Clinical Biomechanics 30 (2015) 485–492

Contents lists available at ScienceDirect

Clinical Biomechanics

journal homepage: www.elsevier.com/locate/clinbiomech

The structural and mechanical properties of the Achilles tendon 2 years after surgical repair

Jeam Marcel Geremia [a,b,*], Maarten Frank Bobbert [c], Mayra Casa Nova [a], Rafael Duvelius Ott [d], Fernando de Aguiar Lemos [a], Raquel de Oliveira Lupion [a], Viviane Bortoluzzi Frasson [e], Marco Aurélio Vaz [a]

[a] Exercise Research Laboratory, School of Physical Education, Federal University of Rio Grande do Sul, Porto Alegre, Brazil
[b] Faculty of Physical Education Sogipa, Porto Alegre, Brazil
[c] Faculty of Human Movement Sciences, Move Research Institute Amsterdam, VU University Amsterdam, Amsterdam, The Netherlands
[d] São Lucas Hospital, Pontifical Catholic University of Rio Grande do Sul, Porto Alegre, Brazil
[e] Physique Physiotherapy Center, Porto Alegre, Brazil

ARTICLE INFO

Article history:
Received 10 December 2014
Accepted 4 March 2015

Keywords:
Stress–strain relation
Achilles tendon rupture
Immobilization
Tendon healing
Ultrasound

ABSTRACT

Background: Acute ruptures of the Achilles tendon affect the tendon's structural and mechanical properties. The long-term effects of surgical repair on these properties remain unclear.
Purpose: To evaluate effects of early mobilization versus traditional immobilization rehabilitation programs 2 years after surgical Achilles tendon repair, by comparing force-elongation and stress–strain relationships of the injured tendon to those of the uninjured tendon.
Methods: A group of males with previous Achilles tendon rupture ($n = 18$) and a group of healthy male controls ($n = 9$) participated. Achilles tendon rupture group consisted of patients that had received early mobilization ($n = 9$) and patients that had received traditional immobilization with a plaster cast ($n = 9$). Comparisons of tendon structural and mechanical properties were made between Achilles tendon rupture and healthy control groups, and between the uninjured and injured sides of the two rehabilitation groups in Achilles tendon rupture group. Ultrasound was used to determine bilaterally tendon cross-sectional area, tendon resting length, and tendon elongation as a function of torque during maximal voluntary plantar flexion. From these data, Achilles tendon force-elongation and stress–strain relationships were determined.
Findings: The Achilles tendon rupture group uninjured side was not different from healthy control group. Structural and mechanical parameters of the injured side were not different between the Achilles tendon rupture early mobilization and the immobilization groups. Compared to the uninjured side, the injured side showed a reduction in stress at maximal voluntary force, in Young's modulus and in stiffness.
Interpretation: Two years post-surgical repair, the Achilles tendon mechanical properties had not returned to the uninjured contralateral tendon values.

1. Introduction

The incidence of Achilles tendon (AT) acute ruptures has risen mainly due to an increased participation in sports-related activities (Huttunen et al., 2014; Lantto et al., 2015). Open repair is one of various techniques used for the treatment of AT acute ruptures (Rosenzweig and Azar, 2009). This technique has been used successfully (Del Buono et al., 2014), provides good strength to the repaired tendon and low re-rupture rates (Del Buono et al., 2014; Inglis et al., 1976), and is usually followed by a traditional rehabilitation program. This program involves ankle immobilization with a plaster cast (PC) that is removed 6 weeks after surgery (Maffulli et al., 2003a).

Tendons adapt to physical activity regimens (Barone et al., 2009; Fouré et al., 2013; Kubo et al., 2000, 2012). Immobilization causes a reduction of collagen synthesis and an increase in collagen degradation (Kangas, 2007). This reduces the size and number of collagen bundles as well as water and glycosaminoglycan content (Kannus et al., 1997). Furthermore, damaged and healed tendons contain a greater proportion of weaker type III collagen, while normal tendons are composed of type I collagen (characterized by a higher tensile strength) (Kannus et al., 1997). Thus, the immobilization and the healing process can affect the tendon mechanical properties as a whole (Kannus et al., 1997).

