SWIVEL WALKERS FOR PARAPLEGICS—Considerations and Problems in Their Design and Application

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INTRODUCTION

The principle of the swivel walker is no longer new. Previous papers have given details of the use of this type of appliance for amelic children (1–8). Following early work at the University of California (1), Spielrein suggested using a pylon arrangement with a forward center of gravity and side-to-side oscillation to promote ambulation (3). Following this, the Ontario Crippled Childrens' Centre, Toronto, successfully applied these principles to children with bilateral lower-extremity amelias. The Shrewsbury appliance has now extended the swivel walker principle to full body splints for both children and adults where the patient has complete but paralyzed lower limbs. The object of the appliance in all cases is to provide the patient with a frame which permits him not only to stand upright but also to ambulate with his hands free.

TECHNICAL CONSIDERATIONS

Technically the Shrewsbury Paraplegic Walker is a combination of a full length body brace and a motivating mechanism. Efficient operation is dependent upon the appliance being correctly designed and engineered and particularly upon the patient being correctly fitted into the appliance. This latter is important because, as will be seen later, one of the principal motivating forces is the displacement of the center of gravity of the patient and appliance. This can be critical with very weak patients and if this principle is violated such patients will be unable to move at all or will only do so with exhaustive effort. Nevertheless, it is not necessary in most cases to have a custom-built appliance as the structure need not follow the contour of the body too closely provided that the various attachments necessary for the three-point support of the patient's skeleton are correctly arranged and the balance is satisfactory.

The Shrewsbury Appliance

This is essentially a stiff, lightweight structure consisting of a body brace mounted on swiveling feet with return springs. Double row ball bearings are used in the mountings to carry the heavy loads imposed and to ensure a low-friction swiveling movement. The foot plates which are of adequate size to ensure anterior-posterior stability, have a dihedral angle of up to 6 deg. to permit sufficient sideways roll to allow each foot to clear the ground for ambulation. (See Fig. 7.) A swiveling angle of up to 30 deg. is allowed for each footplate.

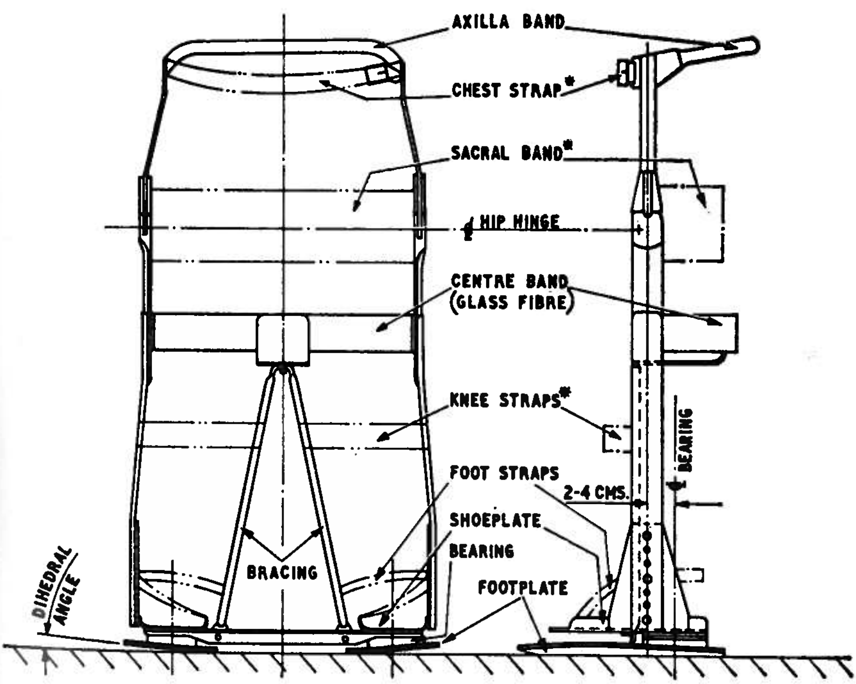

FIGURE 1.—Shrewsbury Paraplegic Walker. (*Denotes the bands supporting the patient in the appliance.)

All of the designs are based on modular construction, and, although they vary somewhat in detail with the different sizes, all are similar in that the structure consists of side struts which may be articulated or not at the hip and, in the larger models, may be articulated also at the knee. Two or more posterior stiffening arches, either of light alloy tube or glass or carbon-reinforced plastic, provide lateral rigidity. Technical details of a child's appliance articulated at the hip are given in Figure 1 while Figure 2 shows a child in the appliance.

