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A DYNAMIC ORTHOTICS SYSTEM TO ASSIST PELVIC EXTENSION: A PRELIMINARY REPORT[1,2]

John Glancy, C.O.[3]
Richard E. Lindseth, M.D.[3]

Myelomeningocele has been described as "the most complex, treatable congenital anomaly consistent with life" (*2*). About five years ago, we began to focus our attention on musculoskeletal deformities that occur after birth. First priority was given to the child with lower lumbar paraplegia (L3 through L5) because these children have the potential to walk indoors and outdoors. Yet, few of these youngsters are still capable of independent ambulation when they reach adulthood. Throughout their growing years, a losing battle is waged against pathomechanical changes that affect the musculoskeletal system, resulting in flexion deformity of the hip and excessive lordosis of the lumbar spine.

Flexion deformity of the hip develops in the L3-level myelomeningocele child because all of the active muscles, iliopsoas, rectus femoris and sartorius, are located anterior to the hip joint and both of the normal hip extensors, the gluteus maximus and the hamstrings, are paralyzed, and thus there is no dynamic extending force to resist anterior rotation of the pelvis when the patient is in the upright position.

The youngster with a lesion at the L4 level, in addition, has innervated semitendinosus or gracilis muscles or both. Unfortunately, the presence of the medial hamstring is of little or no use in preventing hip flexion. When this muscle contracts to prevent unwanted hip flexion (pelvic forward rotation), it inadvertently flexes the knee. The knee's bending is then opposed by the rectus femoris, which, in turn, flexes the hip, thus negating whatever extension force the semitendinosus may have on the pelvis.

Although at the L5 level of paraplegia the medial hamstrings are fully innervated, the gluteus maximus is paralyzed and the same muscle imbalance exists as is the case of the L4 paraplegic. However, although the stronger force of the hamstring muscles improves the anteroposterior balance across the hip joints and prevents the development of fixed hip flexion contractures, a dynamic or functional hip flexion posture is developed in order to accommodate for the excessive lordosis that is essential for these children to achieve balance.

Despite surgical procedures such as posterior transfer of the iliopsoas (which appears to prevent the deformity when the child is recumbent) to correct the flexion deformity, we have found such procedures to be inadequate in preventing hip flexion and excessive lordosis when the child stands. Therefore, we feel that an external orthosis is necessary to control unwanted hip flexion and excessive lordosis. Past experience with external orthoses of our own design as well as designs of others led us to the following conclusions:

1. Pelvic control can be maintained by passive "prepositioning" when normal range of motion of the hips and lumbar spine has been maintained *prior* to application of the orthoses.

2. Control of the pelvis cannot be achieved by external means unless there is a mechanical connection between the pelvic component and the thigh components of an orthosis.

3. Pelvic control for the "low-level" myelomeningocele child should be limited to rotation in the anteroposterior plane only. Rotation in the transverse and mediolateral planes is useful and should not be inhibited by an appliance.

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[3]Indiana University/Purdue University at Indianapolis School of Medicine, 1100 West Michigan Street, Indianapolis, Indiana 46207.

4. No orthotics system, now known, is available for reduction or prevention of an increase in hip flexion contractures when they exist at the time the orthosis is applied. (This is true as to both the short and the long term.)

5. No orthoses currently available provide a dynamic force that creates an extension moment about the hip axis, which is essential in the prevention of hip flexion contractures in the L3 and below myelomeningocele child.

6. An orthotics system designed to provide an extension moment about the hip joints should allow motion in those planes in which the child has control so that the overly confining features of contemporary orthoses can be avoided.

7. The orthotics system must offer stability and guidance to motion that is the product of muscle activity. It must not inhibit such activity.

Our latest prototype orthotics system, evolved from five earlier designs, is shown in Figure 1. We believe that this type of system meets the needs of the growing, low-level myelomeningocele patient by providing freedom of motion for the child's immediate use while, at the same time, providing protection from hip flexion deformity and excessive lordosis throughout the growing years. The system consists of:

1. A polypropylene thoracic "girdle" with a movable pelvic section. The adjustable pelvic section of the thoracic unit permits passive control of the lumbar region by prepositioning and maintaining an optimal relationship between pel-

