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Quantifying balance deficit in people with ankle fracture six months after surgical intervention through the Y-Balance test

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Highlights

- The YBT test reliably detects dynamic balance deficits in people with ankle surgery
- Non-operated leg scores can be used as reference values for balance restoration
- Bilateral YBT differences >3.3% can be considered as clinically relevant
- Balance restoration should also focus on improving hip weakness

ABSTRACT

Background: Ankle fractures are among the most common traumatic fractures and have a great socio-economic impact. Consequences of an ankle fracture requiring surgical treatment (e.g. pain, reduced ankle range of motion (ROM), muscle weakness, etc.) lead to balance deterioration, which has a profound impact on activities of daily living. However, to the best of the authors' knowledge, no reliable clinical tests are available to monitor balance in patients after ankle surgery.

Objectives: To quantify single-leg dynamic balance in patients with bimalleolar ankle fracture through the Y-Balance test (YBT). The second objective was to analyze the impact of ankle dorsiflexion ROM and hip strength on balance to optimize balance rehabilitation programs.

Design: Cross-sectional study.

Methods: 22 participants, who had undergone surgery after bimalleolar ankle fractures, were assessed for ankle ROM, hip strength, and dynamic balance six-months after the surgical intervention. The within-session reliability of YBT was calculated through the

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intraclass correlation coefficient (ICC) and the standard error of measurement (SEM). Student's t-tests were used to assess leg differences. A multiple regression analysis was performed to evaluate the role of ankle dorsiflexion ROM and hip abductor and adductor strength in predicting balance performance.

Results: YBT showed high-to-excellent within-session relative reliability (Healthy leg: $0.85 \leq ICC \leq 0.96$; Operated leg: $0.84 \leq ICC \leq 0.96$). SEM values were below 3.3%. The operated leg showed significant lower YBT scores for anterior reach direction (-9.0%; g=-0.70) and composite score (-4.5%; g=-0.34). Multiple regression analysis showed that both, ankle dorsiflexion and hip abductor and adductor strength explained 66% of the variance in the YBT anterior direction of the operated leg.

Conclusions: The YBT is a reliable tool that allows the quantification of single-leg dynamic balance impairments from 6-months after surgery in patients with bimalleolar ankle fracture. Between-leg YBT differences in the anterior direction can be used as reference scores (3.3%) for balance restoration. Balance rehabilitation programs should focus on improving ankle functionality and reducing hip muscle weakness with specific hip strength exercises and balance exercises with similar demands to the reaching tasks of the YBT to promote a faster recovery.

Keywords: ankle fractures, single-leg dynamic balance, test consistency, range of motion, hip muscle strength.

Introduction

Orthopedic trauma, including ankle fractures, have a profound socioeconomic impact on patients, especially in the first year after the injury. Many patients still haven´t returned to work after this period [1]. In particular, ankle fractures are among the most common traumatic fractures with an incidence ranging from 71-187 per 100,000 people/year [2]. Surgical treatment is recommended whenever there is a displacement of bone fragments and conservative treatment cannot ensure anatomical restoration and fracture stability [3]. After the surgical intervention, joint-instability, anatomical misalignment, and residual displacements can lead to biomechanical and functional ankle alterations [4] such as pain, stiffness, reduced joint range of motion (ROM), alteration of soft-tissue, impaired proprioception and muscle weakness, which, in turn, may worsen patients' balance and gait [5]. The period of disability is usually much longer than the time it takes for the boney structures and connective tissues to heal, as this period of disability is prolonged until years after the surgery [6]. The greater the injury severity, the surgery complexity, and the immobilization time, the more severe and longer-lasting these alterations are, leading to different pathological conditions like osteoarthritis [3].

Among the physical consequences of ankle fractures, balance disturbances have a profound impact on walking and functional mobility [7]. They are responsible for limiting daily living activities and thus, impairing patients' quality of life [5,8,9]. Previous works have linked poorer performance in balance and related activities in this population with the musculoskeletal conditions of the foot and ankle, especially reduced ankle dorsiflexion ROM [5]. This relationship is supported by previous findings observed in healthy populations and people with chronic ankle instability in which reduced ankle dorsiflexion ROM alters the lower limb kinematics and reduces balance, especially during dynamic actions in the sagittal plane such as single-leg reaching or landing tasks [10-12].

