Risk Factors for Medial Tibial Stress Syndrome Associated with the Kinetics of the Countermovement Jump in Cadets Undergoing Training

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Abstract

Medial Tibial Stress Syndrome (MTSS) is one of the most-often reported and incapacitating pathologies in military personnel. Given that the muscles of the lower limb conduct an important task in attenuating impact forces when running and landing, deficiency and asymmetries in the neuromuscular function are associated with greater risk of having musculoskeletal injuries (MSI). **Objective:** the work sought to determine the risk factors for MTSS associated with the kinetics of the *countermovement jump* (CMJ) in cadets undergoing training. **Methodology:** a cohort of 164 cadets was monitored prospectively during 24 weeks. Upon starting the research, the study recorded the anthropometric and demographic data of the participants and inquired on some of their life habits and antecedents in using orthopedic material, injuries in lower limbs, and MTSS. Jump height (cm), eccentric deceleration of rate force development (EDRFD

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[N/s*kg]), EDRFD asymmetry (% and %/NV), concentric mean force (CMF [N*kg]), CMF asymmetry (% and %/NV), peak landing force (PLF [N*kg]), and PLF asymmetry (% and %/NV) were assessed through the Bilateral CMJ with a pair of uniaxial force platforms. Upon ending the follow up, it was possible to identify cadets who had MTSS through the clinical history. **Results:** at the end of the study, 91 men and 32 women (n = 123) remained. The MTSS incidence was at 13% (n = 16). Female sex (RR = 2.84; 95% CI = 1.16-6.94), rural origin (RR = 2.65; 95% CI = 1.04-6.72), and MTSS antecedent (RR = 5.71; 95% CI = 2.23-14.62) were associated significantly with MTSS (p ≤0.05). For the EDRFD asymmetry (%/NV), significant differences were found among cadets with and without MTSS (9.4% vs. -3.4%; p = 0.016). In the binary logistic regression, female sex (OR = 4.91; 95% CI = 1.38-13.37), rural origin (OR = 4.82; 95% CI = 1.04-6.72), and EDRFD asymmetry (OR = 1.03; 95% CI = 1.00-1.07) were associated significantly with MTSS (p ≤0.05). The MTSS antecedent was significant in p ≤0.1 (OR = 8.95; 95% CI = 0.68-118.73). The prediction model was significant for MTSS (p ≤0.01), with sensitivity of 31.3% and specificity of 99.1% (global prognosis at 90.2%). **Conclusions:** female sex, rural origin, MTSS antecedent, and large asymmetry in the EDRFD are important risk factors for the development of MTSS. These findings will permit better predicting MTSS in military personnel, being especially useful to classify the risk and implement a primary prevention program aimed at cadets who begin their military training upon entering the ESMIC.

Key words: risk factors, military personnel, medial tibial stress syndrome, biomechanical phenomena, kinetics, countermovement jump

Introduction

Medial Tibial Stress Syndrome (MTSS) is one of the most-often reported and incapacitating pathologies in military personnel (1-5), being the principal cause of pain in the lower part of the leg related with physical exercise (3). Although not of serious nature, if not treated adequately, it can cause injuries, like tibial stress fracture (6). The incidence reported in military personnel for this pathology ranges between 7.2% and 35% (3, 4).

The MTSS is characterized by diffuse pain in the middle third of the posteromedial border of the tibia (1-3, 5, 7), which increases when engaging in physical exercise (7). Although the symptoms are perceived at subcutaneous level between the crural fascia and bone, MTSS is associated with specific bone changes (1). In most cases, this pathology involves cortical bone microfractures (5). The most sensitive way for the clinical diagnosis of MTSS is palpation (2, 7).

During physical exercise, the mechanical stress endured by the tibia provokes microtrauma necessary to construct, strengthen, and adapt the bone; in fact, the tension produced by the muscle during muscle contraction stimulates osteogenesis (3, 4, 6). Nevertheless, exceeding the microtrauma threshold (due to excessive workloads), can lead to injury, like MTSS (3, 4, 6). Bone stress generates overload in bone remodeling (imbalance between bone matrix resorption and synthesis) that results in osteopenia (6, 8). It has been observed that subjects with MTSS have lower bone mineral density (23% ± 8% less) compared with healthy athletes in the zone where the pain is located (9).

The average duration of the rehabilitation treatment for MTSS is three months, even reaching from 4-5 months (10). According to data reported by the *Australian Defense Force Academy*, the time of disability for this pathology is of 57.5 days on average per individual, which translates into costs for the state of AUD $6,410 per case (11). In summary, MTSS – like the rest of musculoskeletal injuries (MSI) – results in a high number of medical encounters (12-16), high costs in medical care and rehabilitation (12, 14, 17, 18), a high loss of work days (14, 16, 19-23), limitation in the physical and operational/tactical preparation (18, 19, 24, 25), diminished military personnel deployed and operational performance during combat situations (13, 25, 26), functional impairment and physical disability (20, 27-29), and a high percentage of premature desertion (30, 31).

