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ORIGINAL ARTICLE

Early Neuromechanical Outcomes of the Triceps Surae Muscle-Tendon After an Achilles' Tendon Repair

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Abstract

Objectives: To compare the neuromechanical and functional characteristics of the legs of athletes who underwent unilateral Achilles' tendon repair and their controls, and to determine any correlation between the characteristics.

Design: A case-control and cross-sectional study.

Setting: A university institute.

Participants: Male athletes (N=33) were recruited; 23 in the ≥3- and <12-month postsurgical group (median age, 29.8y; age range, 21.9−40.0y) and 10 in the control group (median age, 30.0y; age range, 21.1−39.5y) who had not undergone any surgery.

Intervention: Surgical Achilles' tendon repair in the study group.

Main Outcome Measures: Bilateral measurements of activation strategy involving the triceps surae and tibialis anterior muscles, mechanical properties of the Achilles' tendon, and explosive performance tests were conducted.

Results: Compared with the noninjured legs and the control legs, the repaired legs showed lower normalized rates of electromyographic rise (RER) in the soleus, gastrocnemius medialis, and gastrocnemius lateralis (P ranged between .006 and .001); and less tendon stiffness, greater hysteresis, and less rates of force development (RFD) (P ranged between .006 and <.001). Repaired legs had less ankle dorsiflexion, a shorter 1-leg hopping distance, and lower balance scores ($P \leq .001$). The noninjured legs of the athletes who underwent surgical Achilles' tendon repair had a lower normalized RER (0−50ms) in the soleus and lateral gastrocnemius when compared with the legs of the healthy controls ($P = .011$). The neuromechanical outcomes and explosive performances showed correlations with RFD, 1-leg hopping distance, and balance score.

Conclusions: The athletes who underwent unilateral Achilles' tendon repair demonstrated bilateral neuromechanical deficits within the 1-year postsurgical period.

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Achilles' tendon ruptures are common in ball games.[1] Ruptures of tendinous tissue that connects the muscles under neural control lead to altered neural or mechanical transduction in the muscle-tendon unit.[2,3] Within 1 year of Achilles' tendon repair surgery, young adults show altered soleus muscle activation and antagonist coactivation, as well as increased passive ankle stiffness (Δmoment/Δdegree of dorsiflexion angle) in their repaired legs during walking.[2] Image studies have demonstrated that tendon stiffness was decreased within a follow-up period of 6 to 18 weeks to 1 year after Achilles' tendon repair in recreational athletes. The tendon module of elasticity (strain under defined loading/

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transverse area) was correlated to the heel raise index; that is, the product of the number of heel raises and height is normalized as a percentage of the other side.[3] The healing process after repairs seems to be regulated by a mechanism that tries to obtain optimal tendon stiffness.[3] Collectively, this neuromechanical evidence in the triceps surae muscle-tendon unit within 1 year of Achilles' tendon repair indicates altered neural control and tissue mechanical properties in the region surrounding the ankle joints and suggests slow force production.[4-6] Nonetheless, it was controversial to accept the noninjured legs as references for rehabilitation because these studies were performed without a healthy control group. We hoped to investigate the linkages between these post-surgical neuromechanical alterations and clinical performance deficits in order to improve the rehabilitation of injured athletes. To this end, we have focused on the neuromechanical profiles of the triceps surae muscle-tendon unit and functional assessments in the lower extremities within a period of 1 year after Achilles' tendon repair.

Electromyography, including rates of electromyographic rise (RER), is used to determine the ability for rapid activation of limb muscles.[7] The RER is also a determinant for the rate of force development (RFD).[7] Increases in absolute RFD imply a decrease in the time to develop a specific level of force output. In addition, RER ratios for the tibialis anterior and soleus muscles are used to indicate antagonist coactivation of the plantar flexor and dorsiflexor muscles during the early phase of explosive muscle contractions.[6] The in vivo viscoelastic properties of the tendon-aponeurosis complex including stiffness and mechanical hysteresis are often measured with real-time ultrasonography.[8] Tendon stiffness is determined by tendon elongation over a given force range, and hysteresis refers to the ratio between dissipated and stored elastic energy under a stretch-recoil condition.[9] Stiffness and mechanical hysteresis of tendons are relevant to mechanotransduction and movement efficiency.[10] These parameters are associated with either the balance or fast force capacity that relates to skill fitness.[7,11] A previous study[6] has shown lower strength-independent force development in plantar flexion and concomitantly higher RER ratios between the tibialis anterior and soleus in athletes with middle-portion Achilles' tendinopathy. These sophisticated techniques enable us to investigate profiles of neural control of leg muscles regarding the activation of the agonist-antagonist muscles and tendon mechanical properties involving mechanotransduction and elastic energy utilization in an individual with tendon injuries. However, these techniques were not used to study subjects with an Achilles' tendon repair.

