International Journal of Current Research and Review
DOI: https://doi.org/10.31782/IJCRR.2023.152201

Original Research

IJCRR
Section: Healthcare

Reliability, Agreement, and Validity of FDM Zebris Pressure Platform to Measure Lower Limb Weight Distribution during Quiet Standing

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ABSTRACT

Introduction: Maintaining an erect posture is essential for carrying out every day functional tasks. The ability to maintain balance while standing is influenced by factors such as visual signals and how weight is distributed in the lower extremities. Symmetrical distribution of weight on both legs is deemed as balanced limb loading. Certain key activities like transitioning from sitting to standing, standing, walking, and running are considered energetically advantageous when both lower limbs exhibit symmetrical load distribution.

Aim/Objectives: To assess the Reliability, Agreement, and Validity of FDM Zebris pressure platform to measure Lower Limb weight distribution during quiet standing.

Methods: One hundred healthy adults (53 males, 47 females) were recruited through convenience sampling method from the Employees of CHARUSAT University. The participants were required to perform a quiet standing task during the measurement of LLA. The measurements were taken over three trials. LLA was measured through FDM Zebris pressure platform and compared with the digital weighing scales method. All data was collected in kilograms. Intra-class correlation coefficient (ICC) analysis, standard error of measurement, and coefficient of variation were performed to assess reliability and validity. The Bland-Altman plot was used to test the degree of agreement between FDM Zebris pressure platform and the digital weighing scales.

Results: FDM Zebris pressure platform was 0.916, suggesting excellent intrarater reliability, and 0.915, suggesting excellent Interrater reliability. Pearson and ICC correlations of FDM Zebris pressure platform and DWSs were supporting concurrent validity (Right side r – 0.948 and Left side r – 0.946). The discrepancy in measurements between the digital weighing scale and the FDM Zebris pressure platform was minimal, with a bias of 0.290 on the right side and -0.290 on the left side.

Conclusion: The FDM Zebris pressure platform stands as a reliable and valid tool for evaluating limb load asymmetry in both clinical and research environments.

Key Words: Validity, Reliability, Normally, Agreement, FDM Zebris pressure platform, limb load asymmetry, Lower limb weight distribution

INTRODUCTION

Upright posture is a crucial fundamental posture to perform day-to-day functional activities. The capacity to sustain bodily equilibrium while standing is impacted by elements like visual cues and the distribution of weight across the lower limbs.[1] Limb loading distribution is considered symmetrical when there's an equal load on lower limbs. Some important activities like sit to stand, standing, walking, and running are considered energetically efficient when both lower limbs exhibit symmetrical loading behavior.[2]

Nonetheless, prolonged imbalances in limb loading can result in issues like osteopenia, cartilage deterioration, and joint degeneration. As a result, accurately measuring weight distribution across the lower limbs is imperative in clinical scenarios to effectively aid patients recovering from conditions such as stroke, lower-limb fractures, osteoarthritis, amputations, and joint replacement complications.[2-7]

The consequences of modified or lacking mechanical loading due to immobilization have been examined extensively in various studies involving populations dealing with stroke[6,7,8],

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ISSN: 2231-2196 (Print) **ISSN:** 0975-5241 (Online)

Received: 26.09.2023 **Revised:** 18.10.2023 **Accepted:** 12.11.2023 **Published:** 30.11.2023

spinal cord injury[9], and extended bed rest.[10,11,12] These investigations have highlighted outcomes like muscle atrophy and Disuse Osteopenia as a result of these conditions. Disuse Osteopenia is a state marked by decreased bone mineral density (BMD) and alterations in micro-architecture. These changes can weaken bone structure, elevating the likelihood of fractures.[13] Prolonged immobility, diminished weight-bearing activities, and changes in left/right weight-bearing inevitably accompany leg injuries or surgeries. This can potentially lead to a decline in BMD and muscle mass, affecting one or both legs.

