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

P. B. BUTLER, R. E. MAJOR and J. H. PATRICK

Orthotic Research and Locomotor Assessment Unit,
The Robert Jones and Agnes Hunt Orthopaedic Hospital, Oswestry.

Abstract

An orthotic method of providing reciprocal walking for high thoracic levels of paralysis is detailed. The essential features of the hip guidance orthosis are described, as well as the basic muscle requirements for this form of walking (shoulder, arm and hand function plus Latissimus Dorsi). The walking sequence is described at each stage under the three main headings: mechanics, muscle action and hip guidance orthosis reaction—to build a complete picture of the walking process. The importance of considering the input made by the patient in addition to the purely mechanical orthotic contribution is illustrated.

Introduction

Orthotics has, for many people, the aura of being an empirical science. This may be true, not only in that mechanical principles are seldom used in the design of orthoses, but more particularly in that the contribution made by the patient in combining with the orthosis to make a functional system is often ignored. An example of such an empirical system is the provision of body brace and calipers (HKAFO, or traditional "full set") to provide walking function in total paraplegia.

When considering walking in complete paraplegia above L1, the choice lies between swing-through gait and reciprocal (step-by-step) walking. The latter, by reducing the vertical excursion of the centre of mass, can provide a theoretically more efficient form of walking. The orthoses provided to achieve these forms of gait are long-leg calipers for the lower levels of lesion, generally used in traumatic paraplegic adults, and body brace/calipers, most commonly used in congenitally paraplegic children. The hip guidance orthosis (hgo) (Rose, 1979; Major et al, 1981) is now becoming available and is applicable to both groups of patients (Fig.1.).

Swing-through gait using long leg calipers has been the subject of biomechanical analysis (Abramson, 1949) in which attention was drawn to orthotic function and user (patient) input. However, this form of gait with unstable hips,

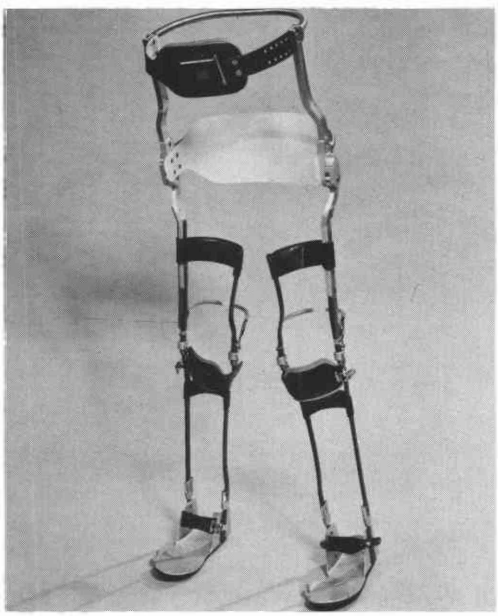

Fig. 1. Hip guidance orthosis.

All correspondence to be addressed to Mrs P. Butler, Orthotic Research and Locomotor Assessment Unit, The Robert Jones and Agnes Hunt Orthopaedic Hospital, Oswestry, Shropshire, SY10 7AG, U.K.

tends to require high energy input. Reciprocal gait can be obtained in long-leg calipers but is seldom achieved by patients with lesions above T12, in part due to the energy cost and the slow mode of progression, Body brace/calipers can also be used for reciprocal walking. The hip hinges are used only for sitting and when they are locked for walking the orthosis restricts desirable flexion/extension. The hgo provides stability and control of the hip joints, thus allowing reciprocal walking in complete paraplegia, including high level lesions.

This paper outlines the design and principle of operation of the hgo from both the mechanical and user viewpoint.

Hip guidance orthosis: description

This orthotic system can provide low energy reciprocal ambulation with crutches for both children and adults with spinal cord lesions between T1 and L1 (Fig. 2.).

The essential features of the orthosis are:

i) A rigid body brace which helps maintain the relative abduction of the legs during the swing phase of the gait cycle.
ii) A hip joint with a limited flexion/extension range and friction free operation.
iii) Stabilization of the knees and ankles.
iv) A shoe plate incorporating rocker sole.
v) Simple fastening arrangements of the orthosis to ease application and removal.

