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Asia-Pacific Journal of Sports Medicine, Arthroscopy, Rehabilitation and Technology 2 (2015) 49–55
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Original article

The Achilles tendon resting angle as an indirect measure of Achilles tendon length following rupture, repair, and rehabilitation

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Received 6 October 2014; revised 9 December 2014; accepted 17 December 2014
Available online 20 February 2015

Abstract

Background: Rupture of the Achilles tendon may result in reduced functional activity and reduced plantar flexion strength. These changes may arise from elongation of the Achilles tendon. An observational study was performed to quantify the Achilles tendon resting angle (ATRA) in patients following Achilles tendon rupture, surgical repair, and rehabilitation, respectively.
Methods: Between May 2012 and January 2013, 26 consecutive patients (17 men), with a mean (standard deviation, SD) age of 42 (8) years were included and evaluated following injury, repair, and at 6 weeks, 3 months, 6 months, 9 months, and 12 months, respectively (rehabilitation period). The outcome was measured using the ATRA, Achilles tendon total rupture score (ATRS), and heel-rise test.
Results: Following rupture, the mean (SD) absolute ATRA was 55 (8)° for the injured side compared with 43 (7)° ($p < 0.001$) for the noninjured side. Immediately after repair, the angle reduced to 37 (9)° ($p < 0.001$). The difference between the injured and noninjured sides, the relative ATRA, was −12.5 (4.3)° following injury; this was reduced to 7 (7.9)° following surgery ($p < 0.001$). During initial rehabilitation, at the 6-week time point, the relative ATRA was 2.6 (6.2)° ($p = 0.04$) and at 3 months it was −6.5 (6.5)° ($p < 0.001$). After the 3-month time point, there were no significant changes in the resting angle. The ATRS improved significantly ($p < 0.001$) during each period up to 9 months following surgery, where a score of 85 (10)° was reported. The heel-rise limb symmetry index was 66 (22)% at 9 months and 82 (14)% at 12 months. At 3 months and 6 months, the absolute ATRA correlated with the ATRS ($r = 0.63$, $p = 0.001$, $N = 26$ and $r = 0.46$, $p = 0.027$, $N = 23$, respectively). At 12 months, the absolute ATRA correlated with the heel-rise height ($r = -0.63$, $p = 0.002$, $N = 22$).
Conclusion: The ATRA increases following injury, is reduced by surgery, and then increases again during initial rehabilitation. The angle also correlates with patient-reported symptoms early in the rehabilitation phase and with heel-rise height after 1 year. The ATRA might be considered a simple and effective means to evaluate Achilles tendon function 1 year after the rupture.

Keywords: Achilles rupture; elongation; repair

Introduction

Rupture of the Achilles tendon leads to functional limitation,[1] loss of functional strength,[2] and endurance.[3] Many patients fail to resume sporting activities in the short term, and the injury causes problems for as long as 10 years after rupture.[4]

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http://dx.doi.org/10.1016/j.asmart.2014.12.002

The general aim of modern management is to optimize function, as promptly as possible, while minimizing complications. Research has previously focussed on determining optimal methods of treatment, either surgical or nonsurgical, with randomized controlled studies.[5–12] Rerupture is the primary outcome variable in almost all studies with secondary variables being functional outcome, range of motion, calf circumference, and plantar flexion strength.

Some previous studies have reported reduced plantar flexion strength of 10–20% following Achilles tendon rupture,[2,4,10,13] particularly at the end range of plantar flexion.[14] Compared with the noninjured side, calf muscle activity following rupture is greater during gait and this moderately correlates with the changes in Achilles tendon length ($0.38 < r < 0.52$).[15] Accordingly, it is reasonable to assume that reduced strength during plantar flexion is related to lengthening of the tendon during healing.[12,13]

The Achilles tendon elongates during the healing and rehabilitation stages.[16–19] The length of the tendon has been measured either directly using radio-opaque markers being placed within its substance[16–19] or using imaging modalities such as ultrasound[13,15] or computed tomography.[20] Thus, there is a need to develop a clinically applicable, noninvasive, accurate, and easy-to-perform method to evaluate the length and elongation of the Achilles tendon.[21]

Alteration of the arc of movement of the ankle is an indirect measurement of the Achilles tendon length. Ten millimetres of tendon elongation was shown to result in a 10° increase in dorsiflexion.[22] Matles test is a diagnostic sign indicating loss of the tenodesis effect during knee movement from extension to flexion, resulting in increased ankle dorsiflexion after acute Achilles tendon rupture.[23] The resting position of the ankle, due to the tenodesis effect of the Achilles tendon, has been termed the *Achilles tendon resting angle* (ATRA).[24] This angle, compared with the noninjured side, may change following rupture, repair, and subsequent rehabilitation.

