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Seating for Children and Young Adults with Cerebral Palsy

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Introduction

This paper will reflect the experience, perspective, and design rationale of one institution rather than attempt to give a comprehensive survey of the full spectrum of experience and designs.

Several examples are given and references made to Duchenne muscular dystrophy (D.M.D.). The D.M.D. examples are used when they are particularly good illustrations of a general principle which helps complete our understanding of seating for children with cerebral palsy. For more information on our experience and rationale relative to seating boys with Duchenne Muscular Dystrophy, refer to the reference section.[2]

The study of seating has many facets (cosmetic, functional, economic, etc.) and many professional perspectives (engineer, therapist, orthotist, physician, manufacturer, etc.). Engineers tend to relate to biomechanics and the economics of standard design. Therapists are concerned with function, development, inhibition of spasticity, etc. Each medical specialist has a different predominant focus. In different settings, it is inevitable that availability of professionals, availability of funds, age and severity of client population culture, etc., vary, and these factors will direct the seating program. Another important factor is that orthotists have not traditionally been trained in the provision of special seating, most are not active in special seating, and in most communities, there is a shortage of orthotists. These realities are a major reason why pre-manufactured, easy to assemble, and adjustable designs have predominated in many regions. The potential for commercial success and profit for the manufacturer, the ability to provide a system without the involvement of orthotic professionals (who are scarce and often inexperienced in seating), and the need to minimize costs, all seem to be best served by the wide distribution of pre-manufactured designs. In many communities, that is the best option available at this time. However, there are communities and settings wherein the circumstances make it possible to have the advantages of custom fabricated designs.

To help you put this paper into perspective, we need to provide some information on the history of our seating program. The Orthotic/Prosthetic Laboratory at Gillette Children's Hospital became involved with seating in 1974. Our seating program developed out of almost ideal circumstances. Orthotic services were strong and there was a close working relationship between our orthotists, therapists, and medical specialists. Weekly clinics brought a steady stream of clients through our outpatient clinic where the team members worked together to solve both general and individual problems. Also extremely important was our strong tradition and mechanisms for follow-up, which provided us with excellent feedback. Our early entry into seating, and the growth of the program, quickly gave us a significant volume so that specialists could be assigned and efficient procedures developed.

Another factor bearing positively on our program is Gillette's extensive experience in spinal orthopedics. Spinal support to resist the development of spine deformities is therefore an ever-present consideration.

Although we have some experience with people of middle and advanced age, our experience at Gillette Children's Hospital is primarily with people from birth into young adulthood. This younger age group will be the focus of this paper. Our client population with cerebral palsy includes the full spectrum of severity, but the very severe cases far out number the less severe.

It is important that we all endeavor to recognize and respect the various aspects, perspectives, and variable circumstances mentioned earlier. Two very different seating programs may offer equally excellent care, but both can be even better if they "compare notes." This paper is a compilation of our "notes."

Fundamental Goals

The seating systems we provide must benefit the impaired person, those who care for that person, and society. Balanced against that, every piece of equipment inherently carries costs and disadvantages. Our systems cannot be all things to all people, but we will most nearly approach the ideal by keeping our sights aimed directly at the fundamental benefits and goals, while we endeaver to minimize the negatives.

What are the fundamental goals? The main categories are outlined below.

1) Function
2) Orthopedic/Neurologic
3) Cosmesis
4) Safety
5) Economy

Function is primary. It affects a range of activities and benefits which can be best explained by examples: recreation for the child and family; making it easier for a care worker to feed a youngster; improving the child's field of vision; increasing his comfort; increasing the level of independence, etc. A functional seating system improves the child's development, decreases the amount of work required to take care of the child, and promotes a more enjoyable existence for the entire family.

From an orthopedic/neurologic standpoint,

Figure 1. A typical example of sitting alignment control in a young person with severe cerebral palsy provided with only minimal propping aid (wide spaced arm rests). He is much more able to control his head and neck position than his pelvis. (Also see Figure 5, an example of an x-ray taken under the same conditions.)

the ideal would be to prevent the progression of hip and spine deformities, and maintain body positions which reduce spastic reflex patterns. The expected benefits are better voluntary control, less severe deformity, less surgery, and a corresponding decrease in the work and cost of daily care. The advantages are perhaps most apparent to those of us who have visited state hospitals and have seen severely involved adult patients who were maintained only in recumbent positions during their earlier years. Positioning options for these adults are so severely limited that constant and expensive care is required to prevent ulcers and maceration. Also, hospitalization for those problems and pneumonia tend to be more frequent.