The addition of crutches and training in the total use of the hgo completes the system.

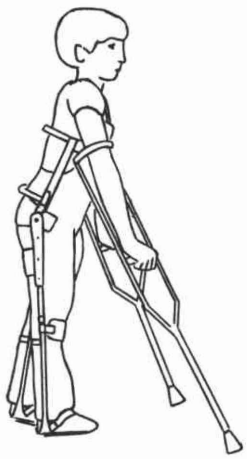

Fig. 2. Hip guidance orthosis can provide low energy reciprocal ambulation for patients with spinal cord lesions between T1 and L1.

The current design uses an aluminium alloy tubular and channel section body brace to provide a rigid lightweight structure. A support point on the chest is provided by a leather chest strap with a seat belt fastening for easy fixation, and on the buttocks by a polypropylene support band attached directly to the bearing housing.

The user's shoe rests on a shoe plate which is provided with a rocker section at heel and toe. The foot and shoe are held in place by a strap with a simple latch fastening enabling the user to retain normal footwear. The shoe plate is fixed to the caliper section, with the appropriate amount of dorsiflexion. The knee is held in extension by a simply latched padded strap reacted by the posterior thigh band and a vertical extension on the rear of the shoe plate. Knee joints are provided, and both these and the hip joints release to allow the user to sit.

The limited flexion/extension range at the hip ensures that step length is controlled. In some cases the physiological extension stop of the hip may operate before the orthotic stop.

Muscles involved in hip guidance orthosis walking

The following provides a brief guide, for those not familiar with anatomy, to the function of the major muscles involved in hgo walking.

Latissimus Dorsi: this large muscle acts when the flexed arm is extended against resistance until the arm reaches the plane of the body; it also acts as a tie between the shoulder and the pelvis on the swing leg side.

Pectoralis Major: acting as a whole, the muscle adducts the humerus; the lower fibres act in conjunction with Latissimus Dorsi.

Deltoid: is also capable of acting in parts or as a whole; the rearmost fibres co-operate with the Latissimus Dorsi; it acts to steady the shoulder; it acts as an abductor of the shoulder joint.

Trapezius: assists in steadying the scapula and maintains the level and poise of the shoulder.

Triceps: the principal extensor muscle of the elbow.

The mechanics of walking using the hip guidance orthosis with crutches.

In any efficient mode of ambulation there is a constant exchange of energy between the potential and kinetic states. Therefore any discussion of the forces involved must include inertial forces to be complete. The complete

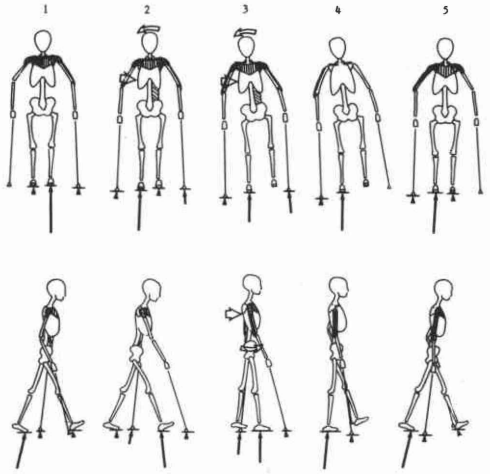

Fig. 3. Hgo walking, stages 1–5 anterior and lateral. Key – ↑ ground reaction forces. ⇨ essential hgo reaction forces. ⥲ selected rotations. ▨ active muscles.

sequence for one step of hgo walking is illustrated in Figure 3. In the following description of ambulation using the hgo the cycle will be described from Right Crutch Strike (Fig. 4) but the reader is advised to follow the full cycle and then return to Stage 1, Right Heel Strike, in order to understand fully the nature of these inertial forces.

It should be noted that not all users pass through the phase of gait described by Stage 4 but will go from Stage 3 straight to Stage 5. The user here described is a "Group III" user (see Classification of hgo users), those omitting the Stage 4 being Group II.

