Effect of Age on Partial Weight-bearing Training

JOSHUA W. HUSTEDT, BA; DANIEL J. BLIZZARD, BS; MICHAEL R. BAUMGAERTNER, MD; MICHAEL P. LESLIE, DO; JONATHAN N. GRAUER, MD

abstract

Biofeedback devices are increasingly used to train orthopedic patients to comply with partial weight-bearing instructions for an injured or postoperative extremity. In a previous study, the authors showed that biofeedback was effective in training young participants. However, because many partial weight-bearing orthopedic patients are of advanced age, the current study was designed to test the effect of age on partial weight-bearing training.

Fifty asymptomatic participants aged between 20 and 78 years completed 3 interventions: (1) verbal instructions on weight bearing, (2) training with a bathroom scale, and (3) training with a biofeedback device. Participants given only verbal touchdown weight-bearing instructions (25 lb) initially bore an average of 61.25±4.80 lb. This was reduced to 51.50±4.47 lb after training with a bathroom scale and further reduced to 30.01±2.33 lb after biofeedback training. Likewise, participants given verbal partial weight-bearing instructions (75 lb) initially bore an average of 89.06±5.58 lb. No improvement was observed with the use of a bathroom scale (average, 88.47±4.75 lb). After training with the biofeedback device, weight bearing improved to an average of 68.11±2.46 lb. Mixed-model analysis revealed that age was not a significant predictor of compliance. However, a higher body mass index and male sex were predictive of worse compliance and heavier weight bearing.

Biofeedback training leads to superior compliance to weight-bearing instructions compared with verbal instructions or training with a bathroom scale. Because partial weight-bearing instructions are commonly given to orthopedic patients, biofeedback training may be appropriately considered in any age group with similar effect.

Messrs Hustedt and Blizzard and Drs Baumgaertner, Leslie, and Grauer are from the Department of Orthopaedics and Rehabilitation, Yale University School of Medicine, New Haven, Connecticut. Messrs Hustedt and Blizzard and Drs Baumgaertner, Leslie, and Grauer have no relevant financial relationships to disclose. Funding for this study was provided by The Community Foundation for Greater New Haven. No funding was provided by the company producing the biofeedback device being studied. Correspondence should be addressed to: Jonathan N. Grauer, MD, Department of Orthopaedics and Rehabilitation, Yale University School of Medicine, PO Box 208071, New Haven, CT 06520-8071 (jonathan.grauer@yale.edu).

doi: 10.3928/01477447-20120621-23
Orthopedic patients are often instructed on how much weight to bear on an injured or postoperative extremity. Common instructions are for touchdown weight bearing, partial weight bearing (often prescribed in number of pounds), or weight bearing as tolerated. The rationale for restricting weight bearing is to limit the load on an injured or operative site.1

A single load or repetitive loading above a tolerance point could potentially lead to deformation or loss of the alignment or fixation of a surgical construct.2 Conversely, the rationale for advancing weight bearing is that loads can stimulate osteoblastic activity in certain fracture patterns and fixation constructs.3 Thus, a common recommendation for an injured extremity is for restricted weight bearing that is gradually liberalized as healing occurs.

Although specific weight-bearing instructions are given to a majority of lower-extremity orthopedic patients, it is difficult for patients to learn to comply with these instructions.4,5 In an effort to find an effective teaching method for training patients to comply with restricted weight bearing of the lower extremities, the authors previously conducted a trial of the SmartStep biofeedback weight-bearing system (Andante Medical Devices, Ltd, Omer, Israel).6

In a young, asymptomatic population, initial results suggested that training with biofeedback was superior to training with a bathroom scale or verbal instructions alone in aiding patients to comply with partial weight-bearing instructions.6 To determine the clinical applicability of this new biofeedback training method, its use in older age groups needed to be validated.

The authors’ initial hypothesis was that, even with biofeedback training, older patients would have a harder time complying with partial weight-bearing instructions, thus possibly limiting the effective use of a biofeedback device. To determine this, a prospective clinical trial was conducted in asymptomatic participants of varying ages.

MATERIALS AND METHODS

Participants

For the previous study, 20 asymptomatic participants (10 men and 10 women) aged between 20 and 30 years were recruited for an initial evaluation of the biofeedback device.6 For the current study, an additional 30 participants (11 men and 19 women) aged between 30 and 78 years were recruited to determine the effect of age on partial weight bearing. All participants were recruited from within the authors’ institution.

For statistical evaluation of the effect of age, both sets of recruited participants were combined, yielding 50 asymptomatic participants (21 men and 29 women) aged between 21 and 78 years (average age, 41.48 years). Average weight was 159.7 lb (range, 98-300 lb), average height was 67.74 in (range, 59-75 in), and average body mass index (BMI) of 24.33 kg/m² (range, 15.8-40.7 kg/m²).