Early mobilization has been proposed to accelerate tendon repair (Maffulli et al., 2003a,b). The best physical therapy program after AT repair should allow for early weight bearing and joint mobilization, and minimize the abovementioned deleterious effects to the tendon.

* Corresponding author at: Exercise Research Laboratory (LAPEX), Federal University of Rio Grande do Sul (UFRGS), Rua Felizardo, 750, Bairro Jardim Botânico, CEP: 90690-200, Porto Alegre, RS, Brazil.
E-mail address: jeam_geremia@hotmail.com (J.M. Geremia).

http://dx.doi.org/10.1016/j.clinbiomech.2015.03.005
0268-0033/

Nonetheless, evidence of functional recovery, together with structural and mechanical tendon properties from different rehabilitation programs, seems to be lacking in the current literature.

Long-term studies evaluating the AT's structural and mechanical properties after surgical repair are also scarce. Studies have shown that, long after surgery, muscle strength is still reduced (Bressel and McNair, 2001; Maffulli et al., 2003a), tendon morphology has not returned to normal (Maffulli et al., 2001; Rosso et al., 2013), and the functional deficits persist (Olsson et al., 2011). Knowledge of these long-term effects is important because patients are released from rehabilitation to return to their normal activities 6 months post-surgery on average without a clear assessment of their tendon structural and mechanical properties. Evidence for restoration of the AT structural (cross-sectional area—CSA, tendon length—TL) and mechanical (stress, strain, stiffness, Young's modulus) properties in these patients are scarce (Bressel and McNair, 2001). Moreover, the lack of well-defined rehabilitation programs further emphasizes the clinical relevance of determining the exact effects of well-defined rehabilitation programs on these AT structural and mechanical properties, as well as these programs' effectiveness by way of their effects on these properties.

The purpose of this study was to determine if early physical rehabilitation of surgically repaired Achilles tendon ruptures leads to different long-term (more than 2 years after surgical repair) structural and mechanical results than traditional post-surgical techniques. Specifically, we addressed the following questions: (1) Are the long-term effects of early mobilization different from those of a traditional rehabilitation program? (2) Are the force-elongation and stress–strain relationships of the injured tendon in patients 2 years after surgical repair different from those of the uninjured AT? Based on the literature (Kannus et al., 1997) we hypothesize that previously injured tendons display inferior structural and mechanical properties than uninjured tendons, which constitutes an increased risk for AT re-injury.

2. Materials

2.1. Subjects

The study, conducted according to the provisions of the Declaration of Helsinki, was approved by the ethics and research committee of two Brazilian universities (Protocols 07/04008 and 13202). In order to show a between-rehabilitation groups difference, G* Power 3 software (Kiel University, Germany; effect size = 0.33; significance level = 0.05; required power = 0.80) estimated a sample size of 18 subjects ($n = 9$ per group). Eighteen patients, admitted to the University Hospital for a unilateral AT rupture (ATR) from June 2008 to July 2009, signed an informed consent form prior to participation in the study. An orthopedic surgeon, based on clinical examination (positive Thompson test), established the diagnosis of total acute ATR. Surgical repair occurred within 15 days after injury, and more than 2 years (29 (4.1 months)) prior to the study. In selecting subjects for the ATR group, we excluded patients who suffered from arterial insufficiency, diabetes, autoimmune disease, and patients who used systemic antibiotics or steroids or showed any other clinical contraindication to perform maximum voluntary contractions on a dynamometer.