The three horizontal forces necessary to hold the body upright in the frame are shown in Figure 3. In the appliance these forces are provided by a chest strap, sacral band, and upper tibial bands or knee straps respectively as shown in Figure 1. Held in this way the skeleton is stabilized within the frame so that the body weight is supported by the bones themselves, the weight on the feet then being carried by the footplates. This is not only comfortable and beneficial to the patient but the arrangement is such that the appliance frame is carrying minimum load.

Figure 2.—Child in appliance.

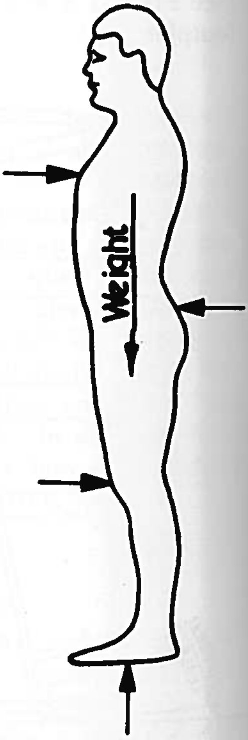

Figure 3.—Horizontal forces required to stabilize the skeleton within the frame.

The structure itself is constructed of duralumin or high-tensile steel depending upon the size of the appliance and the loading, but in all cases the appliance is designed for minimum weight to minimize fatigue in operation and to enable it to be used by the very weak patient. Perhaps it should be mentioned here that while weight may not be critical it is important in practice, partly because compound pendulum theory applies only approximately in swivel walker ambulation (and sometimes not at all) and partly because the appliance must be handled when fitting by mother or physiotherapist or, in some cases by the patient himself.

Figure 4 shows an adult standing in her appliance while Figure 5 shows the same patient sitting down. Figure 6 shows an early teenage appliance.

FIGURE 4.—Adult in appliance.

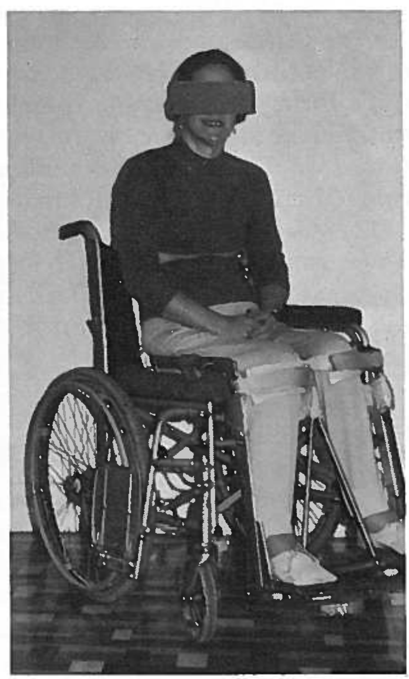

FIGURE 5.—Adult sitting in appliance

FIGURE 6.—Early teenagers in appliance.

One of the major problems in the design of these appliances is the provision of efficient articulation arranged to enable the paralyzed patient to rise and sit down unaided. On the very small appliances this is not usually necessary. For older children and adults, however, some form of articulation is highly desirable. In the case of children this can be overcome by the introduction of a joint at the hip as shown on Figure 1. The adult appliance shown on Figure 5 is of course hinged at knee and hip.

The major problem of articulation is achieving a design of joint which can be opened under load without undue effort, which will close automatically, and which when introduced into the structure will allow adequate structural stiffness to be retained within the permissible weight.

Forces Involved in Ambulation

The forces to operate a swivel walker are of course created by the patient. Simplified, these are as follows:

1. A side force to roll the appliance sideways and so allow each foot to rise in turn. It is important that the rising foot should clear the ground; otherwise drag is created and energy is wasted. To achieve this roll the footplates should, theoretically, be curved laterally but in practice it is satisfactory to bend the footplate to an angle up to 6 deg. as shown on Figure 7.

2. An unbalanced force S (a component of the weight) acting about the inclined axis of the bearing of the standing foot causing the raised foot to rotate forward. (See Fig. 7b and c.)

3. A twist about a vertical axis produced by the muscles of the patient's trunk. This latter force will, of course, depend upon the strength of a patient's trunk. A strong patient can in fact, motivate a swivel walker by using this force alone although progress is clumsy and energy-consuming.