Note: In the description of muscle action it is accepted that the muscles of the hand and arm are used throughout, as are the small muscles of the shoulder and Serratus Anterior. Their action is not individually described. The muscle action of moving the crutch forward is also not detailed, the description being confined to the muscles directly involved in producing ground reaction forces. A full analysis of ground reaction forces may be found in the paper by Major et al, (1981).

Inertial forces are only shown where they are essential to an understanding of the mechanics.

In discussing hgo action, it is accepted that stabilization of the lower limb and control of hip adduction are functional at all times. Descriptions are limited to those where reaction forces produced by the device are essential to comprehension of hgo function.

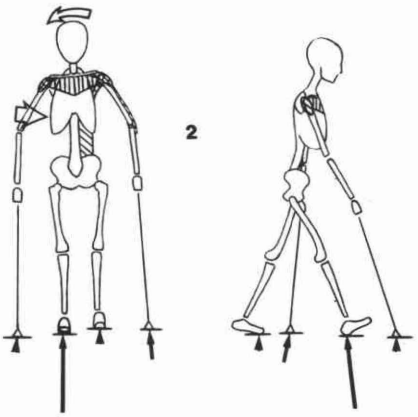

Fig. 4. Hgo walking, stage 2. Right crutch strike, commencement of lateral movement to right.

This work has been confirmed by electromyographic studies of hgo users.

Stage 2. Right Crutch Strike. Lateral movement to right commencing. (Fig. 4)

Mechanics. Most weight is transmitted through the right foot. The right crutch is positioned well forward, providing a small, stabilizing reaction. The left crutch is positioned slightly ahead of the left toe pushing down and back. This starts to tilt the user to the right to clear the left leg. Forward momentum of the trunk gained from the previous step, assisted by the rearward left crutch forces will cause the right hip to move through the "uphill" phase over the right stance foot (Fig. 5).

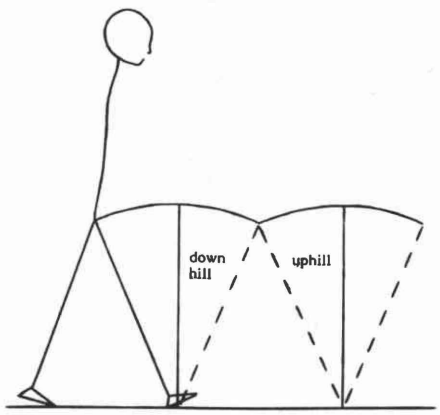

Fig. 5. Crutch force and trunk momentum move the hip "uphill". Potential energy is returned in the "downhill" phase.

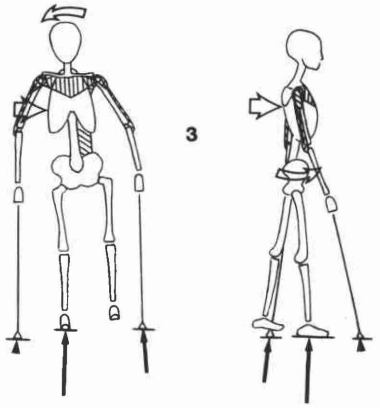

Fig. 6. Hgo walking, stage 3. Early to mid swing of the left foot. Lateral tilt to right; rotation of the trunk in the sagittal plane.

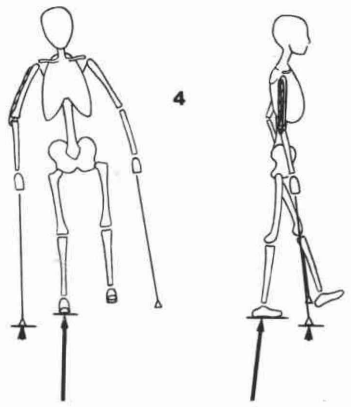

Fig. 8. Hgo walking, stage 4. Peak of right lateral tilt (Group III user only).

