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ORIGINAL ARTICLE

Observational Study

Normative values of ankle strength and its importance for rehabilitation and return to activity: A cross-sectional study

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Abstract

BACKGROUND

Ankle normative values are limited compared to isokinetic knee assessments. Chronic ankle instability correlates with agonist-antagonist imbalances, decreased evertor/invertor ratio, and plantar flexion deficits. Strengthening programs targeting evertor/invertor and dorsiflexor/plantar flexor balance help reduce injury recurrence. Bilateral neuromuscular deficits compromise the contralateral side, rendering healthy limbs unsuitable as recovery references. Defining normative healthy ankle parameters is crucial for establishing precise limits in non-surgical treatments and sports return criteria. While the limb symmetry index (LSI) is used for knees with a cutoff of > 90%, no such standardization exists for the ankle.

AIM
To comprehensively evaluate isokinetic ankle strength profiles in non-athletic individuals.

METHODS
This is a cross-sectional study. Two hundred ankles were evaluated using the Biodex 3 System to assess eversion, inversion, dorsiflexion, and plantar flexion. Healthy individuals with an active lifestyle and no previous injuries were evaluated. The Maximum Torque, Agonist/Antagonist Ratio, LSI, and Muscular Deficiency Index (MDI) and the correlation with demographic variables were evaluated.

RESULTS
The mean age (mean ± SD) was 38.5 ± 13.5 years, and the body mass index (BMI) was 25.8 ± 4.2 in 69 men and 31 women. The mean maximum torque values by gender were (mean ± SD): 22.3 ± 6.6 female (F) and 33.4 ± 9.9 male (M) N/m for eversion; 30.10 ± 10.0 (F) and 37.0 ± 11.6 N/m (M) for inversion, 37.4 ± 10.0 (F) and 53.6 ± 13.0 N/m (M) for dorsiflexion, and 100.4 ± 37.2 (F) and 158.1 ± 33.4 (M) N/m for flexion. There was no correlation between age or BMI and maximum torque. The evertors/invertors ratio was 88.8%, and the dorsiflexors/plantar flexors ratio was 36.1%. The MDI and LSI were balanced between sides for every movement, having an average global difference of less than 10%.

CONCLUSION
These findings provide gender-specific normative isokinetic values for the ankle in healthy, physically active adults. These reference parameters—especially LSI and MDI above 90%—can support clinical decision-making in rehabilitation planning and return-to-sport assessment, offering objective benchmarks for functional recovery.

Key Words: Ankle ligament injuries; Ankle tendinopathies; Isokinetics; Dynamometry; Isokinetic strength

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Core Tip: Normative isokinetic strength values for non-athletic ankles serve as essential benchmarks for guiding rehabilitation and return-to-sport criteria. The findings reveal notable gender-based differences in maximum torque values, while showing no significant correlation with age or body mass index. Balanced Limb Symmetry Index and Muscular Deficiency Index across movements highlight the importance of standardization. These outcomes offer a robust framework for refining non-surgical treatments, developing targeted strength restoration programs, and reducing the risk of recurring injuries.

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INTRODUCTION

In 1967, Hislop and Perrine introduced the first concept of isokinetic dynamometry[1]. Currently, dynamometers are widely used to measure muscle function and are the "gold standard" for limb strength tests[2,3]. They help evaluate post-surgical or post-rehabilitation performance using objective criteria for returning to regular sports activity.