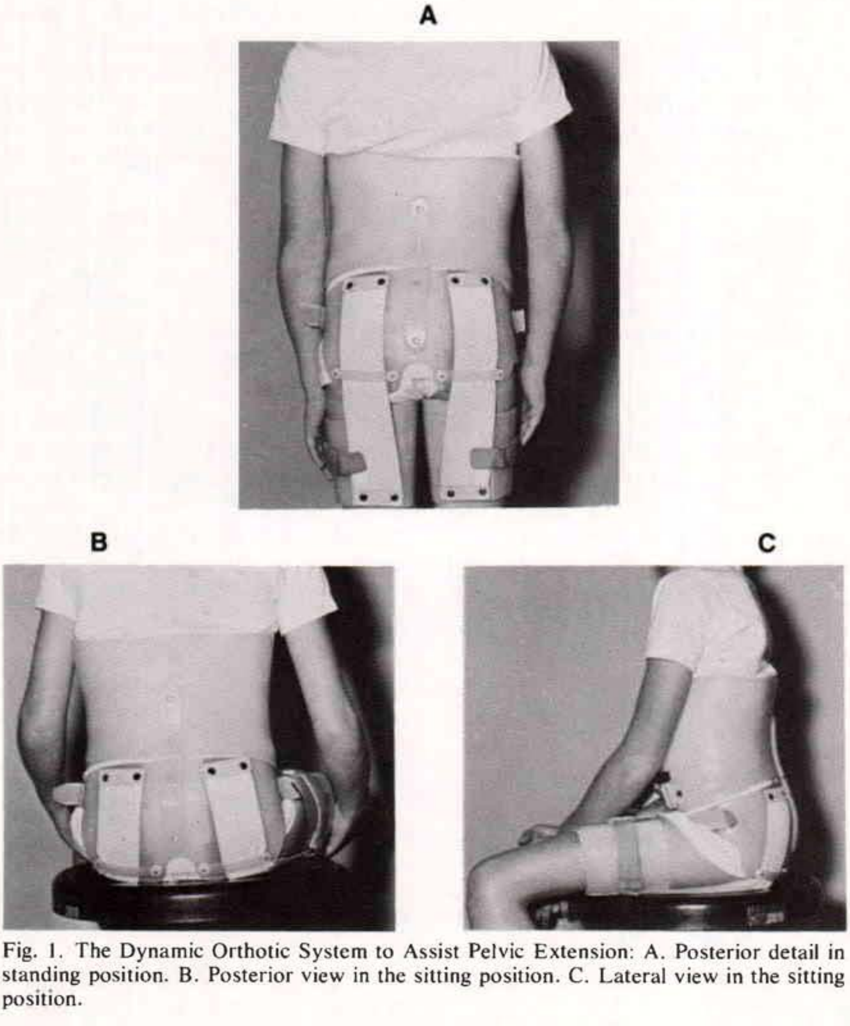

Fig. 1. The Dynamic Orthotic System to Assist Pelvic Extension: A. Posterior detail in standing position. B. Posterior view in the sitting position. C. Lateral view in the sitting position.

vis and thorax. Both sections are lined with ¼-in. Plastazote.

2. Bilateral, quadrilateral-type polypropylene thigh cuffs lined with ⅛-in. thick Plastazote.

3. Bilateral woven elastic panels that provide the force that produces the extensor moment about the hip joints.

At their proximal ends, the elastic panels are riveted just below the upper edge of the movable pelvic section of the thoracopelvic unit. The distal ends of the two woven elastic panels are riveted to the posterior side of the quadrilateral cuffs. In this arrangement, the force is transferred from one side to the other by the polypropylene pelvic section. The total weight of the orthotics system is 655 g for the average five-year-old child. The thoracopelvic unit weights 440 g, and each of the quadrilateral thigh cuffs, including its elastic panel, weighs 107.5 g.

DISCUSSION

The development of plastics has opened up new design possibilities for orthotics devices within the past few years. Major advantages include reduction in weight, better cosmesis, and a more intimate fit that permits an efficient application of the three-point pressure system to the trunk. For example, a polypropylene body jacket, lined with Plastazote and Silastic and utilizing the Milwaukee brace technique for the waist and abdomen (*1*,*5*) increase intra-abdominal pressure (*6*), makes it possible for the patient with insensitive skin to receive excellent support day after day, free from pressure sores. These materials are waterproof and impervious to body excretions (Fig. 2).

We have taken advantage of the characteristics of polypropylene to fatigue to build into spinal jackets an adjustable pelvic panel that permits adjustment to the wearer's optimum position of balance in the anteroposterior plane and also gives the wearer freedom to rotate his pelvis in the transverse plane and thus to walk with a gluteus medius sway. These features are obtained without loss to the efficiency of the three-point pressure system necessary to prevent excessive lordosis. The pivotable pelvic band of the Williams brace (*7*) permits "prepositioning" of the lumbar curve. It is this feature of the Williams brace that we have incorporated into our thoracopelvic design in the form of a molded adjustable pelvic section (Fig. 3).