Theoretically, a correctly aligned and balanced swivel walker should start to walk as soon as the lateral rolling moment lifts the opposite foot from the ground. The system of forces is then unbalanced with the center of gravity forward of the bearing center as described in "2" above, and both apparatus and patient will swivel round the inclined axis of the bearing of the standing foot until the moving foot either strikes the ground or is "grounded" by contra-rocking action of the patient as he returns to the vertical.

Whatever the reason for the moving foot returning to the ground, its position at that time will determine the length of "stride" which the patient makes. This, and the speed of ambulation will, therefore, depend upon the distance between the centers of the foot bearings,

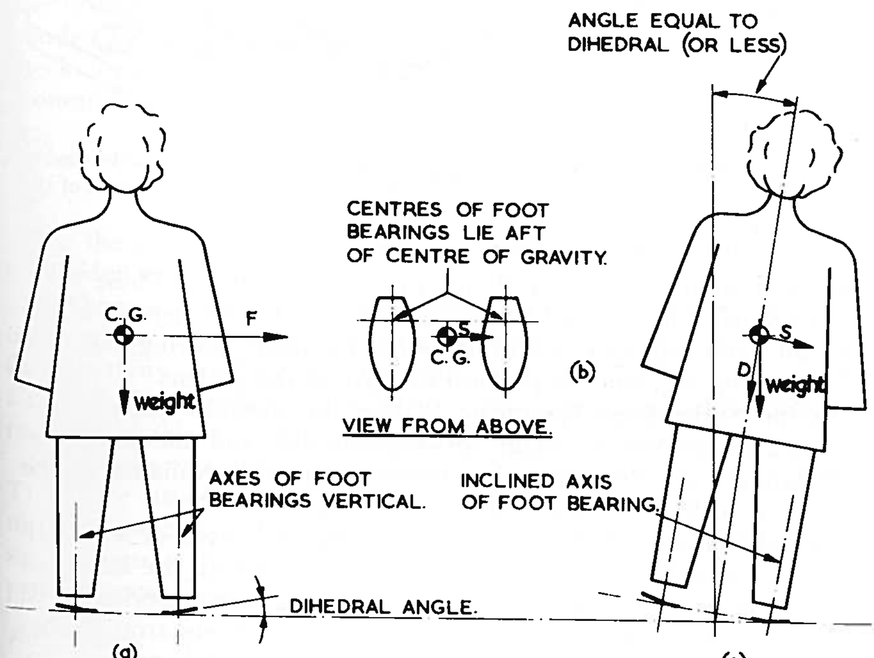

FIGURE 7.—Forces involved in ambulation.