According with the most recent systematic reviews with meta-analysis, only 10 risk factors evidenced a significant association with MTSS development: female sex (odds ratio [OR] = 2.35; 95% confidence interval [CI] = 1.58-3.50; $p < 0.05$) (1), increased body mass index (BMI/weighted mean difference [WMD] = 0.79; 95% CI = 0.38-1.20; $p < 0.001$) (4), greater range of motion in the hip external rotation (standardized mean difference [SMD] = 0.44; 95% CI = 0.23-0.65; $p < 0.05$) (1), greater navicular drop

(SMD = 0.44; 95% CI = 0.21-0.67; p <0.05) (1), greater range of motion in the plantar flexion of the ankle (WMD = 5.94°; 95% CI = 3.65-8.24, p <0.001) (4), MSI antecedents (OR = 2.18; 95% CI = 1.00-4.72; p <0.05) and MTSS (relative risk [RR] = 3.74; 95% CI = 1.17-11.91; p =0.03) (1, 8), increased weight (SMD = 0.24; 95% CI = 0.03-0.45; p <0.05) (1), lower experience in athletic practice (SMD = 0.74; 95% CI = 1.26-0.23; p = 0.005) (8), and prior use of orthopedic material (RR = 2.31; 95% CI = 1.56-3.43; p <0.001) (8).

Although some kinematic biomechanical variables have been associated with the MTSS, evidence is limited with respect to kinetic variables. Particularly, the association has not been examined between the kinetic variables implicit in jumping and the MTSS (in athletes, civilian or military population), although some of these have been associated with diverse MSI (32-44).

Jumping is a functional movement (given that it resembles different sports gestures) (45) and permits evaluating easily and cost effectively the neuromuscular function in comparison with other methods (like isokinetic strength tests) (46). Specifically, the *countermovement jump* (CMJ) is a widely used tool to monitor neuromuscular status in military personnel (47). Because the muscles of the lower limb perform an important task in attenuating impact forces when running and landing (48), deficiency and asymmetries in the neuromuscular function are associated with higher risk of having MSI (32, 45, 49-51).

The principal objective of this study was to determine the risk factors for MTSS associated with the CMJ kinetics in cadets undergoing training. The secondary objective sought to establish the actual MTSS incidence in a sample of cadets from the Colombian military population, on which nothing has been reported to date.

Materials and methods

In this observational study (descriptive with analytic component), a cohort of 164 first-semester cadets belonging to Escuela Militar General

José María Córdova (ESMIC-Bogotá, Colombia) was followed up prospectively during 24 weeks. This cohort included subjects from both sexes and from all regions of the country. Although a convenience sample was taken, it included the entire target population at the beginning of the research. All the participants were previously invited to participate voluntarily. During a prior meeting at the start of the protocol, they were explained the objectives, methodology, and all the details of the study, as well as assuring them of the confidentiality of the data.

The exclusion criteria proposed *a priori* for this study were subjects who had not signed the informed consent, had MSI or lower-limb neuropathies, hip dysplasia, or any pathology affecting the physical performance of the cadets during the military training and the CMJ measurements. All the subjects were subjected to a medical revision and to the pertinent clinical tests, according to the criteria of the health professional in charge, to confirm said assumptions. Lastly, the research excluded those with incomplete data (*a posteriori*).

Voluntary withdrawal from the study had no repercussions on the cadets' military career, or on the timely management of the MTSS when it was diagnosed. This research was approved by the Ethics Committee in Social and Exact Sciences (CECSE, for the term in Spanish) at ESMIC, according to act # 4363 REG-AL-FOL-71/02-2018.

Measurements

At the start of the research, age, sex, and origin of the participants was recorded, and they were asked about their physical activity habits, smoking habits, and alcohol consumption habits. This was carried out through the Global Physical Activity Questionnaire (GPAQ) and the Global Adult Tobacco Survey (GATS). Likewise, they were asked about their antecedents in using orthopedic material, lower-limb injuries, and MTSS. Basic anthropometric measurements (height, weight, and BMI) were taken by using calibrated instruments (SECA mBCA 515/514 height rod and Tanita BC-1500 ANT + wireless scale).

The jump height (cm), eccentric deceleration of rate force development (EDRFD [N/s*kg]), EDRFD asymmetry (%), concentric mean force (CMF [N*kg]), CMF asymmetry (%), peak landing force (PLF [N*kg]), and PLF asymmetry (%) were evaluated through the Bilateral CMJ at the base line. Through these variables, the study assessed the neuromuscular function of the lower limb during the different CMJ phases: impulse (EDRFD), rise/take off (CMF) and landing (PLF). Before its execution, the jump technique was explained and the cadets had the opportunity to rehearse it.