A primary goal of rehabilitation is to establish an imbalance in weight-bearing, aiming to enhance equilibrium and mitigate the risk of excessive stress on joints and bones across various medical conditions. Research exploring the consequences of variances or prolonged shifts in weight distribution between the left and right legs might necessitate minimal data regarding postural attributes. This information could be easily obtained through a straightforward approach employing two equally calibrated standard weighing scales. Numerous studies delving into ambulatory capabilities, activity levels, and post-injury or post-surgery recuperation opt for advanced techniques like pressure platforms and portable devices (like accelerometers). These technologies aid in evaluating alterations in weight-bearing activity and the restoration of a 'normal' gait pattern.[13]

Measuring limb loading can be achieved through various means, including the pressure platform, MatScan (Tekscan Inc; South Boston, Massachusetts) digital weighing scales (DWSs), biofeedback systems, and ambulatory devices.[14] Compared to DWSs, biofeedback systems, MatScan, ambulatory devices, and pressure platforms offer superior accuracy and reliability.[14] Nonetheless, these advanced tools are costlier, necessitate skilled personnel, and are not widely accessible in routine clinical settings.[1,14] As a result, their utilization for quantifying limb load asymmetry (LLA) is infrequent.

On the other hand, the traditional approach employed by professionals to assess lower limb weight-bearing asymmetry involves the utilization of two digital weighing scales (DWSs). These scales offer immediate quantitative measurements of weight in kg Units [1,8,13], with a level of precision extending to 2 decimal points.[7,14] DWSs possess advantageous attributes: they are portable, cost-effective, consume less time, are readily available, compact, and lightweight.[1,14] Neither clinicians nor patients require additional training to operate DWSs, and these systems exhibit commendable accuracy when gauging static weight-bearing.[14]

Employing a dual-scale technique could present a straightforward and trustworthy option, necessitating only fundamental data regarding leg weight-bearing during a standing posture. This approach is presently employed in certain clinical scenarios to track shifts in weight distribution between the left and right sides of individuals recuperating from conditions that lead to posture modifications.[1, 13, 18, 19, 21]

The analysis of reliability demonstrated the remarkable consistency of digital weighing scales in evaluating limb load asymmetry (LLA) during standing. The intra-class correlation coefficient (ICC) value for DWSs in this investigation (0.983–0.988) surpasses that noted in the study by Bohannon and Waldron in 1991, which found reliability rates of 0.829 and 0.876 for the affected and unaffected lower limbs, respectively. As a result, the reliable outcomes of this study affirm the potential use of DWSs in clinical settings for LLA assessment[15]. Hence, DWSs represent a precise instrument for quantifying differences in limb loading, as supported by earlier research.[1, 19]

Repetitive measures within and between DWSs indicated excellent reliability, and validity along with good agreement LLA measures compared to MatScan. Hence, DWSs can be incorporated by practitioners as beneficial tools to measure LLA during quiet standing positions. DWSs are handy, compact, cost-effective, and simply available. DWSs could substitute objectively evaluated and subjective clinical examination of lower limb loading in clinical and research settings.[1]

The Zebris FDM instrumented with a pressure platform, has been used for clinical and research purposes for gait examination in different orthopaedic and neurologic conditions. However, data concerning the reliability and validity of the Zebris FDM pressure platform is still not identified especially to measure Lower limb weight distribution during quiet standing.

The purpose of this research has been to assess the reliability and validity of Lower limb weight distribution during quiet standing obtained from the Zebris FDM with a focus on lower limb weight distribution. For comparison purposes, the Dual digital weighing scale was utilized, a method with established exceptional reliability and validity for gauging weight distribution in the Lower limb weight distribution during quiet standing.