Inclusion criteria included age older than 18 years, overall good health, the ability to walk while bearing total body weight on either lower extremity, and sufficient upper body strength and coordination to use crutches. Exclusion criteria included any restriction to full weight bearing on the lower extremities and any reason to be unable to use crutches to offset lower-extremity weight (eg, upper-extremity injury, weakness, or neuropathy).

This study was approved by the Yale University Human Investigative Committee.

Monitoring of Weight Bearing

Weight bearing was monitored with the mobile SmartStep device, which offers continuous weight-bearing monitoring of the forefoot and hindfoot (these were treated as a combined total weight-bearing measure for the purpose of this study).

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Figure 1: Photograph of the SmartStep weight-monitoring device (Andante Medical Devices, Ltd, Omer, Israel).

Figure 2: Graph showing comparison of verbal instructions to train with a scale and a biofeedback device at touchdown weight bearing (25 lb). Mean values for all 50 participants are presented. Bars represent the standard error, asterisks represent a statistical difference from verbal instructions, and the arrowhead represents a statistical difference. The reference line shows the 25-lb weight-bearing goal.
The device consists of 3 components: (1) a 5-mm-thick, air-inflated insole worn in the participant’s shoe; (2) a measurement device strapped to the participant’s ankle that is connected to the air-inflated insole (Figure 1); and (3) a software program that allows for continuous Bluetooth (Belkin, Playa Vista, California) communication between the measurement device and a laptop computer. Previous studies have found this system to be highly accurate compared with a force plate \( (P<.05; R^2 = 0.907) \), with a standard error of ±0.116 lb.

Participants were asked to walk for 50 consecutive steps for each activity. A 50-step increment has been shown to offer a representative sample of a participant’s average weight bearing.

**Weight-bearing Goals**

One goal of this study was to measure the clinical effectiveness of different forms of training for partial weight bearing. To do so, specific weight-bearing goals needed to be established. However, no universally accepted increments of weight bearing exist for patients requiring partial weight-bearing status. As previously noted, the most common instructions are for touchdown weight bearing, partial weight bearing, and weight bearing as tolerated.

For the purpose of this study, touchdown weight bearing was defined as 25 lb and partial weight bearing was defined as 75 lb. Although alternative numbers could have been chosen for these groups, these definitions afforded specific goals that could be studied and sufficient spread between the goal weights to create distinct study groups.

**Weight-bearing Instruction Methods**

Three different methods of weight-bearing instruction were used in this study: verbal instruction, bathroom scale training, and biofeedback training. Each method was administered in a standardized fashion.

Verbal instruction consisted of simple descriptions of different weight-bearing goals. This is the most common level of intervention provided directly by an orthopedist. Standard weight-bearing instructions were used throughout the study as defined by our orthopedic traumatologists (M.R.B., M.P.L.).

Bathroom scale training used a spring-loaded bathroom scale. Participants were instructed to place a crutch on either side of the scale and practice transferring weight on and off the scale to a given weight restriction of 25 or 75 lb. This is the most common type of training provided by staff and physical therapists at most institutions.

Biofeedback training used an internal function from the gait monitoring system.
In addition to measuring ground reaction forces, the device can be configured to offer 2 types of auditory feedback to participants—a lower-limit alarm (single beep) and an upper-limit alarm (triple beep)—to help train them to comply with a specified range of weight bearing. This feature can be turned on and off, and, in this study, the auditory feedback was only used during the biofeedback training session. At all other times, the device was configured to measure ground reaction forces.

Data Collection

Participants were first instructed on the use of crutches by a member of the research staff (J.W.H.). Participants were taught a 3-point crutch stance to offset weight from their right lower extremity (a single extremity was chosen for consistency). Participants were asked to practice walking with the crutches for a minimum of 50 steps and were continually instructed until they felt comfortable.

Testing began with verbal instructions (no training). Participants were asked to walk with crutches at weight-bearing instructions of 25 and 75 lbs. The order in which the weight limitations were given was randomized for each participant. Throughout the study, participants took a short break in between each activity to ensure they were not fatigued.

Next, participants were instructed on the use of a bathroom scale as previously described. Participants practiced with the use of the scale and then immediately walked without the scale for 50 consecutive steps. The order in which the participants performed the 25- and 75-lb weight-bearing instructions was randomized.

Finally, participants were instructed on the use of the biofeedback mechanism of the SmartStep device. For the 25-lb weight range, a lower limit of 15 lb and an upper limit of 35 lb were used. For the 75-lb weight range, a lower limit of 65 lb and an upper limit of 85 lb were used. These weight ranges were used because previous studies have reported a lag time in responding to biofeedback. Therefore, optimal training is achieved when a weight limitation signal is set just below the desired weight-bearing goal.

