

Application of the Veterans Administration Prosthetics Center Below-Knee, Weight-Bearing Brace to a Bilateral Case¹

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The Veterans Administration has many beneficiaries who suffer from an inability to bear weight on their feet. Etiologies include gunshot wounds, crushing injuries, painful ankylosis, arthritis, and other conditions which produce pain upon bearing weight. For many years, these patients have been fitted with long leg (leg-thigh) braces in an attempt to unweight the leg at the level of the ischium, or they have been required to use crutches and braces. Either method results in the loss of knee function in order to treat a condition of the feet, ankles, or tibiae.

In an effort to provide more effective orthotic treatment, the Veterans Administration Prosthetics Center developed⁴ a brace designed to unweight the foot at the level of the patella and tibial condyles, an adaptation of the patellar-tendon-bearing prosthesis. It consists essentially of a PTB-type prosthetic socket modified to permit donning by means of a posterior "door," or hinged section, which is closed with Velcro fasteners. Attached to the hinge and sandwiched between the layers of

the laminate is a framework which permits vertical adjustment of the socket on the sidebars. Conventional stirrups are used with sidebars which insert into channels provided in the socket. In general, ankle joint motion is completely restricted in dorsiflexion and limited in plantarflexion. The shoes are modified to include a resilient heel pad (SACH foot principle) and a rocker bar. Details of the construction have been reported previously (2,3).

During the past four years, approximately 80 veterans have been fitted with this device. On a clinical basis, this treatment is considered successful because patients continue to wear and prefer the below-knee, weight-bearing brace, returning at regular intervals for replacement. The Veterans Administration Prosthetics Center has not attempted an objective evaluation of its own development, but the Orthotic Study Group of New York University is now independently evaluating the cases that have been fitted in an attempt to determine the general utility of the brace. The Veterans Administration Prosthetics Center is participating in this study only to the extent of providing the electronic instrumentation to measure the loads borne by the braces, or the degree to which the brace unweights the leg.

Until recently, all the patients fitted with this brace at the Center were unilateral brace wearers. However, in July 1964 a veteran was fitted bilaterally, and the results were highly successful, if not dramatic.

The patient, first examined at the Veterans Administration Prosthetics Center in July 1964, was 46 years old, 5 ft. 4 in. tall, and

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⁴ This development was stimulated by a difficult case referred to the Veterans Administration Prosthetics Center by Dr. G. Rubin, of the Veterans Administration Brooklyn Outpatient Clinic, who suggested that his patient "be fitted as a below-knee amputee."



Fig. 1. Anterior view of VAPC below-knee, weight-bearing braces, showing the alignment of sidebars to conform to deformities of the legs and the elevation of the patellae as weight is borne by the patellar tendons.

weighed 129 lb. with braces. Although unemployed, he was active in working around his home and the community. Both legs were deformed as a result of an explosion in 1944, during World War II. The severe damage included incomplete union of the right tibia, with bone spurs, shortening of the left leg, complete ankylosis of both ankles, and loss of muscle power in the thighs, due to disuse atrophy. He experienced severe pain when he bore more than a small fraction of his body weight on his feet.

He had been fitted in 1957 with bilateral, short leg braces consisting of molded leather cuffs with anterior lacing, one-piece sidebar-stirrups without ankle joints, and custom or-

thopaedic shoes. For 17 years he walked with the aid of his two braces and two axillary crutches, using the swing-through gait.

PRESCRIPTION

The clinical evaluation resulted in a prescription for bilateral below-knee weight-bearing braces with unitary sidebar-stirrups providing no ankle motion. Also prescribed were orthopaedic shoes with high quarters, soft inner molds, soft-cushion heels, and rocker bars (Figs. 1, 2, and 3).