During the CMJ, the hands are placed on the waist, a 90° squat is performed and without pausing during the impulse, carry out the rise/take off (vertical jump). Each participant conducted three valid attempts and the average was taken for each of the variables. Thereafter, these were adjusted according to the subject's body weight (N/s or N divided between weight in kg). In case of asymmetries, the absolute value (N/s or N) was taken of the lower limbs separately and the relative difference (percentage) was determined between these (% asymmetry= [right absolute value-left absolute value /highest absolute value]*100).

A pair of uniaxial force platforms (PASCO®) was used, with capacity to measure force vectors > 4,400 N or 1000 Lb. The data obtained were processed through the ForceDekcs® software. It should be highlighted that, for asymmetries, normalized data were obtained (disregarding the dominance of the asymmetry) and negative values (NV), as were designated the values that considered the dominance of the asymmetry (left dominance = negative [-]), with this variable being analyzed in different ways (% and %/NV, respectively).

At the end of the follow up, the study identified cadets with MTSS through the electronic clinical history based on the health information system of the Colombian military forces. The dispensary doctors were in charge of making the clinical diagnosis of the pathology and including such in the Salud.SIS® software.

At the onset of the research, the health professionals were trained to standardize the protocol for the clinical diagnosis of the MTSS. Based on an exploration procedure proposed by Yates et al., the study included the history of the pain (that the pain was induced by engaging in physical exercise and remained for some hours or even days), location of pain (diffuse pain along the posteromedial border of the tibia), performing the palpation test (manifestation of discomfort and pain in the zone mentioned when proceeding with the palpation), and identification of symptoms associated with other MSI (52), like cramps, paresthesia, focal pain, immediate cessation of pain upon ending the practice of physical exercise, among others (common in the tibial stress fracture and the compartment syndrome) (2, 5).

Statistical analysis

The study determined measurements of absolute and relative frequency (categorical variables) and measurements of central tendency and dispersion (continuous variables). For the categorical variables, independence (with respect to the presence of the MTSS) was evaluated through the Chi-squared test and the relative risk (RR). In the case of continuous variables, the difference of means/medians among the groups (with and without MTSS) was determined, which called for the evaluation of the data distribution and the variance homogeneity. Data normality was established with the Kolmogorov-Smirnov test (>50 subjects) and the variance homogeneity with the Levene test. For variables with $p \leq 0.05$ in any of these two assumptions, nonparametric statistics (Mann-Whitney U/difference of medians) was used; on the contrary, parametric statistics (Student's t test for independent samples/difference of means) was used.

The significant variables in the bivariate analysis were used to create a prediction model. This was carried out through a binary logistic regression (multivariate analysis), which determined the significant variables for the MTSS based on $p \leq 0.05$, with their respective OR (exp[B]). The study determined the model's goodness of fit by Hosmer and Lemeshow, Nagelkerke's R squared, sensitivity and specificity, and significance (Omnibus test).

The data were organized in Excel (Microsoft Office 2016) and exported to the *Statistical Package for Social Science* (SPSS version 25.0) software for their statistical analysis.

Results

Of the 164 cadets comprising the initial sample, at the end of the follow up, 91 men and 32 women (n = 123) remained. The MTSS incidence was 13% (n = 16), specifically for the men it was 8.8% (n= 8) and for the women it was 25% (n = 8). The mean age was 18.15 ± 1.17 years. In turn, average weight, height and BMI was 61.8 ± 9.9 kg, 1.71 ± 0.08 m and 21.1 ± 2.9 kg/m^2, respectively. No significant differences were noted for BMI between the groups with and without MTSS (21.3 ± 2.7 vs. 21.1 ± 2.9; p = 0.636).

It was found that sex, origin and MTSS antecedent were associated significantly with the MTSS (Table 1). Women were at greater risk than men of suffering this pathology (RR = 2.84), as well as cadets from rural zones (immediately prior to entering the military training) and who had suffered MTSS in the past in comparison with their counterparts (RR = 2.65 and 5.71, respectively) (Table 1).