Cosmetically the ideal is a well camouflaged, hidden, or attractive seating system which helps the youngster sit upright with the

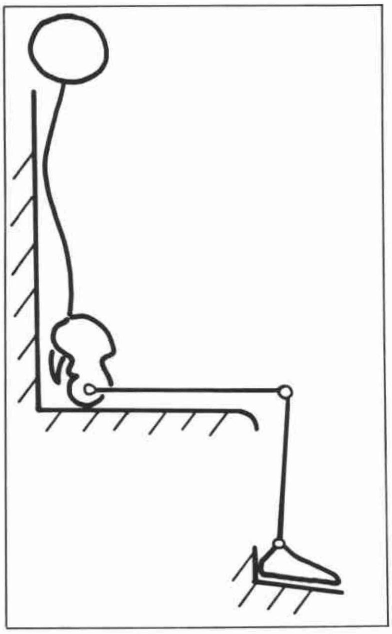


Figure 2. Sagittal view of "standard" sitting posture. In most cases, seats should be designed to biomechanically urge the sitting posture toward this configuration, with variations as necessary to inhibit spastic reflex patterns.

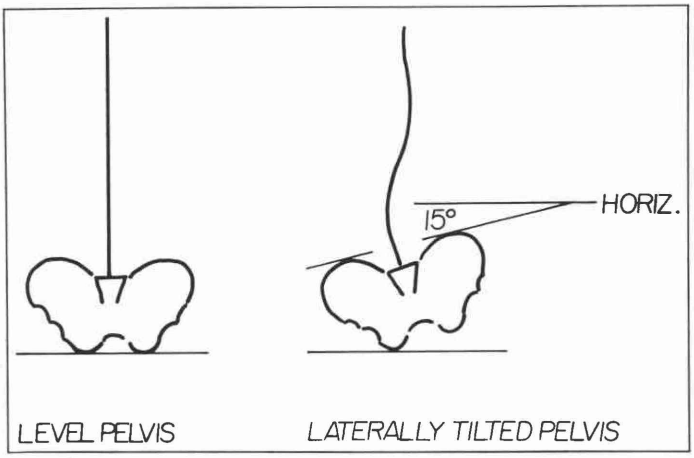


Figure 3. Proposed nomenclature to describe seated pelvic misalignment in the frontal plane.

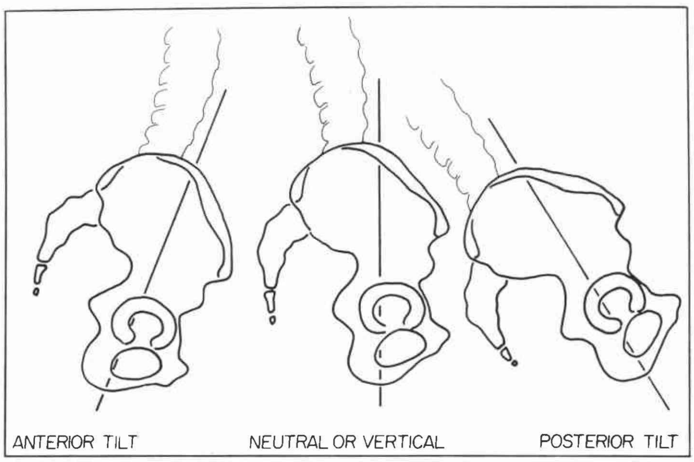


Figure 4. Proposed nomenclature to describe seated pelvic misalignment in the sagittal plane.

head in a position to see and be seen. The aesthetic and emotional benefits of a cosmetically appealing seating system accrue to the child and everyone in his environment.

Federal laws passed in the U.S. in the early and mid 1970's mandated that children be transported from their living environments to educational settings. Safe transportation necessitates secure seating. Ultimately, society benefits, both tangibly and intangibly.

