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Intrinsic Risk Factors for the Development of Achilles Tendon Overuse Injury

A Prospective Study

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Background: Although Achilles tendon overuse injuries occur commonly, our understanding of the pathologic changes and the factors that predispose athletes to them is limited.

Purpose: To identify measurable intrinsic risk factors for Achilles tendon overuse injuries.

Study Design: Cohort study (prognosis); Level of evidence, 2.

Methods: Sixty-nine male officer cadets followed the same 6-week basic military training. Before this training, each subject was evaluated for anthropometrical characteristics, isokinetic ankle muscle strength, ankle joint range of motion, Achilles tendon stiffness, explosive strength, and leisure and sports activity. During military training, Achilles tendon overuse injuries were registered and diagnosed by the same medical doctor. To identify the intrinsic risk factors, a multivariate analysis with the use of stepwise logistic regression was performed. The sensitivity, specificity, and cutoff values of the risk factors were evaluated by receiver operating characteristic curve analysis.

Results: Ten of the 69 male recruits (14.5%) sustained an Achilles tendon overuse injury diagnosed on the basis of medical history and clinical examination. Analysis revealed that male recruits with lower plantar flexor strength and increased dorsiflexion excursion were at a greater risk of Achilles tendon overuse injury. The cutoff value of the plantar flexor strength at 85% sensitivity was 50.0 N·m, with a 4.5% specificity; the cutoff value of the dorsiflexion range of motion at 85% sensitivity was 9.0°, with 24.2% specificity.

Conclusions: The strength of the plantar flexors and amount of dorsiflexion excursion were identified as significant predictors of an Achilles tendon overuse injury. A plantar flexor strength lower than 50.0 N·m and dorsiflexion range of motion higher than 9.0° were possible thresholds for developing an Achilles tendon overuse injury.

Keywords: muscle strength; ankle range of motion; prospective; Achilles tendon overuse injury; military recruits

Overuse injuries of the muscle-tendon unit, resulting from leisure activities, sports, and military training, represent a major problem. They account for approximately 30% to 50% of all sports injuries.[23,25] Of these overuse injuries, Achilles tendon problems are frequent, especially in people who run often.[27] In a cohort study with 11 years of follow-up, Kujala et al[33] reported that 79 (29%) of the 269 male orienteering runners and 7 (4%) of 188 controls reported an Achilles tendon overuse injury on a questionnaire; the age-adjusted odds ratio (OR) was 10.0 in runners compared with controls.

Although Achilles tendon overuse injuries occur commonly, the identification of the factors that predispose athletes to them is minimal. The strength, imbalance, and flexibility of the muscles are frequently mentioned in the literature as possible intrinsic risk factors. However, these proposed factors have been based on the results of retrospective studies or the clinical experience of sports medicine experts.[30,36] Review articles agree that well-devised prospective studies of the possible risk factors for an Achilles tendon overuse injury are lacking. Because no high-quality prospective studies are yet available, the conclusions that

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can be drawn regarding possible intrinsic risk factors are limited.[48]

The purpose of this study was therefore to investigate if some of these proposed intrinsic risk factors contribute to the development of Achilles tendon overuse injuries. To attain this goal, we designed a comprehensive, prospective cohort study in military recruits.

MATERIALS AND METHODS

Study Population

Sixty-nine male officer cadets volunteered for the study; these persons were recruited from the 191 male cadets entering the Belgian Royal Military Academy in August 2003. Ethical approval was obtained from the Ethics Committee of the Belgian Department of Defense. All participants were orally briefed about the methods and aims of the study and gave written informed consent. The age of the subjects was 18.41 ± 1.29 years (mean ± SD). Height and weight measurements were obtained before the training. Body mass index (BMI) was calculated as weight × height^{-2}.

Basic Military Training

All 69 male officer cadets in this study followed the same 6-week basic military training during the same period (August-September 2003). This training mainly consists of running, roadwork, military tactical exercises, drills, shooting, marching with backpacks, and some theoretical classes. Because all recruits followed the same training program with the same equipment, environmental conditions, food, and daily schedule, the extrinsic contributing factors that could affect the incidence of Achilles tendon overuse injuries were kept mainly under control.

Before starting the 6-week training period, each subject completed a questionnaire and underwent the same physical tests (muscle strength, range of motion measurement, stiffness of the Achilles tendon, and explosive strength).

