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Etiologic factors associated with Achilles tendinitis in runners

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Abstract

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Purpose: The purpose of this study was to determine whether relationships exist between selected training, anthropometric, isokinetic muscular strength, and endurance, ground reaction force, and rearfoot movement variables in runners afflicted with Achilles tendinitis.

Methods: Specifically, we examined differences in selected measures between a noninjured cohort of runners (N = 58) and a cohort of injured runners with Achilles tendinitis (N = 31). Isokinetic, kinetic, and kinematic measures were collected using a Cybex II+ isokinetic dynamometer (Medway, MA), AMTI force plate (500 Hz), and Motion Analysis high-speed videography (200 Hz), respectively.

Separate discriminant function analyses were performed on each of the five sets of variables to identify the factors that best discriminate between the injured and control groups.

Results: Years running, training pace, stretching habits (injured runners were less likely to incorporate stretching into their training routine), touchdown angle, plantar flexion peak torque at 180[degrees][middle dot]s-1, and arch index were found to be significant discriminators.

Conclusion: A combined discriminant analysis using the above mentioned significant variables revealed that plantar flexion peak torque, touchdown angle, and years running were the strongest discriminators between runners afflicted with Achilles tendinitis and runners who had no history of overuse injury.

Of the estimated 34 million runners in the United States, two of every three will sustain an overuse injury that may prevent them from running (14,20). Injuries to the Achilles tendon, the most common overuse syndrome of the lower leg (19), account for 5-18% of the total number of running injuries (2,5,6,14).

The Achilles tendon, the thickest, strongest tendon in the body (25), connects the gastrocnemius and soleus muscles, the prime movers of plantar flexion, to the calcaneal tuberosity. The tendon consists of fibers from the gastrocnemius and soleus, with the fibers from each muscle interweaving and twisting as they descend, producing an area of high stress 2-6 cm above the distal tendon insertion (23). The blood supply in this area is decreased, making the tendon vulnerable to injury (19,29).

Pain is the dominant symptom of Achilles tendinitis and is exacerbated by activity. In the early stages of Achilles tendinitis, morning stiffness may be the only symptom, whereas pain is felt even at rest in the advanced stages (25).

There is also a decreased range of ankle motion, swelling, and weakness during activity. In advanced cases, the affected area has a nodular appearance (29).

The underlying mechanism of Achilles tendinitis is not well understood. Current knowledge concerning its etiology in runners is based on surveys (2,10,12) and expert opinion (11). The most prominent hypothesis regarding a possible mechanism for injury asserts that immediately after the foot makes contact with the ground in a supinated position, it pronates, and then supinates as toe-off approaches. The rapid and repeated transitions from pronation to supination cause the Achilles tendon to undergo a "whipping" or "bow-string" action.

Moreover, if the foot remains in a pronated position after knee extension has begun, the lateral tibial rotation at the knee and the medial tibial rotation at the foot results in a "wringing" or twisting action of the tendon (5). The overpronation may be a compensatory factor for a number of anatomical abnormalities, including a cavus foot or a varus alignment of the lower extremity. Running shoes with an inadequate medial heel wedge, running on crowned roads, or uneven or slippery terrain have also been suggested as contributing to compensatory overpronation (4).

The second proposed mechanism involves the eccentric contraction of the triceps surae during support. Smart and coworkers (28) stated "at impact, the calf muscles undergo a rapid shortening, lengthen as the tibia rotates forward over the foot, and shorten again during the forward propulsion phase." These quick muscle action alternations may cause microtears in the tendon. Finally, poor ankle flexibility, excessive training, and hill training were also suggested as etiological factors in the onset of Achilles tendinitis (6,8,23,28).

Prevention of, and treatment of runners afflicted with, Achilles tendinitis is inhibited by the lack of definitive evidence concerning its etiology. Hence, the purpose of this study was to extend our knowledge of running-related injuries by determining whether relationships exist between selected kinematic, kinetic, anthropometric, muscular strength, and endurance, and training variables and runners afflicted with Achilles tendinitis.