Comparing the costs of various seating approaches is difficult because of the many costs which should be taken into account and the complexity of the various alternatives. We must take into account the cost of the seat, the cost of wheeled bases, repairs, frequency of replacement, and the cost of therapist involvement. The most important economic factor is the impact of a particular seating decision or system on the long range cost of daily care and health care. Long range costs must be considered, but they are very hard to estimate.

Biomechanics of Seating

The unimpaired human trunk-neck-head complex receives its stability partly from the spinal column acting as a controlled stack of compression elements and partly from a multitude of muscles acting in several different

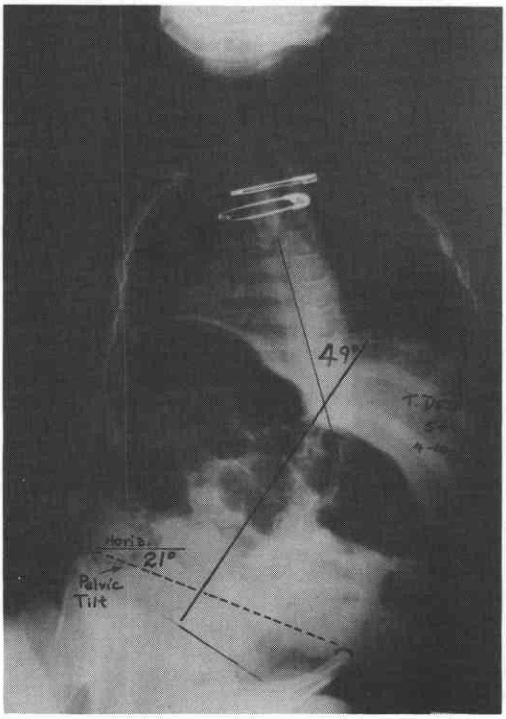


Figure 5. This is an x-ray illustrating the typical tilt of the pelvis in the direction of the convexity of the major scoliosis curve.

ways. The paraspinal muscles have a direct action on the configuration of the spine through extension, lateral flexion, and rotation. The abdominal (and to some extent, costal) muscles, in addition to being direct skeletal motors, affect the spine's stability and configuration indirectly, but importantly, through their action on the viscera. Muscle action to constrict and control the circumference of the abdomen and thorax allow compressive body weight loads to be taken partly down through the fluid filled abdomino-thoracic cylinder rather than all acting down through the spinal column. This adds significantly to the stability of the torso. We must note that recent research by Nachemson, et al.[6] (indicating that the Valsalva maneuver fails to lower pressure in the intervertebral disks) challenges this classical explanation of Morris,[5] but does not propose a new analysis of abdominal muscle function in trunk stabilization. Swedish data suggests that we don't fully understand what the Valsalva maneuver consists of and how it functions biomechanically. (The Valsalva maneuver is a general tensing of abdominal muscles.)

The normal activity of sitting consists of a series of frequently changed postures. Each of those postures would be non-functional, uncomfortable, and even injurious if it were the only posture available to us and maintained for hours. It is the frequent voluntary change which makes those postures collectively safe, acceptable and tolerably comfortable for more than ten minutes. It is quite an undertaking to design a seating system in which our client can safely and comfortably sit, with little or no change, for a matter of hours. In the case of a person with cerebral palsy, the abnormally high muscle tone about the pelvis and thighs is the major reason this an be accomplished.

It is important to note that when a child has some limited postural alignment capability, that capability is greatest at the head and neck. There is less ability to control the pelvis (Figure 1). (This capability reflects the early developmental stages of an infant, but when we see it in the older child, it represents delayed or arrested development.) Arm-propping is typically used to stabilize the upper thorax for effective

Figure 6. When abdominal and lower costal muscles are flaccid, a simple corset, providing snug circumferential constraint helps to create a hydraulic load bearing column. This reduces the collapsing load on the spinal column.