Questionnaire

The questionnaire was intended to assess the subjects' exercise, medical, and injury histories of the past 2 years. It was completed according to guidelines provided by an instructor, who was also present throughout the session. Subjects were briefed on each section of the questionnaire, were asked to answer each question honestly, and were informed that their responses would be kept strictly confidential and would only be seen by one of the study investigators (N.N.M.). This investigator was not related to the Belgian Department of Defense. The questionnaire also included a subjective assessment of the subject's current physical fitness level.[2] To estimate physical activity patterns, the Baecke Questionnaire was used.[2] This inventory quantifies work, sports, and leisure activities using a 5-point scale with descriptors ranging from *never* (1 point) to *always* (5 points). For instance, a sports activity index was calculated as intensity × time engaged and was proportioned according to yearly participation. By adding the scores on the 3 items of the Baecke Questionnaire, the global activity of each subject was calculated. Research has shown that this questionnaire is a valid and reliable tool to measure physical activity.[49,50]

Evaluation of Muscular Strength

Before the beginning of training, each cadet's calf muscle strength was evaluated. The isokinetic performance of the calf muscles was measured with a Cybex Norm dynamometer (Lumex Inc, Ronkonkoma, NY), which was calibrated as part of the regular schedule of equipment maintenance for the testing device.[11] The same investigator (V.S.), who was familiar with isokinetic testing, performed all tests. Plantar flexors and dorsiflexors were concentrically measured at 30 deg/s (3 repetitions) and 120 deg/s (5 repetitions). Before the tests, subjects received instructions about the procedures and were asked to perform a warm-up familiarization exercise of 10 submaximal repetitions at 90 deg/s. All subjects were tested in the standard position for testing ankle kinetic movement according to the guidelines of the Cybex system.[11] For assessment, the subject lay supine with the knee fully extended, and the foot was placed on a footplate and strapped twice for further stabilization. The ankle joint was aligned with the axis of the dynamometer. The reference angle corresponded to the ankle's neutral position (90°). The movement range covered the entire comfortable range of motion of the subject's ankle joint. The other leg was strapped with Velcro® (VELCRO USA Inc, Manchester, NH) to avoid compensatory movements. All testing was conducted with the subject's hands placed on the hips.

Subjects were instructed to give 100% effort and received positive feedback during testing. Between each test, the cadets were allowed to rest for 1 minute. This same protocol was repeated similarly for the other leg. Alternatively, the right leg and the left leg were tested first. The peak torque values of the plantar flexors and the dorsiflexors were used for data analysis.

Range of Motion Measurement

Ankle joint range of motion was measured with a universal goniometer (NV Gymna, Bilzen, Belgium) and by the same investigator (N.N.M.) to provide consistent intrarater reliability. Both ankles were evaluated. For this measurement, the subject was positioned supine with both limbs supported and the foot projected off the end of the table so that the ankle movement was unimpeded. Maximal range of motion was evaluated with the knee in 2 positions, 45° flexed and extended. Measurements taken with the knee in flexion were considered to represent primarily soleus extensibility, whereas the measurements with the knee in extension were considered to be influenced primarily by gastrocnemius extensibility.[55] Care was taken to maintain a neutral calcaneal position during all evaluations. The bony landmarks used for these assessments were defined with the method used by Elveru et al.[15] The proximal arm of the universal goniometer was aligned with the head of the fibula, and the axis of the goniometer was positioned 0.5 cm below the lateral malleolus. The distal arm was aligned parallel to an imaginary line joining the projected point of the heel and the base of the fifth metatarsal. The subject was asked to perform maximal active plantar flexion and dorsiflexion. Consequently, the same measurements were taken passively. These evaluations were found to be valid and reliable[‖]; in the study by Elveru et al,[15] the intraclass correlation coefficient (ICC) values were 0.86 for plantar flexion and 0.90 for dorsiflexion.

