randomized controlled trials have not proven functional benefits from surgical treatment, and numerous meta-analyses have concluded the same.[10,14,15,21,22] Recently, a randomized controlled trial involving 554 patients found no difference in patient-reported or functional outcomes comparing nonsurgical, minimal invasive surgery, and open surgery.[15]

The efficacy of the surgical technique is a prerequisite for the CARTA to work. The algorithm is obsolete if surgery does not provide the desired biomechanical stability and reduce calf muscle atrophy and elongation. The surgical technique used in the present trial was developed by experienced foot and ankle surgeons (K.W.B. and P.H.) with >20 years of experience and has been used with good results in our department for years before the project, but without a formal evaluation of the technique. It is possible that a different surgical technique would yield a different result.

The CARTA is based on an ultrasonographic evaluation of rupture morphology in 2 steps: (1) an evaluation of tendon overlap and (2) an evaluation of tendon elongation.[8] The evaluation of tendon elongation has shown good reliability and validity, but the overlap measure is not validated and might be the more subjective and difficult part of the algorithm.[1]

TABLE 2
Muscle Volume and Achilles Tendon Elongation 12 Months After Rupture[a]

				P	
Measurement	CARTA (n = 19)	Nonsurgical (n = 17)	Surgical (n = 18)	CARTA vs Nonsurgical	CARTA vs Surgical
Muscle Volume					
Triceps surae				.60	.36
LSI, %	73.1 ± 10.6	76 ± 10.5	73.6 ± 13.6		
Volume affected limb, cm^3	473 ± 157	499 ± 132	478 ± 167		
Volume unaffected limb, cm^3	650 ± 202	660 ± 159	636 ± 167		
Atrophy, cm^3	177 ± 92.6	161 ± 75.4	157 ± 71.7		
P (affected vs unaffected)	**<.01**	**<.01**	**<.01**		
Soleus				.82	.35
LSI, %	73.7 ± 11.2	76.2 ± 11.3	74.1 ± 12.5		
Volume affected limb, cm^3	318 ± 80	332 ± 67	324 ± 90		
Volume unaffected limb, cm^3	435 ± 105	438 ± 86	428 ± 90		
Atrophy, cm^3	117 ± 62.2	108 ± 56.9	106 ± 44		
P (affected vs unaffected)	**<.01**	**<.01**	**<.01**		
Medial gastrocnemius				.08	.47
LSI, %	70.4 ± 15.8	75.2 ± 10.1	72.6 ± 26		
Volume affected limb, cm^3	104 ± 57	110 ± 45	101 ± 53		
Volume unaffected limb, cm^3	144 ± 69	146 ± 57	133 ± 59.8		
Atrophy, cm^3	40.3 ± 26.0	36.5 ± 20.1	33.4 ± 30		
P (affected vs unaffected)	**<.01**	**<.01**	**<.01**		
Lateral gastrocnemius				.30	.94
LSI, %	75.1 ± 21.2	75.7 ± 19.1	69.8 ± 20.3		
Volume affected limb, cm^3	51 ± 31	57 ± 39	53 ± 37		
Volume unaffected limb, cm^3	71 ± 46	74 ± 42	71 ± 33		
Atrophy, cm^3	19.5 ± 20.3	16.3 ± 15.2	17.7 ± 19		
P (affected vs unaffected)	**<.01**	**<.01**	**<.01**		
Deep flexors[b]				.08	.09
LSI, %	103.7 ± 9.84	104.3 ± 5.6	102.7 ± 10.9		
Volume affected limb, cm^3	194 ± 36	222 ± 54	212 ± 42		
Volume unaffected limb, cm^3	190 ± 41	213 ± 52	207 ± 36		
Hypertrophy, cm^3	4.9 ± 19	8.7 ± 10	4.9 ± 22		
P (affected vs unaffected)	.26	**<.01**	.35		
Tendon Length					
Soleus tendon				.88	.06
LSI, %	174.1 ± 56.5	176 ± 47.5	159.1 ± 70.7		
Length affected limb, cm	8.1 ± 2.1	8.3 ± 2.2	6.5 ± 2.3		
Length unaffected limb, cm	4.8 ± 1.7	5.1 ± 2.2	4.7 ± 2.1		
Elongation, cm	3.3 ± 1.8	3.2 ± 1.6	2.1 ± 2.1		
P (affected vs unaffected)	**<.01**	**<.01**	**<.01**		
Medial gastrocnemius tendon				.52	.41
LSI, %	114.2 ± 11.3	113.8 ± 6.6	114.1 ± 7.7		
Length affected limb, cm	20.4 ± 2.8	20.1 ± 2.3	20.8 ± 2.8		
Length unaffected limb, cm	17.8 ± 2.5	17.7 ± 2	18.3 ± 2.3		
Elongation, cm	2.7 ± 1.5	2.4 ± 1.2	2.5 ± 1.3		
P (affected vs unaffected)	**<.01**	**<.01**	**<.01**		
Lateral gastrocnemius tendon				.91	.27
LSI, %	110.3 ± 6.7	110.4 ± 10	107.9 ± 8.3		
Length affected limb, cm	22.3 ± 2.1	22.2 ± 2.4	22.4 ± 2.9		
Length unaffected limb, cm	20.2 ± 1.9	20.3 ± 2.8	20.8 ± 2.4		
Elongation, cm	2.1 ± 1.1	1.9 ± 1.6	1.6 ± 1.8		
P (affected vs unaffected)	**<.01**	**<.01**	**<.01**		