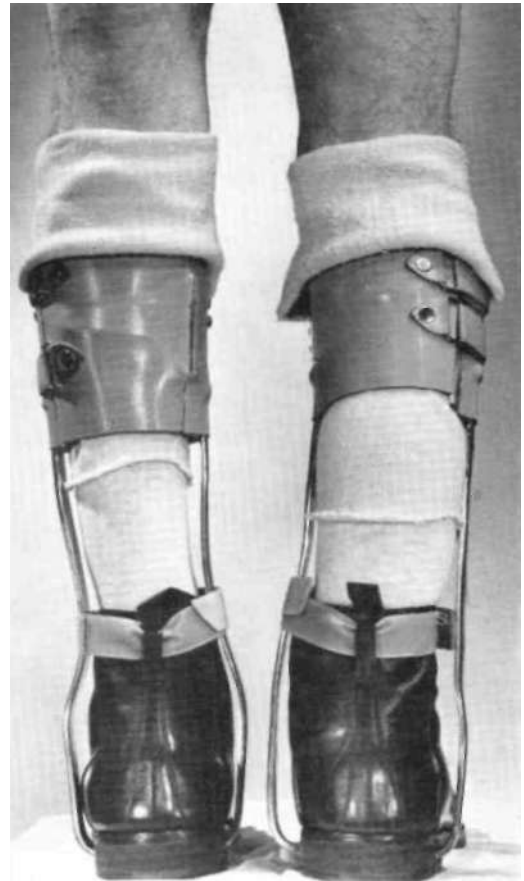


Fig. 2. Posterior view of VAPC below-knee, weight-bearing braces, showing the rear openings. The detachable stirrups are provided with ankle straps for added safety.



Fig. 3. Lateral view of VAPC below-knee, weight-bearing braces, showing the Velcro fastenings, the absence of ankle joints, the resilient heel pads, and the rocker bars.

PROGRESS

The below-knee braces were delivered in August 1964, whereupon it was observed that the patient could walk for short distances without the aid of crutches. He was cautioned to try to walk without crutches gradually in order to avoid excessive and unaccustomed stresses. In addition, physical therapy was recommended to improve the strength of the knee flexors and extensors. One month later, in September 1964, he reported swelling of the right leg, and the socket was relieved slightly to reduce constriction. The clinic team report during that visit revealed that:

1. The patient had been wearing the below-knee weight-bearing braces 12 hours per day, every day.
2. He walked for approximately three to five hours per day with the assistance of one axillary crutch.
3. He had used the below-knee braces without crutches during the first three to five days after delivery.
 - i. Walking without crutches for a distance of approximately 80 feet caused fatigue. But after a two- to three-minute rest, he was able to continue.
5. He commented to the effect that "These are the best braces. . . ."

During the next three months the patient reported no significant difficulties and indicated great satisfaction and substantially improved mobility, with less dependence on his crutches. The relatively dramatic change in

this case gave rise to several significant questions:

1. To what extent was the below-knee brace unweighting the foot during the period from heel contact to toe off?
2. What was the character of the gait pattern without crutches in relation to standards of normal locomotion?
3. What were the patient's reactions and experiences?

In January 1965, after approximately four months of continuous wear of the below-knee braces, the subject's performance was evaluated in a series of biomechanical analyses conducted by the Bioengineering Research Service of the Veterans Administration Prosthetics Center in an effort to answer these questions.

EVALUATION

This study was not designed on the "before-and-after" model of a comparative analysis since there is no basis of comparison between

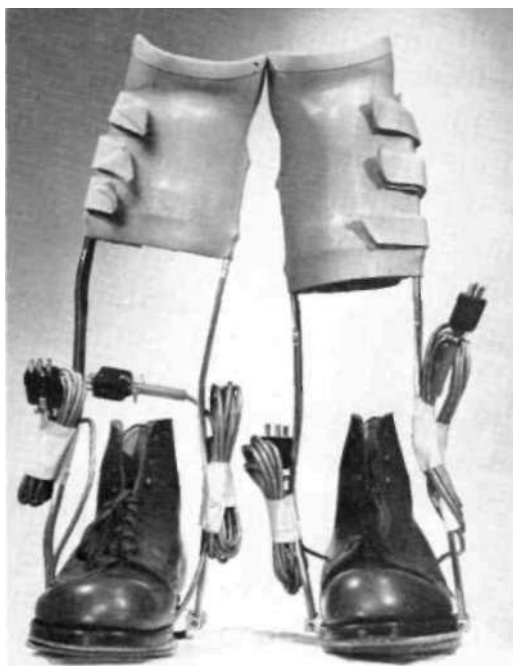


Fig. 4. VAPC below-knee, weight-bearing braces equipped with instrumented stirrups to measure amount of body weight applied to the ground via the brace sidebars.

walking with crutches and unaided gait. It was primarily planned to measure the forces transmitted to the ground as the patient walked and, in order to determine the extent to which the brace "unweighted" the leg, to identify the portion of body weight that bypassed the tibia and was applied to the ground via the brace sidebars. A second purpose was to describe the character of the gait exhibited by the patient in relation to normal locomotion patterns. The first purpose was accomplished by means of a specially designed, instrumented brace stirrup (Fig. 4) and the second by means of conventional force plate and cyclographic recording techniques previously described in *Artificial Limbs* (1,4) and elsewhere.