Although the literature addresses isokinetic knee assessments, ankle normative values are scarce[4]. In 2002, Willems *et al*[5] demonstrated that chronic ankle instability was associated with an imbalance between agonists and antagonists and decreased strength ratio between evertor and invertor muscles (EV/INV). This was later substantiated by Terrier *et al*[6] through a relationship between lateral ankle instability and weakness of the evertor musculature. Previous studies demonstrated peak torque deficits of the invertor musculature significantly higher than those of the evertors and also for average power at both test velocities (30°/s and 120°/s)[7]. These authors suggested restoring a normal evertor/invertor strength ratio through an isokinetic ankle strengthening program[7]. In 2007, Hubbard *et al*[8] verified that chronic ankle instability was related to plantar flexion strength loss, increasing the dorsiflexor/plantar flexor (DF/FP) ratio, which was reconfirmed in a subsequent meta-analysis[9]. Recently, restoring the EV/INV and DF/FP balance prevents sprain relapses and should be one of the goals during rehabilitation[10,11]. Therefore, conflicting data have been reported due to an absence of ankle data standardization.

Moreover, studies examining the balance of the peroneal and invertor muscles in the context of ankle stability, both for chronically unstable and stable joints, are absent from the literature. Amid this evidence, and to prevent injury recurrences, it is suggested that the restoration of dorsiflexor/plantar flexor and evertor/invertor muscle functions should be optimized[10,11]. However, without clearly defined normative parameters for a healthy ankle, it is challenging to recommend any criteria for return to sport[12]. Furthermore, evidence suggests that bilateral neuromuscular deficits

from chronic injuries[3,13] could compromise the contralateral side. Therefore, resorting only to the supposedly healthy side as a reference for post-injury recovery should be avoided. In addition, by understanding healthy leg musculature under isokinetic evaluation, precise limits could be established for deciding on non-surgical treatment for orthopedic injuries. The limb symmetry index (LSI) for knee joints is adapted for return to sport if values are above 90%[13]. However, little is known about ankle LSI using a comparative interval (< or ≥ 90%).

Therefore, our objective was to characterize ankle motor performance during isokinetic assessment, involving: (1) Torque strength; and (2) Agonist/antagonist balance, to achieve normative values for the studied population.

MATERIALS AND METHODS

In this study, a physiotherapist and an orthopedist evaluated the participants using the Biodex III machine (Biodex Medical Systems, Inc.; NY, United States) at the Sports Traumatology Center/Federal University of São Paulo. The study protocol was approved by the ethics committee of the Federal University of São Paulo (number 3.696.560).

All participants were asked to read and sign an informed consent form, and the methods were performed according to the relevant guidelines and regulations. For proper and safe positioning on the machine, participants were seated and secured with straps to stabilize the trunk and hips. The ipsilateral knee remained at 20° of plantar flexion, so the leg remained parallel to the ground, on padded support, and was secured with a Velcro strap. The foot was fixed to the platform in a plantigrade position, using the same straps to allow free ankle movement in all directions (Figure 1)[14].

The sample consisted of 200 ankles (100 patients). The inclusion criteria were individuals aged between 20 and 60 years, with an active lifestyle, independent, practicing physical activity on a regular or recreational basis (defined as engaging in structured exercise or recreational sports at least three times per week), and with no complaints in the lower limbs or reported back pain. The exclusion criteria were unhealthy individuals with uncompensated systemic co-morbidities (*e.g.*, congestive heart failure, severe COPD, requiring non-surgical, or surgical treatment, such as tendon ruptures, ligament injuries, tendinopathies, or fractures and spinal pathologies with neurological signs or symptoms).

The parameters evaluated followed widespread protocols in the literature, namely Peak Torque at 30°/s (N/m – 5 repetitions), maximum power at 120°/s (W – 10 repetitions), Agonist/Antagonist Ratio for the Torque variable involving the dorsiflexion/plantar flexion and eversion/inversion movements and the Muscular Deficiency Index (MDI)[11,15,16]. This index refers to the overall balance of one limb relative the other for each of the four movements. In contrast, the Agonist/Antagonist ratio analyzes the balance of muscle groups in the same limb. MDI is calculated for each movement (dorsiflexion, flexion, inversion, and eversion) and is the sum of the differences between sides for the Peak Torque, Power, and Work parameters, divided by 3, thus establishing a single value for this deficit. The value represents the average impairment of the studied limb compared to the contralateral side. They are essential for returning to activities or sports, unlike evaluating only torque strength[17]. Lower-limb dominance was operationally defined by the participant's preferred leg for kicking a ball, a standard approach in isokinetic studies[15].