Participants were asked to walk with the use of biofeedback until they felt comfortable with the weight-bearing instructions (average, 1-2 minutes). Immediately following, the biofeedback was turned off and the participants were assessed for 50...
consecutive steps. The process was repeated for the other weight-bearing limit. The order in which the 25- and 75-lb weight limits were performed was randomized for each participant.

**Data Analysis**

For each activity, the first 5 steps and the last 5 steps for each participant were omitted, leaving 40 steps to be used for determination of each participant’s average on each activity. A repeated-measures analysis of variance with post hoc paired t testing with Bonferroni adjustment was used to compare the means of the verbal instructions, the bathroom scale training, and the biofeedback training for the 25- and 75-lb weight instructions for all 50 patients. Significance was set at *P* ≤ .05.

To determine statistically significant predictors associated with partial weight-bearing compliance, a mixed linear-effects model was created. Covariates recorded in the study included: (1) participant characteristics of age, sex, BMI, weight (lb), and height (in); and (2) testing parameters including weight designation (25 or 75 lb) and instruction type (verbal, scale, or biofeedback training). Significance in the multivariate model was set at *P* = .05.

Because the purpose of the study was to estimate the population mean based on the use of the sample means collected, standard error calculations were used throughout the study. Data analysis was conducted using SAS version 9.2 statistical software (SAS Institute Inc, Cary, North Carolina).

**RESULTS**

**Determining the Most Effective Training Methodology**

All 50 participants completed each activity (verbal instructions, scale training, and biofeedback training) at 25 and 75 lb. Averages for each activity are presented for the 25- and 75-lb goals in Figures 2 and 3, respectively.

Figure 2 shows the average weight bearing for participants asked to bear 25 lb. When given verbal instructions, participants bore an average of 61.25 ± 4.80 lb on their extremity, far exceeding the given instructions of 25 lb. This was reduced to 51.50 ± 4.47 lb after training with a bathroom scale and further reduced to 30.01 ± 2.33 lb after biofeedback training.

At 25 lb, training with a bathroom scale (*P* = .010) and a biofeedback device (*P* < .001) showed improvements over verbal instructions alone. In addition, biofeedback offered an additional improvement over training with a bathroom scale (*P* < .001).

At 75 lb, only training with a biofeedback device offered improvements over verbal instructions alone. No statistically significant difference existed between verbal instructions and training with a bathroom scale (*P* = 1.000). However, training with a biofeedback device offered a statistically significant improvement over both verbal instructions (*P* = .001) and scale training (*P* < .001).

**Identifying Significant Predictors of Partial Weight-bearing Compliance**

To determine statistically significant predictors affecting partial weight bearing, a mixed linear-effects model was used to control for covariates, as previously described. Because BMI and weight were highly correlated (*r* = 0.863; *P* < .001), as were weight and height (*r* = 0.647; *P* < .001), only BMI or weight could be included in the multivariate model. Participant BMI was chosen to be included in the model because it accounted for both weight and height. Therefore, the multivariate model included BMI, age, sex, instruction type, and weight designation (25 or 75 lb). Thus, it was possible to predict a participant’s outcome weight while controlling for confounding variables, thereby identifying possible clinical risk factors associated with partial weight-bearing patients.
BMI Is a Significant Predictor of Weight Bearing

The mixed model found BMI to be a significant predictor of partial weight bearing ($\beta=1.432; \ p=.003$); the higher the BMI, the more likely it was that the participant exceeded given weight-bearing instructions. Figure 4 illustrates the effect of BMI compared across each activity type. Therefore, patients with higher BMIs will be at a high risk of exceeding given weight-bearing limitations.

Touchdown Weight Bearing (25 lb) vs Partial Weight Bearing (75 lb)

The type of weight-bearing limitation given also affects participant compliance. When participants were given touchdown weight-bearing instructions (25 lb), they were significantly more likely to exceed the instructions than when given partial weight-bearing instructions (75 lb). This was true for verbal instructions ($P<.001$), scale training ($P<.001$), and biofeedback training ($P<.001$). The model-predicted mean difference from the given weight-bearing instruction is shown in Figure 5.

Effect of Sex on Partial Weight Bearing

Sex had a significant effect on weight bearing for verbal instructions ($P=.009$) and scale training ($P=.041$) but not for biofeedback training ($P=1.000$). Men were more likely to exceed instructions when given verbal instructions or after scale training, even after the model controlled for other confounders, such as higher weight and BMI. Therefore, with verbal and scale training, men will be more likely to exceed weight-bearing limitations (Figure 6).

Age Is Not a Significant Predictor of Partial Weight Bearing

Age was not found to be a significant predictor of partial weight bearing ($\beta=0.159; \ p=.126$). Figure 7 represents weight-bearing outcomes for different ages as predicted by the mixed model. Although a slight increase in weight bearing existed as age increased at 25 lb, this was not found to be statistically significant. Therefore, age is not a significant predictor of weight bearing after training with a biofeedback device.