An observational study was performed to quantify the ATRA following rupture, surgical repair, and rehabilitation. The hypothesis was that the ATRA, an indirect measurement of elongation, would relate to the functional outcome of Achilles tendon rupture.

Materials and methods

Between May 2012 and January 2013, 26 consecutive patients with a midportion rupture of the Achilles tendon were evaluated and included in this study. All patients demonstrated the triad of a palpable gap, the absence of plantar flexion on a calf squeeze, and an abnormal Matles test[23] confirming the diagnosis of rupture of the Achilles tendon.[25] Exclusion criterion included the occurrence of a previous contralateral Achilles tendon rupture, although none of the patients had prior rupture in this series. There were 17 male and nine female patients with a mean [standard deviation (SD)] age of 42 (8) years. In 16 patients, the right side was injured.

Patients underwent a minimally invasive repair of the Achilles tendon rupture using an established technique.[26,27] Although the majority of patients had their surgery performed under local anaesthesia, 38 (10)% chose general anaesthesia. Repairs were performed using a number 1 absorbable Maxon suture (Covidien, Dublin, Ireland)—eight strands of polyglycolic acid in the configuration of a Bunnell suture proximally and a Kessler suture distally. A 2-cm longitudinal incision was used rather than a transverse stab incision to aid visualization of apposition of the ruptured tendon ends during the repair. A second 2-cm incision was made at the midlateral incision, 8–10 cm proximal to the Achilles insertion. This allowed the sural nerve to be identified and protected during the surgical repair. Patients received prophylactic antibiotic, flucloxacillin (1 g), and 2 weeks of low-molecular-weight heparin [tinzaparin 4500 IU once a day (LEO Pharma, Berkshire, UK)]. Patients were encouraged to bear weight on their metatarsal heads soon after the surgery depending on their tolerance level, using crutches and a protective equinus splint cast for 2 weeks and a dorsal shell for 6 weeks. Thereafter, a 15-mm heel raise was provided. Active movement exercises, plantar flexion, inversion, and eversion contractions (each for 10 seconds) were performed with 10 repetitions, three times/d, and these were commenced at 2 weeks after the surgery.

The ATRA is the angle between the long axis of the fibula and the line from the tip of the fibula to the head of the fifth metatarsal.[24] The absolute ATRA is the resting angle of the injured Achilles tendon. The relative ATRA is the difference between the ATRA on the injured side and the noninjured side (Fig. 1A–C). A negative relative ATRA indicates that the injured side is in dorsiflexion; a positive relative ATRA indicates plantar flexion compared with the noninjured side. The ATRA and calf circumferences at 15 cm below the medial joint line of the knee were evaluated at presentation, following surgery, and at 6 weeks and 3 months, 6 months, 9 months, and 12 months after the surgery (Fig. 2A–G). The ATRA was measured using a standard 15-cm arm goniometer with 2° increments. The calf circumference was measured using a standard tape measure with 0.1-cm increments. The ATRA was also measured under general anaesthesia in the 10 patients who chose this option. Patients symptoms and physical activity were evaluated with the Achilles tendon total rupture score (ATRS)[1,28] and Tegner activity score.[29] A test of heel-rise height was used to evaluate recovery of calf muscle function.[30] For this test, the maximal single-leg heel-rise height in centimetre was documented and the injured and noninjured sides were compared to determine the limb symmetry index (LSI).

All patients gave consent for participation in this study and as their names were removed, the Ethics Committee confirmed that a formal ethical review was not required.