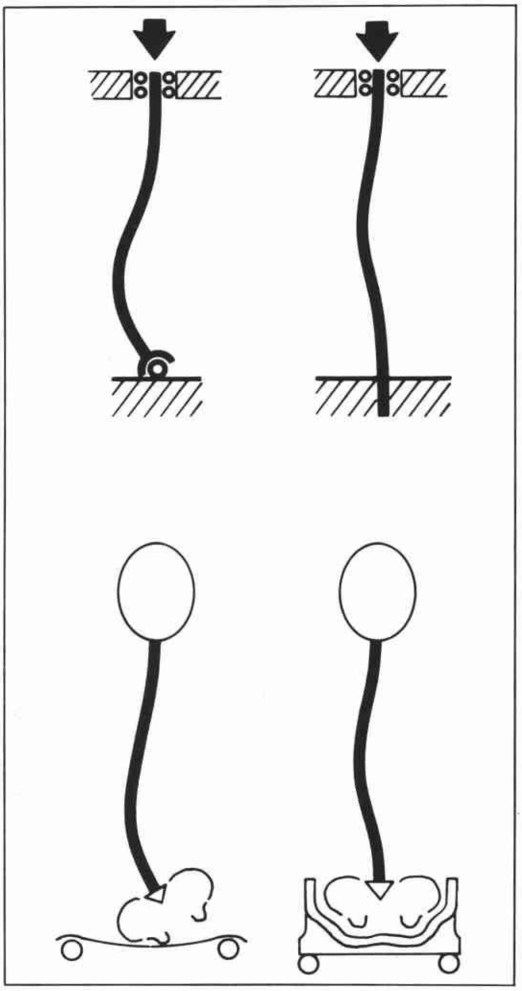


Figure 7. The unconstrained-pelvic condition illustrated on the lower left is similar to the pin jointed base end-condition represented above it. The constrained-pelvis condition illustrated on the lower right can be compared to a built-in base end-condition. The column with the built-in end is approximately twice as stable as the column with the pin jointed end.

neck and head control. This illustrates two seating principles. The first is that the postural control and use of the superior body elements is dependent on the stability of body elements inferior to them. Second, the seat should bring the stability from the pelvis upward to meet the descending/decreasing voluntary stability of the client. Terminating stability too low will fail to maximize the child's function. Carrying stability too high will deprive the client of his full voluntary movement capability.

Since "normal" sitting postures are so variable and changeable, we cannot relate supported sitting postures to a specific normal posture. We must reason and choose a sitting posture which has the most advantages, and propose it as a "standard."

We choose the "sitting at attention" sagittal configuration (Figure 2), because it represents a mid-range spine configuration, it allows significant weight bearing on the proximal thighs as well as the bottom of the pelvis, it is a cosmetic posture (chest and head upright, facing outward), and it is a functional posture (head in a position to observe and thorax and shoulders forming a secure base for the neck and arms to move). In the sagittal plane, the sacrum is tilted anteriorly a moderate amount. There is moderate lumbar lordosis, thoracic kyphosis, and cervical lordosis. We would further propose that the "standard" posture consists of a pelvis level and the spine straight in the frontal plane. When the left side of the pelvis is elevated, the pelvis is said to be "tilted rightward," and when the right side is elevated, it is "tilted leftward" (Figure 3). Likewise, in the sagittal view, the pelvis is "tilted posteriorly" or "tilted anteriorly" depending on which direction the upper parts of the pelvis are oriented relative to "standard" (Figure 4). In the transverse plane, if the right side of the pelvis is rotated forward relative to the shoulders, we would say the pelvis is "torqued leftward." We do not present this nomenclature as the most correct, but offer it for use in the absence of standard nomenclature.

Cerebral palsy is a disease that expresses itself in a wide variety of static and dynamic patterns, and we cannot go into the mechanics of all those variations. We will limit ourselves to a discussion of what, in our experience, is the most common combination.

Fortunately, even some of the children with severe cerebral palsy do not have a significant deformity or collapse in the frontal plane. This is not to say, however, that scoliosis is rare in this group. Scoliosis is quite common, and we see very severe cases. When we examine a child with scoliosis, we should evaluate whether or not the scoliotic collapse is aggravated by asymmetric trunk muscle spasticity.

