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ORIGINAL REPORT

EVALUATION OF A DUAL-SCALES METHOD TO MEASURE WEIGHT-BEARING THROUGH THE LEGS, AND EFFECTS OF WEIGHT-BEARING INEQUALITIES ON HIP BONE MINERAL DENSITY AND LEG LEAN TISSUE MASS

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Objective: **To investigate: the accuracy of measuring relative left/right weight-bearing using two identically calibrated weighing scales; the short-term weight-bearing tendencies in a general population of 9 participants and long-term in 42 females; the effect weight-bearing inequalities on hip bone mineral density and leg lean tissue mass.**

Method: **Participants were measured standing astride two scales. Short-term volunteers were measured 10 times on one visit, with repositioning between measurements and the long-term group were measured on three visits at 6 month intervals. Baseline bilateral hip and total body Dual X-ray Absorptiometry scans were performed on the long-term group.**

Results: **The short-term Coefficient of Variation is 5.41% and long-term 7.01%. No significant correlations were found between hip bone density differences and weight-bearing inequalities, although a weak correlation of $r=0.31$ ($p=0.047$) was found for differences in leg lean tissue mass.**

Conclusion: **Left/right weight-bearing measured using two scales is a consistent method for evaluating weight distribution through the legs. The short- and long-term weight-bearing tendencies showed a similar degree of variation. Weight-bearing inequalities were not associated with any significant left/right differences in bone mineral density at the hip, but were weakly associated with left-right differences in leg muscle mass.**

Key words: weight-bearing; scales; bone density; muscle.

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INTRODUCTION

Studies investigating the effects of differences, or long-term changes, in relative left/right weight-bearing (L/R WB) through the legs may require only limited information on postural parameters that could be provided by a relatively simple and convenient method using two identically calibrated standard weighing scales. A number of studies investigating re-ambulatory function, activity and recovery following injury or surgery, use technologically sophisticated methods, including force plates and portable monitoring devices such as accelerometers, to assess changes in patients' weight-bearing activity and return to 'normal' gait (1–5). Although these devices provide comprehensive information, they may not be readily available in a clinical or research setting and a simpler, cheaper alternative may need to be employed. Force plates are generally fixed in position and require specialist installation. Even when this equipment is available, its use may prove prohibitively difficult where it is not readily accessible to patients with limited mobility. Manual handling issues, safety and convenience for both participant and researcher need to be considered. A simple and effective method using two sets of identically calibrated, high quality weighing scales, may therefore be preferable in some situations where patients are required to undergo a number of different tests, but cannot be conveniently and safely transferred between sites where other more specialised equipment may be available. Portable force plates are available but are relatively expensive. Data acquisition by this method can be time-consuming and may not be suitable for study populations suffering from severe pain that limits their ability to participate in extensive physical testing. Whilst the broad range of biomechanical information provided by force plates and accelerometers may be desirable in complex gait analysis, its clinical utility may be limited by the technical expertise required to use and interpret it (6). A dual-scales method could provide a simple and reliable alternative where only basic information on standing weight-bearing through the legs is required. It is evident that this method is currently used in some clinical situations to monitor changes in left/right weight distribution in patients recovering from conditions that are associated with alterations in posture. Although this is a simple option, no published studies have been found that have investigated the accuracy of this method.

The effects of altered or absent mechanical loading, resulting from immobilization, have been investigated in numerous studies of populations affected by stroke (7–9), spinal cord

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injury (10), bed-rest (11–13) and spaceflight (14, 15) where muscle loss and Disuse Osteopenia have been reported as a consequence. Disuse Osteopenia is a condition characterized by a loss of bone mineral density (BMD) and micro-architectural changes that may result in a reduction to the structural integrity of bones predisposing them to increased fracture risk (16–19). Prolonged immobilization, reduced weight bearing activity and altered L/R WB are inevitably associated with leg injury or surgery and potentially result in either unilateral or bilateral loss in BMD and leg muscle mass (20–27). In order to investigate the effects of altered L/R weight distribution in an injured study population using the dual- scales method, it is first necessary to assess the accuracy of the method, and the normal L/R WB variation of a general population in the immediate short term. Using the dual-scales method, L/R WB in an uninjured control sample from a current study on Disuse Osteopenia in a postmenopausal female population was used to investigate if minor/normal inequalities in L/R WB at a baseline visit were associated with any differences in L/R BMD and Lean Leg Tissue Mass (LLTM). Participants from this control group returned at 6 and 12 month intervals and were re-measured to assess the long-term variation in their L/R WB tendencies.