Statistical analysis

All data were analysed using IBM SPSS statistics version 22 (IBM Corp., Armonk, NY, USA). Descriptive statistics for the ATRS were reported using median (range) and mean ± SD. The LSI was calculated to compare the results from heel-rise

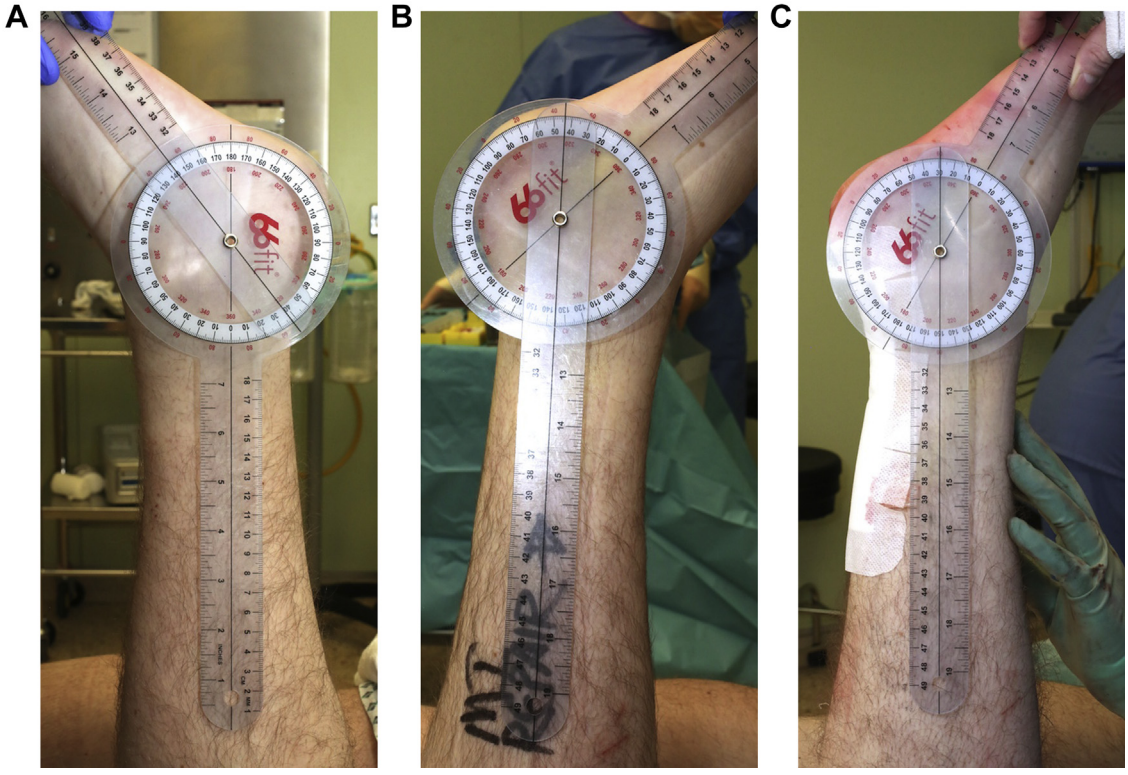

Fig. 1. (A) Measurement of the absolute Achilles tendon resting angle (ATRA; 37°), the acute angle between the long axis of the fibula, the tip of the fibula, and the head of the fifth metatarsal. (B) The absolute ATRA (44°) of the injured ankle prior to surgery. This ankle is currently in the dorsiflexed position, with a relative ATRA of −7°. (C) The absolute ATRA of 29° following surgery. The ankle is currently in the plantar flexed position, with a relative ATRA of 8°. Note the fingers are supporting the tibia rather than the calf.

test with the relative ATRA. The LSI was defined as the ratio between the involved limb score and the uninvolved limb score expressed as a percentage (involved/uninvolved × 100 = LSI). A level of significance was set at $p < 0.05$. A paired t test was used to compare side-to-side differences. A repeated measures analysis of variance, using Bonferroni correction for pairwise analysis, was used to evaluate changes over time. Bivariate correlations were performed using Spearman correlation.

Results

Of the cohort of 26 patients, three were lost to follow-up at 12 months ($N = 23$). On clinical assessment following injury, the mean (SD) absolute ATRA was 55 (8)° on the injured side compared with 43 (7)° ($p < 0.001$) for the noninjured side. Immediately following repair, the ATRA was 37 (9)° ($p < 0.001$). This had not increased by the 6-week time point, when it was measured to be 40 (7)° (not significant); however, the ATRA had increased at the 3-month time point to 52 (8)° ($p \leq 0.001$; Fig. 3A). The relative ATRA was −12.5 (4.3)° following injury and this was reduced to 7 (7.9)° following surgery ($p < 0.001$). At the 6-week and 3-month time points, the relative ATRA had significantly decreased to 2.6 (6.2)° ($p = 0.04$) and −6.5 (6.5)° ($p < 0.001$). After the 3-month time point, the ATRA did not change significantly (Fig. 3B).