Nine of the ATR subjects completed a short-term physical therapy (STPT) program, starting 2 weeks after the surgery and lasting 6 weeks, during which a removable brace was used. As at the time of the study there were no well-defined rehabilitation programs available, we decided to aim only at range of motion (ROM) gain in order to avoid possible AT re-rupture. Therefore, therapy sessions, three times per week in the six-week period, included one to two hours of exercises for regaining ROM and muscular endurance (Table 1).

The other nine ATR subjects, who were matched in age and anthropometric measurements to patients in the STPT group, completed a PC immobilization program. After surgery, they were immobilized with the ankle in gravitational equinus; weight bearing was not allowed. Two weeks post-operatively, when the swelling was reduced, the cast was removed and the patient was immobilized in the same position with a new PC. Four weeks post-operatively, the ankle was plastered in neutral position (i.e., with the sole of the foot perpendicular to the shank), and weight bearing was encouraged. Six weeks post-operatively, the PC was removed and the patients received instructions on how to perform a home-exercise program, consisting of active exercises and stretches to improve ankle ROM, and resistance and balance exercises (Table 2). At the time of the study, more than 2 years after the surgery, all patients were fully functional and received no further treatment.

Patients were allocated into groups based on practical considerations. Individuals who lived close to the university and could come to the laboratory on a daily basis were enrolled in the STPT program, whereas individuals who lived in other cities were enrolled into the PC group.

Nine healthy subjects served as controls (CTR). Subjects in the CTR group had no history of lower limb injury and were matched in age and anthropometric measurements (height and body mass) to patients in both STPT and PC groups.

2.2. Experiment outline

In the experimental session, the subjects' body mass, height, and leg length (defined as the distance between popliteal crease and the center of the lateral malleolus) were determined. Both legs were tested in the experimental session. Subjects were asked about the leg they used to kick a ball, which was considered the dominant leg; this way of establishing leg dominance was preferred over asking, for example, about handedness (Elias et al., 1998). After applying surface electromyography (EMG)-electrodes over m. tibialis anterior and several skin markers on the back of the leg, the subject was seated in a dynamometer (Biodex Medical Systems, New York, USA) with the knee fully extended (180°) (Karamanidis and Arampatzis, 2006) and the hip flexed at 85°. The ankle was kept in neutral position (tibia perpendicular to the sole, ankle angle 90°) (Karamanidis and Arampatzis, 2006), the plantar/dorsiflexion axis was aligned with the axis of rotation of the dynamometer, and the foot was firmly fixed to the dynamometer's footplate to prevent the calcaneus from lifting off the footplate. Velcro straps stabilized the thigh and trunk. In this position, we measured (1) AT structural properties using ultrasound while the subject was relaxed, (2) AT elongation using ultrasound during isometric plantar flexion ramp contractions as a function of ankle joint torque, and (3) the relationship between tibialis anterior EMG and dorsiflexion torque, to be used for correction of the ankle torque for an antagonistic dorsiflexion torque of this muscle during the plantar flexion ramp contractions. All ultrasound data were collected using a linear probe (60 mm, 7.5 MHz—Aloka, Tokyo, Japan) connected to an ultrasound system (SSD 4000, 51Hz,Aloka Inc., Japan), and the images were recorded by an external DVD unit (R130/XAZ, 32Hz, Inc. Samsung Seoul, South Korea). A small bag containing conductive gel was used as interface between the probe and the skin for better visualization. From the data collected, we calculated the relationship between AT elongation and AT force, as well as AT Young's modulus. Details of each of these measurements and calculations are provided below. Six subjects (ATR group, $n = 3$; and CTR group, $n = 3$) were measured twice on two separate days to determine test–retest reliability of measures used. The timeline and content of the experimental session are shown in Fig. 1.

2.3. AT structural properties

The AT structural properties, i.e., CSA and TL, were determined while the subject was sitting relaxed. To obtain CSA, the ultrasound probe was placed perpendicular to the tendon and three transverse images were obtained at 2 cm, 4 cm, and 6 cm from the tendon's insertion on the