METHODS

This cross-sectional study was conducted with 100 healthy adults (53 males, 47 females) recruited through convenience sampling method from the Employees of CHARUSAT University. Participants with a history of lower-limb surgery, impairments to the lower limb, insufficient visual and hearing ability, neuro-musculoskeletal impairment, and limb-length discrepancy of more than 1 cm were excluded from participation. Examination with a DWSs and Zebris pressure platform was administered in the Motion Analysis lab of the Physiotherapy department. The research plan has been endorsed by CHARUSAT University's research ethics

committee. Prior to study, every participant has provided an informed agreement.

The FDM Zebris pressure platform has been used to measure lower limb weight distribution with its specification of Accuracy ± 5 % (FS), Measuring range 1-120 N/cm^2, Dimensions: 212.2 x 60.5 x 2.5 cm (L x W x H), Sensor area: 203.2 x 54.2 cm (L x W), Number of sensors: 15360, Sampling rate: 100 Hz to 200 Hz. Participants were positioned without shoes, their feet naturally aligned on the pressure plate, with around 20 cm of separation between each foot and no external support. Their limbs were individually positioned on each weighing scale. Participants were given instructions to maintain a comfortable upright posture, gazing ahead at a fixed point on a wall situated at a distance of 10 feet. The test lasted for a duration of 10 seconds, followed by a 3-minute resting interval between each trial. To minimize human error, the same test was conducted thrice. Following each trial, participants were required to walk around the room. The software provided data in percentage values, categorizing metrics such as right forefoot, right back-foot, left forefoot, left back-foot, right total, and left total. After a week, participants underwent a retest, with all the aforementioned procedures repeated identically during the retest phase.

Weight distribution measurements under each lower limb were acquired utilizing two parallel, calibrated digital display scales with a maximum capacity to measure weight is 150 kg, offering a precision of 0.1 kg. Participants stood barefoot, positioning their feet naturally aligned on the scales with around 20 cm of separation between each foot and no external support. The participants have to place their limbs individually on each scale. Participants were advised to stand in a comfortable upright position while gazing at a fixed point on a wall located 10 feet away. The digital display of each weighing scale exhibited whole number values in kilograms (kg), with a single decimal place denoting tenths of a kg. Regardless of the potential decimal instability, once the displayed whole number value for each scale stabilized, the bilateral integer reading was recorded. Subsequently, the equivalence between the cumulative body weight and the combined values from both scales was validated. In cases where the combined sum deviated from the total body weight, readings were retaken. To minimize potential measurement errors, participants conducted sets of three consecutive trials.

The data underwent analysis using IBM SPSS Statistics Version 23. To assess the reliability, both within-day and between-day measures were computed using intra-class correlation coefficients along with their corresponding 95% confidence intervals (ICC and 95% CI). For calculating bilateral reliability estimations of each system, the ICC (2,1) model was employed. ICC values were categorized as follows: ≥0.9 denoting excellent, ≥0.8 indicating good, ≥0.7 signifying acceptable, ≥0.6 suggesting questionable, ≥0.5 representing poor, and <0.5 classifying as unacceptable. The relative standard error of measurement (SEM %) values were derived from the ICC values. Additionally, the smallest detectable differences (SDD) values were calculated to gauge measurement error, with SDD values computed as 1.96 multiplied by the square root of 2 and further multiplied by the absolute SEM. Furthermore, a coefficient of variance (CV %) was established for both within-day and between-day assessments of the standing position.

For the purpose of assessing the validity of the variables acquired through the Zebris FDM system, the mean difference (Zebris FDM minus DWS) was computed along with the corresponding 95% limits of agreement. This analysis was also executed separately for each side of the body. To ascertain the statistical significance of the mean disparities, linear mixed models were applied, utilizing pooled data where the observations (comprising steps 1–5 for both the left and right foot) were designated as a random factor, and the system (DWS and Zebris FDM) was considered a fixed factor. The calculation of limits of agreement incorporated multiple observations (steps 1–5) for each trial, adhering to the methodology presented by Bland and Altman in 2007.

To assess the agreement between the instruments, the Bland-Altman plot was utilized. This plot was created using the measurements collected from both the DWSs and Zebris FDM pressure platform. It involved plotting the score differences against the corresponding mean for each individual.

