Partial Weight-Bearing Gait Using Conventional Assistive Devices

James W. Youdas, PT, MS, Brian J. Kotajarvi, PT, MS, Denny J. Padgett, PT, Kenton R. Kaufman, PhD


Objective: To determine if subjects can offload the right lower extremity to a targeted amount of weight bearing using assistive devices.

Design: Case series.

Setting: Motion analysis laboratory.

Participants: Ten healthy subjects (5 men, 5 women) without lower-extremity injury and minimal experience using ambulatory aids.

Interventions: Before data collection subjects were trained by a physical therapist to offload the right lower extremity by 50% by using an assistive device and a bathroom scale for feedback on weight reduction.

Main Outcome Measures: Vertical ground reaction force was measured by using forceplates while subjects walked at a self-selected speed by using a 3-point partial weight-bearing (PWB) gait pattern with axillary crutches, forearm crutches, and wheeled walker. We also measured vertical ground reaction force by using a single-point cane.

Results: Each gait aid significantly reduced the right lower-extremity peak vertical ground reaction force. Participants were able to achieve the target of approximately 50% weight reduction with the axillary (50% reduction) and forearm (56% reduction) crutches. The wheeled walker resulted in a peak vertical load of 64% of body weight, which was in excess of the target load. A single-point cane produced a peak vertical load of 76% of body weight.

Conclusions: By using a bathroom scale, healthy subjects could be trained to achieve a target goal of 50% PWB with axillary and forearm crutches. A wheeled walker resulted in weight bearing greater than the target of 50% of body weight. Subjects were able to offload the right lower extremity by about 25% of body weight by using a single-point cane.

Key Words: Assistive devices; Biomechanics; Gait; Kineti cs; Rehabilitation

© 2005 by American Congress of Rehabilitation Medicine and the American Academy of Physical Medicine and Rehabilitation

Patients are frequently instructed to use an ambulatory assistive device after lower-extremity injuries and surgeries. At times, the aid is used merely for balance. However, for other patients, limited weight bearing is essential to the recovery process and a successful partial weight-bearing (PWB) gait is central to a patient’s rehabilitation program. It has been reported that PWB is not easy to perform.1,2 Although physical therapists routinely instruct patients in the correct use of various gait aids and gait patterns to reduce load on the affected lower extremity (LE), a therapist cannot easily and accurately determine the actual load placed on the patient’s involved limb.

Clinically, 1 strategy for estimating a patient’s weight-bearing status requires the patient to stand with his/her assistive device while the therapist places his/her hand under the foot of the involved LE. The therapist can then estimate the amount of PWB the patient is placing on the involved limb.1 Another similar strategy requires the patient to stand in place with a bathroom scale substituted for the therapist’s hand, and the patient gradually loads the limb to a prescribed weight. Researchers1 examining the usefulness of these 2 strategies with healthy subjects have shown considerable variability between the target load and actual load placed on the limb. One weakness of these studies is that force measurements were taken in static postures. Reproducibility of a prescribed load may differ during a dynamic activity such as gait.

Studies evaluating load bearing during gait are limited in number and have had mixed results. For instance, Warren and Lehmann2 conducted a series of experiments in which they trained healthy female college students to ambulate on parallel bars by using a 3-point gait pattern while attempting to load the designated limb at a series of target loads. Training methods included use of a bathroom scale and a limb load monitor with auditory feedback. Although the subjects mastered the criterion load during the training session, their performance was short lived and diminished a day or 2 after training. Warren and Lehmann2 concluded that it is clinically difficult or impossible to prescribe with reasonable accuracy a load-bearing limit for patients using crutches, canes, or prosthetic devices. Most recently, Li et al13 reported variability in the vertical ground reaction force during PWB using axillary crutches. These investigators studied 12 healthy subjects who practiced placing 10%, 50%, and 90% of their body weight on their designated “affected” extremity by using a 3-point gait pattern during level walking. Subjects were more consistent at placing 50% of body weight on the affected LE than they were with the other target percentages.