The stirrup of the instrumented weight-bearing brace consists of two cantilever, rectangular, prismatic beams (Fig. 5). The ends of the beams are connected to the sidebars of the brace by means of low-friction pin joints. Equidistant from the center line on each beam surface are two SR4, A-7 Constantin wire strain gauge grids.

When the sidebars bear weight, the beams bend causing a resistance change in the gauges and producing a voltage potential directly proportional to the force. Under torsional bending (twisting action equivalent to plantarflexion or dorsiflexion) all four gauges are equally affected causing no voltage change; only the axial force is recorded. Calibration studies indicated that variations in linearity and repeatability did not exceed 0.50 per cent.

By means of the instrumented stirrup it was possible to measure the portion of body weight carried by the brace during the stance phase. As the patient walked across the force plates, the axial loads borne by the sidebars and the total vertical and shear forces applied to the ground were recorded simultaneously. Linear displacements of the ankle, knee, and hip, the angular displacement about the knee, and the time spent in the stance and swing phases were recorded by means of the cyclograph.

RESULTS

UNWEIGHTING THE LEG

Depicted in Figure 6 (for the left leg) and Figure 7 (for the right leg) are curves repre-

senting ground reaction forces resulting from the application of the patient's body weight to the ground during a typical stance-phase portion of the walking cycle. The vertical and the fore-and-aft shear components of the ground reaction forces are shown in the upper portion of each figure, and their orthogonal projections into axial loads are shown in the lower portions. The axial load borne by the sidebars of each brace is shown under the axial component of the ground reaction force.

Figure 6 indicates that the brace on the left leg carried approximately 96 per cent of the total axial load applied to the ground during the first 20 per cent of the stance-swing cycle, a point well past foot flat and within the region of mid-stance. Thereafter, the distribution of axial load changed with the brace bearing decreasing loads through the next 20 per cent of the cycle (just past heel off), where it bore about 60 per cent of the axial load. Sixty per cent of the diminishing axial load was carried by the brace for the remaining 20 per cent of the cycle until swing phase began.

Figure 7 indicates that the brace on the right leg continuously supported approximately 25 per cent of the axial load during the entire stance phase of the stance-swing cycle.

From the foregoing it can be seen that the subject was capable of tolerating approximately 75 per cent of the load on his right foot and loads ranging from 4 per cent to 40 per cent on the left leg. This distribution of loads (body weight plus inertial forces) between the foot and the brace permitted him to walk comfortably and in a reasonably normal manner. Adjustment of the load distribution between the foot and the brace can be accomplished by changing the length of the sidebars, or by changing the resiliency or the depth of the innersole.

GAIT PATTERN WITHOUT CRUTCHES

In addition to unweighting the patient, these braces also permitted him to walk with a reasonably satisfactory, normal-appearing gait. To describe his gait pattern several techniques were employed. Motion pictures of his walking performance were analyzed to identify deviations from the normal gait pattern. Cy-