Stiffness of the Achilles Tendon

To identify Achilles tendon stiffness, the ultrasonic measurement technique described by Fukashiro et al[18] was used. These researchers determined the elastic properties of the Achilles tendon structures in vivo by observing the lengthening of the tendon and aponeurosis during isometric contractions of the plantar flexors.[18] The test-retest reliability of measuring Achilles tendon stiffness using ultrasonography has been shown to be good (ICC, 0.80-0.82).[40]

Measurement of Torque. A dynamometer (Biodex System 3, Biodex Medical Systems Inc, Shirley, NY) was used to determine torque output during isometric plantar flexion. The subject lay prone on a bench. First, the right ankle was placed in a 90° position (anatomical position) with the knee joint at full extension and the foot securely strapped to a footplate connected to the lever arm of the dynamometer. The standard Biodex ankle unit attachment with Biodex-provided Velcro® straps was used in this study. To maintain ankle joint and dynamometer axis alignment during plantar flexion contraction, the foot was firmly attached to the footplate of the dynamometer with a strap. Before the test, the subjects performed 3 to 5 submaximal contractions to become familiar with the procedure. After warm-up, subjects were instructed to develop an isometric maximal voluntary contraction during 5 seconds. The task was repeated 3 times per subject with a 30-second rest between the trials. Each subject was orally encouraged to exert maximal voluntary effort by contracting as hard as possible. The same protocol was repeated similarly for the left leg. Isometric strength was expressed as peak torque. The force of the tendon was estimated from plantar flexion torque, the physiological cross-sectional area ratio of the medial gastrocnemius to all the plantar flexors, and the moment arm.[32] Consequently, the value of the calculated force was used to determine the stiffness of the Achilles tendon.

Measurement of Tendon Elongation. As described earlier, the method by Fukashiro et al[18] was used to obtain the measurement of tendon elongation. The contractile component activates and the muscle-tendon unit shortens during a concentric activation, but only the muscle belly shortens during an isometric activation. Therefore, an increase in plantar flexion is accompanied by a shortening of the fascicles and lengthening of the tendon and aponeurosis. This process indicates that the muscle fibers produce mechanical work, which was observed in the tendon even in the so-called isometric contraction. During isometric plantar flexion on the Biodex dynamometer in the present study, a real-time ultrasonic apparatus (Sonoline SL-1, Siemens AG, Erlangen, Germany) was used to obtain a longitudinal ultrasonic image of the medial gastrocnemius muscle at 30% of the lower leg (ie, central). An electronic linear array probe with a wave frequency of 7.5 MHz was secured with Velcro® straps to the skin. The ultrasonic images were recorded by a digital camera (Sony Corp, Tokyo, Japan). The tester visually confirmed the echoes from the aponeurosis and the medial gastrocnemius fascicles (Figure 1). The point at which 1 fascicle was attached to the aponeurosis was visualized on the ultrasonic image. This point (x) moved proximally during isometric torque output. The distance traveled by x (Δx) indicated the lengthening of the aponeurosis and therefore also the tendon.[21,32,39,43] The displacement was measured with a multimedia player, Light Alloy 1.D (Softdepia, Nicosia, Cyprus), and the average score of the 3 measurements was used as a representative score for tendon elongation (ELONG). The same examiner (N.N.M.), who was familiar with the method, performed all tests throughout the study. The obtained value, together with the calculated force, was used to compute the stiffness of the Achilles tendon.

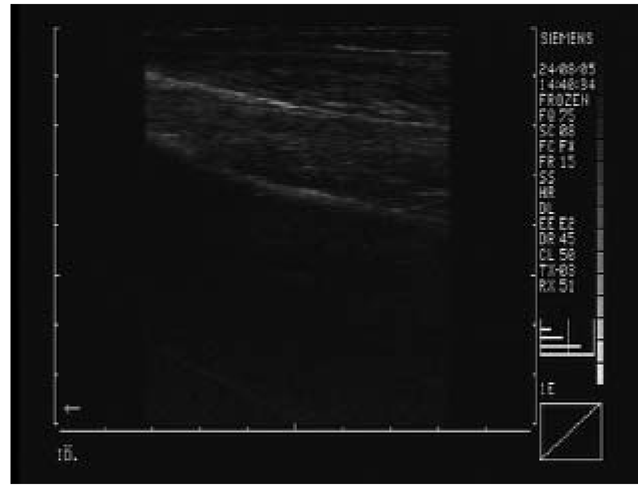

Figure 1. Parallel echoes running diagonally represent the collagen-rich connective tissue between the fascicles of the medial gastrocnemius. The darker areas between the bands of echoes represent the fascicles. The echo that runs longitudinally in the middle is from the aponeurosis.