Table 1. Relative risk for the MTSS according to demographic and lifestyle variables

	n	**MTSS incidence (%)**	**RR**	**95% CI**	**p-value†**
Sex					0.019**
Male	91	8.8	REF	-	
Female	32	25.0	2.84	1.16-6.94	
Origin					0.044**
Urban	105	10.5	REF	-	
Rural	18	27.8	2.65	1.04-6.72	
Current cigarette consumption					0.698
No	122	13.1	-	-	
Yes	1	0.0	-	-	
Prior cigarette consumption					0.768
No	113	13.3	1.32	0.19-9.03	
Yes	10	10.0	REF	-	

	n	MTSS incidence (%)	RR	95% CI	p-value†
Prior alcohol consumption					0.861
No	9	11.1	REF	-	
Yes	114	13.2	1.18	0.17-7.97	
Alcohol consumption in the last three months					0.77
Never	47	12.8	1.03	0.37-2.88	
1 or 2 times	57	12.3	REF	-	
Monthly	16	12.5	1.01	0.23-4.42	
Weekly	3	33.3	2.71	0.47-15.53	
Current practice of physical exercise or sports					0.593
No	11	18.2	1.45	0.37-5.58	
Yes	112	12.5	REF	-	
Weekly frequency of physical exercise or sports					0.122
≤ 2 days	26	7.7	1.3	0.19-8.67	
3-5 days	63	19.0	3.23	0.76-13.63	
≥6 days	34	5.9	REF	-	
Daily time of physical exercise or sports					0.413
< 1 h	34	14.7	2.35	0.49-11.27	
1-2 h	57	15.8	2.52	0.58-10.98	
> 2 h	32	6.3	REF	-	
Prior use of orthopedic material					0.918
No	116	12.9	REF	-	
Yes	7	14.3	1.1	0.16-7.20	
MTSS antecedent					0.005***
No	120	11.7	REF	-	
Yes	3	66.7	5.71	2.23-14.62	
MSI antecedent in the lower limb					0.593
No	112	12.5	REF	-	
Yes	11	18.2	1.45	0.37-5.58	

** Significance of p ≤0.05; *** Significance of p ≤0.01; † Chi-squared test. Material created by the authors.

Based on the kinetic variables evaluated, only the EDRFD asymmetry (%/NV) was significant when comparing cadets with and without MTSS (Table 2). In individuals with said pathology, right dominance (positive) prevailed for the EDRFD asymmetry unlike healthy subjects (left dominance [negative]) (Table 2). Upon evaluating the risk of having MTSS based on the dominant lower limb, it was found that cadets with right asymmetry for the EDRFD had 2.06 (95% CI = 0.79-5.31; p = 0.125) times greater risk of suffering MTSS than those with left asymmetry.

Table 2. Difference of the groups with and without MTSS for the CMJ kinetic variables

	MTSS (n = 16)		**No MTSS (n = 107)**		**p-value†**
	$\bar{x}$ (SD)	**95% CI**	**$\bar{x}$ (SD)**	**95% CI**	
Jump height (cm)	26.1 (7.4)	22.2-30.1	28.6 (5.8)	27.5-29.7	0.129
EDRFD asymmetry (%)	19.4 (14.5)	11.7-27.1	15.7 (11.0)	13.6-17.8	0.417
EDRFD asymmetry (%/NV)	9.4 (22.8)	-2.8-[21.5]	-3.4 (18.9)	-7.0-[0.3]	0.016**
EDRFD (N/s*kg)	43.8 (11.1)	37.9-49.7	41.4 (15.2)	38.5-44.3	0.314
CMF asymmetry (%)	5.8 (4.0)	3.7-7.9	7.3 (5.4)	6.2-8.3	0.434
CMF asymmetry (%/NV)	1.1 (7.1)	-2.6-[4.9]	-2.3 (8.8)	-4.0-[-0.6]	0.138
CMF (N*kg)	9.7 (1.3)	9.0-10.4	9.3 (1.2)	9.1-9.6	0.636
PLF asymmetry (%)	12.1 (8.6)	7.5-16.7	18.4 (14.4)	15.7-21.2	0.139
PLF asymmetry (%/NV)	0.8 (15.1)	-7.2-[8.9]	3.6 (23.2)	-0.8-[8.1]	0.642
PLF (N*kg)	29.3 (5.6)	26.3-32.3	29.9 (7.8)	28.4-31.4	0.774

** Significance of $p \leq 0.05$; † Student's t or Mann Whitney U tests; EDRFD= eccentric deceleration of rate force development. Material created by the authors.

When analyzing separately the group with right dominance for the EDRFD asymmetry (n = 55), significant differences were found between the groups with and without MTSS (Table 3). Asymmetry for those injured was found above 20%, while for the healthy subjects it was below 15% (Table 3). Cadets with asymmetries ≥ 20% had 2.84 (0.91-8.86; p = 0.061) times greater risk of suffering MTSS than those with asymmetries < 20%.