Statistical analysis

The normality of the quantitative data was verified with the Shapiro-Wilk test. Descriptive statistics involved mean and standard deviation, median values, and quartiles 1 and 3. Categorical variables were presented in absolute and relative frequencies, using the χ^2 test to verify associations. The Wilcoxon test was used to compare the dominant and non-dominant sides of the measured variables. The Friedman test was used for the Muscle Deficiency Index to compare the four movements (Eversion, Inversion, Dorsiflexion, and Plantar Flexion).

For the covariates involving gender and non-dominant side in relation to the Muscle Deficiency Index, the Mann-Whitney test was used. The correlation between quantitative variables was verified using Pearson's correlation. All analyses used a significance level of 0.05% and 95% statistical confidence interval (CI). For a sampling error of 7%, the sample size was calculated to be approximately two hundred ankles.

RESULTS

The population mean age was 38.5 ± 13.5 years, body mass index (BMI) 25.8 ± 4.2 and weight 77.1 ± 16.5 kg. The proportion was 31% female and 69% male, and 22% right-dominant and 78% left-dominant. A total of n = 200 ankles were measured. For Peak Torque at 30°/s, the non-dominant side was consistently stronger and statistically significant for eversion, dorsiflexion, and flexion (Table 1). However, for inversion, there was no difference in peak torque between the dominant and non-dominant sides (Table 1).

The average agonist/antagonist ratio for the overall evertor/invertor group was 88.8% (95%CI: 3.1; 85.7–91.9) and 36.1% (95%CI: 1.3; 34.8–37.4) for the extensor/flexor group (Table 2). The MDI found were within the –10% to +10% range and were not significant for any movement (P = 0.062; Table 3). No significant correlation between demographic variables (age, weight, height, and BMI) and MDI was found, so these variables were considered statistically independent (Table 4).

We tested for the relationship between age and BMI with peak torque since the sample, although showing low variability, was composed of individuals with different age groups and body weights/heights. We concluded that there was no correlation between age and BMI with peak torque, either for the dominant or non-dominant sides (Table 5). The total work was statistically significant for eversion, inversion, dorsiflexion, and flexion. The non-dominant side consistently showed higher average values than the dominant side (Table 5). The average peak torque was calculated for

Table 1 Peak Torque variables for the four movements studied (*n* = 200)

Range of motion		Average	Median	SD	*P* value
Eversion	Dominant	28.7	28.3	9.8	< 0.001
	Non-dominant	31.2	30.6	10.8	
Inversion	Dominant	34.6	31.8	12.2	0.466
	Non-dominant	35.1	33.4	11,.0	
Extension	Dominant	47.9	48.1	14.3	0.029
	Non-dominant	49.4	50.5	14.3	
Flexion	Dominant	136.4	140.0	43.5	< 0.001
	Non-dominant	144.0	146.8	43.7	

Table 2 Agonist/antagonist ratios for left and right ankle and overall values (*n* = 200)

Agonist/antagonist ratios		Average	Median	SD	CV, %	Min	Max	CI
Evertors/invertors ratio	Left	81.8	79.0	22.6	28	45.0	173.0	4.4
	Right	95.8	96.0	19.9	21	53.0	160.0	3.9
	Overall	88.8	86.0	22.4	25	45.0	173.0	3.1
Extensors/flexors ratio	Left	36.2	36.0	9.6	26	17.0	69.0	1.9
	Right	36.1	36.0	8.9	25	15.0	73.0	1.7
	Overall	36.1	36.0	9.2	26	15.0	73.0	1.3

CV: Coefficient of variation; Min: Minimum; Max: Maximum; N: Sample size.