The purpose of the present study was to describe the peak vertical ground reaction force of both LEs, as a percentage of body weight, while subjects walked at self-selected speeds and attempted to maintain 50% of their body weight on the right LE while using axillary crutches, forearm crutches, and a wheeled walker. Although PWB guidelines vary with limb pathology and practitioner preference, we chose 50% offloading based on the investigators’ clinical experiences. The hypothesis of this study was that, after brief training, healthy subjects would be able to consistently unload, as measured by vertical ground reaction force, their right LE by 50% of body weight with a wheeled walker. They would be less successful maintaining 50% PWB on the right LE with the axillary and forearm crutches and single-point cane. Although a single-point cane is...
pushed the wheeled walker forward without any pauses. We pattern was used for the axillary and forearm crutches. Subjects was repeated for each device. A 3-point walk-through gait particular device for approximately 15 minutes. This procedure reproduce the feeling of 50% of body weight on the right LE approximately 50% of their body weight. Subjects were told to they observed the numbers on the scale until they reached wood the same vertical height as the bathroom scale. While the right LE on a bathroom scale and the left LE on a block of lines.4-6 Subjects stood erect holding each assistive device with each subject with the gait aids according to established guide- proctors who were allowed to continue in the study. The Mayo Clinic Institutional Review Board approved the study.

Instrumentation
Temporal-distance factors (stride length, step length, walking speed, cadence, percentage in stance time, step width) were obtained by a 10-camera, video-based, motion analysis sys-
tem.5 Ground reaction force data were obtained at a sampling rate of 600Hz from 2 AMTI forceplates6 and 2 Kistler forceplates.5 Data from these forceplates were time-synchronized with the motion measurement system to determine gait events.

Procedures
Two days before data collection, a physical therapist fitted each subject with the gait aids according to established guidelines.4-6 Subjects stood erect holding each assistive device with the right LE on a bathroom scale and the left LE on a block of wood the same vertical height as the bathroom scale. While bearing weight solely on the right LE, subjects gradually transferred their body weight to the assistive device. As they did so, they observed the numbers on the scale until they reached approximately 50% of their body weight. Subjects were told to reproduce the feeling of 50% of body weight on the right LE when walking with the assistive device. Immediately after this visual feedback, subjects practiced the gait pattern for that particular device for approximately 15 minutes. This procedure was repeated for each device. A 3-point walk-through gait pattern was used for the axillary and forearm crutches. Subjects pushed the wheeled walker forward without any pauses. We acknowledge that use of a single-point adjustable aluminum cane with 50% of weight bearing is not recommended clinically. However, we chose to examine how much healthy subjects could offload the right LE using a cane. Therefore, in the case of single-point cane assisted gait, each subject advanced the right LE simultaneously with the cane, which was held in the left hand. For proper unloading of the LE, the right heel and cane tip contacted the ground together.

Data Collection
On the day of testing, data on normal unaided walking were collected first, followed by testing with the assistive devices in random order to reduce the effects of learning. Subjects traversed a 25-m walkway using the crutches, single-point cane, and front-wheeled walker, while attempting to load only 50% of body weight onto the right LE. Five trials were collected for each condition and then averaged for data analysis.

Table 1: Summary of Spatial and Temporal Descriptors

<table>
<thead>
<tr>
<th>Descriptors</th>
<th>No Assistive Device</th>
<th>Axillary Crutches</th>
<th>Forearm Crutches</th>
<th>Single-Point Adjustable Aluminum Cane</th>
<th>Wheeled Walker</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Right</td>
<td>Left</td>
<td>Right</td>
<td>Left</td>
<td>Right</td>
</tr>
<tr>
<td>Stride length (cm)</td>
<td>138.4±12.5</td>
<td>124.3±7.0</td>
<td>124.6±6.1</td>
<td>120.6±5.6</td>
<td>112.9±70</td>
</tr>
<tr>
<td>Walking speed (cm/s)</td>
<td>128.1±14.1</td>
<td>76.1±11.4</td>
<td>75.6±10.0</td>
<td>76.2±13.2</td>
<td>65.3±14.6</td>
</tr>
<tr>
<td>Cadence (steps/min)</td>
<td>110.9±5.4</td>
<td>73.4±9.0</td>
<td>73.2±8.5</td>
<td>75.7±10.7</td>
<td>69.4±12.4</td>
</tr>
<tr>
<td>Step width (cm)</td>
<td>11.1±2.1</td>
<td>9.7±2.0</td>
<td>9.3±2.6</td>
<td>11.1±3.3</td>
<td>9.3±1.8</td>
</tr>
<tr>
<td>Step length (cm)</td>
<td>69.4±5.9</td>
<td>68.5±6.5</td>
<td>59.9±4.7</td>
<td>64.3±4.3</td>
<td>61.3±3.6</td>
</tr>
<tr>
<td>Stance time (%)</td>
<td>61.3±1.3</td>
<td>61.4±1.1</td>
<td>50.0±11.5</td>
<td>65.2±3.3</td>
<td>60.0±2.3</td>
</tr>
</tbody>
</table>