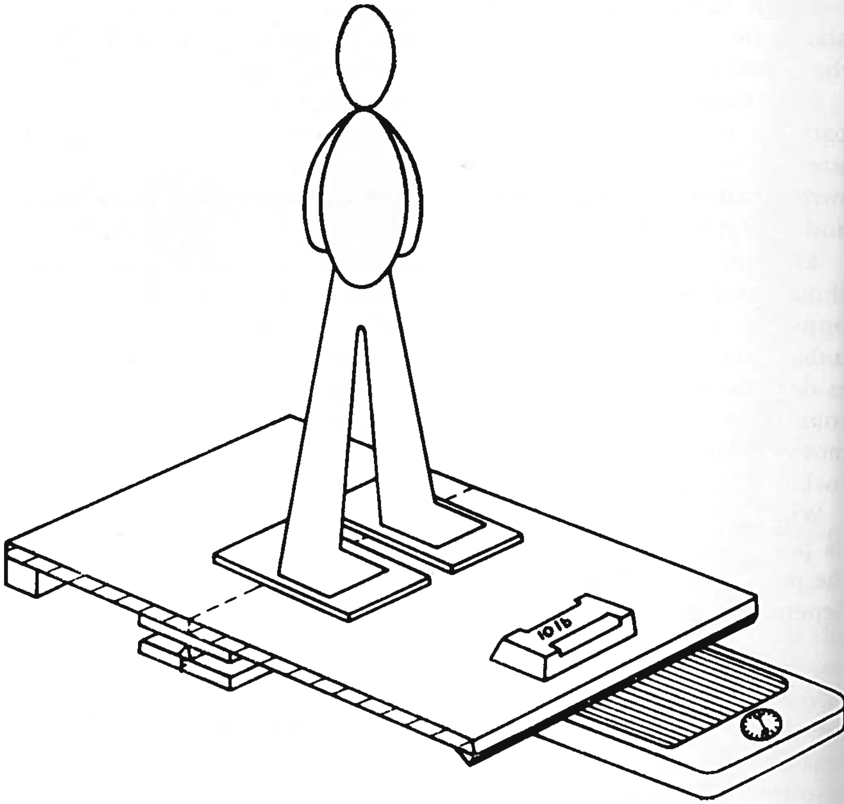

FIGURE 8.—Balance consisting of wooden platform and standard bathroom scales used to check that center of gravity of patient and appliance is forward of the centers of the foot bearings.

the duration of the lateral roll, and the angular velocity. These latter will in practice be affected by such features as the unevenness of the ground, the coefficient of friction of the footplate covering, the type of floor covering, and the physical strength of the patient.

In the Shrewsbury Paraplegic Walker the distance between the foot bearing centers is usually between one-fifth and one-quarter of the patient's height depending upon the power available in the patient to rock the appliance sideways as required by "1."

In practice this means that appliances used for weak or inexperienced patients will have foot-bearing centers one-fifth the height of the patient or less while those with more strength or experience will be able to use a wider stance with foot-bearing centers around one-quarter of their height, with consequent improvement in ambulation. On the latest models we have incorporated in the foot assembly an arrangement whereby the rocking edges of the footplate are moved inwards and the bearing centers moved outwards in the coronal plane. This reduces the effort needed to roll the appliance and at the same time increases the length of stride. Further improvement is being obtained by the introduction of linked feet having parallel movement.

With a correctly aligned and balanced patient the motivating forces will be resisted only by the friction in the bearing and the restoring moment created by the return spring with which the swivel feet are fitted. For this reason the spring should be the weakest possible to return the foot plate to normal, although it is essential that this movement should be positive and fast.

The optimum design of the appliance should, therefore, be based on "1" and "2" above with any extra-ambulating force from "3" being regarded as a bonus.

Center of Gravity Measurement

The assessment of the important center of gravity position in the anterior-posterior plane presented many problems particularly with children who would not keep still. This has now been solved by the use of the simple apparatus consisting of bathroom scales and wooden platform shown in Figure 8. The balance can also be used to check the offset of the center of gravity of patients who have a pronounced scoliosis or similar deformity.

MEDICAL CONSIDERATIONS

For the purpose of this paper, severely handicapped patients can be divided into two groups:

1. Those who have either total paralysis from the waist downwards or in whom the muscles functioning below this level are reflex in their activity and are not therefore controllable by the patient although they can deform limbs. Such patients are insensitive both as regards the skin and their sense of position of their limbs.

2. Patients who have some strong voluntary muscles in their legs. These are usually the flexors of the hips with a variety of other muscles lower in the leg. In all cases the extensors are missing. The sensory loss is lower than in group 1 and the voluntary muscles provide some feedback information with regard to position.

Advantages

The Shrewsbury Paraplegic Walker is applicable only to the first group as a potentially permanent form of orthosis, but can be used with great advantage in the second group after one year of age as a primary means of achieving experience in the erect posture and in locomotion, particularly if the child is weak and/or has spinal defects.

The appliance can provide:

1. Safe, prolonged standing at the age of 1 year or soon after. The value of this cannot be over-emphasized. Psychologically, it is essential to the full development of a child and may be reflected in a change from a dull, uninterested child to an alert and ambitious one. Physiologically, it improves the drainage of the urinary tract, eliminates recurrent spontaneous fractures and improves bowel function and peripheral lower-limb circulation.

2. Bipedal locomotion with low energy consumption which highly paralyzed patients can use confidently without conscious preoccupation with the maneuvers required to achieve this.

Because of the severe inherent deficiency of motor and sensory components, whatever surgical or orthotic skills are applied to the problem of locomotion, there will be a finite limitation of the aid which any particular appliance can give. At this time, this apparatus has the following limitations:

1. A rather slow rate of locomotion when compared with acceptable normal gait, e.g., a speed of up to 40 feet per minute (12 meters per minute), compared with 100 feet per minute for a slow stroll (30 meters per minute).

2. While the static cosmesis is satisfactory in the standing position, the dynamic cosmesis, because of the mode of progression, is clearly very different from normal gait and less acceptable to the older patient, though our experience shows that cosmesis comes a long way behind function and low energy usage in determining patient acceptability.