Table 3. Difference of the groups with and without MTSS based on dominance for the EDRFD asymmetry

	MTSS (n = 10)		No MTSS (n = 45)		p-value†
	x̄ (SD)	95% CI	x̄ (SD)	95% CI	
Right dominance for EDRFD asymmetry (%)	23.0 (14.0)	13.0-33.0	14.7 (9.8)	11.7-17.6	0.029**
	MTSS (n = 6)		**No MTSS (n = 62)**		**p-value†**
	x̄ (SD)	**95% CI**	**x̄ (SD)**	**95% CI**	
Left dominance for EDRFD asymmetry (%)	-13.4 (14.4)	-28.5-[1.8]	-16.5 (11.8)	-19.4-[-13.5]	0.552

** Significance of p ≤0.05; † Student's t test. Material created by the authors.

Of the 10 subjects with MTSS who had right dominance for the EDRFD asymmetry, 20% suffered this pathology in the right lower limb, 20% in the left, and 60% in both legs. Of the six cadets with MTSS who had left asymmetry for the EDRFD, 16.7% suffered this pathology in the left lower limb, 50% in the right, and 33.3% in both legs. These data reveal that MTSS affected in lesser proportion the dominant lower limb against the non-dominant lower limb (18.3% vs. 35%); however, the most common was the bilateral MTSS (46.7%).

The variables included in the logistic regression and which contribute most to predicting MTSS were sex, origin, MTSS antecedent, and EDRFD asymmetry (%/NV). The model was significant for MTSS (p = 0.001), had 31.3% sensitivity and 99.1% specificity (global prognosis of 90.2%), goodness of fit of 0.57 (Hosmer and Lemeshow test), and Nagelkerke's R squared of 0.26.

All the variables incorporated in the model had a significance of p ≤0.05, except for the MTSS antecedent (p ≤0,1) (Table 4). Women were at greater risk than men of suffering this pathology (OR = 4.91), as well as cadets from rural zones (immediately before entering the military training) and who had suffered MTSS in the past compared with their counterparts (OR = 4.82 and 8.95, respectively) (Table 4). Similarly, a 1% increase in the EDRFD asymmetry (right) increases the risk of enduring MTSS (OR = 1.03) (Table 4).

Table 4. Risk factors associated with the MTSS in the multivariate prediction model

	B (coefficient)	Standard error	Wald	p-value	OR (Exp[B])	95% CI
Sex	1.590	0.65	6.08	0.014**	4.91	1.38-13.37
Origin	1.572	0.69	5.18	0.023**	4.82	1.24-18.66
MTSS antecedent	2.192	1.32	2.76	0.097*	8.95	0.68-118.73
EDRFD asymmetry (%/NV)	0.034	0.02	4.49	0.034**	1.03	1.00-1.07
Constant	-3.037	0.53	32.57	0.000	0.05	

* Significance of $p \leq 0.1$; ** Significance of $p \leq 0.05$. Material created by the authors.

Discussion

The MTSS is one of the MSI of higher incidence in military personnel (3, 4). This pathology impacts negatively on the military career of the cadets, their short- and long-term health, and the health costs of the military institutions (11, 12, 14, 25, 27, 30). Numerous risk factors have been related with MTSS (1, 4, 8); however, the kinetic variables implicit in jumping have not been associated with this pathology unlike other MSI (32, 45, 51). This study focused on determining the risk factors for MTSS associated with the CMJ kinetics in cadets undergoing training.

The findings show that the BMI is not associated significantly with the MTSS in this study, contrary to that observed in other research. Two systematic reviews with meta-analysis found that increased BMI is associated significantly with MTSS (WMD = 0.79, 95% CI = 0.38-1.20, p

<0.001; SMD = 0.24, 95% CI = 0.08-0.41, p = 0.003) (4, 8). Moreover, research conducted in the German army found significant differences for BMI between the groups with and without MTSS (p = 0.04), but when this variable was examined in the multivariate analysis, it was not significant (p = 0.3) (53). In a prediction model developed by Garnock et al., the BMI was not significant for MTSS in navy recruits (11). Yates and White also found no significant differences for the BMI between the groups with and without MTSS (p = 0.917) in a sample of Australian navy recruits (52). Another two studies evidenced that the BMI is not associated significantly with the pathology reported in the military personnel (p >0.05) (54, 55). One of the reasons for the differences found is that the systematic reviews with meta-analysis showed heterogeneity in the samples evaluated (athletes, civilian or military population).

Plisky et al., indicated that subjects with a BMI ≥ 20.2 had 5.3 times greater risk of suffering MTSS than their counterparts (p <0.05); nevertheless, said study was conducted in a population of *runners* with a mean age of 16.0 ± 1.0 years (56). In turn, Grier et al., found that subjects with a BMI ≥ 25 and ≥ 30 had 1.77- and 2.72-times greater risk of suffering MSI in a combat brigade in comparison with those with a BMI < 25 (p <0.01) (57). Although the previous study did not discriminate directly the MTSS, another explanation for the results obtained in this research is that the average BMI in the cadets with or without MTSS was < 25.