Interestingly, these balance impairments seem to be not only associated with the ankle dysfunction, but they could also be related to the collateral weakness of the other lower limbs, for example, the hip muscles [13,14].

The coordination between the neuromuscular hip and ankle complex is essential for postural stability, especially in those tasks with high balance demands induced by a reduced medial-lateral support base (e.g., one-leg stance, tandem stance, etc.). In these tasks, postural corrections carried out by ankle muscles cannot cope with the large body fluctuations that usually occur, requiring the coordinate participation of the hip muscles to keep the balance [13,14]. In a study using ultrasound imaging of the gluteal muscles, individuals with chronic ankle instability increased reliance on hip muscles compared to healthy people during a single leg reaching test [15]. In comparison, individuals who undergo ankle surgery will have an extended period of immobilization and reduced physical activity which could result in hip muscle weakness and therefore experience greater balance deficits. However, the extent to which the ankle and potential hip deficits after surgery hinder balance performance is still not clear.

Based on balance relevance, clinical monitoring of patients' balance status is crucial to modulate and optimize rehabilitation programs [7]. However, to the best of the authors' knowledge, no reliable clinical tests are applied to assess balance in patients after ankle surgical treatment subsequent to fracture and further rehabilitation. Among the available balance test protocols which rely on either double limb or single leg balance stance, the Y-Balance™ (YBT) is used to assess single leg balance [5,7]. This test (the YBT), which was developed from the Star Excursion Balance Test (SEBT) [16,17], quantifies balance through a single-leg reaching test. A proper YBT performance depends on a successful combination of factors such as range of motion (ROM), flexibility, neuromuscular control and strength of the ankle, knee and hip muscles [18]. YBT has been broadly used in other

populations because it is inexpensive, easy-to-use and it has shown a high reliability [16,17,19,20]. It has mainly been used in the sports field to determine ankle injury risk [19], identify individuals with chronic instability [17], or monitor injury rehabilitation (e.g., after anterior cruciate ligament surgery, ankle sprains, etc.) [21]. In a recent study, the SEBT (i.e., the YBT predecessor) has been used to assess whether manual therapy induces balance improvements in people who undergo operative fixation of the ankle and/or hindfoot fractures [5]. However, it is still unknown whether the YBT is reliable enough for the clinical monitoring of balance status in these patients.

Therefore, due to the lack of clinical tools for monitoring balance status in patients who have suffered an ankle fracture, the main aims of this study were to analyze the ability of the YBT to 1) provide reference scores which help to identify if changes during rehabilitation are caused by treatment or by within-subject variability (i.e., absolute reliability); and 2) classify patients according to their balance status (i.e. relative reliability). As a second objective, we assessed the YBT capability to quantify between limb differences six months after surgery. Finally, the potential influence of ankle dorsiflexion ROM and hip adductor (ADD) and abductor (ABD) strength on balance was also analyzed in order to optimize balance rehabilitation programs.

Methods

Type of study

This investigation is a cross-sectional study with patients evaluated in a single-session 6 months post-surgery after bimalleolar ankle fractures. The surgical technique used was open reduction and internal fixation (ORIF). During the first 6 weeks, the rehabilitation program consisted of passive stretching, kinesiotherapy and dorsiflexion strengthening exercises. Once the orthopedic surgeon team authorized the progressive loading phase,

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participants performed a balance, proprioceptive, and walking training program. The duration of the rehabilitation lasted from 12 to 16 weeks, 5 days per week. This duration was established by the hospital rehabilitation service based upon individual symptoms and therefore varied in each case.

Participants

Twenty-two participants (10 women/12 men) took part in this study (Table 1). All of them had suffered a bimalleolar ankle fracture and had been operated on by the same surgeons at the Trauma Unit of the Marqués de Valdecilla Hospital (HMV). The Hospital Research Ethics Committee approved this study (reference: 2017.072). Patients were selected through their clinical records and invited to participate after surgery. Patients were not included in the study if: 1) they had undergone other surgical interventions in the lower extremities (i.e., open, pathologic, and/or tibial pilon fractures); 2) they presented functional alterations of the non-operated lower extremity; 3) they had any neurological or rheumatic pathology; 4) they were younger than 18 years or over 55. Informed written consent was obtained from all patients before data collection.