For the 10 patients who chose general anaesthesia, the ATRA was compared between the injured and noninjured sides when the patients were awake (measured in the clinic) and when they were under general anaesthesia. The absolute and relative ATRAs were 50.6 (4.6)° and −11.3 (1.7)° when awake and 52.2 (4.4)° and −14 (3.7)° when measured under general anaesthesia (not significant).

There was a significant ($p < 0.001$) improvement in symptoms, as measured with the ATRS, over time (Table 1). However, there was no significant improvement in the ATRS between 9 month and 12 months following surgery, 85 (10)° and 88 (13)°, respectively. At 3 months and 6 months, the absolute ATRA showed evidence of a statistically significant positive association with the ATRS ($r = 0.63$, $p = 0.001$, $N = 26$ and $r = 0.46$, $p = 0.027$, $N = 23$, respectively).

The mean heel-rise height LSI was 66 (22)% at 9 months and 82 (14)% at 12 months. At 12 months, the absolute ATRA correlated with heel-rise height LSI ($r = -0.63$, $p = 0.002$, $N = 22$) but not at 9 months.

The maximal mean reduction in calf circumference occurred at the 6-week time point [−1.9 (1.5) cm]. This hypotrophy decreased with time, but had not recovered by 12 months following repair [−1.1 (1.5) cm].

At the 9-month time point, only 14% of patients had returned to the same or an improved level of sport activity compared with the preoperative period; at 12 months, 59% had returned to the same or improved perceived level of sports and