METHODS

This study investigated: 1) (a) The accuracy of a method for measuring L/R weight distribution using two sets of identically calibrated scales, and (b) the short-term variation of L/R WB tendencies in a general population sample comprising a mixed age and sex group of 9 volunteers (Group A). 2) (a) The effect of L/R WB inequalities at baseline on BMD at the hip and on LLTM measured by Dual Energy X-ray Asorptiometry (DXA), and (b) the long-term L/R WB tendencies in a control group of women from a current study investigating Disuse Osteopenia (Group B).

Participants

Group A comprised a mixed sex group of 9 volunteers (aged 19–54 years). Volunteers were recruited from students, staff and members of the public available at the Children's Health and Exercise Research Centre, University of Exeter. No exclusion criteria were applied other than absence of an adult history of leg fracture or surgery. Data were analysed from the control population, Group B, of an existing study investigating the effects of changes in L/R WB during recovery from leg injury or surgery. This group comprised 42 postmenopausal women >45 years, with no history of leg or ankle fracture. Participant characteristics for Groups A and B are shown in Table I.

The project was reviewed and approved by the Devon and Torbay Research Ethics Committee REC Ref: 09/H0202/64.

Table I. *Participant demographics of Group A (4 males and 5 females) and Group B (42 females)*

	Group A Mean (SD)	Group B Mean (SD)
Age, years	36.2 (17.0)	64.6 (7.6)
Height, m	1.68 (0.08)	1.64 (0.05)
Weight, kg	73.8 (8.2)	68.7 (10.0)
Body mass index, kg/cm^2	26.1 (2.9)	25.5 (3.13)

SD:standard deviation.

Methods

Group A. (a) Three participants from Group A were weighed on one set of scales to establish their true total weight. The scales were calibrated equally by placing identical weights on each. Ensuring stability of the scales, participants were then positioned in a natural standing posture astride two sets of scales (Seca 877, Germany) as shown in Fig. 1. Participants were instructed to stand in a forward facing position that they would naturally adopt when standing still with no specific instruction given regarding the placement of their feet on the scales. They were asked to look directly ahead, (to prevent participants adjusting their stance when seeing their readings), and were also asked not to speak during the measurement to avoid unnecessary movement. As it is not possible to simultaneously read both left and right digital readouts (due to the inherent tendency of participants to sway slightly), the measurement was recorded photographically. This procedure was repeated 10 times for each participant. The combined weight measured on the two scales was compared to the true total weight measured on one scale to calculate the error in the method. Recording the measurement photographically for routine use of this method was impractical due to the problem of glare from the camera flash that frequently obscures the weight reading in the image. The following technique was therefore applied for the remainder of the study. Participants were weighed on one set of scales to measure their total weight. To account for the natural tendency for participants to sway slightly when standing still, the mean of 3 random consecutive readings, recorded from the left hand side, was taken as representative of the participant's left side weight-bearing. The right measurement was calculated as the difference between left mean weight-bearing and the participant's total weight. Measurements were taken with the researcher standing slightly behind the participant to minimise any influence on their balance. To assess the possible influence of the researcher's proximity to the participant, the mean of 3 measurements was also recorded from the right side and compared to the calculated result. (b) The technique described above was repeated 10 times with repositioning after participants had walked across the room between measurements.