In spite of the increased BMI being a risk factor for MTSS – given that it represents a greater load on bone system in the lower limbs (4, 8), in the military personnel the evidence is not clear. Considering that the BMI has important limitations because it does not permit discriminating the distribution of fat and lean mass (58), it is indispensable to use different tools to assess body composition.

This is the first study relating origin (rural and urban) with MTSS. One of the possible explanations for the results found is the socioeconomic status. In Colombia, the National Administrative Department of Statistics (DANE, for the term in Spanish) indicated higher monetary and multidimensional poverty in the country's rural zones (59). A study carried out with Tunisian adolescents evidenced that those with low socioeconomic status had significantly lower results in the CMJ height and power compared with those with higher socioeconomic status ($p < 0.01$) (60). Said same research also found that poorer subjects had lower lean mass unlike their counterparts ($p < 0.05$) (60). El Hage et al., found that the hip BMD (Bone Mineral Density) was correlated positively with the performance of the vertical jump ($r = 0.78$, $p < 0.01$) and longitudinal jump ($r = 0.67$, $p < 0.05$) (61). Although many hypotheses exist regarding the results obtained, further research is needed to interpret the association between rural origin and MTSS.

Female sex and MTSS antecedent were also associated significantly with the MTSS, agreeing with existing evidence. Two systematic reviews with meta-analysis demonstrated that female sex is associated significantly with the MTSS (OR = 2.35, 95% CI = 1.58-3.50, $p < 0.05$; RR = 1.71, 95% CI = 1.15–2.54, $p = 0.008$) (1, 8). Likewise, a systematic review with meta-analysis found that the MTSS antecedent se associated significantly with this pathology (RR= 3,74, 95% CI= 1,17-11,91, p= 0.03) (8).

Women are more prone to suffering diverse MSI in the lower limbs in comparison with men, due to important anatomical, hormonal, and biomechanical differences (8, 62, 63). The most important of these include increased Q angle/width of pelvis, decreased intercondylar notch of the femur, increased articular laxity, increased flexibility of the hamstrings, increased anterior translation of the tibia, increased pronation of the foot and navicular drop, effects of estrogens in the neuromuscular control and function, decreased H:Q ratio (hamstrings/quadriceps), the magnitude and altered timing of muscle activation, decreased proprioception, imbalance of the medial-lateral muscle contraction patterns of the quadriceps, and greater dynamic knee valgus among others (62).

Different studies have also shown that women had lower physical condition, unlike their counterparts (19, 20, 64). This makes them more vulnerable to suffering any type of injury within the military context, where requirements are equal for men and women. In the case of the MTSS antecedent, it is felt that subjects injured again have had incomplete bone healing; however, the hypothesis also exists that after the first episode there is loss of BMD for up to eight years (8).

From the biomechanical analysis, it was found that jump height is one of the variables most associated with diverse MSI. A study conducted on professional soccer players found that greater height in the *squat jump* was associated significantly with greater risk of suffering any type of hamstring injury (OR = 1.47; 95% CI = 1.02-2.12; p ≤0.05) (33). Research by Gómez-Piqueras et al., also with professional soccer players, reported significant differences in the CMJ height (during the preseason) between injured subjects and those not injured (p ≤0.05), being lower in healthy soccer players (35.56 ± 3.94 vs. 40.43 ± 4.42) (36). Contrary to the aforementioned, Iguchi et al., found that a height ≤ 66 cm (in contrast with > 66 cm) in the *vertical jump* was related significantly with greater risk of suffering hamstring strain (HR = 0.15; 95% CI = 0.03-0.74; p ≤0.05) (34). Orr et al., evidenced that subjects who reached a height between 30 and 34 cm in the *vertical jump*, in contrast with those who reached a height ≥ 55 cm, had 2.12 (95% CI = 1.07-4.20) times greater risk of suffering diverse MSI (p ≤0.05) (35).

Although the EDRFD, CMF, and PLF have less evidence than the jump height, existing studies have been determinant for the development of this analysis. Hewett et al., found that women athletes with rupture of the anterior cruciate ligament (ACL) had – at the start of the follow up – a 20% increase in the vertical ground reaction force (vGRF) during landing in the *drop jump* (DJ) test, compared with those not injured (p ≤0.05) (32). A systematic review with meta-analysis reported no differences in the vGRF (during the impact and propulsion phases) between subjects with antecedents of stress fracture (tibial and metatarsal) and those with no such antecedents, however, the load rate in the vertical ground reaction force (LRvGRF) during landing was significantly higher in the injured population (p ≤0.01) (37). Powell et al., found that subjects with prior Achilles tendon rupture exhibited higher LRvGRF during the landing phase in the *drop countermove-*

ment jump ($p \leq 0.01$), unlike their counterparts (38). Research conducted with volleyball players reported that subjects with antecedents of patellar tendinopathy (in contrast without such) had a higher knee moment development rate (KMDR) during the eccentric phases (during impulse and landing) during the *spike jump* ($p \leq 0.05$) (39). Another study by Bisseling et al., reported that subjects with prior patellar tendinopathy had higher LRvGRF in the DJ during landing, in comparison with individuals without this condition ($p \leq 0.01$), however, no significant differences were found in the peak vGRF (40).