Calculation of Achilles Tendon Stiffness. The relationship between the supplied muscle force and the elongation of the Achilles tendon was calculated to obtain a measurement of Achilles tendon stiffness. First, the measured torque during maximal isometric plantar flexion, TQ, was converted to muscle force, F_m, by the following equation:

$$F_m = k \times TQ \times MA^{-1},$$

where k is the relative contribution of the physiological cross-sectional area of the medial gastrocnemius within the plantar flexor muscle (18%), and MA is the moment-arm length of the triceps surae muscle at 90° of ankle joint (0.05 m)[19,38,54,65]:

$$F_m = 18/100 \times TQ \times (0.05)^{-1}.$$

‖References 3, 6, 14, 15, 34, 42, 45, 46, 51-53.

The proportion between F_m and ELONG (N/mm) indicates the stiffness of the tendon. In this article, the calculations used were according to Kubo et al.[32]

Explosive Strength

The standing broad jump was used to measure explosive strength. This test was chosen because it represents an explosive type of movement. In addition, it is commonly used in the training and testing of athletes in various sports, and it was found to be highly reliable (ICC, 0.984).[16,28] The standing broad jump correlates well with the other types of explosive movement such as the vertical jump and sprinting.[1,12,61]

The jump required takeoff and landing from a single foot. Takeoff was from behind a line on the floor, and subjects were instructed to land on the same foot they used for takeoff. The distance from the takeoff to the point where the heel touched the mat was measured. The broad jump was executed 3 times for each leg, and the best of the 3 recorded trials was used as the performance score.

Registration of Injuries

During the training, overuse injuries of the Achilles tendon were registered and diagnosed by the same doctor (P.R.) and were listed on separate sheets containing information about the injury. To be considered a patient with an Achilles tendon overuse injury, the following criteria needed to be present: (1) characteristic history and symptoms of an Achilles tendon overuse injury (stages I, II, III, and IV of the injury criteria by Blazina et al[8]), (2) impaired performance, and (3) pain. The combination of Achilles tendon pain and impaired performance indicated the clinical diagnosis of an Achilles tendon overuse injury. Patient history and the moment of onset indicated the overuse nature of the injury. Subjects with an insertional Achilles tendinopathy were excluded from the study. Local tenderness had to be present and was evaluated by palpating the tendon with the ankle in neutral position or slightly plantar flexed. The tendon had to be thickened over a length of 2 to 5 cm. This area may or may not have demonstrated increased warmth, depending on the extent and duration of the overuse injury. Resisted plantar flexion and passive dorsiflexion at the ankle had to worsen the pain, making it difficult for a patient to stand on the toes or to climb stairs. Morning stiffness needed to be present. An injury was only considered if it was serious enough for the subject to seek and obtain medical consultation and if it resulted in 1 or more days of limited duty. To be included in the study, a recruit had to have all of the listed characteristics. Persons with injuries to the skin and subcutaneous tissue, such as abrasions and blisters, were not included. In this study, we were primarily interested in studying first-incidence Achilles tendon overuse injuries. Because previous tendon injury is an important and well-established intrinsic risk factor for musculotendinous injuries, we excluded all recruits who had sustained a muscle injury to the lower extremities in the previous 2 years.[¶]

[¶]References 10, 17, 23, 24, 36, 37, 48, 59, 60.

Statistical Procedures

Statistical analysis was performed with SPSS version 11.0 (SPSS Inc, Chicago, Ill). To examine possible differences between the injured and uninjured groups for each test parameter (interval or ratio data), we used either the Student *t* test (if the distribution of the data was normal) or the Mann-Whitney *U* test (if no normal distribution of the data was obtained). A *P* value less than .05 was considered significant.

Logistic regression analysis was then performed to establish the presence of the major risk factors for Achilles tendon overuse injuries. Bivariate ORs of the variables with 95% confidence intervals (CIs) were calculated for injured and noninjured subjects. The CIs were calculated using $\alpha = .05$, meaning that we had a 95% chance that the true OR was between those 2 boundary marks. Consequently, all variables were entered into a forward stepwise logistic regression analysis. A logistic model for the prediction of an Achilles tendon overuse injury was obtained, with adjusted ORs of the variables with their 95% CIs. The Hosmer and Lemeshow[20] test was used to test the fit of the models.

The sensitivity, specificity, and cutoff values of the obtained risk factors were evaluated by receiver operating characteristic (ROC) curve analysis. These ROC analyses allow an investigator to determine possible cutoff values. A list of specificities and sensitivities for subsequent cutoff values was calculated.[29,41,67] To decide how likely these statistics would be able to detect significant effects in this given sample size, a power analysis was executed for the different variables.