(INSERT TABLE 1 NEAR HERE)

Procedure

Data collection was arranged six-months after the surgical intervention. Data extracted from medical records included sociodemographic data and patients' functional status evaluated through the American Orthopaedic Foot and Ankle Society (AOFAS) Ankle-Hindfoot score [22] and the Olerud Molander Ankle Score (OMAS) [9]. Bimalleolar and calf perimeters and leg length were collected with a tape measure according to previous recommendations [23].

Subsequently, ankle dorsiflexion ROM was evaluated using a digital inclinometer (Acumar, Lafayette Instrument, Lagatette, IN, USA), with the patient standing according to the procedure previously described (intraclass correlation coefficient, ICC=0.96-97; standard error of measurement, SEM=1.3º-1.4º) [24]. Specifically, ankle ROM was measured using the weight wearing lunge (WBL) method with the knee bent. This method was selected instead of a passive ROM measurement because it allows a more functional assessment of the ankle dorsiflexion flexibility, which seems to be more related to lower limb compensatory movement patterns caused by a reduced ankle dorsiflexion ROM during functional activities such as squatting tasks [25]. In addition, this method has shown very high reliability (CCI >0.9) [25,26]. WBL was performed with the patient facing a wall. The patient was barefooted at a 30 cm distance from the wall with the knee aligned with the second toe. Finally, the patient leaned on the wall and advanced their body by flexing the knee until reaching the maximum dorsiflexion ROM. Three attempts were allowed for patients to familiarize with the test and to facilitate tissue adaptation to the stretching. During the test, heel lifting was not allowed. Once the patient reached their maximum range, the inclinometer was placed at the tibial tuberosity. The test was performed three times, and the two most similar values were averaged.

Subsequently, participants' hip strength of the abductor/adductor muscles was assessed using a hand-held dynamometer (microFET@2, Hoggan Scientific L.L.C, Salt Lake City, USA) [27] with the participants lying in a supine position on an examination table with legs extended. Participants were asked to perform abduction and adduction isometric exertions with both their operated and their healthy leg. A researcher manually helped to maintain each isometric maximal voluntary contraction for 5 seconds. Prior to the measurement, a warm-up of two progressive contractions was performed. Three trials

were carried out, registering the force peak of each trial. Force peaks were normalized by the body mass (force peak in kg x 100 / body mass in kg).

Finally, the YBT (Y-Balance Test Kit™, Move2Perform, Evanville, IN) was performed [16]. The tool kit used to carry out the YBT consists of a central plastic plate on which the support foot must be placed, with three tubes marked at an interval of 1 cm and attached in anterior, posteromedial and posterolateral direction. Each tube has a plastic box that can be moved along it. Following previous recommendations [16], while maintaining a single leg stance, the participants, who were barefooted, were asked to move the plastic box as far as they could, using their free foot and then return to the starting point without losing their balance. Prior to the test, a visual demonstration and an explanation in each direction were provided. Two familiarization attempts were allowed in each direction until participants felt comfortable with the protocol. During the test, participants were allowed to make enough attempts until they were able to carry out two valid trials. An attempt was discarded if the participant: i) lost their balance, ii) leaned on the upper part of the box to reach further; iii) hit the box losing contact with it, iv) lost contact with the box during the pushing phase or v) or failed to return the reach foot to the starting position. In order to avoid fatigue, trials were balanced between the healthy and the operated limb. The rest time between tests was 20 seconds. The distance reached in each direction was collected (cm) and then normalized according to each patient's respective leg length (%) [28]. In addition, each patient's degree of balance asymmetry considered as the difference between legs observed in each YBT direction was calculated. Finally, a composite score was calculated as the average of the maximum distance reached in the three directions.

Statistical analysis

Descriptive statistics were calculated for all variables. Data normality was analyzed using the Shapiro-Wilk test.