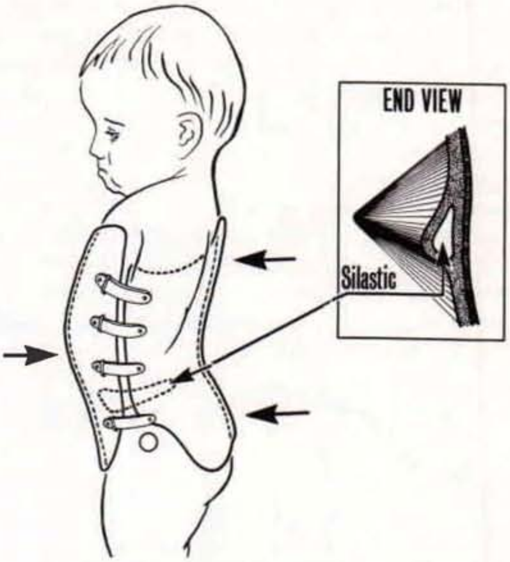

Fig. 2. Earlier polypropylene thoracopelvic unit showing incorporation of Silastic for insensitive skin. Note the natural contour of the outer surface.

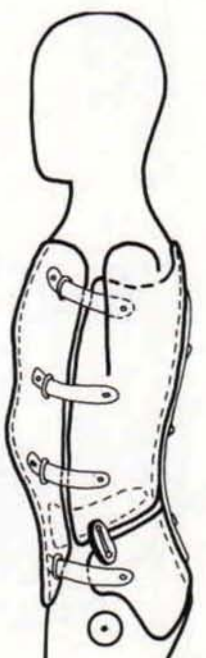

Fig. 3. Present model of a polypropylene thoracopelvic unit showing molded, adjustable pelvic section.

In order to show the importance of pelvic control to the overall biomechanical problems of the L3, 4, and 5 myelomeningocele child as they relate to balance and gait, it is necessary to refer to previous work (*4,6*) done with these children related to the foot/ankle complex and knee (Fig. 4). The beneficial effect of the SA braces to the myelomeningocele child's foot/ankle complex and knees is evident and gratifying, but it is equally evident that no benefit toward pelvic control could be attributed to them. On the contrary, an uneasy feeling persists that serious further deformity to the lumbar spine may be a direct result of long-term use of *any* type of bracing that stabilizes the ankle and knee joints to facilitate more efficient ambulation, unless a means of controlling the pelvis can be devised (Fig. 5) since the mere act of standing without bracing also leads to deformity of the lumbar spine (Fig. 6).

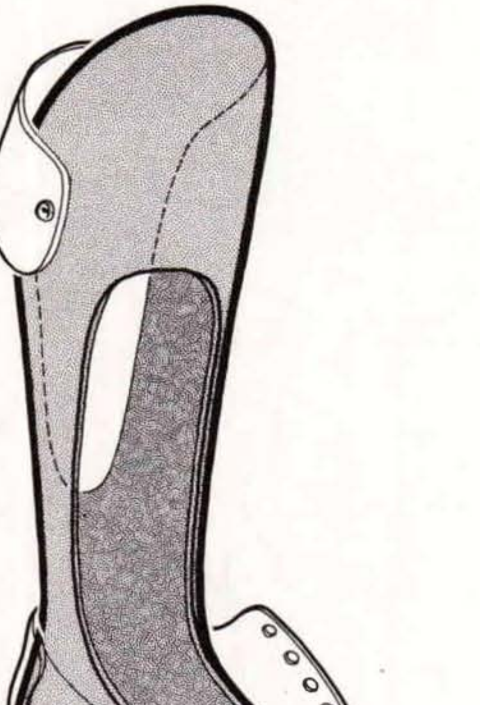

Fig. 4. Polypropylene solid-ankle (SA) below-knee orthosis with Plastazote lining.