METHODS

Subjects.

The subjects for this investigation were recreational and competitive runners who had been running a minimum of 10 miles[middle dot]wk-1 for at least 1 yr. A noninjured control group (N = 58) and an Achilles tendinitis injury group (N = 31) were analyzed. In the Achilles tendinitis injury group, 18 subjects had sustained injuries to their left leg, whereas 13 subjects were injured on their right leg. No subjects were affected bilaterally. The control group consisted of runners who had no history of an overuse injury that had prevented them from running or had caused them to seek medical attention. Achilles tendinitis was defined as inflammation and irritation of the Achilles tendon 2-6 cm above its insertion into the calcaneus. An orthopaedic surgeon diagnosed each subject in the Achilles tendinitis group

Procedures.

To determine eligibility, a series of clinics were held in which the injured runners were diagnosed by an orthopaedic surgeon. Subsequently, noninjured runners and runners afflicted with Achilles tendinitis were evaluated during two testing sessions. In the first session, an informed consent was explained and signed, a runners' history questionnaire was completed, and anthropometric and isokinetic strength measurements were collected. In the second visit, rearfoot motion and kinetic analyses were performed. At the conclusion of this visit, each subject received an explanation of the results and an evaluation by a physical therapist.

Training evaluation.

Each subject was asked to complete a runners' history questionnaire that included information regarding training shoe model, training pace, weekly mileage, years running, training surface, stretching habits, and various other running experiences. Pre- and post-injury data were collected from the injured subjects.

Anthropometric evaluation.

Anthropometric measurements were collected on both legs of each subject. Three trials of each measurement were taken and averaged to yield representative values. An inked footprint, used to evaluate the subject's medial longitudinal arch, was obtained by having the subject place half of his/her weight via one foot on an ink pad. An arch index was calculated by dividing the length of the foot into three equal sections: forefoot, midfoot, and rearfoot and then dividing the area of the midfoot by the total area of the footprint (3).

Q-angle, the angle between a line that connects the anterior superior iliac spine and the midpoint of the patella and a line that connects the tibial tuberosity and the midpoint of the patella, was measured using a goniometer and anatomically placed lines (24).

Ankle flexibility was assessed with the subject in a supine position. The ankle joint was set to a neutral position by placing the subject's foot in a wooden former. Using a goniometer, the angle between the neutral angle and the subject's maximum dorsiflexed position was termed dorsiflexion range of motion, and the angle between the neutral angle and the subject's maximum plantar flexed position was termed plantar flexion range of motion.

Isokinetic evaluation.

A Cybex II+ isokinetic dynamometer was used to determine the strength and endurance of the subject's ankle dorsiflexors and plantar flexors. While in the prone position on the testing table, the subject was secured with straps around the chest and gluteal area. The input axis of the dynamometer was aligned with an imaginary line that would horizontally bisect the distance between the medial and lateral malleoli. An explanation of the test protocol was given to the subject along with a brief warm-up consisting of five repetitions.

The first four repetitions were easy and the last repetition was a maximal effort. Subsequently, the subject was asked to perform seven repetitions at an angular velocity of 60[degrees][middle dot]s-1. The middle five repetitions were used to calculate muscular strength values. The protocol for the muscular endurance test was explained and five warm-up repetitions administered. The subject performed 32 repetitions at an angular velocity of 180[degrees][middle dot]s-1. The middle 30 repetitions were used for subsequent analysis as an indicator of muscular endurance.

To keep testing procedures uniform among subjects, no encouragement was given to the subject during the test. Although subjects were tested bilaterally, the first leg tested was randomized. Torque was defined as the force that the subject exerted at a given distance from the dynamometer axis. Work was the product of this torque and the range of motion through which it was applied, whereas power was the rate at which this work was performed.

Rearfoot motion analysis.