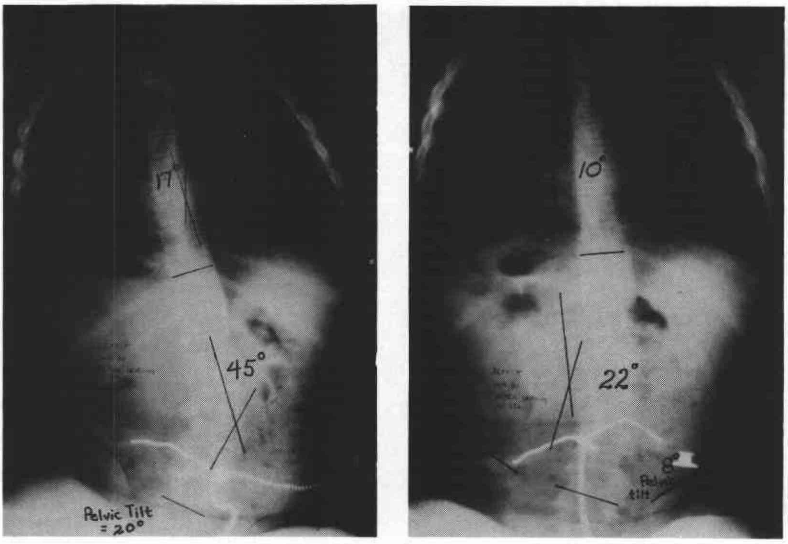


Figure 8. Photos of x-rays taken before (left) and just after (right) the child's pelvis was leveled in the sitting support orthosis illustrate the stabilizing benefit of pelvic control.

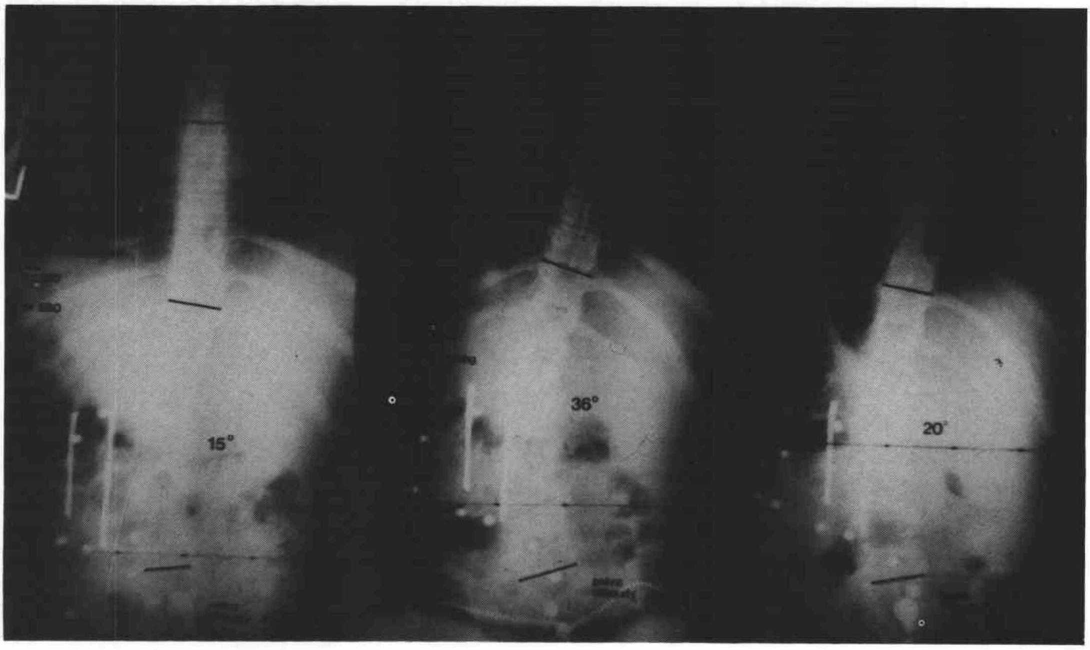


Figure 9. Left and center x-rays show the deterioration which occurred during a time period when the pelvic leveling procedure was not used. The x-ray on the right shows the immediate effect of leveling (to the extent then possible) and controlling the pelvis.