The within-session reliability of each YBT parameter was calculated using the two valid trials. Similarly, within-session reliability for strength measures was determined from the two highest scores achieved during the measures of hip abduction and hip adduction isometric test, respectively. Relative reliability for each YBT measures and hip strength was assessed through the $ICC_{2,1}$ and interpreted as follows: excellent (0.90-1.00), high (0.70-0.89), moderate (0.50-0.69) and low (<0.50) [29]. The SEM and the minimum detectable change (MDC) with a 95% confidence interval were calculated for the analysis of absolute reliability. The SEM was calculated as the standard deviation of the difference between Trial 1 and 2, divided by $\sqrt{2}$.

In order to analyze ROM, strength, and YBT differences between legs, a Student's t-test for repeated measures was performed for each parameter using the best score. Hedges' *g* was calculated to quantify the magnitude of leg difference. Student's t-tests were carried to assess which YBT direction showed a higher degree of asymmetry. The relationship between ROM, hip abductor and adductor strength, and YBT parameters was analyzed through the Pearson's correlation coefficient.

Subsequently, in the YBT directions that presented differences between legs, ankle ROM and hip strength were introduced in a multivariate stepwise linear regression of the least square with backward elimination (p≤0.1) to determine the extent to which both could predict the YBT performance (i.e., explain variance, R^2). Since the hip strength of the abductor and adductor muscles showed multicollinearity (r>0.7), the average of both parameters was used for the linear regression analysis. The assumptions of normality, linearity, and homoscedasticity were previously confirmed for ankle ROM and hip strength.

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SEM, $ICC_{2,1}$, Pearson's correlations, regression analysis, and Student's t-test were calculated through the Statistical Package for Social Sciences (version 22 for Windows, SPSS Inc, Chicago, IL, USA). The significance level for the analyses was established at p<0.05.

Before performing the ANOVAs and the correlational analyses, the sampling software package GPower 3.1.53 was used to calculate the minimum sample size needed to detect significant results. Based on the effect size estimation (g=0.7) of previous studies [5,30], a sample size of 19 participants was found to be necessary to detect between leg differences (power=80%; α=0.05). Twenty-two patients were recruited to allow up to a 10% dropout rate.

Results

Twenty-two participants (10 women/12 men) took part in this study. Their age was 43.5±10.2, with a range of 19 to 55 years. The mean ± SD of days from injury until surgical fixation was 4.7±7.6, with a range of 0 to 30 days. Immobilization time was 3.4±1.2 weeks, with range of 1 to 6 weeks. They carried out an average of 3.35 months of rehabilitation. The AOFAS and OMAS scores were 74.7±12.0 and 57.0±21.6 respectively (Table 1).

Analyzing the feasibility of the YBT for balance assessment in patients with an ankle fracture, it was observed that 21 participants (95.5%) were able to complete the two trials of the test in the anterior direction, 20 of them (91%) in the posteromedial direction and 19 of them (86.5%) in the posterolateral direction. Analyzing the healthy leg, 21 patients (95.5%) performed the two trials in the anterior and posteromedial direction and 20 participants (91%) in the posterolateral direction.

As Table 2 shows, YBT parameters showed high to excellent within-session relative reliability (Healthy leg: $0.85 \leq ICC \leq 0.96$; Operated leg: $0.84 \leq ICC \leq 0.96$). Absolute reliability analyses showed SEM values were below 6% (Healthy leg: $1.8\% \leq SEM \leq 5.9\%$; Operated leg: $3.3\% \leq SEM \leq 5.4\%$). MCD scores were lower than 16.4%.

Concerning hip strength parameters (Table 2), excellent within-session relative reliability scores were found ($0.91 \leq ICC \leq 0.98$). In addition, SEM scores were below 2% (Healthy leg: $1.0\% \leq SEM \leq 1.3\%$; Operated leg: $0.9\% \leq SEM \leq 1.8\%$). MCD scores were lower than 5.0%.

(INSERT TABLE 2 NEAR HERE)

Analyzing between-leg differences (Table 3), the operated leg only showed significant lower YBT scores for the anterior reach direction (-9.0%; $g = -0.70$) and the composite score (-4.5%; $g = -0.34$). The operated leg also showed significant lower ankle dorsiflexion ROM (-12.7°; $g = 1.85$) and lower hip strength of the abductor muscles (-3.8%; $g = 0.47$). In addition, a significantly increased asymmetry was observed in the anterior direction of the YBT compared to the other directions ($p < 0.05$).