Table 3 Muscle deficiency index values for each movement (*n* = 200)

Range of motion	Average	Median	SD	CI	*P* value
Eversion	8.66	9.0	16.15	3.17	0.062
Inversion	4.20	5.5	17.75	3.48	
Extension	3.41	4.0	15.50	3.04	
Flexion	5.18	5.5	12.82	2.51	

each gender. Peak torque was consistently lower for females compared to males across all parameters ($P < 0.001$; Table 6).

For the agonist/antagonist ratio at maximum torque (30º/s), there was a statistically significant difference between sides for the evertor/invertor group, with an average of 91.4 for the non-dominant side and 86.3 for the dominant side ($P = 0.011$; Table 7).

DISCUSSION

This study found maximum torque (MT) values for each gender. The values for females and males were, respectively: Eversion 22.3 (95%CI: 1.6; 20.7–23.9) and 33.4 (95%CI: 1.7; 31.7–35.1); inversion 30.0 (95%CI: 2.5; 27.5–32.5) and 37.0 (95%CI: 1.9; 35.1–38.9); dorsiflexion 37.4 (95%CI: 2.5; 34.9–39.9) and 53.6 (95%CI: 2.2; 51.4–55.8); flexion 100.4 (95%CI: 9.3; 91.1–109.7) and 158.1 (95%CI: 5.6; 152.5–163.7). The agonist/antagonist ratio for the eversion/inversion and dorsiflexion/flexion movements averaged 88.8 (95%CI: 3.1; 85.7–91.9) and 36.1 (95%CI: 1.3; 34.8–37.4), respectively. The non-dominant ankle was stronger for maximum power and total work.

The LSI for the isokinetic ankle assessment was > 90%, as previously reported[18-20]. Similarly, the MT values were comparable to those of other studies[3,5,21-24]. An LSI higher than 90% aligns with the classic criterion for return to sports activities[17,25]. Although this threshold of LSI ≥ 90% is well established for return-to-sport decisions in knee rehabilitation[12], there is a lack of normative data for ankle isokinetic parameters in healthy populations. One of the main objectives of our study was precisely to address this gap and propose reference values for the ankle, similar to what is already accepted for the knee.

Table 4 Correlation between demographic variables and Muscular Deficiency Index (*n* = 200)

Range of motion		Age	Weight	Height	BMI
Eversion	*r* value	-0.066	0.046	0.037	0.041
	P value	0.514	0.654	0.717	0.686
Inversion	*r* value	0.079	0.060	0.002	0.030
	P value	0.438	0.560	0.985	0.768
Extension	*r* value	-0.085	-0.085	-0.050	-0.059
	P value	0.401	0.406	0.621	0.564
Flexion	*r* value	0.027	-0.049	-0.004	0.026
	P value	0.789	0.633	0.972	0.800

(*r* value): Correlation, ranges from -1 to 1. BMI: Body mass index.

Table 5 Correlation of age and body mass index with peak torque (*n* = 200)

Range of motion		Age × movement	*P* value	BMI × movement	*P* value
Eversion	Dominant	0.049	0.832	0.133	0.564
	Non-dominant	0.046	0.843	0.053	0.821
Inversion	Dominant	0.130	0.575	0.189	0.413
	Non-dominant	0.132	0.567	0.042	0.858
Extension	Dominant	-0.177	0.444	0.102	0.660
	Non-dominant	-0.199	0.388	0.046	0.845
Flexion	Dominant	-0.090	0.699	-0.256	0.263
	Non-dominant	0.074	0.750	-0.110	0.635

Table 6 Peak torque values and gender differences (*n* = 200)