Group B. (a) Group B measurements acquired at their baseline visit by DXA (GE Lunar Prodigy, Bedford, MA) from bilateral hip and total body scans were correlated with L/R WB measurements at baseline to assess whether any inequalities in L/R WB at this time point were associated with differences in L/R LLTM or BMD at the Total Hip or Neck of Femur (NOF). These regions were selected as they are most clinically relevant for the assessment of fracture risk. (b) L/R WB measurements were recorded in Group B by the dual-scales method at each of 3 visits at baseline, 6 months and 12 months.

Fig. 1. Participant standing astride two identical scales in a natural standing posture.

Table II. *Dual Energy X-ray Asorptiometry results at baseline visit for Group B*

	Left leg Mean (SD)	Right leg Mean (SD)
BMD, g/cm^2 – NOF	0.89 (0.13)	0.90 (0.13)
BMD, g/cm^2 – total Hip	0.94 (0.15)	0.95 (0.15)
LLTM, kg	6.34 (0.76)	6.31 (0.79)

BMD: bone mineral density; NOF: neck of femur; LLTM: lean leg tissue mass; SD: standard deviation.

Statistical analysis

The mean percentage difference between total weight measured on one scale and the combined weight distributed over two scales was calculated. The Intraclass Correlation Coefficient (ICC) between the right calculated and right recorded results, for Group A, was computed (SPSS version 18.0). Short- and long-term consistency in L/R weight-bearing was calculated using the Root Mean Square Coefficient of Variation (RMSCV%) using the formula described by Gluer et al (28). Linear regression analysis (SPSS version18.0) was used to investigate relationships between left/right differences in weight-bearing and differences in BMD (at total hip & NOF sites) and LLTM from Group B results recorded at their first visit.

RESULTS

Group A. (a) The difference between total weight measured on one scale compared to dual-scales was 0.34%. The ICC between right calculated and right recorded WB was 0.77 ($p<0.05$). (b) The mean percentage L/R WB for Group A was 50/50 and the short-term CV for L/R WB was 5.41%.

Group B. (a) Measurements of hip BMD and LLTM, at baseline for Group B, are shown in Table II. No significant correlation was found in Group B between hip BMD differences and L/R WB at baseline. A weak, but statistically significant correlation of $r=0.31$ ($p=0.047$) was however found for differences in LLTM and L/R WB differences. (b) The mean percentage L/R WB at baseline for Group B was 51:49. The long-term CV for L/R WB in Group B was 7.01%.

DISCUSSION

The results demonstrate that total weight distributed over dual scales accurately reflects total weight measured on one scale, and this is an effective method for evaluating weight distribution through the legs in a natural standing posture. The posture of participants was only minimally affected by the proximity of the researcher when recording the measurements. The short- and long-term L/R WB tendencies in Groups A and B, respectively, showed a similar level of variation. In a healthy postmenopausal population, inequalities in L/R WB were not associated with any significant L/R differences in BMD at the hip, but were weakly correlated with L/R differences in leg muscle mass.

To assess the accuracy of two sets of identically calibrated scales to record the L/R distribution of total weight, it was necessary to establish that the combined weight measured whist standing astride two scales equalled the total weight measured conventionally on one scale. A photographic method was employed because the digital readout of the scales was highly sensitive to minor participant movements and it was therefore impossible to simultaneously read both digital readouts visually. The small amount of measurement error (0.34%) indicates that this is an accurate method. This photographic method is not however practical for routine use as the digital readout from the scale can often be obscured in the image due to glare from the camera flash. For this reason, having established that the dual scales are accurately measuring the distribution of total weight, an alternative visual method was adopted. To allow for the natural side-to-side sway of participants whilst standing on the scales, 3 consecutive readings were taken from the left-hand side and the mean of these calculated as representative of weight-bearing on that side. The right side was calculated as the difference between the left side mean weight-bearing and the participant's total weight (recorded on one set of scales). It should be stressed that the equipment used in this study were very high quality 'bathroom style' scales with large flat surfaces and no protruding dials as shown in Fig. 1. Participants were therefore able to place their feet on the scales in any position without adapting their normal stance. The efficacy of this method may not therefore be applicable to scales of a different design or poorer quality.