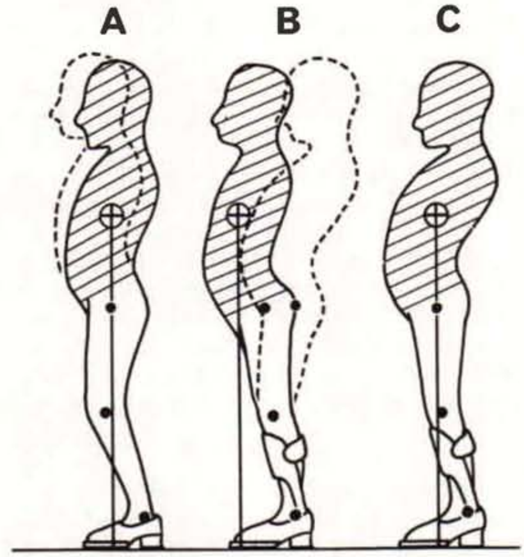

Fig 5. Effects of stabilizing the foot/ankle complex and knee upon AP balance of the trunk when hip flexion contractures are present. Solid-ankle orthosis is shown. However, any type of bracing produces similar effects: A. Solid-lined figure shows posture necessary to balance without bracing. B. That knee flexion alone cannot accommodate for hip flexion contractures is demonstrated. It can be seen that forward flexing of the thorax to restore balance, without active trunk extensors, is not a practical alternative. C The only anatomic option left is to increase lordosis. (⊕ represents C.G. of trunk only.)

Protection for the hip is provided by our design by permitting a "preload," or extension force, to be applied by introducing slight stretch to the elastic panels when the unit is placed on the patient. This provides a mild stretching force upon the hip flexors and quadriceps muscles to prevent the gradual contracture of the muscles when the child is standing at ease. Furthermore, whenever the wearer flexes either his leg or his pelvis, the force provided by the woven elastic panels is increased which, in turn, increases the extensor moment about the hip joints. This increase in force is proportionate to angular changes, thereby aiding control of motions about the hip joint.

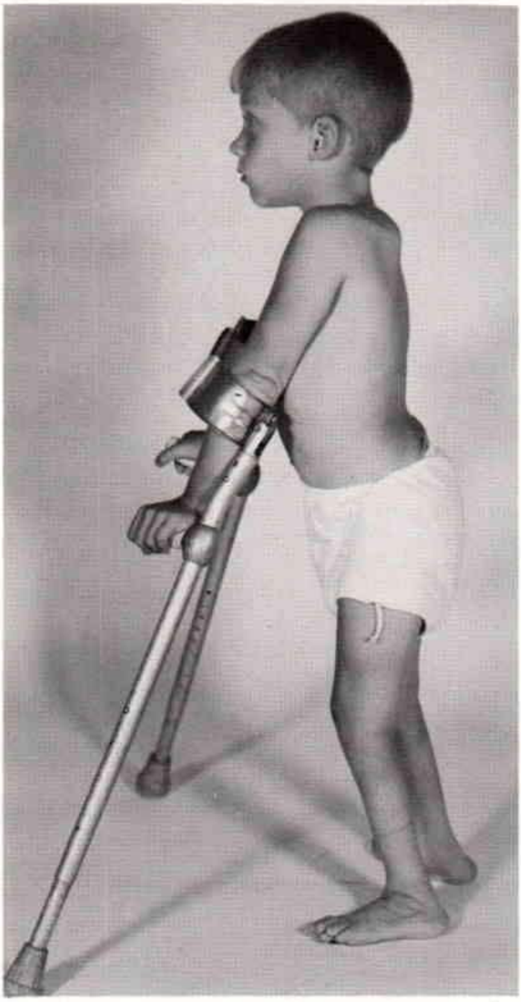

Fig 6. Effects of standing, without bracing, upon the lumbar spine. Note the proportion of body weight being supported through the arms and crutches. Without the crutches, the child must assume an excessive lordotic posture in order to bring and maintain his trunk over a much smaller base of support.

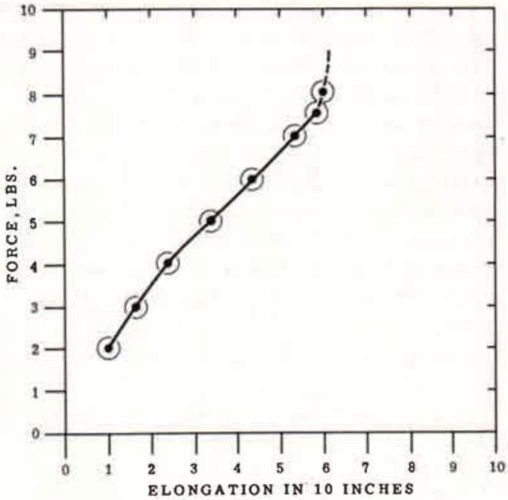

Fig. 7. Typical load-elongation curve for elastic panel. The one-inch reading represents the preload.