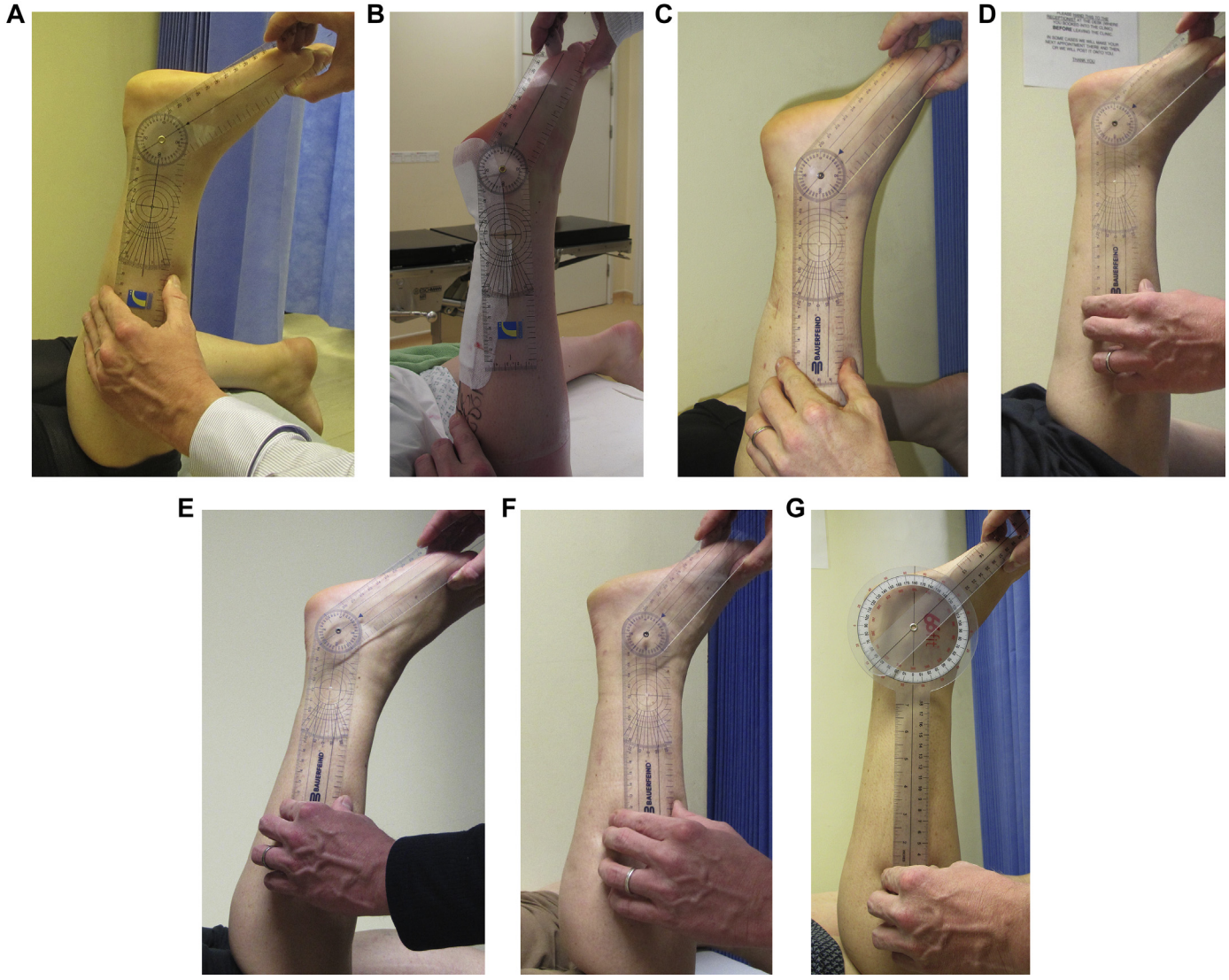

Fig. 2. The Achilles tendon resting angle with time: (A) following rupture, (B) after repair, (C) at 6 weeks, and at (D) 3 months, (E) 6 months, (F) 9 months, and (G) 12 months.

61% to their preinjury Tegner score. The ATRS correlated with the Tegner score at 6 months, 9 months, and 12 months after the injury (Table 1).

One patient sustained a rerupture (slipped on a wet floor) at the 8-week time point, and two others missed the final assessment. One patient sustained a superficial infection, chronic regional pain problems, and a deep venous thrombosis (DVT). Altogether two patients (8%) sustained DVT, despite chemical prophylaxis, and their calf circumference data were excluded from further analysis. One patient sustained an iatrogenic nerve injury related to the incision at the rupture site. The symptoms had resolved by the 3-month time point. There were no other complications.

Discussion

The most important finding of the present investigation is the ATRA can be used in the diagnostic evaluation of Achilles tendon rupture. The angle increases following injury, is reduced by surgery, and then increases again during initial rehabilitation. This angle may reflect the changes in Achilles tendon length during healing. There was no significant difference in the relative ATRA measured in clinic (patients awake) and under general anaesthesia (patients relaxed). This shows that the ATRA measurement is reliable in clinic. Following surgery, the reduced ATRA (increased plantar flexion) while weight bearing using a protective dorsal shell was maintained for up to 6 weeks following the surgery. However, the ATRA increased significantly by 3 months following repair. No further increase in the angle was noted until the 12-month time point. This angle also correlated with patient-reported symptoms early in the rehabilitation phase and with heel-rise height after 1 year, and can accordingly be used as part of the outcome evaluation at 12 months.

In studies that have evaluated both the separation of the tendon ends and the tendon length, it has been found that initially there is elongation up to approximately 3 months followed by a slight subsequent shortening.[13,16–19] This