(INSERT TABLE 3 NEAR HERE)

Regarding the correlation analysis (Table 4), greater ankle dorsiflexion ROM and hip strength of the operated leg were only significantly correlated to greater reach distance in the YBT for the anterior direction (ankle ROM, $r = 0.54$; abductor strength, $r = 0.72$; adductor strength, $r = 0.77$) and the composite score (ankle ROM, $r = 0.46$; abductor strength, $r = 0.47$; adductor strength, $r = 0.56$).

(INSERT TABLE 4 NEAR HERE)

A multiple linear regression analysis was applied to predict the YBT performance in the anterior direction of the operated leg based on participants' ankle dorsiflexion ROM, and hip ABD-ADD strength. A significant regression equation was found ($F_{2,19}=18.310$, $p<0.000$), with an R^2 of 0.658. Patient´s predicted YBT anterior direction is equal to 15.486 + 0.485 (ROM of dorsiflexion) + 0.767 (ABD-ADD strength), in which ROM of dorsiflexion is measured in degrees and ABD-ADD strength is measured in force units relative to the body mass (force in kg x 100 / body mass in kg).

Discussion

The main aim of this study was to provide clinicians and researchers with a tool to monitor the single-leg dynamic balance recovery of people who have undergone an ankle fracture surgery. In addition, the potential influence of the decrease in ankle dorsiflexion ROM and the hip strength on balance were assessed.

Reliability of the Y-Balance Test and hip strength

Overall, the YBT showed a high-to-excellent relative reliability using the most demanding ICC ($ICC_{2,1}$) even when we had to perform a shorter protocol than previous studies [16,31] because these patients presented postoperative sequelae such as ankle stiffness, edema or pain. Although there are no YBT reliability studies carried out on this population, our ICC results are consistent with previous works conducted in sports groups such as basketball players [19] or in young semi-professional football players [31]. All these findings seem to support the robustness of the YBT to assess single-leg dynamic balance in a broad range of populations, avoiding ceiling and floor effect.

Based on SEM scores, between-leg differences lower than 3.3% for the anterior direction, 5.9% for the posterolateral direction and 3.8% for the posteromedial direction are needed to confirm that the operated leg is not impaired after rehabilitation. This is to say; SEM provides reference scores to discriminate between random variability and real change (e.g., between leg asymmetries, intervention effects, etc.). It must be highlighted that most of our SEM scores (1.8%-5.9%) were similar to those reported by other authors: 3.5%-10.0% for children [20] or 3.0%-4.6% in High-school Basketball Players [19]. The high absolute reliability found could be related to the fact that the YBT imposed a high balance challenge on this population which would require a tighter neuromuscular control resulting in a low motor variability [32].

To finish, the normalized strength of the abductor and the adductor hip muscles showed excellent reliability scores (0.91<ICC<0.98; 1.0%<SEM<1.8%) which were similar to those observed in physically-active individuals [33].

Balance, ankle dorsiflexion ROM and hip strength impairment of the operated leg

The between-limbs YBT differences were analyzed to establish the extent to which ankle fracture and further surgery impaired single-leg dynamic balance. In non-injured population, YBT scores usually show non-significant differences between legs [28]. Conversely, confirming previous posturographic results in patients with ankle surgery [7], we observed a significant lower reaching ability of the operated leg but only for the anterior direction (-9.0%; g=-0.70), which was about three times the SEM score (3.3%). This finding is congruent with other studies which found that the anterior direction is the most sensitive direction to detect balance asymmetries [34].