To examine rearfoot movement, a kinematic analysis was performed using a Motion Analysis (Santa Rosa, CA) high-speed video camera (200 Hz). The raw data were smoothed using a fourth-order low-pass Butterworth filter with a cutoff frequency of 10 Hz. Injured runners were tested in the shoes in which they became injured, whereas the control subjects were tested in their regular training shoes. Joint markers were placed on the posterior leg and running shoe heel counters according to the method outlined by Clarke et al. (4).

The video camera was placed 2.5 m from and perpendicular to the subject's posterior aspect. After instrument calibration, the subject walked on the treadmill for 2 min, ran at a slow pace for 3 min, and then ran at his/her training pace for 5 min. Videotaping occurred during the last 30 s of the 5-min run. Subsequently, the camera was then moved directly behind the subject's right leg to compensate for any possible obscuring of the reflective markers. The subject ran at the same pace for an additional 5 min, with videotaping occurring during the final 30 s. Two 50-W lights parallel to the video camera illuminated the reflective markers. Three gait cycles per leg per subject were averaged to yield representative values.

Kinetic evaluation.

To assess ground reaction forces during running, subjects ran on a 22.75-m runway containing an AMTI force platform (500 Hz, Watertown, MA) interfaced with an AMTI six-channel amplifier and an IBM PC microcomputer. Injured runners were tested in the shoes in which they became injured, whereas the control subjects were tested in their regular training shoes. The subject was given time to practice running at his/her training pace on the platform. Running speed was monitored with a photoelectric control system interfaced with a digital timer.

The photoelectric cells were positioned 7.3 m apart, equidistant from either side of the force platform. Each subject ran on the runway at his/her average training pace (+/-3.5%) and attempted to contact the force platform with the designated foot, the order of which was varied to limit any practice effect. Subjects ran until three good trials were obtained. A good trial consisted of running at a predetermined pace without altering gait mechanics. Three trials of each foot were analyzed and averaged to yield representative values. The force variables measured are illustrated in Figure 1.

Statistical analysis.

Bilateral muscular strength and endurance, anthropometric, kinetic, kinematic, and running history data were collected from each subject. The injured side was used for each subject afflicted with Achilles tendinitis, and a random side (with percentages of left to right foot equal to that of the injured group) was chosen for each control subject. The use of the injured leg only was based on the premise that these variables primarily affected the leg of the injured side.

Five discriminant function analyses, each employing a backward elimination variable selection procedure, were performed (13). These analyses were used to select the most important discriminators between injury and control groups separately for muscular strength and endurance, anthropometric, ground reaction force, rearfoot, and training data. The purpose of the preliminary analyses was to identify variables that would be entered into a final discriminant function analysis. Variables significant to the 0.05 level in the final analysis were considered predictors.

RESULTS

Training evaluation.

A Runners' History Questionnaire was used to collect the subjects' training histories. Stretching habits (MAT = 0.89 +/- 0.62; MC = 0.62 +/- 0.06; note: 0 = does stretch regularly, 1 = does not stretch regularly), training pace, and years running (Table 1) were significant discriminators (P

Anthropometric evaluation.

Arch index was the only significant (P P = 0.08) older than the control group.

Muscular strength and endurance analysis.

Dorsiflexion peak torque at 60[degrees][middle dot]s-1 (P = 0.037), dorsiflexion peak torque/body weight ratio at 60[degrees][middle dot]s-1 (P = 0.05), and plantar flexion peak torque at 180[degrees][middle dot]s-1 (P = 0.008) were significant muscular strength discriminators between the injured and control cohorts (Table 3). Flexion/extension work ratio (P = 0.061) and. plantar flexion peak torque/body weight ratio (P = 0.095) were marginally significant discriminators.

The mean values for the strength and endurance measures (180[degrees][middle dot]s-1) are listed in Table 4.

Rearfoot motion analysis.

Maximum pronation (P = 0.004), time to maximum pronation (% stance) (P = 0.008), and calcaneal to vertical touch down angle (P = 0.017) were significant discriminators between the injured and control groups (Table 5). Maximum pronation velocity (P = 0.066) was a marginally significant discriminator.

Kinetic analysis.