An individual's perception of 'personal space' is the area surrounding them within which they do not comfortably tolerate the proximity of a stranger (29), and it was therefore postulated that a participant's stance could be influenced by the proximity of the researcher with a tendency to move slightly towards or away from someone standing very close to them. This phenomenon was assessed by comparing the right side calculated result with the result recorded by the researcher standing on the right side. The ICC between the right calculated and right recorded results was 0.77 indicating that participants' balance was only minimally affected by the proximity of the researcher.

To establish the short-term consistency of L/R WB tendencies, Group A participants were re-measured 10 times after walking across the room and returning to stand on the scales. Their results demonstrated a short-term CV of 5.41% indicating that there is a small amount of short-term inconsistency/variation in participants L/R WB tendencies. The long-term CV over 3 visits at 6 month intervals for Group B was 7.01% indicating a degree of L/R WB variation comparable to the short-term CV in a general population sample represented by Group A. Fig. 2 shows the left side weight-bearing variation of individual participants in Group B over the 12-month period and although a number of participants demonstrated considerable long-term variation in their weight-bearing, most showed a consistent tendency to bear more weight on a particular side.

As participants from both Group A and B were fully mobile with no recent history of lower limb injury, it was not expected that either would demonstrate any notable difference in their left/right weight-bearing. Whilst a number of individuals exhibited large differences between their left and right weight-bearing, the percentage means for groups A and B were 50/50 and 49/51,

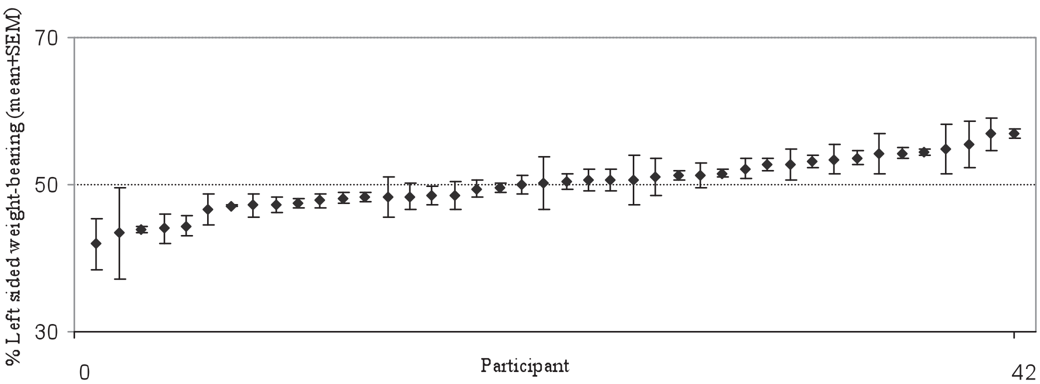

Fig. 2. Group B – Left sided weight bearing, mean of 3 visits, expressed as percentage of total weight-bearing for individual participants ($n=42$). SEM: standard error of the mean.

respectively. It was therefore not anticipated that significant differences would be apparent in the Group B left/right measures of BMD and this was confirmed by the results. A small but statistically significant correlation was however found for differences in LLTM and L/R WB differences. The reason for this result is unclear. Whilst evidence from the literature suggests that any deficit in LLTM or BMD is attributable to reduced mechanical loading, it could also be feasible that weight-bearing inequalities are the result of unilaterally reduced muscle mass. In a study of healthy young adults, Hoffman et al. (30) found no difference in unilateral postural stability between the functionally dominant and nondominant lower limbs and therefore leg dominance (comparable to left or right-handedness) is not thought to account for these side-to-side differences. Leg dominance was not however investigated in this study.