RESULTS

Ten of the 69 male recruits (14.5%) sustained a clinically diagnosed Achilles tendon overuse injury. According to the injury criteria of Blazina et al,[8] 1 subject sustained a stage I, 4 subjects sustained a stage II, 5 subjects developed a stage III, and no one sustained a stage IV (complete rupture of the Achilles tendon) (Table 1). The characteristics of the 10 cadets who sustained an Achilles tendon overuse injury, measured before the start of the military training, were statistically compared with those of the cadets without an Achilles tendon overuse injury.

Anthropometric Evaluation and Physical Activity. Anthropometric data on the subjects are listed in Table 2. No significant differences were found between the injured and uninjured recruits in height, weight, or BMI (*P* = .107, .619, and .083, respectively). In addition, statistical analysis did not reveal any significant difference in physical activity between the injured and uninjured recruits (*P* = .639) (Table 2).

Muscular Strength. Significant differences were found for all plantar force measurements except for one (plantar flexors of the left leg at 120 deg/s; *P* = .128). For all other plantar flexor measurements, the injured group produced significantly less plantar flexor force than the noninjured group

TABLE 1
Classification of Achilles Tendon Overuse Injures[a]

Injury Stage	Criteria	No. of Injured Subjects (n = 10)
I	Pain only after sports activity	1
II	Pain at the beginning of sports activity, disappearing after warm-up and reappearing with fatigue	4
III	Constant pain at rest and during activity; subject unable to participate in sports at previous level	5
IV	Complete rupture of the Achilles tendon	0

[a]According to injury criteria used by Blazina et al.[8]

TABLE 2
Anthropometric Data and Physical Activity Levels for Injured and Uninjured Subjects

	Injured Subjects		Uninjured Subjects			
Variable	Mean	SD	Mean	SD	t^a	P
Age, y	18.00	1.49	18.47	1.26	1.070	.288
Height, cm	177.50	7.85	183.6	6.74	1.635	.107
Weight, kg	72.00	13.60	70.46	8.08	–0.499	.619
Body mass index	22.73	3.00	21.41	2.04	–1.759	.083
Baecke Questionnaire score	8.69	0.64	8.87	1.21	0.472	.639

[a]*t*, the test statistic for the Student *t* test.

before the military training. No statistically significant differences were observed between the groups for the dorsiflexion force measurements ($P > .05$) (Table 3). The statistical power for the plantar flexor strength measurement was .819.

Range of Motion. Table 4 represents the evaluated range of motion data. Statistical analyses of the goniometric measurements revealed no significant differences between the groups. However, a tendency toward significance ($P = .076$) was observed for the right passive dorsiflexion measurement with the knee extended. For this measurement, the injured recruits seemed to have a higher dorsiflexion range of motion in comparison with the uninjured recruits at the start of the military training. The statistical power for the range of motion measurements was .314.

Stiffness of the Achilles Tendon. Results of the analysis performed for Achilles tendon stiffness are presented in Table 5. No significant statistical differences were observed between groups in stiffness for the right and the left Achilles tendons ($P = .117$ and .166, respectively). The statistical power for the stiffness measurement was .781.

Explosive Strength. No statistical differences were found between the injured and uninjured recruits in standing broad jump performance ($P = .863$ and .913, for the right and left leg, respectively) (Table 3). The statistical power for the explosive strength measurement was .069.

Intrinsic Risk Factors. In many fields, the logistic regression model has become the standard method of analysis for studying the relationship between a binary response variable (in our case, presence of an Achilles tendon injury) and one or more explanatory variables (evaluated parameters).[19] To identify the intrinsic risk factors in this study, a multivariate analysis was performed with the use of stepwise logistic regression. Table 6 represents the risk model for the prediction of an injury of the Achilles tendon as a result of a stepwise logistic regression analysis.