Interestingly, comparing the results of this study with previous findings suggests that the balance asymmetries found in this population six-months after the surgery are severe and,

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thus, can have a profound impact on functional independence and quality of life. On the one hand, the anterior balance asymmetries found in this study were almost twice as large as the asymmetries shown by basketball players with a history of ankle injury [35]. Similarly, the asymmetries found in this study in the YBT anterior direction were much larger than the differences observed between adults with and without chronic ankle instability ($\approx 5\%$) [15]. On the other hand, the anterior direction differences are 8.43 cm in absolute values, which are much higher than the 4 cm cut-off reference proposed as an index of lower extremity injury risk in basketball players [19]. Our patients also showed a lower YBT composite-score (82.2%) than those previously associated with a higher risk of injury (<89%) in American football players [36]. Although this study does not aim to assess whether patients are at risk of injury, these findings reinforce the idea that the balance status of this population 6-months after surgery is far from a normal. The results of this study also point out the relevance of not only detecting balance deficits but also of quantifying their magnitude to extend and optimize rehabilitation programs. These data are especially relevant since these patients had received an average of 3.1 ± 2.4 months of rehabilitation. In this sense, these results are in line with previous works, which showed that insufficient or deficient rehabilitation might be a cause of long-term disability in these patients [8]. Therefore, these results suggest that it is necessary to optimize rehabilitation treatments and/or increase their duration in order to reduce these asymmetries as soon as possible.

To finish, confirming previous results [4,5], patients showed a remarkable reduction in the ankle dorsiflexion ROM (-12.7º; g=1.85). Interestingly, this study found that patients also present a reduction of the hip abductor strength (-3.8% of the body mass; g=0.45). These results reinforce the idea that it is essential to optimize rehabilitation programs to

reduce these asymmetries produced directly or collaterally by the ankle fracture and subsequent surgery.

Fractures influence of ankle dorsiflexion ROM and hip strength on single-leg dynamic balance

A significant correlation between the ankle ROM of the operated leg and balance was found, confirming previous findings observed in individuals with chronic ankle instability [10,11]. It must be pointed out that this relationship was only found for the anterior direction (r=0.54) which was the most affected YBT direction in this population. These findings could be related to the fact that single-leg reaching movements in the sagittal plane are highly compromised by the ankle dorsiflexion ROM of the supporting foot [10].

Remarkably, it was also observed that the strength of the hip abductor and adductor muscles of the supporting (operated) leg was only associated with balancing performance in the YBT anterior direction (r= 0.72-0.77). These data are not consistent with those found by other studies in people with ankle instability in which hip abductor strength is related to balance performance in the posteromedial and posterolateral directions [37,38]. However, Francis et al [39], in their study carried out in a healthy population, also observed a positive correlation between hip abductor strength and balance performance in the posteromedial and anterior YBT direction, which is consistent with our findings of the non-operated leg (healthy leg) (Table 4. lower left, color: white). Focusing on the operated leg, from the authors' point of view, patients with ankle fractures would increase their reliance on their hip muscles in those tasks in which a poorer ankle function of the operated leg (i.e., reduced dorsiflexion ROM) is mainly associated with lesser balance (i.e., YBT anterior direction). In this sense, it is known that a limited ankle dorsiflexion ROM hinders the body displacement in sagittal plane tasks, such as squatting or landing, increasing the compensatory movements in the frontal plane [25]. Thus, this increased

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dependence on the neuromuscular hip complex might make the abductor and adductor strength a determinant parameter for maintaining balance stabilizing pelvis movements in the frontal plane [40]. The authors also hypothesize that reduced ankle dorsiflexion ROM could lead the patients to perform a greater hip flexion in order to reach further. In this sense, the muscle strength of the major adductor might also play an important role in the eccentric/concentric control of the hip flexion/extension during the squatting action that YBT anterior direction requires [41].

The controversies found in the literature regarding the relationship between hip musculature and YBT may be due to the different characteristics of the populations studied. This may make the neuromuscular needs of the foot, knee, or hip be different when performing functional tasks [38].

Finally, the multiple regression analysis showed that both hip strength and ankle dorsiflexion ROM had a high predictive power (R^2=66%) on YBT anterior performance. Based on these results, balance rehabilitation programs should focus on improving ankle functionality and reducing hip muscle weakness with specific hip strength exercises and balance exercises with similar demands to the reaching tasks of the YBT to promote a faster recovery.