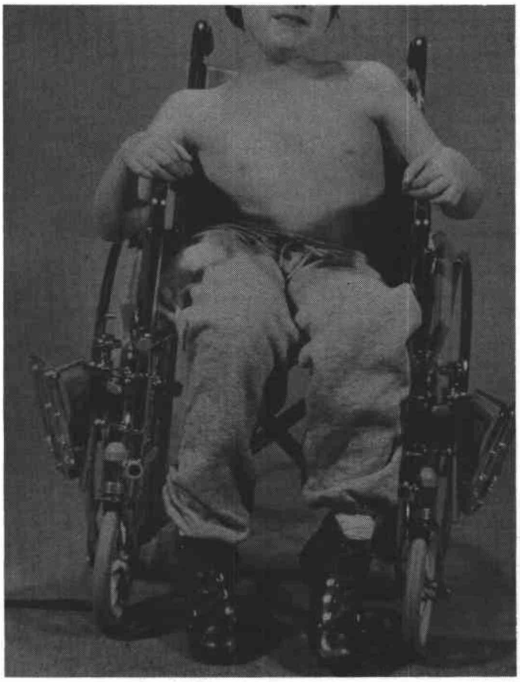


Figure 10a. S.T., a 12 year old boy with Duchenne muscular dystrophy, seated as he was presented to us.

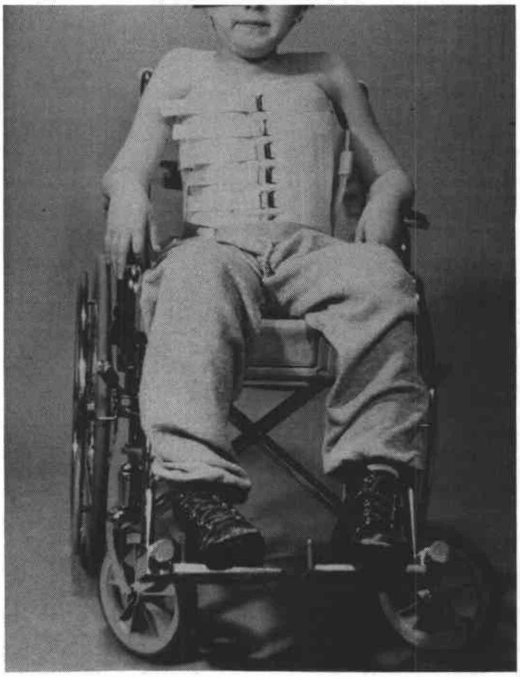


Figure 10b. S.T. in the sitting support system we provided.

We can expect to be much more effective at controlling a scoliosis deformity when asymmetric trunk muscle spasticity appears *not* to be a significant factor.

One of the usual characteristics of scoliosis in neuro-muscularly impaired sitters is lateral tilting of the pelvis in the direction of the convexity of the major scoliosis curve (Figure 5). This is not surprising when we consider that pelvic orientation is usually not under voluntary control. This characteristic will become more interesting later as we discuss the various methods for generating spine stability.

There are several distinct biomechanical schemes for providing spine stability to resist scoliosis. These schemes do not, of course, operate exclusively in the frontal plane. Also, the employment of one scheme does not preclude the simultaneous employment of one or more other schemes. The first and most familiar of these is "three-point-force." We need not explain the principles of this scheme since they are so well known. However, it is appropriate to note that three-point-force schemes are much less effective at stabilizing a multi-joint, multi-axis system such as the spinal column, than stabilizing a single-joint system such as the elbow or knee. The application of the three-point scheme in a spinal support system, which includes a seat, has some advantage over a traditional spinal orthosis in that the most inferior force can be located at greater distance from the more superior forces to give a longer moment arm. However, the more the client functionally moves in his seated position, the less the seat is able to apply three-point support, because it doesn't move with the client. Furthermore, a spinal orthosis can be worn 23 hours per day, if necessary. These latter considerations make the spinal orthosis a stronger orthotic treatment of progressive spine deformity.