Range of motion		Average	Median	SD	CI	*n*	*P* value
Eversion	Female	22.3	22.5	6.6	1.6	62	< 0.001
	Male	33.4	33.2	9.9	1.7	138	
Inversion	Female	30.0	26.7	10.0	2.5	62	< 0.001
	Male	37.0	35.3	11.6	1.9	138	
Extension	Female	37.4	37.1	10.0	2.5	62	< 0.001
	Male	53.6	54.1	13.0	2.2	138	
Flexion	Female	100.4	89.3	37.2	9.3	62	< 0.001
	Male	158.1	158.9	33.4	5.6	138	

Like other studies[3,26-28], the present study found an overall average of 88.8% for the evertor/invertor ratio (E/I) and 36.1% for the dorsiflexor/plantar flexor ratio (D/F). Regarding the agonist/antagonist ratio, the normative values found here are theoretically valid because they establish the balance between the E/I and D/F muscle groups. To our knowledge, our sample is the largest reported in the literature.

The normative values presented in this study—particularly for peak torque, LSI, and MDI—can serve as objective reference parameters during clinical rehabilitation. For instance, clinicians may use these benchmarks to monitor progress in muscle strength symmetry between limbs (*via* LSI), or to evaluate side-to-side deficits (*via* MDI) following injury. Additionally, knowing the expected torque ranges for each gender allows for more individualized strengthening programs. Furthermore, the MDI is a novel concept we introduce in the context of ankle isokinetics. It allows for a broader analysis of bilateral performance, considering not only torque, but also power and work across movements. We believe this index adds clinical value and may complement LSI by providing a more comprehensive view of muscle

Table 7 Agonist/antagonist ratio values for the dominant and non-dominant sides (*n* = 200)

Agonist/antagonist ratio		Average	Median	SD	CI	*P* value
Evertors/invertors	Dominant	86.3	82.5	25.0	4.9	0.011
	Non-dominant	91.4	92.0	19.2	3.8	
Extensors/flexors	Dominant	36.8	36.5	10.1	2.0	0.116
	Non-dominant	35.5	36.0	8.2	1.6	