The strength of the plantar flexors and amount of dorsiflexion excursion were identified as significant predictors of an Achilles tendon overuse injury. The function of the best fitting model is as follows:

$$g(x) = (-0.009) + [(-0.062) \times (\text{PlanLe30})] + 0.207 \times (\text{PassDor right-straight}),$$

where PlanLe30 is the isokinetic plantar flexor strength of the left leg at 30 deg/s, and PassDor right-straight is passive dorsiflexion range of motion of the right ankle with the knee extended. After logit transformation, the following model predicts the risk of an Achilles tendon overuse injury:

$$\pi(x) = \frac{e^{g(x)}}{1 + e^{g(x)}}.$$

The outcome ranges between 0 and 1 and can therefore be interpreted as a percentage, where 0 represents no risk for

TABLE 3
Isokinetic Muscle Strengths and Jump Performances for Injured and Uninjured Subjects

	Injured Subjects		Uninjured Subjects			
	Mean	SD	Mean	SD	t^a	P
Dorsiflexion strength, N·m						
30 deg/s						
Right leg	22.20	4.18	21.24	4.72	–0.605	.547
Left leg	21.80	6.53	21.44	5.29	–0.192	.848
120 deg/s						
Right leg	11.70	1.57	11.14	3.19	–5.46	.587
Left leg	11.30	2.98	11.66	3.38	0.317	.752
Plantar flexion strength, N·m						
30 deg/s						
Right leg	66.60	12.04	83.42	25.05	2.074	.042[b]
Left leg	69.00	19.10	87.56	26.19	2.141	.036[b]
120 deg/s						
Right leg	33.90	9.46	43.76	13.37	2.232	.029[b]
Left leg	37.80	12.04	45.19	14.30	1.541	.128
SBJ[c] performance, cm						
Right leg	162.00	17.35	163.05	17.79	0.173	.863
Left leg	163.50	17.17	164.15	17.55	0.109	.913

[a] t, the test statistic for the Student t test.
[b] Significant difference between the 2 groups ($P < .05$).
[c] SBJ, standing broad jump.

TABLE 4
Range of Motion Data (in degrees) for Injured and Uninjured Subjects

	Injured Subjects		Uninjured Subjects			
	Mean	SD	Mean	SD	t or U^a	P
Plantar flexion						
45° flexed						
Right active	38.20	5.69	40.81	6.25	$t = 1.237$	.220
Right passive	42.00	6.04	44.47	6.35	$t = 1.147$	.255
Left active	41.20	9.81	40.83	8.13	$t = –0.129$	.898
Left passive	46.20	9.82	45.05	8.09	$t = –0.403$	.688
Extended						
Right active	43.20	6.05	45.05	8.92	$U = 261.00$	.556
Right passive	46.80	5.35	47.83	10.73	$U = 273.50$	.712
Left active	38.20	10.81	41.80	11.48	$U = 207.00$	.131
Left passive	42.00	10.11	45.36	12.16	$U = 215.00$	.171
Dorsiflexion						
45° flexed						
Right active	16.10	4.38	14.68	6.41	$t = –0.674$	.503
Right passive	20.60	5.17	18.03	5.68	$t = –1.338$	.186
Left active	18.40	4.79	15.19	6.02	$t = –1.584$	.118
Left passive	23.40	4.43	20.00	6.59	$t = –1.567$	.122
Extended						
Right active	11.20	4.92	9.69	5.16	$U = 220.50$	.199
Right passive	15.20	5.35	12.95	5.39	$U = 192.00$	.076
Left active	13.00	10.25	12.81	9.67	$U = 291.50$	.953
Left passive	17.60	10.74	16.51	9.91	$U = 276.00$	.744

[a] t, the test statistic for the Student t test; U, the test statistic for the Mann-Whitney U test.

TABLE 5
Stiffness Data (in N/mm) for Injured and Uninjured Limbs

	Injured Limbs (n = 20)		Uninjured Limbs (n = 66)			
	Mean	SD	Mean	SD	t^a	*P*
Right leg	35.69	13.86	47.59	22.85	1.590	.117
Left leg	31.57	8.12	40.20	17.98	1.404	.166

[a] *t*, the test statistic for the Student *t* test.

TABLE 6
Risk Model for the Prediction of an Achilles Tendon Injury Versus No Injury[a]

Predictive Variable	B	SE	OR	95% CI	*P*
PlanLe30, N·m	–0.062	0.025	0.940	0.895-0.987	.014
Pass Dor right-straight, deg	0.207	0.089	1.230	1.033-1.465	.020
Constant	–0.009				

[a] Model obtained by binary logistic regression. B, regression coefficient; SE, standard error; OR, bivariate odds ratio; 95% CI, 95% confidence interval; PlanLe30, isokinetic plantar flexor strength of the left leg at 30 deg/s; Pass Dor right-straight, passive dorsiflexion range of motion of the right ankle with the knee extended.

an injury and 1 the highest possible risk. For example, if a recruit has a plantar flexor strength of 39 N·m and a dorsiflexion range of motion of 9°:

$$g(x) = (-0.009) + [(-0.062) \times (39)] + 0.207 \times (9)$$
$$g(x) = (-0.009) - 0.555$$
$$g(x) = -0.564.$$

After logit transformation,

$$\pi(x) = \frac{e^{-0.564}}{1 + e^{-0.564}} = 0.36.$$

The model predicts that this person has a 36% chance of developing an Achilles tendon overuse injury.