3. Difficulties in achieving chair ambulation transfer: problems of hinge design and modes of unlocking are a major present research consideration.

4. Much less important, the clicking noise made in progression by the swiveling footplates returning against the stops, often raises adverse criticism. This sound is useful with the small child because it helps to develop a sense of rhythm in walking, and acts as an indicator to mother as to the progress of the child. Larger appliances are now being made with silent movement.

Uneven floor surfaces cause difficulties, although most patients can safely negotiate a thin carpet or threshold bar and some are able to walk up and down slight inclines.

Choice of Patient

In making the correct choice of patient for the Shrewsbury appliance the following factors must be considered:

1. The production of a skeletal posture which will enable three-point stabilization to be achieved. This has the beneficial effect of putting most of the weight of the patient on to the bones of the skeleton and avoids the adverse effect of excessive pressure on fixation points, which are frequently in insensitive areas. Radical excision of contracted or reflexly acting muscle groups within the first year of life is most helpful. The practical problem is to distinguish reflex muscular activity at this age.

Even with these procedures it is not always possible to achieve the ideal state of aligned bones and in practice it is found, for example, that some 20 deg. flexion of the knees is tolerated surprisingly well, possibly because of the intermittent pressure over the insensitive areas during locomotion. This is fortunate, for an obsession with the theoretical need to straighten the hips and knees could lead to very limited flexion of these joints which, while not interfering with the use of the splint, disastrously handicaps sitting and, even more importantly, transfer facility.

2. Achievement of plantigrade feet in which the weight of the patient is taken over the normal tissues of the sole.

3. Avoidance of external rotation deformity at the hips. This has a double mal-effect. Because of the resolution of forces, it makes the three-point fixation inefficient, and indeed tends to increase the external rotation. Secondly, the externally rotated flexed knees tend to press against the outside bar, with excessive localized pressure.

4. The problem of dislocated hips. Unless these can be reduced by a simple method within the first two years of life, there is often no point in trying to do this. The patients function equally well in the splint with the hips dislocated, and no other disadvantages have accrued from leaving them thus.

5. Consideration of the unsolved and most important problem of spinal stability. Essentially, this splint stabilizes hip and knee, but in patients who have instability of their spine, due to the presence of either kyphosis or, less commonly, lordosis and scoliosis, it will have some stabilizing effect on the deformity, albeit grossly inefficient. This can be modestly improved by the use of an appropriate spinal support, e.g., a reinforced plastic jacket.

Spinal Instability

Various surgical techniques are at present being tried to alleviate this important problem. It illustrates a fundamental need for surgical-orthotic integration in providing splintage for the heavily handicapped, for this is a situation in which, at this time, orthotists cannot be expected to remedy the present defects of surgical intervention.

Lateral displacement of the upper trunk in relationship to the pelvis, due to spinal curvature, clearly makes the displacement of the center of gravity in relationship to the footplate bearing extremely difficult in one direction as indicated in Figure 9. The problem can in part, be helped by insertion of lateral stabilizing bands within the splint but these are difficult to maintain in position and can produce pressure problems in both sensitive and insensitive areas.

DISCUSSION

With this surgical-orthotic integration, there must come another factor, namely the capacity of the orthotist or appliance maker to produce quickly an apparatus which conforms to the criteria indicated, which will be reliable and has parts which are rapidly reparable or replaceable. The orthotist should also be prepared to take part in progressive development and modification of the splint,

