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The dynamics of walking using the hip guidance orthosis (hgo) with crutches

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Abstract
The variation of ground reaction forces with time for a complete hgo gait cycle using crutches has been synthesized from video recordings and force platform data. This has led to an understanding of the dynamics of hgo ambulation. The results show that when a patient uses the orthosis the crutches provide a subtle control mechanism taking maximum advantage of forward momentum and produce small propulsive forces when needed to make up energy losses.

Introduction

Effective reciprocal ambulation for paraplegic patients has long been the aim of many surgeons. Swing through gait on crutches, with the legs and hips braced by means of long leg calipers and body brace is used by many such patients, but carries the penalty of high energy consumption. Other devices such as Swivel Walker (Edbrooke, 1970; Rose and Henshaw, 1972 and Stallard et al. 1978) and the parapodium swivel walker (Motloch and Elliott, 1966) permit lower energy independent ambulation without crutches, but are limited to flat smooth surfaces. Both of these forms of locomotion suffer from poor dynamic cosmesis and are frequently rejected by patients or their parents, on the grounds that they are so far removed from normal walking.

Rose (1974 and 1979) outlined the theoretical means by which reciprocal ambulation might be achieved by paraplegics with stabilized knees. From this analysis a clearer understanding of paraplegic gait emerged and as a result the Hip Guidance Orthosis (hgo) (Rose, 1979) was developed (Fig. 1). The mechanics then described omitted inertial considerations for simplicity. Monitoring the ground reaction forces during the gait cycle of a patient using hgo has enabled the dynamics of such reciprocal ambulation to be demonstrated.

Method and equipment

The subject was an eight year old girl with an L2 lesion who is totally flail in the lower limbs after operative procedures, having a lumbar

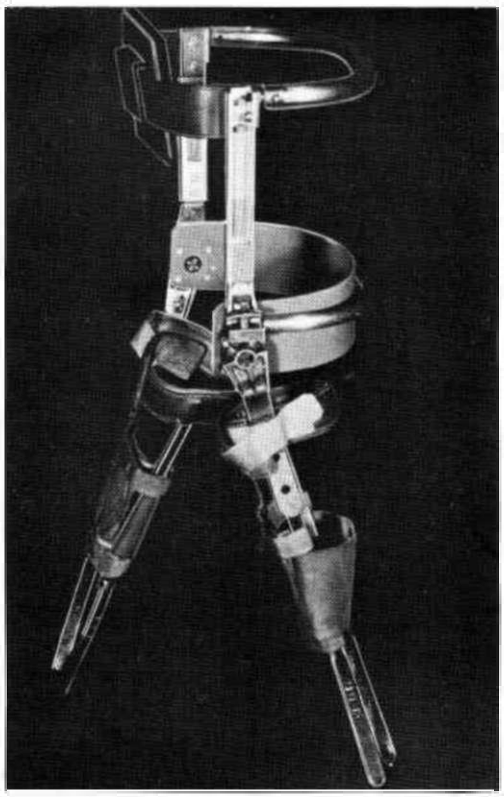

Fig. 1. The hip guidance orthosis (hgo).

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kyphosis, well contained hips, with no hip flexion contractures.

Figure 2 shows the subject wearing the standard hgo which provides freely moving hip articulations with limited flexion extension range (Fig. 3) and abduction guaranteed by a rigid structure. The walking aids used by the subject were Canadian crutches.

Fig. 2. Patient walking in hgo with Canadian crutches.

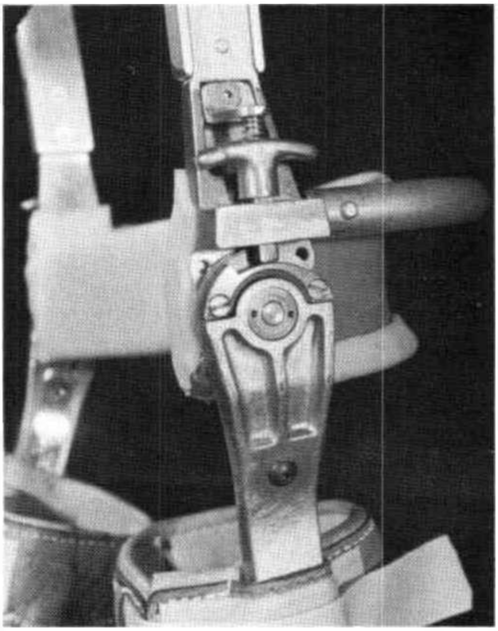

Fig. 3. hgo hip flexion stop.