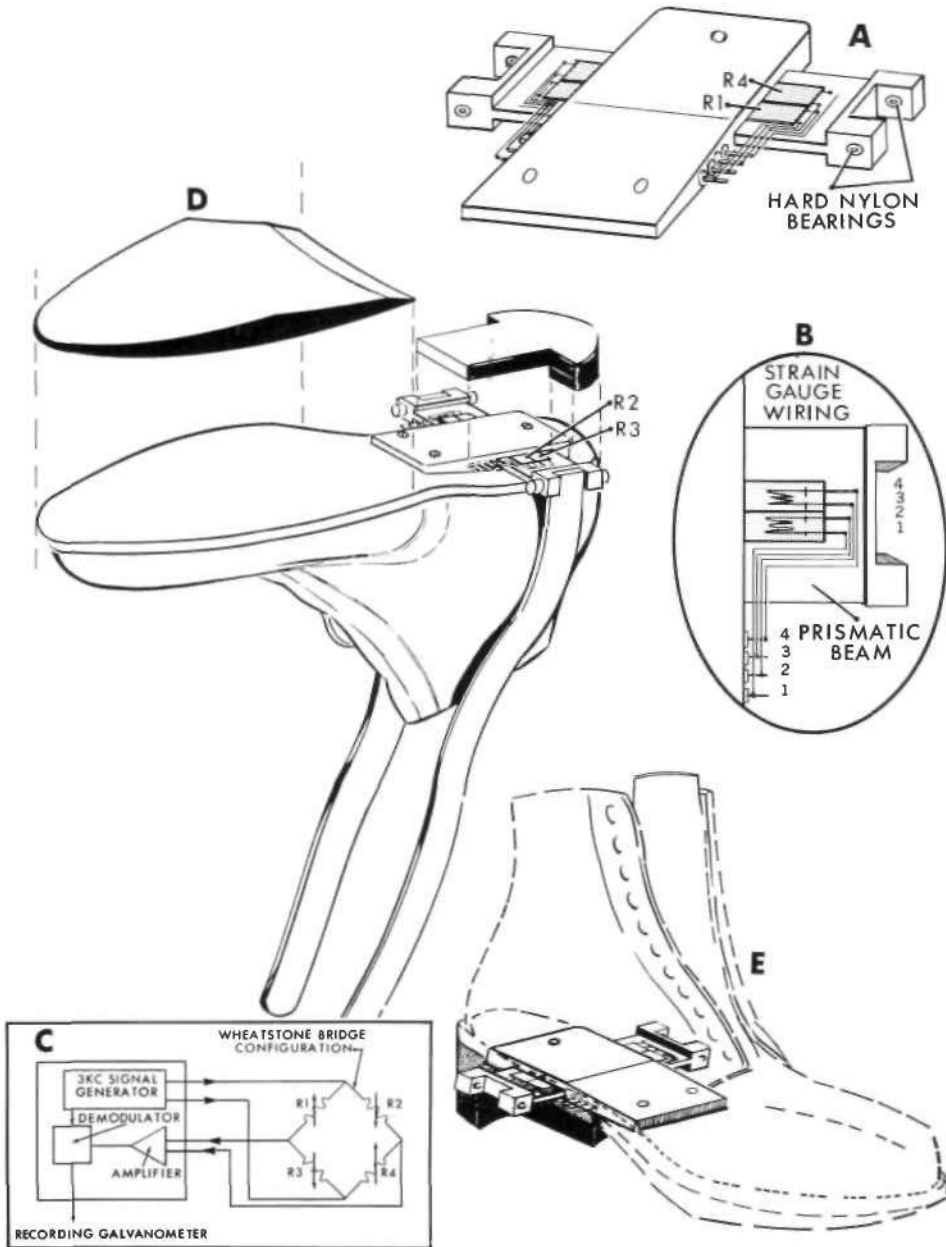


Fig. 5. Schematic representation of instrumented weight-bearing braces. A, Cantilever beam with strain gauges attached; B, close-up of the strain gauges on the beam; C, strain-gauge circuitry; D, E, installation of instruments in orthopaedic shoe.