We hypothesize that within the first year of unilateral Achilles' tendon repair in athletes, there are significant differences in the neuromechanical outcomes and explosive performance in repaired legs when compared with contralateral noninjured legs and the legs of healthy control subjects. In addition, neuromechanical outcomes correlate with explosive performance, including torque development, balance, or 1-leg jump length.

List of abbreviations:

M_{max}	maximal M wave
M_{sup}	supramaximal M wave
MVIC	maximal voluntary isometric contraction
RER	rate of electromyographic rise
RFD	rate of force development
RMS	root mean square
SEBT	Star Excursion Balance Test
VISA-A	Victorian Institute of Sports Assessment—Achilles questionnaire

Methods

Participants

This study was approved by the institutional review board of National Taiwan University Hospital (reference no. 201102012RC). All participants provided written informed consent. Four surgical group practices specializing in foot and ankle disorders were invited to join the study, which took place from April 2011 to March 2012. The surgeons primarily used the Kessler suturing technique to repair ruptured Achilles' tendons and recommend a 16-week protocol after the repairs.[12,13] This protocol was supervised and began with a toe motion/leg cast for the first 6 weeks, followed by a standardized weight-bearing, stretching, and strengthening regimen for 3 months.[12,13] After the 16-week protocol, injured athletes are referred to a physical therapist depending on the demands of their sport and level. For this study, male athletes who had experienced unilateral, complete Achilles' tendon ruptures during sports activities within the year before study recruitment were included from outpatient clinics of these surgeons by the researchers. Male athletes were recruited because female hormones influence tendon-aponeurosis strain.[14] The control subjects were matched to the physical characteristics of the study athletes, but had no history of Achilles' tendon pain or injury causing them to seek medical treatment or surgery; they were recruited from the same sports leagues. Sixteen potential control subjects and 28 subjects with unilateral Achilles' tendon repairs met the inclusion criteria and were recruited.

Before measurements were taken, injury histories, pain questionnaires, physical examinations,[15] and ultrasonographic screenings[16,17] with a 5- to 12-MHz broadband linear array transducer[a] were obtained to ensure that subjects met the inclusion criteria and that there was no evidence of Achilles' tendinopathy in the noninjured legs or legs of the controls. The subjects with repaired Achilles' tendons indicated the clinical severity of their Achilles' tendon pain by filling out the Victorian Institute of Sports Assessment—Achilles (VISA-A) questionnaire.[18] Assistance was provided, as needed, to translate the English content of the questionnaire to Mandarin Chinese. Subjects with repairs were excluded if they (1) had the repairs less than 3 months before recruitment; (2) were unable to partake in the measurements because of a subjective fear of rerupture[19]; (3) had delayed surgery (>1wk after injury) or were diagnosed with a sural nerve injury[2]; (4) did not complete the supervised 16-week protocol with a physiotherapist or trainer; or (5) exhibited any positive signs on physical examinations using the techniques of the Royal London Hospital test,[15] or had ultrasonographic evidence indicating intratendinous local hypoechoic swelling or neovascularization[20] in their noninjured contralateral leg. The exclusion criteria for the healthy control subjects were included in the fifth criterion listed for the subjects with repairs. Five potential subjects with unilateral Achilles' tendon repairs were excluded, 3 because of ultrasonographic evidence of tendinopathy in their noninjured control leg and 2 because of delayed surgery. Physical characteristics and VISA-A scores of the 23 subjects with repaired Achilles' tendons (6 badminton players, 3 football players, 3 basketball players, 3 sprinters, 3 volleyball players, 2 tennis players, 2 gymnasts, 1 long jumper) are summarized in table 1.