Muscle action. The forces on the left crutch are produced by the left Triceps and shoulder girdle depressors (Serratus Anterior, Pectoralis Minor, lower fibres of Pectoralis Major) with stabilization of the shoulder girdle by the right shoulder girdle depressors and the Deltoids. Extension of the shoulder (rearward crutch force) is produced by Triceps, Pectoralis Major (sternocostal part, until the arm reaches the plane of the body) and the left Latissimus Dorsi, whose action also assists commencement of leg clearance by acting as a tie between the shoulder and pelvis (see Stage 3: muscle action).

Orthotic reaction. An essential feature of the above is that the hgo should provide a reaction force on the right chest wall.

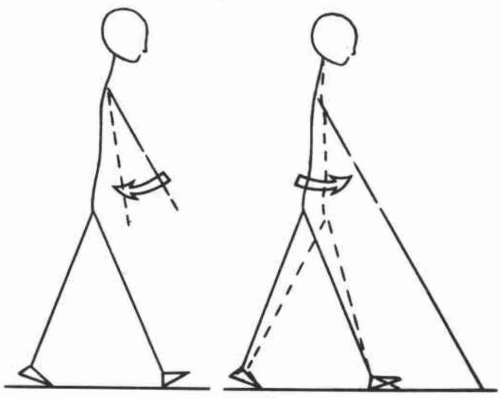

Fig. 7. Left, the normal effect of extending the shoulder is to move the arm relative to the trunk. Right, the introduction of a ground reaction (crutch) stabilizes the arm, thus producing truncal movement.

Stage 3. Early to mid-swing of left foot. Lateral tilt to right. Rotation of the trunk in the sagittal plane. (Fig. 6).

Mechanics. An increase in vertical forces on the left crutch reduces the load transmitted through the right foot, but the backward force is increased. Since the left arm and crutch are grounded and cannot move backwards relative to the floor, an attempt to extend the shoulder must result in trunk rotation in the sagittal plane, moving the pelvis forward. This in turn will produce extension of the right (stance) hip (Fig. 7). As the body moves up over the right foot the trunk momentum decreases. A twisting moment is produced by the horizontal components of force acting at the right leg and left crutch and this is stabilized by the small force through the right crutch.

Muscle action. The vertical force in the left crutch continues to be produced by the Triceps and shoulder depressors. Latissimus Dorsi provides

i) forward motion of the pelvis because the arm position is fixed relative to the floor which in turn produces extension of the stance hip by assisting the forward inertial forces of the pelvis.

ii) Latissimus Dorsi also has an additional function acting as a tie between the crutch supported shoulder and the pelvis. Thus when the hgo user is in mid swing the muscle assists the structure of the hgo in keeping the swing leg clear of the ground and preventing adduction of the hgo structure about the stance hip.

Orthotic reaction. The forward movement of the pelvis relative to the stance foot will carry the hip hinge forward in space, whereas the shoulder girdle makes a relatively small forward movement.

The top rear band ensures that the body brace maintains the correct position relative to the trunk. Reaction forces on the right chest wall will be produced as described in Stage 2 above.

Stage 4. Peak of right lateral tilt (Group III user only). (Fig. 8).

Mechanics. The left crutch force is transferred to the right foot allowing the left crutch to be removed from the ground and moved forward. The right crutch is still providing a small control force. The lateral rocking that has been imposed through the left crutch provides sufficient momentum to carry the centre of gravity towards the right leg support but not past it. In time this motion will be reversed and the body will drop onto the left leg which should have achieved the maximum flexion permitted by the hgo. The forward truncal momentum will have increased due to the "downhill" phase of moving over the stance foot.

Muscle action. There is minimal muscle activity at this point. The left crutch will be moved forward. There is sufficient activity of the right Triceps and shoulder girdle to stabilize the right arm against the small control forces being generated.

Orthotic reaction. The fact that there is very little muscular activity implies that the hgo structure is not reacting muscle force, but is simply resisting adduction and limiting hip flexion.

Stage 5. Left heel strike. (Fig. 9).

Mechanics. Body weight is transmitted through the right foot but transfer to the left foot is about to commence. This will be assisted by the lateral momentum gained by rocking off the right foot. The right crutch is still providing a small control force although this could be increased to assist the rocking if required. At this point the trunk has maximum forward momentum gained from the "downhill" phase.