Limitations

This study presents the inherent weaknesses of a cross-sectional design since inverse causality cannot be ruled out. Another limitation is the lack of testing of some physical parameters that the literature suggests have an impact on balance (e.g., the strength of ankle, knee, or other hip muscles, sensorial perception, etc.). Additionally, analyzing neuromuscular (i.e., EMG testing of lower limb muscles) and kinematic adaptations would also improve the understanding of the underlying mechanisms of the balance

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worsening after an ankle fracture and the subsequent surgery. To finish, the small sample size did not allow for provision of normative data or to analyze the extent to which other factors as the type of fracture, surgical intervention, age, etc., could influence balance recovery.

Conclusions

The YBT is a reliable tool to detect single-leg dynamic balance impairments in patients who have undergone surgery after an ankle fracture. As the YBT is an inexpensive and easy-to-use tool, it could be used for monitoring balance progression during rehabilitation programs. In individuals who have only suffered a unilateral ankle fracture, between leg YBT differences can be used as reference scores for balance restoration (>3.3%). Finally, based on the correlational analyses, rehabilitation balance programs should focus not only on improving ankle functionality but also on reducing the weakness of the hip abductor muscles.

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ACKNOWLEDGMENTS

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Table 1. Demographic characteristics, anthropometrics, and ankle functional status of the patients with ankle fractures.

N=22	Mean ± SD	95% CI
Age (years)	43.5 ± 10.2	(39.0; 48.0)
Sex % women	42.9	
Height (cm)	169.3 ± 9.5	164.8 ; 173.7
Weight (kg)	77.8 ± 16.6	69.9 ; 85.5
Operated limb length (cm)	85.6 ± 5.9	82.9 ; 88.2
Healthy limb length (cm)	85.6 ± 5.9	82..9 ; 88.2
OA Calf Perimeter (cm)	34.2 ± 4.0	32.4 ; 36.0
HA Calf Perimeter (cm)	35.6 ± 4.7	33.5 ; 37.4
OA Bimalleolar perimeter (cm)	25.1 ± 2.1	24.2 ; 26.0
HA Bimalleolar perimeter (cm)	24.1 ± 2.1	23.2 ; 25.0
Days from Injury to Operative Fixation	4.8 ± 7.6	1.4 ; 8.1
AOFAS Anlke-Hindfoot score	74.7 ± 12.0	69.4 ; 80.0
OMAS	57.0 ± 21.6	47.4 ; 66.6
Immobilization (weeks)	3.4 ± 1.2	2.8 ; 3.9
Rehabilitation length (months)	3.1 ± 2.4	2.0 ; 4.1

SD: standard deviation; CI: confidence interval; HA: healthy ankle; OA: operated ankle, ROM: range of motion, AOFAS: American Orthopaedic Foot and Ankle Society; OMAS: Olerud Molander Ankle Score.

Table 2. Descriptive (Mean ± SD) and within-session test-retest reliability of the Y-balance test and hip strength parameters in people with ankle fracture 6 months after surgery

	Direction	Participants	Trial 1	Trial 2	ICC$_{2,1}$ (95% CI)	SEM (units) (95% CI)	MCD (95% CI)
	Normalized Reach distance (%) obtained from the Y-Balance test						
Healthy leg	Anterior	21	62.4 ± 11.1	65.2 ± 12.2	0.94 (0.55 ; 0.98)	1.8 (1.5 ; 2.5)	4.9 (4.2 ; 6.9)
	Posterolateral	21	98.0 ± 16.0	101.3 ± 15.4	0.85 (0.66 ; 0.94)	5.9 (4.7 ; 8.2)	16.4 (13. ; 22.7)
	Posteromedial	20	99.7 ± 13.8	104.0 ± 14.3	0.89 (0.71 ; 0.96)	3.8 (3.1 ; 5.2)	10.5 (8.6 ; 14.4)
	Composite score	20	89.2 ± 11.3	89.6 ± 13.3	0.96 (0.90 ; 0.98)	2.3 (1.7 ; 0.4)	7.2 (3.9 ; 1.1)
Operated leg	Anterior	21	53.8 ± 13.2	55.7 ± 10.8	0.92 (0.81 ; 0.97)	3.3 (2.7 ; 4.6)	9.4 (7.5 ; 12.8)
	Posterolateral	20	92.3 ± 16.2	98.4 ± 15.1	0.84 (0.44 ; 0.95)	5.4 (4.2 ; 7.7)	14.9 (11.6 ; 21.3)
	Posteromedial	17	99.0 ± 14.4	101.9 ± 12.9	0.94 (0.85 ; 0.98)	3.3 (2.6 ; 4.6)	9.2 (7.2 ; 12.8)
	Composite score	17	82.2 ± 13.0	85.4 ± 12.7	0.96 (0.78 ; 0.99)	2.1 (2.9 ; 0.6)	5.8 (8.0 ; 1.7)
	Hip muscle strength normalized by body mass (%)						
Healthy leg	Abduction	22	29.3 ± 8.7	27.2 ± 8.9	0.96 (0.33 ; 0.99)	1.0 (0.76 ; 1.28)	2.6 (2.11 ; 3.55)
	Adduction	22	25.8 ± 8.6	24.0 ± 7.9	0.95 (0.71 ; 0.99)	1.3 (1.06 ; 1.79)	3.7 (2.94 ; 4.96)
Operated leg	Abduction	22	27.7 ± 8.4	25.5 ± 7.3	0.91 (0.60 ; 0.97)	1.8 (1.45 ; 2.44)	5.0 (4.02 ; 6.76)
	Adduction	22	26.3 ± 9.1	24.8 ± 8.8	0.98 (0.72 ; 0.99)	0.9 (0.75 ; 1.26)	2.6 (2.09 ; 3.49)