A typical load-elongation curve for a 10-in. long piece of the elastic panel is illustrated in Figure 7. When the leg is in 90 deg. of flexion, the elastic panel will stretch from a minimum preloaded condition to an extension of approximately 4 in. This will create a force of nearly 6 lb, according to Figure 8, acting on the lower part of the thigh cuff. The moment about the hip is

$$M_{hip} = F\,r \qquad (1)$$

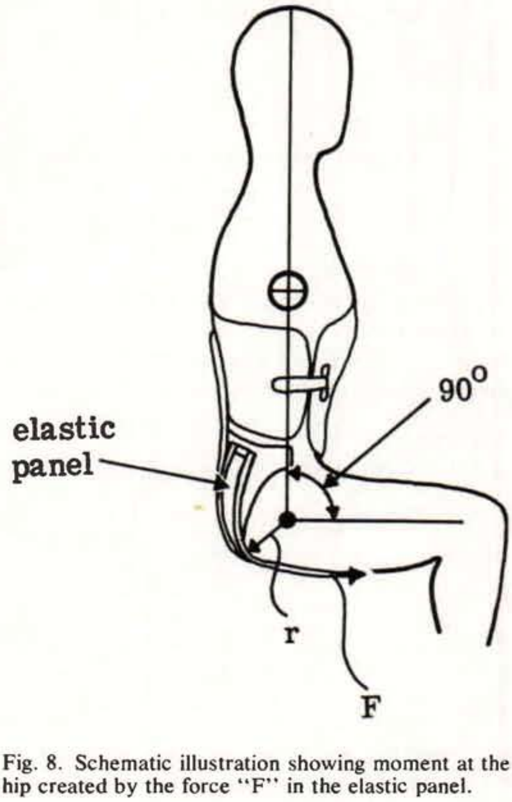

Fig. 8. Schematic illustration showing moment at the hip created by the force "F" in the elastic panel.

where "r" is the radial distance between hip axis and elastic panel. When "r" is 2 ½ in., the moment about the hip is 15 in. lb. Such a moment provides a steadying influence by providing resistance to the active anterior muscles that cross the hip joints. However, the magnitude of the moment is very small compared to the moment due to the weight of the trunk. To illustrate this, consider a subject bending over at the waist, as shown in Figure 9. When the value of the moment, M_R, is that required to maintain equilibrium,

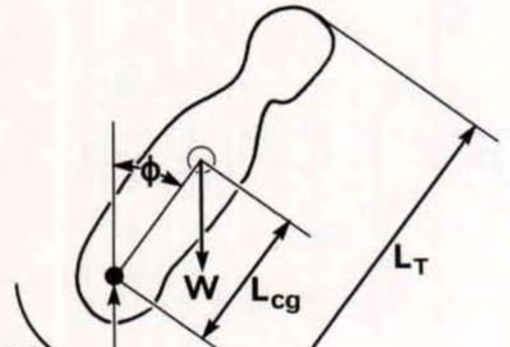

Fig. 9. Free body diagram of trunk.

$$M_R = F \cdot r = WL_{cg} \sin \phi \qquad (2)$$

From W. T. Dempster (*3*): $W \simeq 0.5 \cdot W_B$ where W_B is the total body weight and $L_{cg} \simeq 0.4 \cdot L_T$ for adults. Assuming these ratios are also true for children, the solution to equation 2 becomes:

$$M_R = (0.4)\,(0.5) W_B L_T \sin \phi \qquad (4)$$

As an example, for a subject with

$$W_B = .32 \text{ lbs}$$

$$L_T = 19 \text{ lbs}$$

gives

$$M_R = (.2)\,(19)\,(32) \sin \phi$$

$$= 121.6 \sin \phi$$

As the subject bends, the angle ϕ increases and the restoring moment necessary to maintain equilibrium increases. For this example:

ϕ	M_R (inch pounds)
5°	10.57
10°	20.93
15°	31.37
30°	60.80

which far exceed the moment created by the elastic panel, except in the near vertical positions.

Similarly, the force from the elastic panel is easily overcome by the muscle action, because it is small compared to the forces that the muscles can generate. It appears that the magnitude of extensor moment provided by the elastic is sufficient to check involuntary forward flexion (sway in an anterior direction) of the trunk in the upright position, and thus contributes substantially to the anteroposterior balance in the lower lumbar paraplegic child. We believe that such a contribution is possible with our present design.

SUMMARY

An orthotics system has been developed which provides a dynamic extensor moment to the pelvis. Its purpose is twofold: 1) to prevent the occurrence of hip contractures, excessive lumbar lordosis, and knee contractures that predictably develop in the L3, 4, and 5 level myelomeningocele child, and 2) to improve gait and make physical activities in general easier by making the action of an incremental extensor moment to the pelvis reciprocal. The background and rationale to the system's development is outlined in this preliminary report.

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