NOTE. Values are mean ± standard deviation. The right side was the designated side to be offloaded.

not recommended for PWB gait, we chose to investigate its status because it is a conventional assistive device.

METHODS

Participants
Ten subjects (5 men, 5 women) with a mean age of 24.3±6.0 years (range, 1–38y), body mass of 70.5±9.7kg (range, 62–89kg), and height of 169.4±10.1cm (range, 152–186cm) gave written informed consent to participate in this study. All subjects were recruited from within our institution. Each subject had no history of LE surgery and had minimal experience using assisted ambulatory devices. Minimal experience was defined as any previous consistent usage of an ambulatory assistive device for 1 week or less to reduce LE weight bearing. The muscle performance of each subject’s shoulder depressors, elbow extensors, wrist flexors and extensors, and finger flexors was assessed by standard manual muscle testing to screen subjects for normal upper-extremity strength. These tests were performed by a physical therapist. Only subjects with muscle test grades of normal (5) or good (4) were allowed to continue in the study. The Mayo Clinic Institutional Review Board approved the study.

Data Analysis
A repeated-measures analysis of variance (ANOVA) was used to compare temporal and spatial changes between walking conditions and between sides for each of the 5 conditions (no assistive device ambulation, 4 gait aids). The level used for significance was .05. Newman-Keuls post hoc comparisons were used to compare differences between walking conditions. Paired t tests with Bonferroni adjustment (P=.01) were used to compare right and left sides for step length and percentage of stance time.

The vertical ground reaction force was normalized by body weight for each LE and condition. A repeated-measures ANOVA (α=.05) was used to compare loading levels between conditions and sides. Newman-Keuls post hoc comparisons were used to compare differences between walking conditions. Paired t tests with Bonferroni adjustment (P=.01) were used to compare the vertical ground reaction force for the right and left LE within each of the 5 walking conditions.

RESULTS

Temporal and spatial variables consisted of step length, stride length, walking speed, cadence, percentage of stance time, and step width for each of the 5 walking conditions (table 1). Compared with walking without an assistive device, stride length (F3,36=20.7, P<.001), walking speed (F4,36=59.7, P<.001), and cadence (F3,36=55.6, P<.001) were significantly smaller when subjects used assistive devices. Mean step width was identical for no assistive device ambulation and single-point cane use, whereas a decreased step width was observed when using axillary crutches, forearm crutches, and the wheeled walker (F4,36=4.1, P<.008). When compared with no assistive device ambulation, the right step length for each of the assistive devices was significantly decreased (F4,36=17.6, P<.001). Also, with the exception of the forearm crutches, the

Arch Phys Med Rehabil Vol 86, March 2005
left LE step lengths for the axillary crutches, single-point cane, and wheeled walker were significantly less than during ambulation with no assistive device (F_{4,36}=14.8, \ P<.001). Furthermore, the right-side percentage of stance times were greater for ambulation with no assistive device than for ambulation with axillary or forearm crutches (F_{4,36}=6.59, \ P=.001) but equal to that of ambulation with the single-point cane and wheeled walker. Finally, left percentage of stance time for ambulation with no assistive device was less than the percentage of stance time for each of the devices (F_{4,36}=9.7, \ P<.001). Within each walking condition, we compared the percentage of stance times and step length for the right and left sides. For the percentage of stance times using assistive devices, the left side was significantly larger than the right side (axillary crutches: \ t_9=3.7, \ P=0.005; forearm crutches: \ t_9=3.6, \ P=0.005; single-point cane: \ t_9=4.5, \ P=0.002; wheeled walker: \ t_9=3.5, \ P=0.007). For step length, there was a significant difference only with the forearm crutch condition. The left side step length was greater than the right (t_9=4.4, \ P=0.001).