In contrast, another research evidenced that subjects with ACL reconstruction had lower LRvGRF during landing and takeoff in the DJ, in contrast with healthy individuals ($p \leq 0.05$) (41). A cases and controls study found that injured basketball players had significantly lower eccentric activity in the *jump-shot* during landing in comparison with those not injured ($p \leq 0.01$) (42). Research conducted on subjects with patellar tendinopathy reported that those with complete recovery of their injury (score >80 in the *Victorian Institute of Sport Assessment* [VISA]) had significantly higher values in the LRvGRF ($p \leq 0.01$) and the RMDK ($p \leq 0.05$) in the DJ during landing than their counterparts (40). One of the hypotheses for the results found in these studies is that subjects with recent lesions (or which were not treated adequately) develop a protection mechanism on the affected lower limb, thus, having a lower LRvGRF (39). Unfortunately, the studies examined did not evaluate lower-limb asymmetries in injured individuals.

Considering the findings presented, it is believed that greater LRvGRF (during any of the jump phases) in subjects with injury antecedents may be contraindicated if the tissue affected has not had adequate rehabilitation. If so, this would represent greater load during a shorter period of time on tissue that has not recovered completely (43). Likewise, it is presumed that a lower LRvGRF (in any of the jumping phases) manifests a greater risk of injury (in healthy subjects or who have MSI antecedents), given that the muscle's responsiveness to a motor stimulus is diminished. Greater load rate (LR, also known as rate of force development [RFD]) is translated into the capacity to decelerate more rapidly during the impulse phase by activating the quadriceps and, thus, obtaining increased muscle strength and power during the concentric contraction (65, 66). During landing, greater LR will permit maintaining equilibrium and knee stability, and attenuating the impact forces (energy absorption) through the deceleration of the lower limb (39, 42, 67).

Evidence regarding the kinetic variables and risk of suffering MSI seems contradictory; nevertheless, the findings are reasonable because the studies cited analyzed different MSI and were conducted on diverse populations. Moreover, these were conducted during different moments after the injury. Merely two longitudinal studies found that increased vGRF and diminished eccentric activity during landing are associated significantly with different MSI (32, 42).

Jump height, EDRFD, CMF, and PLF are not associated significantly with the MTSS in this study. Compensatory strategies (in injured subjects), which take place through the different muscle groups of the lower limb, may be the cause for the findings reported. This was denoted in a study by Siegmund et al., in basketball players with patellar tendinopathy (68). Nonetheless, further research is warranted to elucidate this hypothesis.

The CMF and PLF asymmetry (disregarding dominance [%]) were not associated significantly with the MTSS in this research. It is believed that these results are due the average asymmetry for the variables mentioned being < 15%, which is the reference clinical value to evaluate the risk of injury and the return to sports activity in the case of athletes who have suffered MSI (43-45, 69, 70). For the EDRFD asymmetry (%),individuals with MTSS had values > 15%, but were not significant with respect to healthy subjects.

Bearing in mind the asymmetry dominance (%/NV), the EDRFD was the only variable associated significantly with the MTSS. Upon analyzing the results, it was possible to denote that in the subjects with MTSS, the right dominance prevailed for the EDRFD – in contrast with individuals not injured (left dominance prevailed), becoming a factor de risk for developing this pathology, presenting right dominance for the variable mentioned. A study indicated that right-handed people have greater have greater hemispheric asymmetry on the cortical surface (of the sensory cortex) and activation of primary motor cortices, in comparison with left-handed people (71). It is presumed that said cerebral asymmetries are directly related with the motor asymmetries of the lower limb, with right-handed subjects being the most vulnerable to suffering diverse MSI. Given that it was not the objective of this study, it is necessary for this hypothesis to be analyzed carefully and be an incentive to carry out new research.

A secondary analysis examined the group of cadets with right and left dominance separately to clarify this phenomenon. The group with left dominance for the EDRFD showed no significant differences between subjects with and without MTSS, finding the group of those injured below 15%. In the group with right dominance for the EDRFD, the injured cadets had a significantly higher asymmetry percentage than the healthy cadets (23.0% ± 14.0% vs. 14.7% ± 9.8%; $p = 0.029$). Subjects with MTSS exhibited asymmetry > 15% (reaching above 20%), while individuals not injured were below this value. These data agree with the clinical reference point reported in the literature and with results from other research.