In populations sustaining lower limb injury or surgery, it is possible for the range of unilateral weight-bearing to be 0–100% over the period from injury to full remobilization, potentially resulting in marked changes bilaterally in BMD and LLTM during the course of recovery. Although Group B participants had no history of leg or ankle fracture, 11 participants reported previous unilateral leg pathology, and 3 bilateral. These injuries or disabilities ranged in severity from minor arthritis to a ruptured patella tendon, and in incidence from 18 months to 40 years previously. The mean percentage L/R WB of these participants as a sub-group was not however significantly different to the non-injured controls; 49/51 compared to 51/49, respectively.

Although the results in the current paper relate to a fully ambulatory population, in circumstances where injured participants use support from either walking sticks or crutches, weight bearing on their legs is measured by weighing them with the supports resting on the adjacent floor in their normal standing, supported position. Relative left/right weight-bearing is then calculated as a percentage of their total unsupported weight. All participants in this study were able to provide an unsupported weight measurement.

The major limitation of this dual-scales technique is that it measures weight-bearing in an upright stance and this may not be representative of typical weight-bearing during other activities including walking. Participants frequently commented that they rarely stand in this forward facing upright posture and adopt a more casual stance when standing for long periods. This may be less applicable to patient populations whose injuries limit their postural flexibility. It is acknowledged that this dual-scales method can only provide limited postural information on L/R weight distribution and the accuracy of this method has not been compared to the same parameter as measured by alternative, more sophisticated methods; nor does this study attempt to infer any information regarding other parameters of gait or balance. This method, using scales of suitable quality, does however afford sufficient refinement to discriminate between the relatively minor L/R WB inequalities demonstrated by a normal/control population with the greater left/right differences likely to be exhibited in patient populations affected by leg injuries or surgery. It has the advantage of being safe, easy to use and relatively inexpensive compared to alternative methods for weight-bearing assessment using equipment such as force plates or accelerometers.

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REFERENCES

1. Aranzulla PJ, Muckle DS, Cunningham JL. A portable monitoring system for measuring weight-bearing during tibial fracture healing. Med Eng Phys 1998; 20: 543–548.
2. Van den Akker-Scheek I, Stevens M, Bulstra SK, Groothoff JW, van Horn JR, Zijlstra W. Recovery of gait after short-stay total hip arthroplasty. Arch Phys Med Rehab 2007; 88: 361–367.
3. Choquette S, Hamel M, Boissy P. Accelerometer-based wireless body area network to estimate intensity of therapy in post-acute rehabilitation. J Neuroengineering Rehabil 2008; 5: 20.
4. Van Hermert WLW, Meyers WGH, Kleijn LLA, Heyligers IC, Grimm B. Functional outcome of knee arthroplasty is dependent upon the evaluation method employed. Eur J Orthop Surg Traumatol 2009; 19: 415–422.
5. Brandes M, Ringling M, Winter C, Hillmann A, Rosenbaum D.