There were no significant kinetic discriminators between the Achilles tendinitis and control groups. Peak ground reaction forces tended to be higher in the injured group (Tables 6 and 7). This may have been due, in large part, to the faster training pace of the Achilles tendinitis group.

A combined discriminant analysis using the significant variables from the previous five analyses revealed that plantar flexion peak torque, touchdown angle, and years running were the strongest discriminators between runners afflicted with Achilles tendinitis and runners who had no history of overuse injury. Prediction of individual subjects into their respective groups using a cross validation procedure revealed that these variables were good predictors of the control group (87.2%) but were not good predictors of the Achilles tendinitis group (50.0%).

DISCUSSION

The purpose of this study was to determine if a relationship exists between selected training, isokinetic, anthropometric, kinematic, and kinetic variables and runners afflicted with Achilles tendinitis.

Training variables.

Whether or not a runner incorporated stretching into his/her training routine was a significant discriminator between the injured and uninjured cohorts. Specifically, injured runners were less likely to incorporate stretching into their regular training routines. Jacobs and Berson (10) and Pinshaw and associates (21) have related stretching habits to the incidence of overuse injuries, although Brunet et al. (2) and van Mechelen et al. (31) found no correlation between stretching habits and injuries. Our questionnaire did not assess the quality of the stretches being performed; therefore, the type and effectiveness of the stretches was unknown.

Although a greater percentage of the control group stretched regularly, it is interesting to note that a majority of both groups did not stretch regularly. In spite of the statistically significant difference in stretching between the groups, these data do not provide strong evidence that routine stretching is common in healthy runners.

Injured runners ran at a significantly faster training pace than the uninjured runners. The incidence of overuse injuries has been strongly associated with a faster training pace (10,29). Although not significant, the competition pace of the injured group was faster than the pace of the control group. In accordance with the mechanism of Achilles tendinitis proposed by Hess et al. (8), the triceps surae would undergo quicker muscle tension alternations, lengthening as the tibia rotates over the foot during stance and then shortening during the forward propulsion phase. The Achilles tendon would therefore be more prone to develop microtears as pace increased.

The injured runners had been running for significantly more years than the control group. By definition, an overuse running injury is "the result of accumulated impact loading of the lower extremity" (11). Logic suggests the more years a person has run, the more an abnormality may play a role in an overuse injury. Jacobs and Berson (10) and Messier et al. (17) did not find the number of years run to be a factor in the etiology of overuse injuries. Macera and colleagues (16), however, found that both new runners and, to a lesser extent, seasoned runners were at greater risk for injury relative to the middle group.

The results of this study and our previous work (17,18) would support the concept that new and seasoned runners are more likely to be injured than runners with moderate experience.

Isokinetic variables.

Both Clement and coworkers (6) and Renstrom and Johnson (22) cited muscular insufficiency as a significant factor in overuse injuries. Hess et al. (8) suggested that Achilles tendinitis arises if the gastrocnemius and the soleus are insufficient in eccentrically restraining dorsiflexion during the beginning of the support phase of running. The results of the present study agree with this hypothesis. For all of the plantar flexion variables that were significant discriminators at 60[degrees][middle dot]s-1 and 180[degrees][middle dot]s-1, the control group exhibited greater strength than the Achilles tendinitis group.

For the Achilles tendinitis group, the strength and endurance values were similar on the injured and noninjured legs, suggesting that the strength deficiency was likely present before the manifestation of the injury.

In studies that utilize a relatively large sample size, statistical significance is possible with numerically small differences between groups. For example, the control group in this study had a plantar flexion peak torque that was 4 N[middle dot]m greater than that of the injured group. However, is a 4 N[middle dot]m difference in plantar flexion peak torque clinically relevant? The debate between statistically significant and clinically relevant differences should be considered when interpreting the results.

With the exception of the plantar flexion peak torque variables, none of the endurance variables significantly discriminated between the control and injured subjects. A trend was apparent in which the injured subjects exerted less plantar flexion total work than noninjured subjects did. The injured subjects also tended to have less plantar flexion average power. Taken together, our strength data argue in favor of the hypothesis promoted by Clement and coworkers (6) and Renstrom and Johnson (22) that triceps surae insufficiency is common in injured runners.