With the help of the ROC analysis, possible cutoff values of the 2 intrinsic risk factors were determined at 85%, 90%, and 95% sensitivities for detecting an Achilles tendon overuse injury. The results of the ROC analysis are presented in Table 7.

The cutoff value of the plantar flexor strength at 85% sensitivity was 50.0 N·m, with a 4.5% specificity. The cutoff value of the dorsiflexion range of motion at 85% sensitivity was 9.0°, with 24.2% specificity.

DISCUSSION

Although Achilles tendon overuse injury is frequently encountered in the sports injury clinic, its risk factors remain obscure. Several authors cite both extrinsic and intrinsic parameters as causing Achilles tendon overuse injuries.[24,36,37,48,60] Various extrinsic risk factors have already been clearly recognized; changes in training patterns, poor technique, previous injuries, footwear, and environmental factors such as training on hard, slippery, or slanting surfaces are extrinsic factors that may predispose the athlete to tendon overuse injury.[24,36,37,48,60] However, the relationship between intrinsic parameters and the occurrence of an Achilles tendon overuse injury is still obscure. Therefore, the purpose of this study was to investigate which intrinsic risk factors play a part in the development of an Achilles tendon overuse injury. To obtain this goal, a prospective study with male military recruits was designed. Because all subjects followed the same training program with the same equipment, environmental conditions, food, and daily schedule, the impact of extrinsic risk factors was kept to a minimum in the design of the present study. This was the reason we investigated a military population.

One of the most striking findings in our study was that the strength of the plantar flexors was identified as a predictor for an Achilles tendon overuse injury, with subjects having a lower plantar flexor strength at greater risk. The cutoff value with the highest specificity can be seen as a possible threshold value. Consequently, persons with a plantar flexor strength lower than 50.0 N·m were predisposed to an Achilles tendon overuse injury. Several previous prospective studies have shown muscle strength or muscle imbalance to be risk factors for an ankle injury.[4,13,57] However, this is the first study that investigates the relationship between the strength of the plantar flexors and an Achilles tendon overuse injury in a prospective manner. The results reflect that persons with a lower plantar flexor strength have a significantly higher risk of developing an Achilles tendon overuse injury. Presumably, greater muscle strength produces stronger tendons that could deal better with high loads.

During basic military training, the muscle-tendon unit is exposed to many stretch-shortening cycles. During these cycles, the muscle-tendon unit must be able to absorb high

TABLE 7
Cutoff Values of the Risk Factors With Respect to Sensitivity and Specificity[a]

Parameter	85% Sensitivity		90% Sensitivity		95% Sensitivity	
	Cutoff	Specificity, %	Cutoff	Specificity, %	Cutoff	Specificity, %
PlanLe30, N·m	50.0	4.5	42	3.0	39	1.5
Pass Dor right-straight, deg	9.0	24.2	7.0	6.1	5.0	3.0

[a]Sensitivity is defined as the proportion of all injured cases that were correctly identified as such; specificity is defined as the proportion of all uninjured cases that were correctly identified as such. PlanLe30, isokinetic plantar flexor strength of the left leg at 30 deg/s; Pass Dor right-straight, passive dorsiflexion range of motion of the right ankle with the knee extended.

forces. A recruit with less plantar flexor strength is less able to absorb these forces and consequently has a higher risk for an overuse injury of the Achilles tendon simply because he has weaker tendons. In that way, it would be interesting to investigate which injury prevention programs would be able to incorporate the structure and mechanical properties of the Achilles tendon. In the literature, the experimental knowledge of the effect of strength training on tendon tissue is scarce, and clinical human studies are lacking. With regard to human tendon structures, available information on the subject is limited to cross-sectional observations.[26,31] Because the power of this parameter reached an acceptable level (.819), we can conclude that the given sample size was large enough to detect a significant effect for plantar flexor strength.