[a]Data are presented as mean ± SD. Bold *P* values indicate statistically significant differences between groups ($P < .05$). CARTA, Copenhagen Achilles Rupture Treatment Algorithm; LSI, limb symmetry index.
[b]The deep flexors consist of the following muscles: tibialis posterior; flexor hallucis longus; and flexor digitorum longus.

TABLE 3
Analysis of Patients Based on the Final Treatment[a]

	Nonsurgical (n = 23)	Surgical (n = 31)	*P* (Nonsurgical vs Surgical)
Muscle Volume			
Triceps surae			
LSI, %	76.1 ± 11.2	72.8 ± 11.7	.31
Volume affected, cm^3	474 ± 133	482.8 ± 166.5	
Volume unaffected, cm^3	626.8 ± 160.8	657.2 ± 186.2	
Atrophy, cm^3	152.7 ± 80.4	174.4 ± 79.3	
P (affected vs unaffected)	**<.0001**	**<.0001**	
Soleus			
LSI, %	76.1 ± 11.8	73.5 ± 11.4	.41
Volume affected, cm^3	317.3 ± 71.3	324.7 ± 87.4	
Volume unaffected, cm^3	420.3 ± 87.6	440.7 ± 96	
Atrophy, cm^3	102.9 ± 57.1	116 ± 52.2	
P (affected vs unaffected)	**<.0001**	**<.0001**	
Medial gastrocnemius			
LSI, %	74.4 ± 11.9	71.3 ± 21.7	.55
Volume affected, cm^3	103.4 ± 46.6	104.8 ± 55	
Volume unaffected, cm^3	137.3 ± 57	143.7 ± 65.1	
Atrophy, cm^3	33.9 ± 20.3	39 ± 28.9	
P (affected vs unaffected)	**<.0001**	**<.0001**	
Lateral gastrocnemius			
LSI, %	78.1 ± 21.2	70.1 ± 18.8	.15
Volume affected, cm^3	53.4 ± 35.7	53.3 ± 34.8	
Volume unaffected, cm^3	69.3 ± 41.1	72.7 ± 39.7	
Atrophy, cm^3	15.9 ± 17.1	19.4 ± 19	
P (affected vs unaffected)	**.0001**	**<.0001**	
Deep flexors[b]			
LSI, %	105.5 ± 7.05	102.1 ± 10	.16
Volume affected, cm^3	207.7 ± 55.6	208 ± 36.5	
Volume unaffected, cm^3	198 ± 55.3	204.8 ± 35.9	
Hypertrophy, cm^3	9.8 ± 11	3.4 ± 20.5	
P (affected vs unaffected)	**.0003**	.368	
Tendon Length			
Soleus tendon			
LSI, %	181.7 ± 52.9	162 ± 60.7	.22
Length affected, cm	8.55 ± 2.31	7.17 ± 2.35	
Length unaffected, cm	4.95 ± 2.06	4.87 ± 1.91	
Elongation, cm	3.6 ± 1.7	2.3 ± 1.9	
P (affected vs unaffected)	**<.0001**	**<.0001**	
Medial gastrocnemius tendon			
LSI, %	111.6 ± 8.67	115.8 ± 8.38	.078
Length affected, cm	20.1 ± 2.22	20.6 ± 2.88	
Length unaffected, cm	17.8 ± 1.88	17.9 ± 2.53	
Elongation, cm	2.2 ± 1.3	2.8 ± 1.4	
P (affected vs unaffected)	**<.0001**	**<.0001**	
Lateral gastrocnemius tendon			
LSI, %	109.6 ± 9.87	109.6 ± 7.17	≥.999
Length affected, cm	22.1 ± 2.36	22.5 ± 2.51	
Length unaffected, cm	20.2 ± 2.58	20.5 ± 2.18	
Elongation, cm	1.9 ± 1.6	1.9 ± 1.5	
P (affected vs unaffected)	**<.0001**	**<.0001**	