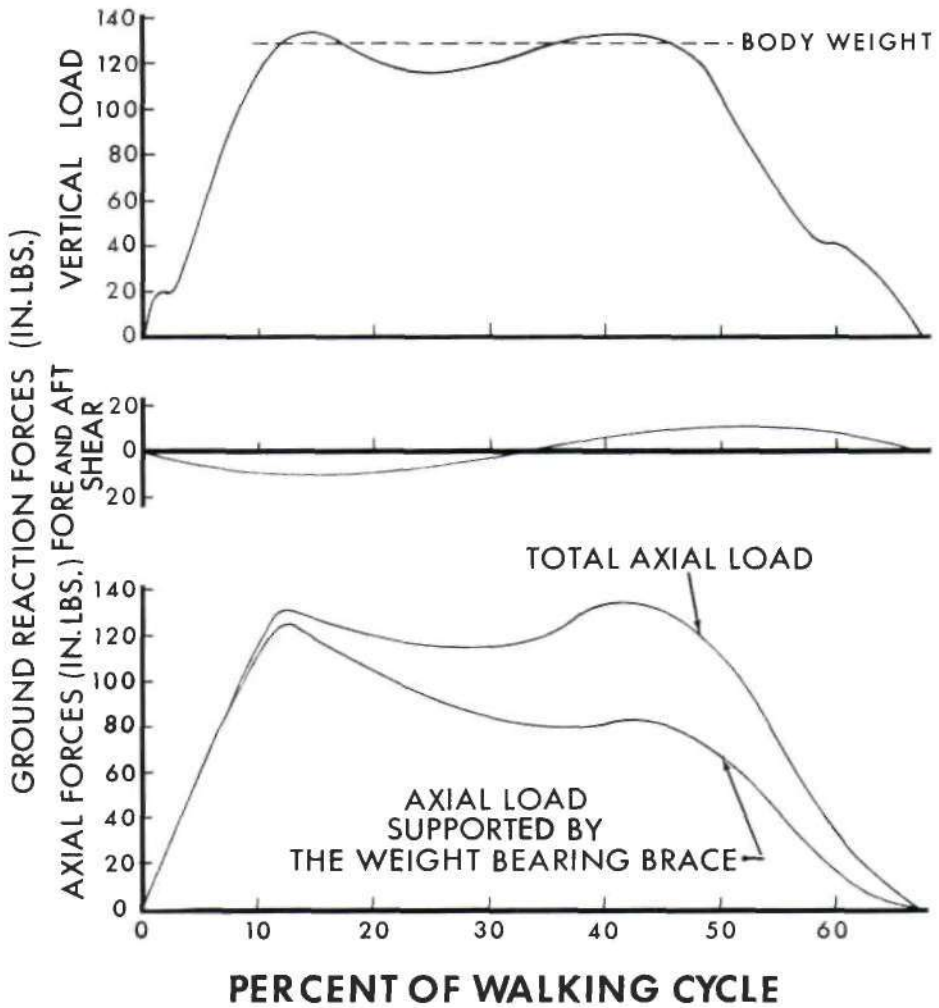


Fig. 6. Curves representing ground reaction forces during the stance phase of the left leg.

olographs were analyzed to provide a more objective analysis of the temporal and kinematic aspects of gait.

Gait Analysis

Motion-picture studies revealed that the subject walked more slowly and deliberately

than the normal nonbrace-wearing subject and exhibited the following gait deviations: moderate abduction, slight sideway, and excessive knee flexion during the stance phase. Neither the abduction nor the sideway were of a magnitude to detract substantially from the