RESULT

Demographic characteristics

Demographic characteristics are shown in Table 1 like age, gender, height, weight, and BMI of the participants. The mean age of participants was 34.26 ± 9.8. Out of 100 participants, 47 (47%) were female, and 53 (53%) were male; the mean BMI was 23.62 ± 4.3. Table 2. Descriptive statistics for FDM Zebris pressure platform measurements at Right and left weight distribution during day 1 and day 2 with both testers.

Table 1: Demographic characteristics of the participants (n = 100).

Characteristics	Mean	SD	Minimum	Maximum
Age (Year)	34.26	9.8	25	65
Height (m)	1.64	0.09	1.45	1.82
Weight (kg)	63.79	13.8	40	117.20
BMI	23.62	4.3	16.41	39.62
Characteristics		**Frequencies**		**Percentage**
Gender	Male	53		53 %
	Female	47		47 %

Table 2: Descriptive statistics for DWS &FDM Zebris pressure platform measurements at Right & Left weight distribution (n = 100).

Measurement		Right				Left			
		Mean	SD	Min	Max	Mean	SD	Min	Max
DWS	Tester 1 Day 1	49.36	2.6	42	56	50.64	2.7	44	58
FDM Zebris Pressure platform	Tester 1 Day 1	49.07	3.1	39	55	50.93	3.1	45	61
	Tester 1 Day 2	49.06	3.6	38	57	50.94	3.6	43	62
	Tester 2 Day 2	49.09	3.8	37	57	50.90	3.8	43	63

Reliability:

To check the repeatability of the FDM Zebris pressure platform, an inter-class coefficient (ICC) was carried out. The Averaged measure ICC of the FDM Zebris pressure platform was 0.916, suggesting excellent intrarater reliability, and 0.915, suggesting excellent Interrater reliability. Table 3 demonstrates further details of ICC testing of the FDM Zebris pressure platform and DWS method.

Table 3: FDM Zebris pressure platform test-retest (multiple-day interrater) and interrater reliability (n = 100).

Measurement	Right			Left		
	ICC (95% CI)	SEM (%)	SDD	ICC (95% CI)	SEM (%)	SDD
Intrarater	0.916 (0.875 – 0.944)	0.89	2.47	0.916 (0.875 – 0.944)	0.89	2.47
Interrater	0.915 (0.873 – 0.943)	1.09	3.03	0.915 (0.873 – 0.943)	1.09	3.03

ICC=Intra class correlation coefficient, CI=Confidence interval, SEM=standard error of measurement, SDD=Smallest detectable differences

The absolute values for the FDM Zebris pressure platform and DWSs converted to a percentage and the relationship between the 2 measurements tools have been reported in Table 4. Pearson and ICC correlations of FDM Zebris pressure platform and DWSs were supporting concurrent validity (Right side r – 0.948 and Left side r – 0.946). Table 4 reports Pearson correlations of the FDM Zebris pressure platform.

Table 4: Statistics for validity testing with Pearson correlations (r) between DWS &FDM Zebris pressure platform

Statistics	RT	LT
Pearson Correlation (r)	0.948**	0.946**
Sig. (2-tailed)	0.000	0.000
N	100	100

**. Correlation is significant at the 0.01 level (2-tailed).

Agreement between digital weighing scales and the FDM Zebris pressure platform.

In the static standing position, the discrepancy in measurements between the digital weighing scale and the FDM Zebris pressure platform was minimal, with a bias of 0.290 on the right side and -0.290 on the left side. This bias closely aligns with the zero-bias line, indicating only a slight divergence between the two tools. The negative bias value indicates that the FDM Zebris pressure platform tends to slightly underestimate measurements compared to the digital weighing scale.