[a]Data are presented as mean ± SD. Bold *P* values indicate statistically significant differences between groups ($P < .05$). CARTA, Copenhagen Achilles Rupture Treatment Algorithm; LSI, limb symmetry index.
[b]The deep flexors consist of the following muscles: tibialis posterior; flexor hallucis longus; and flexor digitorum longus.

Finally, it is possible that the focus of the CARTA, namely the morphology of the rupture at the rupture site, is not of paramount importance in tendon healing, and the focus of an individualized treatment algorithm should be put elsewhere.[5] Healing of a ruptured tendon is a multifactorial process influenced by genetics, cytokines, stem cells, immobilization, rehabilitation protocol, and patient expectations.[5] It is likely that individualized treatment selection should be based on a combination of these factors to be effective.

Treatment selection with the CARTA does not seem to affect calf atrophy and tendon elongation but might affect other relevant outcomes—for example, rerupture. There is convincing evidence that surgical treatment reduces the risk of rerupture with a factor of 3 to 5 compared with nonsurgical treatment.[10,14,15,21,22] It would be of great value if treatment selection with the CARTA could reduce the risk of rerupture to the level of surgical treatment. Rerupture will be evaluated in the ongoing main trial.[8]

Limitations

The study was performed as a predefined secondary analysis, and no power analysis was performed; hence, by definition, the study was explorative, and the results were not conclusive.

The MRI measurement methods are previously described; nonetheless, no formal test of the validity or reliability of the measurements was performed.

CONCLUSION

Individualized treatment of acute ATR using an ultrasonographic selection algorithm did not reduce calf muscle atrophy or tendon elongation compared with surgical and nonsurgical treatment. Surgical treatment did not reduce calf muscle atrophy or tendon elongation compared with nonsurgical treatment.