The dynamic description of ambulation was obtained from video recordings of the patient derived from three orthogonally placed cameras and from the output of a six channel force platform (Kistler 9261A) recorded on a U.V. recorder. Two channels (the vertical force and horizontal force in the line of progression) from the force platform were also displayed on a storage oscilloscope and a video picture of this mixed with the patient/force platform image (Fig. 4) to provide a synchronized reference between the two recording mediums. A diagram of the whole monitoring system is shown in Fig. 5.

An inherent limitation of the force platform is that data will be invalid if more than one limb or crutch is in contact with the measuring surface at any one time. Thus the complete picture of ground reaction forces from the two limbs and crutches requires a minimum of four runs. A run was considered representative when the subject walked without hesitation with only the limb or crutch in question striking the force platform.

The temporal relationship between the resulting force patterns for selected runs was determined by matching known events in the gait cycle (e.g. heel strike, crutch strike, etc.) which can be identified both on individual video frames

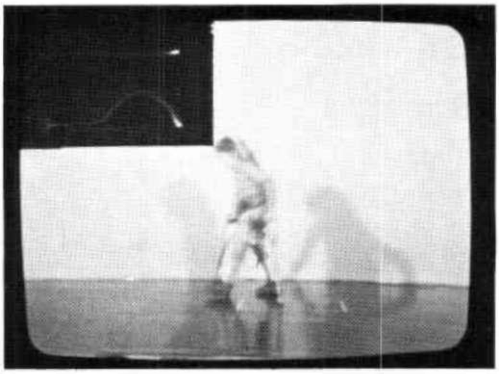

Fig. 4. Composite video picture—used for temporal reference.

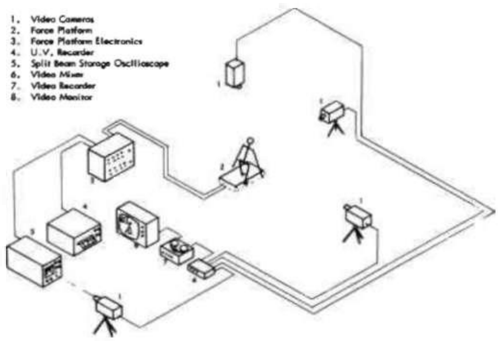

Fig. 5. Schematic diagram of gait analysis apparatus.

and on force diagrams, the video vertical sync. signal providing the overall timebase.

Forces in the gait cycle

In the following description any force directions given refer to the force that the limb or crutch exerts on the ground.

The variation of ground reaction forces with time on the lower limbs of the patient and on the crutches shows that momentum of the patient moving forward plays a very important part in the overall function of gait. During stance phase the body has to rise up over the hip before it can take advantage of gravity and drop onto the opposite leg, which has by then swung forward as a pendulum (Rose, 1979). Momentum carries the body a long way up that "uphill" phase but a small injection of energy via the crutches which is manifested in the form of a backwards force on the ground is necessary to make up inevitable energy losses. This mechanism is clearly indicated from a careful study of the magnitude and temporal relationships of the various ground reaction forces.

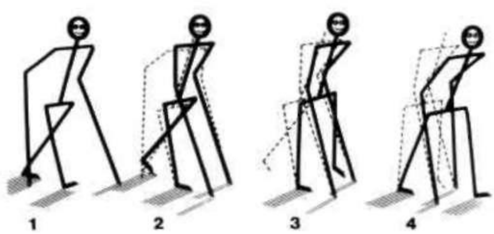

Fig. 6. Diagrammatic representation of hgo ambulation. 1, Right heel strike. 2, Right crutch strike. 3, Left mid swing. 4, Left heel strike.

Figure 6 shows a diagrammatic representation of hgo ambulation and Fig. 7 the synthesized force pattern of the gait cycle.

At right heel strike with the left foot starting to unload, the vertical load on the right leg rises rapidly to 0.9 body weight (B.W.), with the vertical ground reaction force on the left crutch

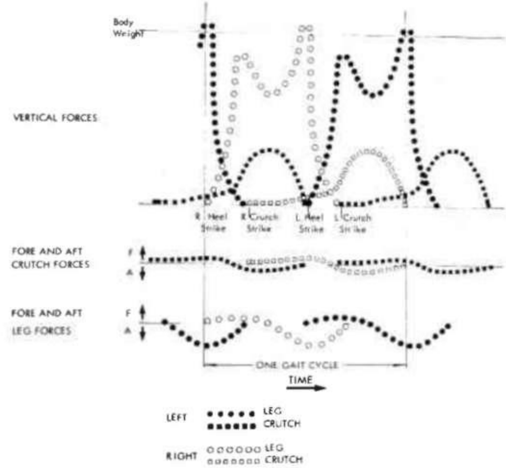

Fig. 7. Ground reaction forces when walking using hgo and crutches.