Muscle action. The only muscle action required is to provide the control force on the right crutch, with increase to assisting force if necessary to rock onto the left foot. This function is fulfilled as before by the right Triceps and shoulder depressors.

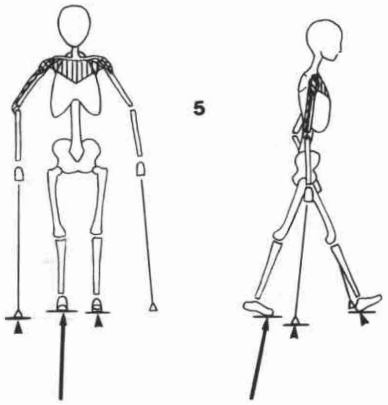

Fig. 9. Hgo walking, stage 5. Left heel strike.

Orthotic reaction. As Stage 4.

The left crutch is then repositioned in front of the left foot ready to begin the sequence for the next step.

Classification of hip guidance orthosis users

The precise mode of hgo walking varies from user to user and may alter with time in an individual user. It is valuable to observe and classify these variations for two reasons:

1. Awareness and understanding of different walking styles is extremely helpful in gaining total understanding of the mechanics of hgo walking.
2. As the user gains familiarity and experience with hgo walking, he may progress from one group to another. Thus classification forms a simple guide to user function and provides a means of monitoring this function.

There are four groups of hgo user:

Group I These are not efficient users of the hgo and demonstrate *inability to perform hgo walking* competently. Their walking is characterised by hesitancy, uncertainty and high energy expenditure. The swing leg may not clear the ground adequately, or the user may swivel on the stance leg. The walking aid may be either *rollator or crutches.*

This group of user will need help with their problems and it is worthwhile

1. Checking the fit of the orthosis (following routine mechanical inspection of the hgo)
2. Training the user further to eradicate problems.

Group II In contrast, these users have a rhythmical form of gait with low energy cost. They perform hgo walking as described (see

mechanics of walking using the hgo, but omitting Stage 4). Thus they always maintain at least *three points of contact* with the ground, the flow of walking being right heel strike, right crutch swing and strike, left leg swing and strike, left crutch swing and strike, right leg swing and strike etc. These users will often demonstrate marked truncal movement in the sagittal plane, which increases as they become more vigorous walkers. Speed of walking is not a factor in determining group of user and the walk may be quite slow but will be classified as Group II if the above factors are demonstrated.

Group II walkers may use either *rollator or crutches* (rollator implying at least three point contact) and this group may be usefully subdivided further into those who use rollator (II R) and those whose use crutches (II C).

The majority of hgo users will be Group II.

Group III These are the more experienced users of the hgo who have developed greater confidence and ability. Observation of their walking often reveals a pronounced side-to-side sway as they walk. Close inspection reveals that they include Stage 4 of the described mechanics of hgo walking. Thus at one point during each step they go to *two point contact* only, using the foot and crutch on the *same side* and it is this which is responsible for the pronounced lateral (coronal plane) sway. These users may also demonstrate sagittal plane truncal movement as in Group II but the effect of the lateral movement often masks this. The flow of walking is thus right crutch swing, right heel strike, right crutch strike, left leg swing, left crutch swing, left heel strike, left crutch strike, etc. (i.e. the crutch on the same side strikes after the foot).

It is obvious, therefore, that to perform this mode of walking the walking aid must be *crutches* to achieve two point contact. Because these users are more proficient, they will usually walk more quickly, and over a greater variety of surfaces than Group II.

Group IV Comparatively few users will be classified into this group. These users demonstrate an assurance not shown in the previous groups. The main feature of this mode is the *apparently random use of crutches*. The crutches may be advanced simultaneously or at random intervals. These users have reached a very refined form of hgo walking, where their awareness and familiarity with walking enables them to inject forces to their own particular needs, and to use inertial forces to greater advantage. The first couple of steps in a walking sequence usually conforms to the previously described pattern, and once in progress the more random mode takes over. Obviously this mode of walking is only achieved with *crutches*.

This group of users generally demonstrates an economy of truncal movement, which, although present, is reduced in comparison to Groups II and III.

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