Changes in physical activity and health-related quality of life during the first year after total knee arthroplasty. Arthrit Care Res 2011; 63: 328–334.
6. Visser JE, Carpenter MG, van der Kooij H, Bloem BR. The clinical utility of posturography. Clin Neurophysiol 2008; 119: 2424–2436.
7. Poole KE, Warburton EA, Reeve J. Rapid long-term bone loss following stroke in a man with osteoporosis and atherosclerosis. Osteoporosis Int 2005; 16: 302–305.
8. Demirbag D, Ozdemir F, Kokino S, Berkarda S. The relationship between bone mineral density and immobilization duration in hemiplegic limbs. Ann Nucl Med 2005; 19: 695–700.
9. Beaupre GS, Lew HL. Bone-density changes after stroke. Am J Phys Med Rehabil 2006; 85: 464–472.
10. Uebelhart D, Demiauxdomenech B, Roth M, Chantraine A. Bone metabolism in spinal cord injured individuals and in others who have prolonged immobilisation. A review. Paraplegia 1995; 33: 669–673.
11. Bloomfield SA. Changes in musculoskeletal structure and function with prolonged bed rest. Med Sci Sport Exer 1997; 29: 197–206.
12. Thomsen JS, Morukov BV, Vico L, Alexandre C, Saparin PI, Gowin W. Cancellous bone structure of iliac crest biopsies following 370 days of head-down bed rest. Aviat Space and Envir Med 2005; 76: 915–922.
13. Berg H, Eiken O, Miklavcic L, Mekjavic I. Hip, thigh and calf muscle atrophy and bone loss after 5–week bedrest inactivity. Eur App Physiol 2007; 99: 283–289.
14. Sibonga JD, Evans HJ, Sung HG, Spector ER, Lang TF, Oganov VS, et al. Recovery of spaceflight-induced bone loss: Bone mineral density after long-duration missions as fitted with an exponential function. Bone 2007; 41: 973–978.
15. LeBlanc A, Spector ER, Evans HJ, Sibonga J. Skeletal responses to space flight and the bed rest analog: A review. J Musculoskelet Neuronal Interact 2007; 7: 33–47.
16. Sarangi PP, Ward AJ, Atkins RM. Fractures after regional disuse osteoporosis. J Orthop Rheumatol 1992; 5: 233–237.
17. Robinson CM, Adams CI, Craig M, Doward W, Clarke MCC, Auld J. Implant-related fractures of the femur following hip fracture surgery. J Bone Joint Surg Am 2002; 84: 1116–1122.
18. Suva LJ, Gaddy D, Perrien DS, Thomas RL, Findlay DM. Regulation of bone mass by mechanical loading: microarchitecture and genetics. Curr Osteoporos Rep 2005; 3: 46–51.
19. Van der Meulen MC, Globus RK. Progress in understanding disuse osteopenia. Curr Opin Orthop 2005; 16: 325–330.
20. Henderson RC, Kemp GJ, Campion ER. Residual bone-mineral density and muscle strength after fractures of the tibia or femur in children. J Bone Joint Surg-Am 1992; 74A: 211–218.
21. Karlsson MK, Nilsson BE, Obrant KJ. Bone-mineral loss after lower-extremity trauma – 62 cases followed for 15–38 years. Acta Orthop Scan 1993; 64: 362–364.
22. Kannus P, Jarvinen M, Sievanen H, Jarvinen TAH, Oja P, Vuori I. Reduced bone-mineral density in men with a previous femur fracture. Bone Min Res 1994; 9: 1729–1736.
23. Van der Wiel HE, Lips P, Nauta J, Patka P, Haarman H, Teule GJJ. Loss of bone in the proximal part of the femur following unstable fractures of the leg. J Bone Joint Surg-Am 1994; 76A: 230–236.
24. Karlsson M, Nilsson JA, Sernbo I, RedlundJohnell I, Johnell O, Obrant KJ. Changes of bone mineral mass and soft tissue composition after hip fracture. Bone 1996; 18: 19–22.
25. Jarvinen M, Kannus P. Current Concepts Review – Injury of an extremity as a risk factor for the development of osteoporosis. J Bone Joint Surg Am 1997; 79: 263–276.
26. Van der Poest Clement E, Van der Wiel H, Patka P, Roos JC, Lips P. Long-term consequences of fracture of the lower leg: cross-sectional study and long-term longitudinal follow-up of bone mineral density in the hip after fracture of lower leg. Bone 1999; 24: 131–134.
27. Knapp KM, Rowlands AV, Welsman JR, MacLeod KM. Prolonged unilateral disuse osteopenia 14 years post external fixator removal: A case history and critical review. Case Rep Med 2010; 2010: 629020.
28. Gluer CC, Blake G, Lu Y, Blunt BA, Jergas M, Genant HK. Accurate assessment of precision errors: how to measure the reproducibility of bone densitometry techniques. Osteoporosis Int 1995; 5: 262–270.
29. Hall ET. A System for the notation of proxemic behavior 1. Am Anthropol 1963; 65: 1003–1026.
30. Hoffman M, Schrader J, Applegate T, Koceja D. Unilateral postural control of the functionally dominant and nondominant extremities of healthy subjects. J Athl Train 1998; 33: 319–322.