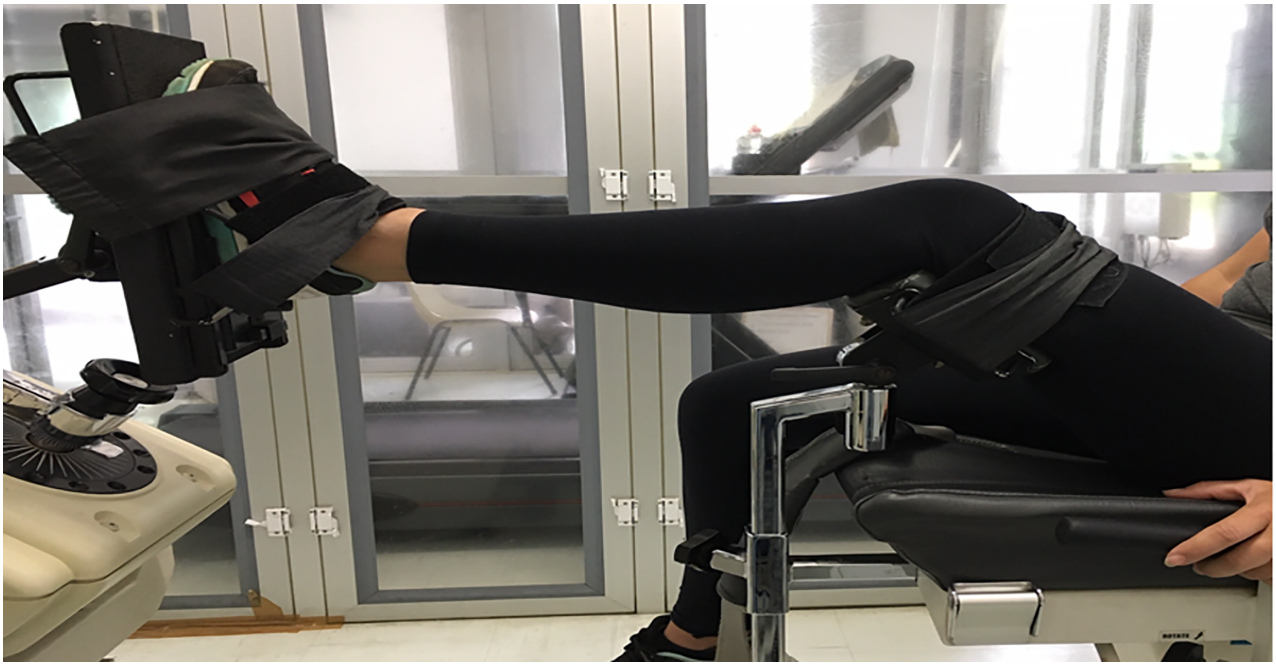

Figure 1 Positioning of the research participant - foot, leg, and knee positions (Note: The participant is positioned seated with the hip and trunk secured by stabilization straps). The test leg is aligned horizontally, supported by padding, and the knee is flexed to approximately 20°, optimizing isolation of the ankle joint. The foot is fixed to the dynamometer's footplate in a neutral (plantigrade) position using straps that allow controlled multiplanar ankle movement during testing.

function symmetry.

Although the literature—especially for the knee joint[29]—associates LSI balance with return-to-sport criteria or post-rehabilitation goals[30], the MDI could be an additional criterion for analyzing side-to-side symmetry. Indeed, an LSI > 90% was the criterion used to determine return to sport in a systematic review[31]. However, MDI is statistically independent of demographic variables (age, weight, height, and gender), supporting the routine use of this index in isokinetic ankle evaluations. Data from our study provide additional guidance regarding normative values for isokinetic ankle assessments in the studied population. Our findings show that healthy individuals consistently achieved LSI and MDI values above 90% across all tested ankle movements, suggesting that the same threshold is applicable and reasonable for ankle assessments.

A limb symmetry index > 90% for quadriceps strength does not ensure that functional equivalence to pre-injury levels is achieved[32]. Mirkov *et al*[33] reported lower quadriceps torque in the uninjured limb of subjects with anterior cruciate ligament (ACL) injury than in control limbs. These "crossover" effects, presumably mediated by neuromuscular alterations and bilateral strength deficits—particularly in the initial contraction phase—could affect peak torque and power recovery. Therefore, using LSI as a sole criterion for decision-making regarding injury recurrence is inadequate. Indeed, normative data would be instrumental.

Here, there was no correlation between BMI or age and torque[28,34]. Furthermore, as the participants were healthy, physically active adults and non-athletes with normal range of motion — features that tend to reduce functional variability — it is expected that strength would not vary with age. There was a statistically significant difference in peak torque values between females and males for all four movements. The difference in muscle strength between males and females is well documented and likely reflects physiological factors such as muscle mass distribution, hormonal influences, and baseline force production capacity[30]. Although athletes are theoretically stronger than the general population, a recent study showed isokinetic strength values similar to ours, except for inversion[3].

Variable positions and protocols are found in the literature: The supine position[34] and various knee flexion angles have been reported. Theoretically, with an extended knee, the gastrocnemius muscle would generate higher tension and strength (peak torque). However, no appreciable variation was detected in plantar flexion strength at different knee

positions[35]. Here, the participants were seated with the knee flexed at approximately 20°, and the evaluated leg was kept parallel to the ground. We assume this protocol is reliable for isolating the ankle and maintaining stable knee and hip positions. Different angular velocity protocols have reported values between 30–180°/s[4,36-38]. In this context, velocities exceeding 300°/s would not be relevant for the ankle[39]. Similarly, power evaluated at speeds between 120–180°/s is consistent with functional demands such as walking and running[39]. In our protocol, isokinetic evaluations of the ankles were performed at an angular velocity of 30°/s for torque and 120°/s for power, as seen in other studies[7,40].