Paterno et al., found that a group of athletes with ACL reconstruction had 37% asymmetry, in contrast with a group of healthy athletes, which exhibited 7.7% asymmetry for the LRvGRF during landing in the DJ (43). The injured lower limb had a lower LRvGRF, in comparison with that not injured ($p \leq 0.01$) (43). In another study, a group of subjects with acute ankle sprain exhibited asymmetry of 15.02% ± 13.09%, while the control group had asymmetry of 5.76% ± 4.16% for the RFD during phase 1 (rise/takeoff) of the DJ ($p = 0.001$) (44). During phase 2 (landing), injured people also exhibited asymmetry significantly greater than their counterparts for the variable indicated (10.62% ± 8.64% vs. 4.35% ± 3.49%; $p = 0.001$) (44). During both phases, a lower RFD was observed in the injured lower limb, in comparison with that of the controls, however, this difference was only significant during phase 2 ($p = 0.01$) (44). These studies support the idea that asymmetries above 15% for the EDRFD are associated with higher risk of suffering MTSS.

According with the research cited herein, it is observed that the dominant leg in jumping for the variables reported was the uninjured leg. Although the results cannot be comparable due to the type of study, population, and type of injury examined, in the present research the cadets mostly injured the non-dominant lower limb (35%) in contrast with the dominant (18.3%), based on the EDRFD. One of the hypotheses employed for the results obtained is that the injured non-dominant leg has a diminished neuromuscular function that influences negatively on the capacity to quickly decelerate during the impulse and landing phases, affecting the achievement of greater muscle strength and power, and attenuation of the impact forces when running and jumping, among others (39, 42, 65-67). Furthermore, it is believed that the injuries that occurred in the dominant lower limb are due to the overload exerted on the musculoskeletal tissue by deploying a force stimulus rapidly and repeatedly. This is especially common in cadets, who undergo an abrupt change of life (26, 72), where they are exposed to great training volume and intensity, and sudden increases in any of these two aspects (73).

From sex, origin, MTSS antecedent, and the EDRFD asymmetry (%/NV), a prediction model was proposed for the MTSS, which had 31.3% sensitivity and 99.1% ($p = 0.001$) specificity. The model proposed in this study is quite similar to that developed by Garnock et al., for the MTSS (11). Said model included sex, MTSS antecedent, and hip external rotation ($p < 0.001$) and had 82% sensitivity 82% and 84% specificity (11). It is expected that future research can study diverse biomechanical variables (kinetic and kinematic), which permit creating a more-robust prediction model for the MTSS.

The principal strength of this study is that it is the first to analyze the association of diverse kinetic variables implicit in the CMJ with the MTSS. Unlike most cross-sectional investigations and which were conducted after the injury, this was a prospective longitudinal study. The design of the present study permitted establishing the principal risk factors associated with the MTSS, prior to starting the military training of the cadets. Bearing this in mind, a significant prediction model was obtained for the MTSS, which will serve to identify subjects at greater risk of suffering this pathology upon entering the ESMIC. This Will permit creating a primary prevention program for said population. Another strength of this study was that it took a representative sample of the population at greater risk of having MTSS and the controlled conditions in which the cadets were found, given that during the follow-up period all the subjects were exposed to similar feeding, training, and resting conditions among others.

The most important limitations were the short follow-up period, high percentage of sample loss, and not having examined other biomechanical variables. As perspectives, it is expected for future research to measure different kinetic and kinematic variables, through tools, like 3D movement analysis, linear dynamometry (linear encoder) and isokinetic tools (isokinetic force machines), among others. The aforementioned to obtain broader knowledge about the biomechanical risk factors (kinetic and kinematic) that can impact on the development of MTSS.

Conclusions

Based on the prediction model proposed, it was found that female sex, rural origin, MTSS antecedent, and greater EDRFD asymmetry are important risk factors for the development of MTSS. These findings will permit better prediction of the MTSS in military personnel, being especially useful to classify the risk in cadets starting their military training. Given that sex, origin, and MTSS antecedent are non-modifiable risk factors, a large EDRFD asymmetry becomes a fundamental element to treat to reduce the risk in a physical training program when entering the ESMIC.

These results may also be potentially beneficial for any type of population exposed frequently to this pathology (like, for example, athletes). Because the results found herein are only recently being described in the literature, it is necessary to conduct new research to elucidate the role of kinetic variables implicit in jumping on developing the MTSS. Likewise, it is necessary to contemplate the evaluation of different variables (biomechanical, anthropometric, sociodemographic, among others) for the MTSS to be analyzed in multifactorial manner, arriving at the creation of a more-robust prediction model than that introduced in this study.

Conflict of interests

The authors declare no conflict of interests in this research.

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