The limits of agreement, spanning from -1.705 to 2.28 on the right side and 1.724 to -2.304 on the left side, encapsulate 95% of the difference marks observed between the devices. The range of the agreement zone, which is the disparity between the upper and lower boundaries, measured 3.98 on the right side and 4.02 on the left side. This width suggests that the agreement is appropriately balanced, neither excessively tight nor overly wide, indicating a satisfactory level of conformity between the device measurements.

The regression line and the zero bias line stayed within the 95% confidence interval of agreement, as illustrated in Figure 1.

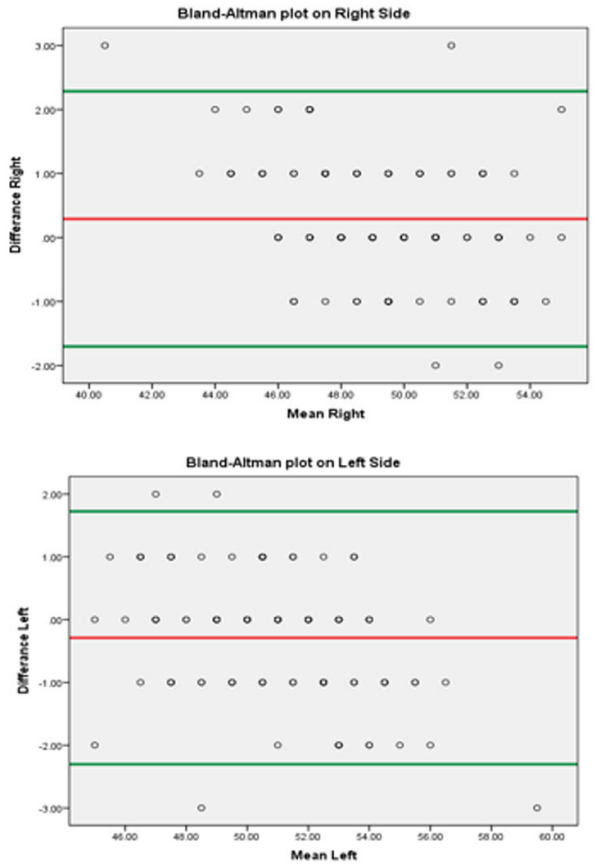

Figure 1: Bland-Altman charts depicting the assessment of the FDM Zebris pressure platform against a digital weight scale.

DISCUSSION

The matter of lower limb loading asymmetry within healthy populations remains a subject of contention in practical scenarios. The assessment of weight distribution in standing positions holds particular significance in various orthopedic and neurological contexts. This study aimed to assess the dependability and accuracy of the FDM Zebris pressure platform in gauging lower limb weight distribution while still standing among a cohort of healthy males and females.

The findings indicate that the FDM Zebris pressure platform is a dependable and accurate instrument for evaluating lower limb weight distribution in stationary standing. The robustness of the test-retest reliability and intrarater reliability of the FDM Zebris pressure platform underscores its consistent performance over time and across different assessors. Furthermore, the excellent validity of the FDM Zebris pressure platform confirms its precise measurement of lower limb weight distribution during quiet standing and its capacity to discern discrepancies between individuals with and without impairments.

Asymmetrical weight distribution often associated with variables like balance. The FDM Zebris pressure platform is applied to quantify the patterns of center of pressure (COP) sway, both along the anterior-posterior (A-P) and mediolateral (M-L) directions. In clinical and research contexts, the FDM pressure platform proves its validity as a tool for evaluating static balance, given that all its metrics display significant correlations with those acquired through the BBS force platform, as demonstrated by a study.[16]

Numerous studies have previously highlighted that digital weighing scales (DWSs) exhibit commendable outstanding reliability and validity for assessing limb loading during stationary standing. DWSs emerge as reliable instruments, demonstrating substantial agreement and validity when pitted against MatScan measurements. While pressure platforms are generally regarded as the benchmark for quantifying limb loading in the lower extremities (1), it's important to note that MatScan's validity has been established at 1.9 % of the average difference in measurements compared to the pressure platform.[17] Additionally, MatScan has demonstrated notable precision alongside moderate to excellent reliability in evaluating plantar pressure during standing position. [17]