Repetitive ankle sprains can cause bilateral alterations, and comparing the injured side with the "non-injured side" is inappropriate[32,41]. Furthermore, inferring the contralateral side as synonymous with pre-injury values—rather than using specific normative values—can affect rehabilitation and increase the risk of re-injury. Therefore, previously injured individuals with functional ankle instability should undergo bilateral neuromuscular reactivation exercises rather than focusing only on the injured joint[42].

Ko *et al*[40] recently published the most extensive series of patients undergoing isokinetic ankle evaluation. The injured side was systematically weaker, with severe weakness observed for inversion at 30°/s. However, in contrast to our series, no evaluations were performed for other movements or agonist/antagonist ratios. Furthermore, an old injury could globally alter neuromuscular control, and they did not include healthy controls, in contrast to our study[40]. The average torque values for the 203 "normal" ankles in that mixed sample (159 men and 44 women) were lower for eversion and inversion compared to ours[40].

A systematic review and meta-analysis involving ACL reconstruction showed that quadriceps strength in the injured limb was lower than in the control limb (not the contralateral side), matched for age, gender, and activity level up to four years after surgery[43]. The authors concluded that comparing the contralateral side might overestimate recovery and strength following ACL surgery. In this context, using paired cohorts (matched by gender, body weight, age, or occupation) is appropriate for decision-making regarding rehabilitation outcomes and return to activities[43]. Our data involved paired cohorts, suggesting additional guidance for future studies examining ankle muscle strength.

The advantages of our study include the large sample size and a comprehensive isokinetic assessment of healthy ankles. Demographic characteristics encompassing several parameters, as well as the expected torque, LSI, and MDI values, were presented. Our study has limitations that should be highlighted. The isokinetic assessments were performed at a constant velocity, whereas joint movements involve concentric and eccentric contractions that generate acceleration and deceleration throughout the range of motion[11]. Another limitation involves the lack of standardization of muscle strength relative to lean mass, which would help account for morphological disparities. Muscle strength is known to correlate more strongly with lean mass than with BMI[44]. Since BMI does not distinguish between muscle and fat mass, its value as a predictor of strength may be limited in this context. This limitation reinforces the importance of including lean mass measurements in future studies to improve the standardization of strength parameters in clinical and research settings.

Additionally, in our study, isokinetic measurements were performed only once, following warm-up and stimulation, which may limit repeatability. The study also did not include an injured population for comparison, and the sample was composed exclusively of non-athletes, which may restrict the generalizability of the findings to athletic or clinical populations. However, by focusing exclusively on non-injured ankles, we ensured a consistent and controlled dataset from which reliable baseline values—such as peak torque, LSI, and MDI—could be derived. These normative values may serve as objective targets in future studies or rehabilitation protocols involving injured individuals.

CONCLUSION

The non-dominant side was stronger in 200 healthy ankles. Moreover, the differences were within the expected range for the LSI and MDI, demonstrating that limb dominance did not appear to significantly influence the isokinetic outcomes in this sample. Demographic variables did not correlate with the parameters measured, except for gender and maximum torque. Based on these findings, we propose correlating normative torque strength values and agonist/antagonist balance separately for males and females.

FOOTNOTES

Author contributions: Da Fonseca LF contributed to conceptualization; da Fonseca LF, Maciel ES, Netto CC, Mansur NS, and Astur DC contributed to acquiring clinical data and performing the data analysis; da Fonseca LF, Jeyaraman M, and Jeyaraman N contributed to manuscript writing; Inojossa TR helped in manuscript revision; da Fonseca LF contributed for image acquisition; Jeyaraman M contributed to proofreading; da Fonseca LF and Jeyaraman M contributed to administration. da Fonseca LF and Jeyaraman M have played an important and indispensable roles in the experimental design, data interpretation and manuscript preparation as the co-corresponding authors. All authors have agreed to the final version to be published and agree to be accountable for all aspects of the work.

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