REFERENCES

1. Barfod KW, Hansen MS, Sandholdt H, et al. The Copenhagen Achilles Length Measurement performed at time of acute Achilles tendon rupture is correlated to tendon elongation after 1 year. *J Foot Ankle Surg*. 2022;61(5):1098-1102.
2. Barfod KW, Hölmich P. Acute Achilles' tendon rupture—surgery or no surgery. *N Engl J Med*. 2022;386(15):1465-1466.
3. Barfod KW, Riecke AF, Boesen A, et al. Validation of a novel ultrasound measurement of Achilles tendon length. *Knee Surg Sports Traumatol Arthrosc*. 2015;23(11):3398-406.
4. Costa ML, Achten J, Marian IR, et al. Plaster cast versus functional brace for non-surgical treatment of Achilles tendon rupture (UKSTAR): a multicentre randomised controlled trial and economic evaluation. *Lancet*. 2020;395(10222):441-448. doi:10.1016/S0140-6736(19)32942-3
5. Cramer A, Barfod KW, Hölmich P, Pedersen DA, Christensen K. Genetic contribution to the etiology of Achilles tendon rupture. A Danish nationwide register study of twins. *Foot Ankle Surg*. 2022;28(7):1050-1054.
6. Ganestam A, Kallemose T, Troelsen A, Barfod KW. Increasing incidence of acute Achilles tendon rupture and a noticeable decline in surgical treatment from 1994 to 2013. A nationwide registry study of 33,160 patients. *Knee Surg Sports Traumatol Arthrosc*. 2016;24(12):3730-3737.
7. Hansen MS, Bencke J, Kristensen MT, Kallemose T, Hölmich P, Barfod KW. Achilles tendon gait dynamics after rupture: a three-armed randomized controlled trial comparing an individualized treatment algorithm vs. operative or non-operative treatment. *Foot Ankle Surg*. 2023;29(2):143-150. doi:10.1016/j.fas.2022.12.006
8. Hansen MS, Vestermark MT, Hölmich P, Kristensen MT, Barfod KW. Individualized treatment for acute Achilles tendon rupture based on the Copenhagen Achilles Rupture Treatment Algorithm (CARTA): a study protocol for a multicenter randomized controlled trial. *Trials*. 2020;21(1):399. doi:10.1186/s13063-020-04332-z
9. Heikkinen J, Lantto I, Flinkkila T, et al. Soleus atrophy is common after the nonsurgical treatment of acute Achilles tendon ruptures: a randomized clinical trial comparing surgical and nonsurgical functional treatments. *Am J Sports Med*. 2017;45(6):1395-1404. doi:10.1177/0363546517694610
10. Holm C, Kjaer M, Eliasson P. Achilles tendon rupture—treatment and complications: a systematic review. *Scand J Med Sci Sports*. 2015;25(1):e1-e10. doi:10.1111/sms.12209
11. Kastoft R, Bencke J, Speedtsberg MB, Penny JØ, Barfod K. Early weight-bearing in nonoperative treatment of acute Achilles tendon rupture did not influence mid-term outcome: a blinded, randomised controlled trial. *Knee Surg Sports Traumatol Arthrosc*. 2019;27(9):2781-2788. doi:10.1007/s00167-018-5058-4
12. Kramer R, Somodi S, Hölmich P, Barfod KW. Foot and ankle surgery calcaneal positioning in equinus immobilization of the ankle joint: a comparison of common orthoses used in the treatment of acute Achilles tendon ruptures. *Foot Ankle Surg*. 2022;28(8):1314-1320. doi:10.1016/j.fas.2022.06.011
13. Lantto I, Heikkinen J, Flinkkila T, et al. A prospective randomized trial comparing surgical and nonsurgical treatments of acute Achilles tendon ruptures. *Am J Sports Med*. 2016;44(9):2406-2014. doi:10.1177/0363546516651060
14. Maempel JF, Clement ND, Wickramasinghe NR, Duckworth AD, Keating JF. Operative repair of acute Achilles tendon rupture does not give superior patient-reported outcomes to nonoperative management: results of a randomized controlled trial at a minimum of 13 years' follow-up. *Bone Joint J*. 2020;102(7):933-940.
15. Myhrvold SB, Brouwer EF, Andresen TKM, et al. Nonoperative or surgical treatment of acute Achilles' tendon rupture. *N Engl J Med*. 2022;386(15):1409-1420. doi:10.1056/nejmoa2108447
16. Nilsson-Helander K, Silbernagel KG, Thomeé R, et al. Acute Achilles tendon rupture: a randomized, controlled study comparing surgical and nonsurgical treatments using validated outcome measures. *Am J Sports Med*. 2010;38(11):2186-2193. doi:10.1177/0363546510376052
17. Ochen Y, Beks RB, van Heijl M, et al. Operative treatment versus nonoperative treatment of Achilles tendon ruptures: systematic review and meta-analysis. *BMJ*. 2019;364:k5120. doi:10.1136/bmj.k5120
18. Reda Y, Farouk A, Abdelmonem I, El Shazly OA. Surgical versus nonsurgical treatment for acute Achilles' tendon rupture. a systematic review of literature and meta-analysis. *Foot Ankle Surg*. 2020;26(3):280-288. doi:10.1016/j.fas.2019.03.010
19. Reijman M, Eggerding V, van Es E, et al. Early surgical reconstruction versus rehabilitation with elective delayed reconstruction for patients with anterior cruciate ligament rupture: COMPARE randomised controlled trial. *BMJ*. 2021;372:n375. doi:10.1136/bmj.n375
20. Svensson RB, Couppé C, Agergaard A, et al. Persistent functional loss following ruptured Achilles tendon is associated with reduced gastrocnemius muscle fascicle length, elongated gastrocnemius and soleus tendon, and reduced muscle cross-sectional area. *Transl Sport Med*. 2019;2(6):316-324. doi:10.1002/tsm2.103
21. Twaddle BC, Poon P. Early motion for Achilles tendon ruptures: is surgery important? A randomized, prospective study. *Am J Sports Med*. 2007;35(12):2033-2038. doi:10.1177/0363546507307503
22. Willits K, Amendola A, Bryant D, et al. Operative versus nonoperative treatment of acute Achilles tendon ruptures: a multicenter randomized trial using accelerated functional rehabilitation. *J Bone Joint Surg Am*. 2010;92(17):2767-2775. doi:10.2106/JBJS.I.01401