**DISCUSSION**

Specific weight-bearing instructions are commonly prescribed for many injured or postoperative orthopedic patients. However, many patients struggle to comply with weight-bearing instructions under current training methods. The current authors previously reported that the SmartStep biofeedback device was successful in training young, asymptomatic participants to comply with given weight-bearing instructions. The current study shows that the SmartStep is effective across age ranges, suggesting that it could have high clinical applicability among partial weight-bearing orthopedic patients regardless of age.

In addition to answering the important question of the effect of age on weight bearing, the study had 2 additional important purposes: (1) to verify that biofeedback training is superior to verbal or scale training in older age groups, and (2) to identify significant predictors associated with partial weight-bearing compliance. The large number of participants in this study allowed the authors to identify clinical factors that place patients at greater risk of exceeding weight-bearing instructions, including high BMI and touchdown weight-bearing instructions.

Many researchers believe that obtaining patient compliance in partial weight-bearing is unachievable. However, the current authors’ studies suggest that, with proper training, it is possible to train asymptomatic participants to comply with instructions for limited weight bearing to the lower extremities. In the current study, values of 25 and 75 lb were used to define touchdown and partial weight bearing. Partial weight-bearing instructions will vary by surgeon based on patient body habitus, nature of the orthopedic pathology/problem, type of treatment, and expected outcome. Therefore, the authors do not claim these values as absolute values, but rather chose them to define the effective use of biofeedback in training patients. Although significant differences were found between verbal, scale, and biofeedback training at the defined weight-bearing limits, the authors’ goal was not to define specific weight-bearing limitations but rather to make a statement on the superiority of biofeedback to other training modalities. The SmartStep can be configured to any given weight as prescribed by the surgeon and as indicated by the individual patient’s circumstance, thereby universalizing it for a broader patient population.

The study had 2 main limitations: (1) training was done in an asymptomatic population, and (2) weight bearing was assessed immediately following the training period. Asymptomatic research participants were assessed as opposed to postoperative patients because the effectiveness of biofeedback has yet to be fully elucidated in the medical literature. To date, the authors could find no study showing the effective use of biofeedback in older age groups. Furthermore, the effective use of biofeedback has not been clearly described in the medical literature, with some authors reporting that biofeedback is effective in certain lower-extremity fracture populations and others reporting that compliance in weight bearing is not attainable in other populations.

This lack of consensus in biofeedback research is in part due to the rapid implementation of the technology without adequate preliminary studies to determine proper uses in defined study populations. Therefore, the current authors decided to conduct their study in an asymptomatic population to first confirm the effectiveness of biofeedback. Undertaking a clinical study prior to doing so would be misguided because no study has yet shown definitive results that biofeedback is effective in older populations.
This study’s results suggest that biofeedback is an effective training methodology in all age groups; therefore, future studies in asymptomatic populations are warranted. Furthermore, the authors anticipate their results will be mirrored in asymptomatic individuals because this has been shown in a weight-bearing side-by-side comparison study of asymptomatic and symptomatic individuals by Dabke et al. 10

The current authors’ previous study showed that biofeedback is effective in a young, asymptomatic population.6 However, a large proportion of orthopedic partial weight-bearing patients are of advanced age. Therefore, it was appropriate to delineate the effectiveness of biofeedback across age groups. A repeated-measures design was used as opposed to a randomized design under the assumption that both verbal instructions and bathroom scales have already been shown to be ineffective in weight-bearing training.11,14,15 It is conceivable that as patients are trained over time, they increase their knowledge of weight bearing and this biases the results toward biofeedback. However, the authors controlled for this confounding factor by using a training period prior to weight-bearing assessment previously validated to eliminate the variability in compliance over time.6

Some researchers claim that although biofeedback is effective in the short term, its effectiveness wanes over time.9 However, initial studies have suggested that training with the SmartStep device shows long-term retention ability.16 Although definitive evidence is forthcoming, the authors argue that even if the effectiveness of biofeedback wanes over time, a role exists for biofeedback in orthopedic patients, with options including the constant use of biofeedback over the rehabilitation period or repeated training with biofeedback titrated to acquire the skills of partial weight bearing. Biofeedback offers training superior to verbal instructions and bathroom scales, making it an essential component of partial weight-bearing training.

**Conclusion**

The use of a biofeedback device was effective in training participants to comply with partial weight-bearing instructions. This effectiveness was seen across age ranges. Because prescribing specific weight-bearing instructions is a routine part of orthopedic practice, finding ways to define and control patient compliance is of clear clinical importance. Therefore, biofeedback devices may be an appropriate avenue to pursue for such training.

**References**