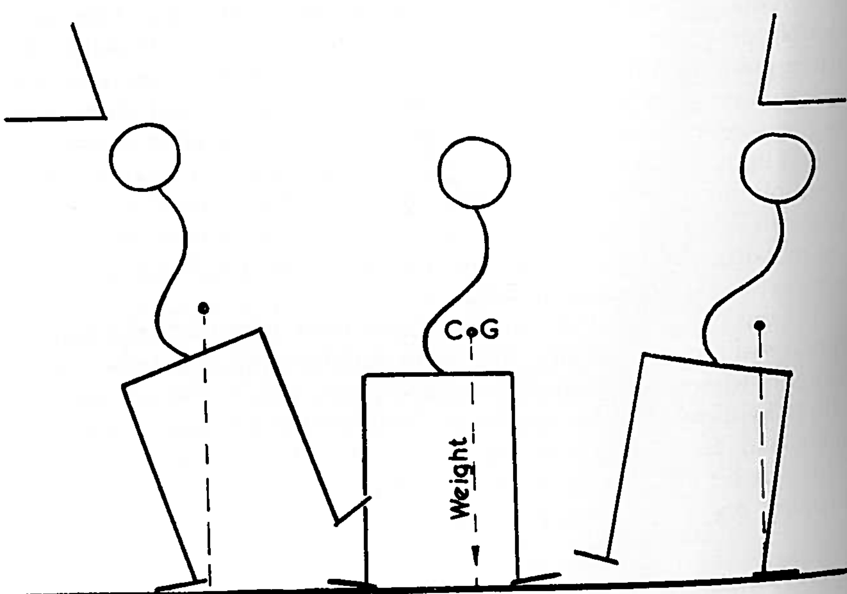

Figure 9.—Effect on balance of lateral deformity of the upper trunk.

in relationship both to the growth of the patient and to a further understanding of the mechanical and surgical problems involved.

Although only one form of splint has been considered, it is not part of our philosophy that this form of orthosis will, of necessity, be the most desirable, nor in those cases where it is at one time the most desirable will it necessarily be the only form to be adopted during the life-time of a patient; indeed, it will not necessarily be the only form of splintage to be used in a single day of a patient's life. Integration and interchangeability with other forms of locomotor assistance could therefore be important factors in future development.

There are now some 100 patients using these appliances daily (mainly at Shrewsbury and Salford), with ages ranging from 12 months to the adult shown in Figures 4 and 5 and convincing evidence is accumulating of their effectiveness and therapeutic value. The earliest appliances have been in use since 1965 and considerable development has taken place since that time. Much further research is, however, envisaged, particularly into the problems of sitting and standing and ease of assumption, while the possibility of power assistance to extend the usefulness of the appliance to the weakest of patients is a development which will be given careful study.

In conclusion, it is perhaps pertinent to say that there are many appliances being supplied as Shrewsbury Paraplegic Walkers which fall short in many respects of the requirements outlined in this paper. As a result many of them either do not work at all, especially where the patient is very weak, or they are so unsatisfactory that frustration of both patient and physiotherapist soon leads to their being discarded.

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REFERENCES

1. University of California, School of Medicine. Child Amputee Prosthetics Project. Report, 196C.
2. Hall, C.B.: Ambulation of Congenital Bilateral Lower Extremity Amelias and/or Phocomelias. Inter-Clinic Infor. Bull., 1(4):1–8, Jan. 1962.
3. Spielrein, R.E.: An Engineering Approach to Ambulation without the Use of

External Power Sources, of Severely Handicapped Individuals. J. of Instit. of Engrs., Australia, Dec. 1963.
4. Klein, R.W.: An Experimental Prosthesis for Lower Extremity Amelia. Med. J. of Australia, 1(13):476–478, 1964.
5. Motlock, W.M. and J. Elliott: Fitting and Training Children with Swivel Walkers. Artif. Limbs, 10(2):27–38, Autumn 1966.
6. Spielrein, R.E.: Some Modern Prosthetic and Orthotic Trends and Developments seen as a Challenge to the Engineering Profession. J. of Instit. of Engrs., Australia, pp. 73–82, June 1969.
7. Barry, R.M. and R.J. Duncan: A New Concept in Swivel Walkers—A Comparison with the Conventional (Canadian Type). Artif. Limbs, 13(1):66–68, Spring 1969.
8. Nichols et al.: Swivel Walkers. Annals of Phys. Med., X(3), Aug. 1969.
9. Lorber, J.: Results of Treatment of Myelomeningocele. Developmental Med. & Child Neurology, 13:279–303, 1971.
10. Rose, G.K. and J.T. Henshaw: A Swivel Walker for Paraplegics: Medical and Technical Considerations, Bio-Med. Engng., 7(9):420–425, Oct. 1972.
11. Henshaw, J.T.: The Bio-Mechanics of the Shrewsbury Paraplegic Walker. Proceedings of 1st International Congress on Prosthetics Techniques and Functional Rehabilitation. Vol. 2, pp. 155–160, Vienna 1973.
12. Rose, G.K.: Orthotic-Surgical Integration of the Shrewsbury Paraplegic Walker. Proceedings of 1st International Congress on Prosthetics Techniques and Functional Rehabilitation. Vol. 2, pp. 161–165, Vienna 1973.