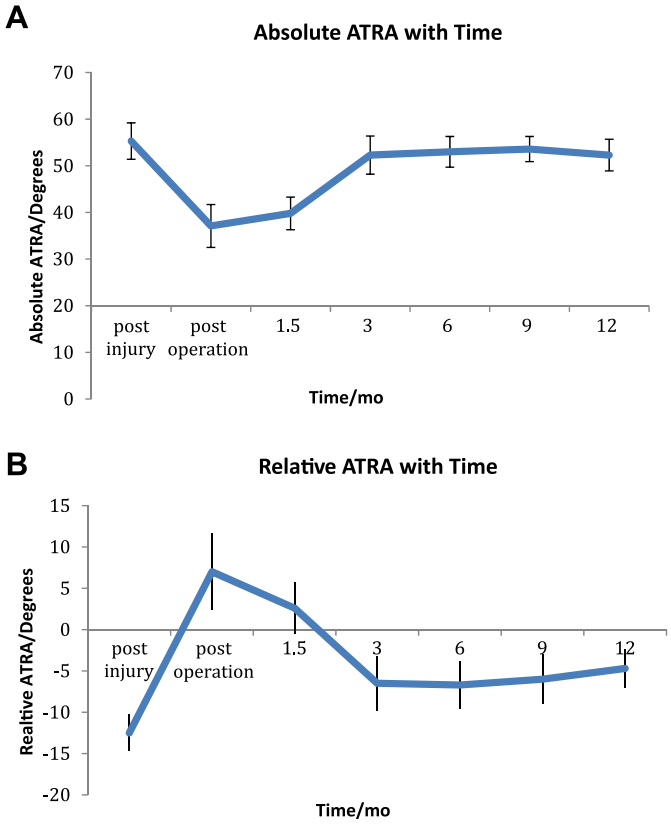

Fig. 3. (A) The behaviour of the mean absolute Achilles tendon resting angle (ATRA) with time. (B) The behaviour of the mean relative ATRA with time.

pattern of elongation and shortening is similar regardless of treatment such as surgery, nonsurgery, or early and late mobilization. This study supports these findings in that a small increase in the ATRA was noted between operative repair and measurement at 6 weeks. A greater increase in the ATRA occurred between 6 weeks and 3 months. Thereafter, the ATRA did not change significantly, although a small nonsignificant reduction of the ATRA was noted at the 12-month time point. The ATRA describes the passive tension from the ankle and possibly other structures around the ankle. The change in ATRA between 6 weeks and 3 months may be the result of tendon elongation after removal of the protective dorsal brace or alleviation of stiffness of the ankle joint. Following brace removal, patients were asked to wear a 15-mm in-shoe heel wedge. Although compliance was not recorded, this suggests that this wedge alone did not prevent an increase in the ATRA. It must be remembered that the postoperative ATRA was recorded following end-to-end apposition of the tendon, under direct vision, before any ankle stiffness had developed. Active plantar flexion exercises were commenced at 2 weeks following repair, and although the plantar flexion component may have been restored, the dorsiflexion component was not. At this time, it is not known whether the change in ATRA is only related to the tendon length, although it appears to be a useful clinical measure.

The patient-reported symptoms (ATRS) in this series are comparable to other cohorts of patients,[12,27] and improved significantly over time up to 9 months following surgery, but thereafter no significant improvement was reported. This could have been a ceiling effect commented upon by Schepull et al[18] or it could be due to the relatively small sample size. During the early stages of recovery at 3 months and 6 months, the absolute ATRA correlated well with the patient-reported symptoms score (ATRS). Previous studies have also reported an association between Achilles tendon elongation and clinical outcome.[16,17]

The patients in the present study had deficits in heel-rise height, and this measure was comparable to other studies.[9,12] This was suggested to be an indirect measure of the Achilles tendon elongation following a rupture.[13] One consideration is that, although the ATRA was measured with the knee in the 90° flexion, the heel rise was performed with the patients keeping their knee straight, explaining a lack of association. Future studies comparing actual measurements of Achilles tendon length through either magnetic resonance imaging (MRI) or ultrasound imaging with the ATRA are needed.

Reasons for the increased ATRA include suture resorption/degradation with time, suture cut out of the tendon, suture failure, and an alteration in the modulus of elasticity (E) of the healing tendon. In this series, surgical repairs were performed using eight strands of number 1 Maxon (Covidien), a synthetic absorbable polyglyconate copolymer of glycolic acid and trimethylene carbonate. Approximately 75% of the initial tensile strength of the polyglyconate suture material was preserved until 2 weeks after insertion, but the strength fell to 50% by 4 weeks. In this series, the greatest elongation occurred between Week 6 and Week 12, possibly indicating that degradation of the suture material could be a factor in the increment of ATRA.

Determination of the ATRA for both the injured and the noninjured sides is a considerable strength of this technique, as this allows for determination of the absolute and relative ATRAs. Unilateral tendon elongation determination may vary

Table 1
Relationship of the ATRS with time and Tegner score.