rising from 0.05 B.W. to 0.22 B.W. As the vertical load on the crutch continues to rise the right leg is then unloaded to 0.65 B.W., at which point the left crutch vertical load peaks at 0.35 B.W. at approximately half way through the right stance phase. The combined support of the right leg and left crutch permits the left leg to swing through due to gravity and inertial reaction to truncal movement. The body continues to move forward under the momentum gained from having dropped onto the right leg and passes through the "uphill phase" with some small assistance from the backwards force on the left crutch making up the inevitable energy losses. On reaching mid stance phase on the right, gravity again propels the body forwards since the centre of mass falls when the hip rotates about the ankle. The right crutch has been previously grounded, well forward, and now exerts only a small force of approximately 0.05 B.W. vertically and 0.01 B.W. forwards to act as a control element. During this phase the left crutch is progressively unloaded until left heel strike.

Immediately prior to left heel strike the vertical loading on the right leg rises rapidly again to a second peak of 1.1 B.W. This happens as a result of the removal of the supporting load on the left crutch, the lack of an effective supporting (as opposed to control) load on the right crutch, and the inertial effect of trunk rotation in the sagittal plane. Left heel strike completes one half of a description of the full gait cycle and since examination of the force patterns confirmed that the opposite side follows a virtually identical pattern, further description is not necessary.

The transverse horizontal forces on the crutches occur in phase with the vertical loadings and come about mainly because of the angle of the crutches to the ground in the medio lateral plane. Their sense is such that they tilt the body to assist clearance of the swing leg, and the peak load is approximately 0.05 B.W. Transverse horizontal loadings on the lower limb again peak in phase with the vertical loadings of the lower limb in the expected senses according to the inclination of the limb in the medio lateral plane. These forces are too low to be conveniently shown on the graphs of ground reaction forces.

Initiating the gait cycle

In order to commence ambulation the patient leans forwards at an angle of approximately 10 degrees with the legs in line and hips at full extension, support being provided by the crutches held in front at an angle of approximately 15 degrees from the vertical. Increased loading on the right crutch tilts the body to the left and causes the right leg to swing forwards under the influence of gravity. As the right leg swings forwards, the body rotates slightly clockwise on the left leg, when viewed from above, which aids the pendulum effect of the right swinging leg, and the body also moves forward slightly over the left ankle, so increasing right step length. At maximum forward swing of the right leg, the right crutch support is removed and this permits the body to fall forwards, so gaining momentum to initiate the gait cycle previously described at right heel strike.

Clearly, lead off with the left foot would be equally effective.

Discussion

The synthesized force pattern has enabled a satisfactory description of the dynamics of hgo walking to be made. Different patterns of gait have been observed on less ideal surfaces, but the same general dynamic system has fitted these variations in ambulation. The observations of the dynamic mode of use reinforce the criteria contained in the description of the static requirements of hgo ambulation elucidated by Rose (1979). This form of walking for handicapped patients is now well understood, which should encourage the development and wider application of effective orthotic ambulation devices.

With the inherent restrictions of the force platform described it is recognised that the force diagrams obtained are of a composite nature and as such represent an idealized picture. The accuracy of this composition was checked by taking the vertical force x time integral of the four wave forms summed for one cycle and showing that this agreed with the equivalent body weight x time integral for the same period to better than five per cent. Although only four runs are necessary for a complete synthesis, in practice considerably more are required because a correct single strike on the platform cannot be guaranteed when working with a handicapped patient having a short step length. Thus the analysis required the co-operation of a particularly helpful and well motivated patient. The fact that she was able to make a large number of runs without getting tired demonstrates vividly that the hgo does provide low energy ambulation.

REFERENCES

Edbrooke, H. (1970). The Royal Shrewsbury Infirmary clicking splint. *Physiotherapy*, **56:4**, 148–153.

Motloch, W. M. and Elliott, J. (1966). Fitting and training children with swivel walkers.

Rose, G. K. (1974). Functional assessment of spina bifida for orthotic prescription and integrated surgical treatment. Paper presented to the World Congress of the International Society for Prosthetics and Orthotics, Montreux.

Rose, G. K. (1979). The principles and practice of hip guidance articulations. *Pros. & Orth. Int.*, **3:1**, 37–43.

Rose, G. K. and Henshaw, J. T. (1972). A swivel walker for paraplegics: medical and technical considerations. *Biomed. Eng.*, **7:9**, 420–425.

Stallard, J., Rose, G. K. and Farmer, I. R. (1978). The ORLAU Swivel Walker. *Pros. & Orth. Int.*, **2:1**, 35–42.