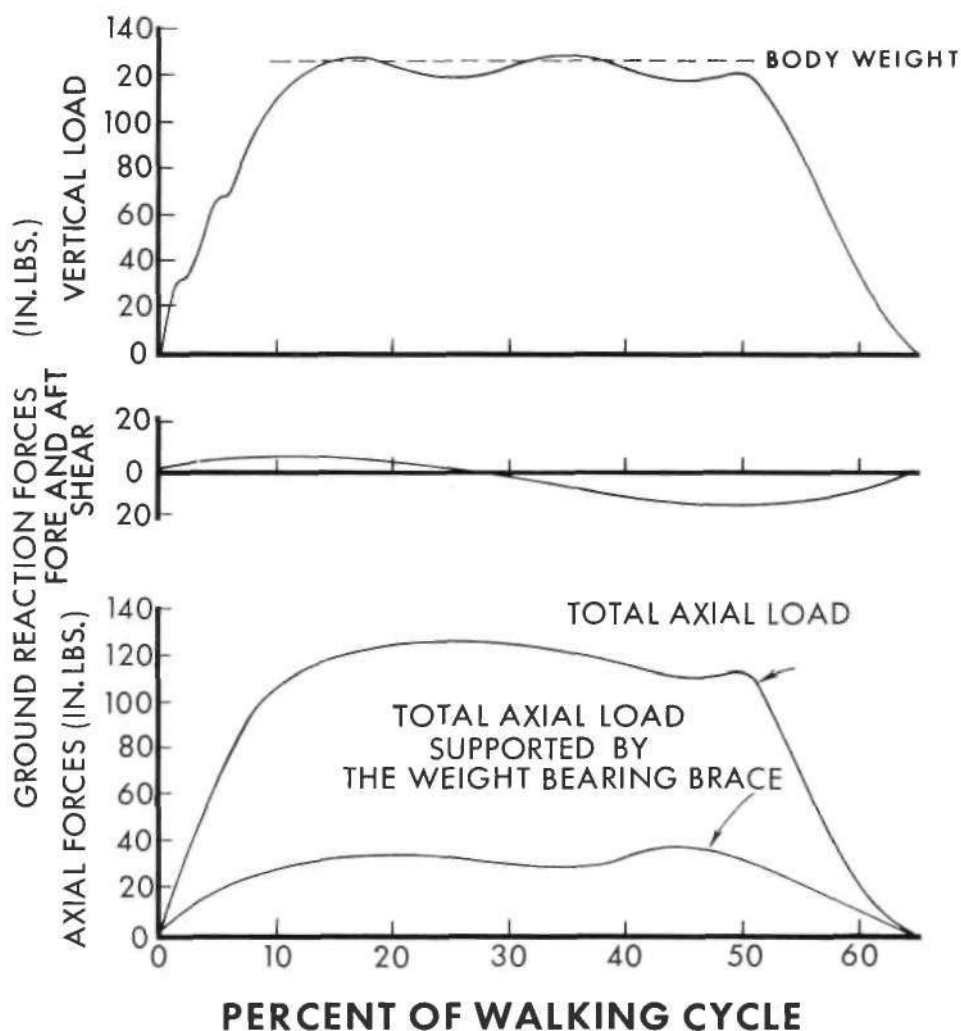


Fig. 7. Curves representing ground reaction forces during the stance phase of the right leg.

normality of his appearance. The excessive knee flexion was quite noticeable. However, in the absence of ankle-joint function and the inability to plantarflex the ankle, this adaptation permitted him to achieve a smoother transition from heel contact to foot flat.

Timing and Symmetry

A major determinant of the normality of gait is the time relation between the swing and the stance phases. A normal individual walking at approximately 80 steps per min. spends 0.53 sec. in the swing phase and 0.94

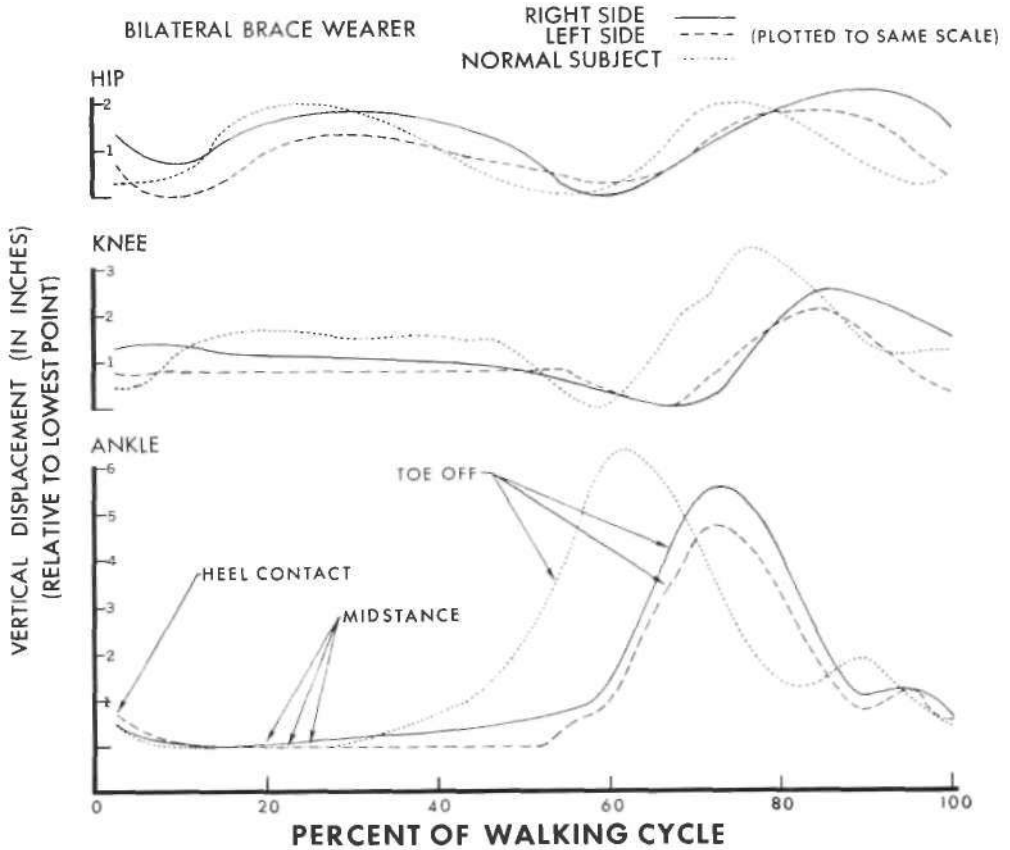


Fig. 8.

sec. in the stance phase. The subject of this study, walking at approximately the same speeds, displayed a gait pattern not significantly different from the normal. At 83 steps per min. he spent 0.52 sec. in the swing phase and 0.92 sec. in the stance phase; at 77 steps per min. he also spent 0.52 sec. in the swing phase but increased his stance-phase time to 1.04 sec.