	Preinjury	3 mo	6 mo	9 mo	12 mo
ATRS					
Mean (SD)		45 (20)	70 (16)[a]	85 (10)[a]	88 (13)
Median (range)		40 (13–82)	72 (39–97)	86 (10–100)	91 (54–100)
Tegner median (range)	7 (1–9)	3.5 (0–5)	5 (1–7)	5 (1–7)	6 (1–8)
Correlation between ATRS and Tegner r (p)		0.291 (n.s.)	0.435 (0.049)*	0.511 (0.013)*	0.52 (0.011)*

ATRS = Achilles tendon total rupture score; n.s. = not significant; SD = standard deviation.
*Significant (<0.01) difference compared with previous measurement.
[a] Significant (<0.01) difference compared with previous measurement.

according to stretch and activity. The measurement of the ATRA is uncomplicated and does not require any expensive equipment. It may also be determined intraoperatively as a guide to the tightness of the Achilles tendon repair and in the presence of skin dressings following surgery.

Limitations of this study include the small sample size ($n = 23$ patients), although this is comparable with other series studying tendon elongation and that each patient had their ATRA measured seven times in total. The absence of a direct measure of tendon length such as MRI or ultrasound is also a limitation of this study. As one surgeon operated on all patients, there is an aspect of performance bias for the outcome compared with other series; however, this also means that there was no interobserver error.

Direct visualization of the apposed tendon ends at the time of surgery is a strength of this minimally invasive technique. Intraoperative measurement of the ATRA allows the resting tone of the ankle to be reduced following repair. The increment in the ATRA beyond that of the opposite side occurred between 6 weeks and 3 months following repair during the phase of fibrosis. This may be a key phase of tendon healing responsible for restoring normal activities, strengthening of the calf muscle, and proprioception of the ankle and yet minimize tendon elongation.

Although the ATRA may reflect the resting posture of the ankle, a direct relationship of this angle to the length of the Achilles tendon has yet to be shown. Other factors such as capsular stiffness may also influence the resting angle in addition to the tendon length.

The ATRA has the potential of being an easy and cost-effective clinical tool for indirect measurement of Achilles tendon length during healing. The angle is reduced by surgery, and then increases again during initial rehabilitation. This angle is correlated with patient-reported symptoms early in the rehabilitation and with heel-rise height after 1 year. The ATRA might be considered as a simple and effective means to evaluate recovery after 1 year following Achilles tendon repair.

Conflicts of interest

There are no conflicts of interest.

Acknowledgements

The authors would like to thank the British Association of Sport and Exercise Medicine for a Research Bursary towards this research.