Mean peak vertical ground reaction force normalized to body weight for each of the 5 walking conditions for both right and left LEs is presented in figure 1. Vertical ground reaction force patterns for each condition are illustrated in figure 2A through E. Each gait aid significantly reduced the vertical ground reaction force on the right side when compared with the left side (F_{4,36}=75.3, \ P<0.001). Furthermore, the left-side vertical ground reaction force under the wheeled walker condition was significantly less than in ambulation with no assistive device or in ambulation with any of the other 3 assistive devices (F_{4,36}=39, \ P<0.001). We also found statistically significant difference between the peak vertical ground reaction force of the right and left sides for each device side (axillary crutches: \ t_6=14.7, \ P<0.001; forearm crutches: \ t_6=12.7, \ P<0.001; single-point cane: \ t_6=8.5, \ P<0.001; wheeled walker: \ t_6=5.6, \ P=0.001).

The characteristic pattern of 2 peaks and a trough associated with a normal vertical ground reaction force during ambulation with no assistive device (fig 2A) was absent on the right side but present on the left side for the crutches (figs 2B, 2C) and single-point cane conditions (fig 2D). In contrast, during use of the wheeled walker neither LE had the typical 2 peaks and trough pattern found during ambulation with no assistive device (fig 2E). The vertical ground reaction force patterns were similar for the right LE using the wheeled walker and single-point cane and between the 2 crutch conditions.
Li et al. was successful in training healthy subjects to apply 50% of body weight on a designated LE using axillary crutches, but, as pointed out earlier, they were loading the left LE to only 85% of body weight. On the other hand, in the present study, healthy subjects, after appropriate training with a standard bathroom scale, were able to show load-bearing levels at a target of 50% of body weight when using axillary crutches (Fig 1). These subjects also applied 108% of body weight to the left LE, which is consistent with normal gait (see Fig 2A). This finding was also nearly duplicated when the subjects used forearm crutches. These healthy subjects were also able to apply 56% of body weight to the right LE and 108% of body weight to the left LE (see Fig 2C). However, the same subjects were less successful at targeting 50% of their body weight when they used a wheeled walker (see Fig 2E). Healthy subjects offloaded the right LE by about 25% of body weight when they used a single-point cane. This finding confirms that a single-point cane is the least effective of the conventional ambulatory devices for unloading an extremity.

Study Limitations

Although our healthy subjects were successfully able to load the right LE at 50% of the vertical ground reaction force using axillary crutches and a 3-point PWB gait pattern, this ability may not be generalizable to patients with limited strength or pain. For example, patients with a recent total hip or knee arthroplasty may not be successful at placing 50% of vertical ground reaction force on the affected LE using axillary or forearm crutches. Pain, reduced upper-extremity muscle performance, balance issues, or a combination of these factors may hinder their efforts. Additional research is needed on long-term users of assistive devices to describe the magnitude of the vertical ground reaction forces generated during protected load bearing. Research also is needed to explore whether healthy subjects and/or patients can accurately offload to other defined PWB guidelines.

CONCLUSIONS

We were able to show that healthy subjects could be trained by using a traditional bathroom scale to place 50% of body weight on a designated LE while ambulating on a level surface with axillary crutches at a self-selected walking speed by using a 3-point PWB gait pattern. The subjects were almost as successful using forearm crutches, applying a mean vertical load of 56% of body weight. These healthy subjects were not as successful using a wheeled walker. The mean peak vertical...
load was 64% of body weight. When using a single-point cane, the mean peak vertical load increased further to 76% of body weight. Finally, the subjects loaded the left LE at values equivalent to 108% to 109% of body weight while using axillary crutches, forearm crutches, or a single-point cane, whereas with the wheeled walker the loads applied to the left limb were only 85% of body weight.

Clinically, during left single-limb stance, the right LE and gait aid (crutches or cane) were simultaneously advanced so that the left LE was fully loaded. However, with the wheeled walker, subjects maintained upper extremity weight bearing throughout the gait cycle, which offloaded the left LE.

References

Suppliers
a. Motion Analysis Corp, 3617 Westwind Blvd, Santa Rosa, CA 95403.
b. Model BP2416; Advanced Mechanical Technology Inc, 176 Waltham St, Watertown, MA 02472.
c. Model 9281B; Kistler Instrument Corp, 75 John Glenn Dr, Amherst, NY 14228-2171.