Apart from bias, the Bland-Altman plot can offer deeper insights through analysis of plot patterns, precision, percentage error, limits of agreement, and bias trend. The pattern exhibited on the plots showcases the variability of measurements, which does not follow funnel, U, or linear patterns.[22] These plots exhibit no discernible relationship between discrepancy and measurement level, leading to the conclusion that 95 percent LoAs would be suitable between the FDM Zebris pressure platform and DWS. While no established definitive values exist for precision and percentage inaccuracy for these 2 devices, smaller precision errors indicate that data points are closer to the mean, implying a higher level of agreement.

LoAs, representing the mean difference ± two standard deviations, describe the range encompassing 95 % of comparison points. For instance, LoA around the right-side bias is described as 0.29 ± 1.017 and on the left side as -0.29 ± 1.02. Although no clinical or statistical consensus exists based on literature, the narrow LoAs provide sufficient confidence to consider using the FDM Zebris pressure platform instead of DWSs for clinical examination of lower limb weight distribution.

Both the regression line and the zero bias line fall within the 95 %CI band on both the Right and Left sides, signifying that the bias trend aligns statistically with the zero bias line. This alignment underscores the substantial agreement between the FDM Zebris pressure platform and DWSs. These collective findings suggest that the FDM Zebris pressure platform holds promise as a viable alternative to DWSs for evaluating weight distribution during standing positions.

In general, remarkable reliability, coupled with a favorable agreement and valid assessments of limb load asymmetry, the repeated measurements taken within and between FDM Zebris pressure platforms displayed (LLA) when compared to DWSs. Consequently, practitioners can consider integrating the FDM Zebris pressure platform into their toolkit as a beneficial tool for gauging weight distribution during standing. However, it's important to note that FDM Zebris pressure platforms lack the compactness, portability, cost-effectiveness, and easy accessibility of DWSs. This disparity raises questions about their practical clinical implementation. Given these considerations, DWSs can serve as a substitute for subjective clinical evaluations, providing an objective means to assess limb loading in clinical practice.[13-18]

As far as our awareness extends, no prior studies have explored the reliability, concordance, and accuracy of the Zebris FDM pressure platform in assessing asymmetrical weight distribution during standing. This study represents the inaugural endeavour to investigate the reliability, concordance, and accuracy of the Zebris FDM pressure platform in this context within a healthy population. The study results indicate exceptional levels of reliability and validity.

LIMITATIONS

Several constraints are associated with the utilization of the FDM Zebris pressure platform. A notable limitation pertains to its relatively high cost, potentially restricting access for certain clinicians and researchers. The fact that this assessment is conducted within a laboratory setting curtails its widespread application. This also restricts its affordability for community-based individuals. Additionally, the study sample was confined to healthy male and female participants. Therefore, the generalizability of these findings to other demographic groups, such as children, the elderly, or individuals with injuries, remains unknown.

CONCLUSION

In summary, the FDM Zebris pressure platform has demonstrated outstanding reliability in assessing lower weight distribution during stationary standing. Likewise, its measurements exhibit favourable agreement and validity when compared to the DWSs approach in the quiet standing position. Consequently, the FDM Zebris pressure platform stands as a viable tool for evaluating limb load asymmetry in both clinical and research environments.

ACKNOWLEDGMENT

We express our gratitude to the dedicated participants who generously contributed their time and cooperation to this study. We would also like to extend our heartfelt appreciation to the management team at Ashok & Rita Patel Institute of Physiotherapy – CHARUSAT University for their guidance and support throughout the research process.

Source of Funding:

Ashok & Rita Patel Institute of Physiotherapy – CHARUSAT University extended equipment support for this study.

Conflicts of Interest:

There are no conflicts of interest.

Authors' Contribution

All the authors have contributed equally.

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