References

1. Nilsson-Helander K, Thomeé R, Silbernagel KG, et al. The Achilles tendon total rupture score (ATRS): development and validation. *Am J Sports Med*. 2007;35:421–426.
2. Olsson N, Nilsson-Helander K, Karlsson J, et al. Major functional deficits persist 2 years after acute Achilles tendon rupture. *Knee Surg Sports Traumatol Arthrosc*. 2011;19:1385–1393.
3. Bostick GP, Jomha NM, Suchak AA, Beaupré LA. Factors associated with calf muscle endurance recovery 1 year after Achilles tendon rupture repair. *J Orthop Sports Phys Ther*. 2010;40:345–351.
4. Horstmann T, Lukas C, Merk J, Bruaner T, Mündermann A. Deficits 10-years after Achilles tendon repair. *Int J Sports Med*. 2012;33:474–479.
5. Nistor L. Surgical and non-surgical treatment of Achilles tendon rupture. A prospective randomized study. *J Bone Joint Surg Am*. 1981;63:394–399.
6. Cetti R, Christensen SE, Ejsted R, Jensen NM, Jorgensen U. Operative versus nonoperative treatment of Achilles tendon rupture. A prospective randomized study and review of the literature. *Am J Sports Med*. 1993;21:791–799.
7. Möller M, Movin T, Granhed H, Lind K, Faxén E, Karlsson J. Acute rupture of tendon Achillis. A prospective randomised study of comparison between surgical and non-surgical treatment. *J Bone Joint Surg Br*. 2001;83:843–848.
8. Twaddle BC, Poon P. Early motion for Achilles tendon ruptures: is surgery important? A randomized, prospective study. *Am J Sports Med*. 2007;35:2033–2038.
9. Nilsson-Helander K, Silbernagel KG, Thomeé R, et al. Acute Achilles tendon rupture: a randomized controlled study comparing surgical and non-surgical treatments using validated outcome measure. *Am J Sports Med*. 2010;38:2186–2193.
10. 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;92:2767–2775.
11. Keating JF, Will EM. Operative versus non-operative treatment of acute rupture of tendo Achillis: a prospective randomised evaluation of functional outcome. *J Bone Joint Surg Br*. 2011;93:1071–1078.
12. Olsson N, Silbernagel KG, Eriksson BI, et al. Stable surgical repair with accelerated rehabilitation versus nonsurgical treatment for acute Achilles tendon ruptures: a randomized controlled study. *Am J Sports Med*. 2013;41:2867–2876.
13. Silbernagel KG, Steele R, Manal K. Deficits in heel-rise height and Achilles tendon elongation occur in patients recovering from an Achilles tendon rupture. *Am J Sports Med*. 2012;40:1564–1571.
14. Mullaney MJ, McHugh MP, Tyler TF, Nicholas SJ, Lee SJ. Weakness in end-range plantar flexion after Achilles tendon repair. *Am J Sports Med*. 2006;34:1120–1125.
15. Suydam SM, Buchanan TS, Manal K, Silbernagel KG. Compensatory muscle activation caused by tendon lengthening post-Achilles tendon rupture. *Knee Surg Sports Traumatol Arthrosc*. 2013. http://dx.doi.org/10.1007/s00167-013-2512-1.
16. Kangas J, Pajala A, Ohtonen P, Leppilahti J. Achilles tendon elongation after rupture repair: a randomized comparison of 2 postoperative regimens. *Am J Sports Med*. 2007;35:59–64.
17. Mortensen HM, Skov O, Jensen PE. Early motion of the ankle after operative treatment of a rupture of the Achilles tendon. A prospective, randomized clinical and radiographic study. *J Bone Joint Surg Am*. 1999;81:983–990.
18. Schepull T, Kvist J, Aspenberg P. Early E-modulus of healing Achilles tendons correlates with late function: similar results with or without surgery. *Scand J Med Sci Sports*. 2012;22:18–23.
19. Nyström B, Holmlund D. Separation of tendon ends after suture of Achilles tendon. *Acta Orthop Scand*. 1983;54:620–621.
20. Rosso C, Buckland DM, Polzer C, et al. Long-term biomechanical outcomes after Achilles tendon ruptures. *Knee Surg Sports Traumatol Arthrosc*. 2013. http://dx.doi.org/10.1007/s00167-013-2726-2.
21. Barfod KW. Achilles tendon rupture; assessment of nonoperative treatment. *Dan Med J*. 2014;61:B4837.
22. Costa ML, Logan K, Heylings D, Donell ST, Tucker K. The effect of Achilles tendon lengthening on ankle dorsiflexion: a cadaver study. *Foot Ankle Int*. 2006;27:414–417.
23. Matles AL. Rupture of the tendo Achilles: another diagnostic sign. *Bull Hosp Joint Dis*. 1975;36:48–51.
24. Carmont MR, Silbernagel KG, Mathy A, Mulji Y, Karlsson J, Maffulli N. Reliability of Achilles tendon resting angle and calf circumference measurement techniques. *Foot Ankle Surg*. 2013;19:245–249.
25. Maffulli N. The clinical diagnosis of subcutaneous tear of the Achilles tendon. A prospective study in 174 patients. *Am J Sports Med*. 1998;26:266–270.

26. Carmont MR, Maffulli N. Modified percutaneous repair of ruptured Achilles tendon. *Knee Surg Sports Traumatol Arthrosc*. 2008;16:199−203.
27. Carmont MR, Silbernagel KG, Edge A, Mei-Dan O, Karlsson J, Maffulli N. Functional outcome of percutaneous Achilles repair. *Orthop J Sports Med*. 2013;1:1−7.
28. Carmont MR, Silbernagel KG, Nilsson-Helander K, Mei-Dan O, Karlsson J, Maffulli N. Cross cultural adaptation of the Achilles tendon total rupture score with reliability, validity and responsiveness evaluation. *Knee Surg Sports Traumatol Arthrosc*. 2013;21:1356−1360.
29. Tegner Y, Lysholm J. Rating systems in the evaluation of knee ligament injuries. *Clin Orthop Relat Res*. 1985:43−49.
30. Silbernagel KG, Nilsson-Helander K, Thomeé R, Eriksson BI, Karlsson J. A new measurement of heel-rise endurance with the ability to detect functional deficits in patients with Achilles tendon rupture. *Knee Surg Sports Traumatol Arthrosc*. 2010;18:258−264.