In the present study, greater dorsiflexion excursion has also been identified by the logistic regression analysis as a risk factor for an Achilles tendon overuse injury. Recruits with significantly higher dorsiflexion range of motion have a greater risk of developing an Achilles tendon overuse injury. A possible threshold, defined from the ROC curve analysis, is a dorsiflexion range of motion of 9.0° (with a sensitivity of 85% and a specificity of 24.2%). Surprisingly, the Mann-Whitney *U* test revealed no significant difference between the injured and uninjured groups. However, there was a tendency to significance, which may explain this statistical oddity. Another reason for the parameter being recognized as a risk factor despite the lack of a difference between the groups is the rather low power of the test (.314). This result implies that presumably a larger sample is needed to find significant differences between the injured and uninjured groups for the flexibility measurements.

Recently, Song et al[58] have shown that the severity of a strain injury in the gastrocnemius of rats depends on the excursion of the ankle. These authors observed that the larger the range of motion of the ankle joint, the more damage was seen after an eccentrically induced strain injury. This finding may explain the clinical results in our military population, which suggest that the more an ankle can dorsiflex during stretch-shortening cycles, the more an Achilles tendon is susceptible to an overuse injury.

Looking at the literature, the relation between range of motion and lower extremity injury remains controversial. In a review by Murphy et al,[44] 3 studies reported an association between increased range of motion and lower extremity injury, whereas 4 reported no association. A possible reason for the disagreement in the literature is that these studies investigated lower extremity injuries as a group and did not focus on specific pathologic factors.

The results of this study revealed no significant relationship between any of the anthropometrical characteristics and the occurrence of Achilles tendon overuse injury. Our results are in agreement with a number of studies that have reported no association between body size and injury.[4,5,7,35,47,62,66] For example, Knapik et al[30] did not find height, weight, or BMI to be risk factors for musculoskeletal injuries among male and female military recruits.

In our study, we did not find any relationship between physical activity and the risk of an Achilles tendon injury. In contrast, other prospective studies on lower extremity injuries have shown a relationship between physical fitness and injury incidence.[9,22,27,30,63] Chomiak et al[9] found that poor physical conditioning was a predictor of overall injury in football players. The different results between these previous studies and this one might be explained by the difference in the method that was used to obtain measurements of physical activity. The level of physical activity in our study was determined on the basis of a questionnaire; other studies used physical fitness tests such as run time measurements or VO_2 (oxygen consumption) determinations. In addition, potential candidates for a military career are aware that good physical condition is a prerequisite for a successful military study career. As a consequence, the physical condition of our study population was possibly higher and more homogeneous compared with the population used in other, nonmilitary prospective studies. However, determining the level of physical activity on the basis of a questionnaire can be considered as a weakness of the present study.

In the present study, the stiffness of the Achilles tendon was not seen as an intrinsic risk factor for an Achilles tendon overuse injury. However, the power of this parameter was of an acceptable level (.781). The fact that no significant differences could be found between the injured and uninjured groups was therefore not because of a low power. This finding might be in contrast with the conclusions of previous studies. In a review by Smith,[56] increased stiffness of a tendon has been shown to be a predisposing factor for exercise-related injuries. Because most of the discussed studies were executed retrospectively however, one cannot say with certainty if the altered stiffness of the tendon was a cause or a consequence of the overuse injury.

Knowing that the contribution of the calf muscles and Achilles tendons is rather limited in the performance of the standing broad jump might be a possible explanation to why a significant difference was not found between the injured and uninjured recruits for Achilles tendon stiffness. Previous studies have demonstrated that the glutei, the hamstrings, and the quadriceps muscles determine the greater part of jump performance, more than the calf muscles.[64]

CONCLUSION

Our study identified increased dorsiflexion range of motion and decreased plantar flexion strength as intrinsic risk factors for the development of an Achilles tendon overuse injury. The statistical analyses revealed that recruits with a plantar flexor strength lower than 50.0 N·m and a dorsiflexion range of motion more than 9.0° were predisposed to an Achilles tendon overuse injury during basic military training. When interpreting these results, however, not only the strengths but also the limitations of the study have to be considered. Therefore, we advise investigators to maintain the prospective character of the present study and to include a larger sample and to screen their population as best as they can. Nevertheless, the results of the present study have important clinical implications, and adequate injury prevention strategies need to take the present results into account.

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