Anthropometric variables.

Arch index was the only significant anthropometric discriminator between the cohorts. Although both groups were found to have normal arch characteristics (0.21

Age had a marginal impact on the incidence of Achilles tendinitis. The injured group was approximately 5 yr older than the control group. Although Barry and McGuire (1) found age was a factor in overuse injuries, Brunet and coworkers (2), Gudas (7), Hogan and Cape (9), Janis (12), and Sheehan (27) found no associations between age and the pathogenesis of running injuries. Subotnick (30) proposed that the etiology of most overuse syndromes is biomechanical.

Pinshaw and associates (21) further confirmed the importance of anthropometric factors and muscular strength in the etiology of running injuries. Because the number of years running was a significant discriminator between the groups, we believe that age is secondary to the fact that the injured runners had been running for a longer period of time. It would be interesting to determine whether a runner who began the sport at an older age would be predisposed to injury simply because of age, with no influence of years running.

Rearfoot motion variables.

The most popular hypothesis of the etiology of Achilles tendinitis suggests that the change in direction of rearfoot motion, from a supinated position at heel strike to pronation through midstance, and a final resupination in preparation for toe off, causes the Achilles tendon to undergo a "whipping" or "bowstring" action (5). This process is exaggerated if the runner displays excessive rearfoot movement.

Our data support the conclusions of Clement and coworkers (5). Calcaneus to vertical touch down angle, maximum pronation, time to maximum pronation, and maximum pronation velocity were significant discriminators between the injured group and the control group. More specifically, the injured group was more inverted at touchdown, had more pronation, a shorter time to maximum pronation, and a greater maximum pronation velocity.

Although these results appear to argue strongly in favor of enhanced rearfoot control for runners predisposed to Achilles tendinitis, the differences in mean values between the groups warrants further discussion. The 28% difference in the calcaneus to vertical touchdown angle between the groups suggests that this variable is both statistically and clinically relevant. Similarly, the 8% difference in time to maximum pronation indicates that the timing of subtalar motion may play an important role in Achilles tendinitis. In contrast, statistically significant differences (P

Kinetic variables.

No kinetic variables were found to be significant discriminators between the cohorts. Similarly, no studies in the literature have revealed a relationship between ground reaction forces and the incidence of Achilles tendinitis. Scott and Winter (26) estimated the internal forces of the Achilles tendon were between 6.1 and 8.2 BW. They stated that the impact force at heel contact had no effect on the peak forces placed on the Achilles tendon. It was not surprising, therefore, that we found no significant kinetic discriminators.

SUMMARY

To determine the best discriminators between the control and injured groups, variables that were significant discriminators for each of the training, anthropometric, isokinetic, kinematic, and kinetic analyses were modeled in a backward variable elimination procedure. Years running (P = 0.01), plantar flexion peak torque normalized to body weight at 180[degrees][middle dot]s-1 (P = 0.03), and calcaneus to vertical touch-down angle (P = 0.03) were significant overall predictors of Achilles tendinitis. Training pace (P = 0.08), and stretching habits (P = 0.09) were marginally significant predictors.

Excessive rearfoot motion (5) and gastrocnemius-soleus insufficiency (19,28) are the most common mechanisms believed to precipitate the onset of Achilles tendinitis. Our results tend to support clinical opinion. More specifically, the injured cohort's larger inversion angle at touchdown resulted in a compensatory overpronation and a mistiming of the pronation phase. We speculate that this resulted in an exaggerated torsion of the tendon.

Plantar flexion peak torque normalized to body weight at 180[degrees][middle dot]s-1 was a significant overall discriminator. In general, the injured runners tended to be weaker than the healthy cohort on most of the strength variables.

Clearly, a number of variables contribute to the development of Achilles tendinitis. The combination of variables that identify injured runners may be useful not only in treatment, but in prevention.

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