ICC: Intraclass correlation coefficient; SEM: Standard error of measurement; MCD: Minimal change differences; CI: Confidence interval.

Table 3. Differences in the Y-Balance test, hip strength parameters, and ankle dorsiflexion ROM between healthy and operated legs in individuals with ankle fractures 6 months after surgery

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	Operated leg (Mean ± SD)	Healthy leg (Mean ± SD)	p	Differences between legs (units) Mean (95% CI)	Hedges' g
Normalized Reach distance (%) obtained from the Y-Balance test					
Anterior (N=22)	56.2 ± 13.1	65.2 ± 12.2	<0.001	-9.0 (-12.5 ; -5.8)	0.70
Posterolateral (N=22)	98.5 ± 14.9	100.0 ± 16.0	0.09	-2.8 (-7.2 ; 1.6)[a]	0.18
Posteromedial (N=21)	101.2 ± 14.8	103.3 ± 14.2	0.20	-2.8 (-5.9 ; 0.4)[a]	0.19
Composite score (N=21)	85.8 ± 12.9	90.4 ± 1.6	0.001	-4.5 (-7.0 ; -2.1)	0.34
Ankle Dorsiflexion ROM (°)					
(N=22)	22.8 ± 7.7	35.4 ± 5.3	<0.001	-12.7 (-15.1 ; -10.3)	1.85
Hip muscle strength normalized by body mass (%)					
Abduction (N=22)	25.5 ± 7.2	29.3 ± 8.7	0.006	-3.8 (-6.4 ; -1.2)	0.47
Adduction (N=22)	26.3 ± 9.1	25.8 ± 8.6	0.49	0.6 (-1.1 ; 2.2)	0.06

ABD: hip abductor muscle strength, ADD: hip adductor muscle strength; ROM: range of movement; CI: Confidence interval; a: differences with the anterior direction.

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Table 4. Pearson correlations between Y-Balance test scores, hip strength, and ankle dorsiflexion ROM in individuals with ankle fracture 6 months after surgery in both, operated leg (top-right, color: light grey) and healthy leg (left-bottom, color: white).

	YBT Anterior	YBT Posteromedial	YBT Posterolateral	Ankle ROM	Abduction strength	Adduction strength
YBT Anterior		0.64**	0.68**	0.54*	0.72**	0.77***
YBT Posteromedial	0.84***		0.80***	0.36	0.32	0.37
YBT Posterolateral	0.82***	0.80***		0.36	0.24	0.39
Ankle ROM	0.44*	0.28	0.07		0.39	0.39
Abduction strength	0.66**	0.53*	0.42	0.52*		0.81
Adduction strength	0.59**	0.62**	0.43*	0.25	0.86***	

YBT: Y-Balance test, ROM: range of motion. *$p < 0.05$. **$p < 0.01$. ***$p < 0.001$.