A comparison between the swing and stance times of the right and left legs provided a measure of the symmetry of his gait; that is, the degree of similarity between the timing and rhythm of each leg. This was expressed as a ratio of swing-to-stance time for each leg, as follows:

	Strides per Min	Subject.	Normal
Left leg	83	.562	.552
Right leg	77	.493	.575

It may be seen that the subject walked with reasonably equal, normally timed steps. At 83 steps per min., swing and stance times were quite normal, and the ratio 0.562 was quite close to the normal ratio 0.552. However, at 77 steps per min. the patient's swing-to-stance-time ratio fell to 0.493, demonstrating the effect of increased stance time at 77 steps per min. (1.04 sec. as against .92 sec. at 83 steps per min.). Thus, he attained optimum symmetry as regards swing and stance times at approximately 83 steps per min.

Although not necessarily a temporal factor, stride length also provided a good measure of gait normality. Stride length is the horizontal distance between successive heel contacts by the same leg. Variations in the length of stride reveal asymmetrical patterns as well as deviations from the normal which may not be shown in a study of the swing and stance times. The following is a comparison of the patient's stride length with that of a normal person at comparable cadences.

<i>Stride Length in Inches</i>		
Strides per Min.	Subject	Normal
83	42.5	54.0
77	43.8	53.0

Clearly indicated is the shorter-than-normal stride length typical of this patient's gait. Although the minor variation in stride length with changing cadence is quite comparable to the normal variation, it tends to change inversely; that is, normal stride length increases slightly with cadence while the subject's stride length decreased slightly with increased cadence. This was attributed to the effect of an increased stance time at the lower cadence permitting a longer step to be taken with the opposite leg.

Kinematic Factors

In general, the displacements of hip, knee, and ankle were not substantially different from the normal, as shown by the similarity of the waveforms depicted in Figure 8. Differences in phase—that is, in the occurrence of significant events such as toe off—were primarily due to variations in cadence and to the inability of the patient to plantarflex his ankle. In order to achieve a smooth transition from heel contact to foot flat, he flexed his knee excessively with respect to normal values, and extended slowly through the range until toe off. The net result was to prolong stance phase.

PATIENT REACTIONS AND EXPERIENCES

Time of Wear

The subject wore both braces approximately 13 hr. a day, five of which were spent in activities involving walking. With the old braces,

he used axillary crutches and a swing-through gait, resting every 10 to 15 min. With the new braces he did not use crutches in the house or for walking short distances outside the house. He did use crutches and a swing-through gait for longer distances, traveling continuously (without intervening rest periods), up to one and a half hr.

Comfort

With the old braces he was subjected to constant pain and ache; the weight-bearing braces gave no pain but caused swelling and considerable itching, particularly of the right leg.

Activity

With the old braces and crutches he was completely dependent on others for carrying packages, as when shopping or handling chores around the house. The below-knee, weight-bearing braces allowed him to discard the crutches and to carry small packages, to shovel snow off his sidewalk, and to carry out trash. The subject attached a great deal of importance to this type of activity as it represented a level of independence which permitted him to contribute substantially to the management of his home.

Disadvantage

With the old braces he could kneel in church; with the new braces he was not able to flex his knees sufficiently to kneel.

SUMMARY

This analysis revealed that the below-knee, weight-bearing braces unweighted the subject's left foot to an extent varying with the phase of the walking cycle between 96 per cent and 60 per cent of his total body weight. The load on the right leg was reduced by 25 per cent of the body weight throughout the stance phase. This adjustment permitted the patient to discard his crutches for reasonably long distances and to walk without them in a fairly normal manner. As a result of his increased mobility and freedom from crutches, his activity patterns broadened, and his sense of independence improved.

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