The second scheme we will discuss has to do with the Valsalva maneuver, given earlier, in which the abdominal and costal muscles function to relieve the spinal column of compression and bending loads. No matter what exactly happens during the Valsalva maneuver, the Morris explanation is a valid biomechanical analysis of how a snug corset contributes to

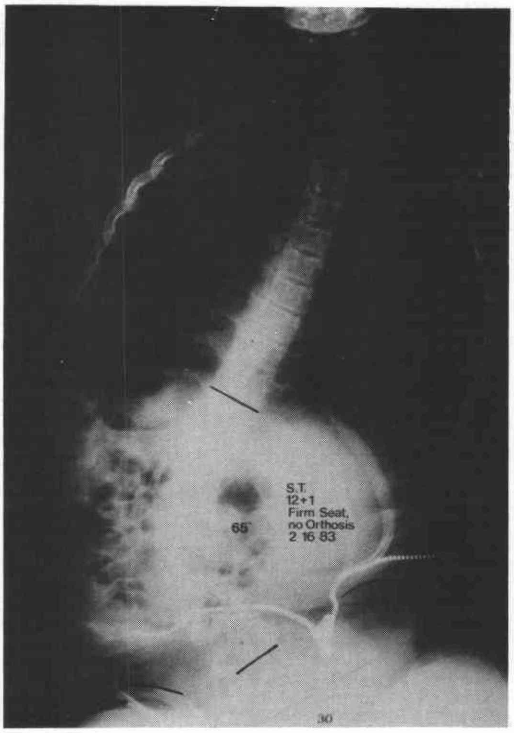


Figure 10c. Spine x-ray of S.T. sitting unsupported as presented, showing a scoliosis of 65° and a lateral pelvic tilt of 30°.

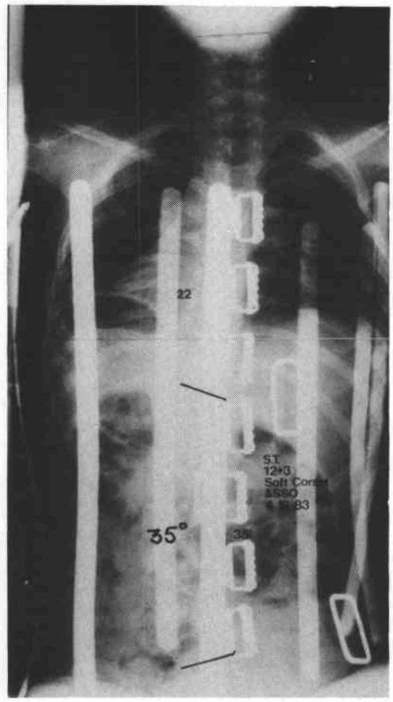


Figure 10d. Spine x-ray of S.T. sitting in the support system we provided. The scoliosis is reduced to 35° and the lateral pelvic tilt to 14°.

trunk/spine stability in the presence of flaccid paralysis of abdominal and costal muscles. Engineering analysis and empirical evidence indicate that when we passively apply circumferential abdominal constraint (ie. a snug corset), a hydraulic load bearing column is created and we reduce the magnitude of flexible collapse (Figure 6). In our experience, the corset is seldom used for children with cerebral palsy, but is virtually always useful for children with muscular dystrophy.

The third scheme for enhancing spine stability derives from the fact that the sacro-pelvic complex forms the foundation on which the flexible spinal column rests. Voluntary pelvic control is an important component of spine stability in the unimpaired trunk. If, by a conforming design about the pelvis and a proper donning procedure, we can increase the foundation (bottom end) constraint conditions, much is added to spinal stability. The pair of diagrams on the left side of Figure 7 illustrates the similarity between the spinal column in the case of an uncontrolled pelvis and the slender column pin jointed (free to tilt) at its lower end. The two diagrams on the right in Figure 7 illustrate the similarity between the controlled pelvic case and the built-in base end condition. Elastic column buckling equations for the two beams indicate that the built-in beam will withstand almost twice as much load as the other before buckling.[4] To achieve this end condition stability, we need a well made seat, as well as a procedure to level the pelvis each time the child is seated.

To fully appreciate the strength of this scheme in practice, compare the two x-rays in Figure 8. Figure 8a is the x-ray taken just before the pelvic leveling procedure was performed and Figure 8b is the x-ray taken a few minutes later, after the pelvic leveling procedure was performed. The Cobb angle is reduced from 36 degrees to 20 degrees by this quick procedure, which is normally performed as a routine part of positioning the child in the sitting support orthosis. These x-rays are of a

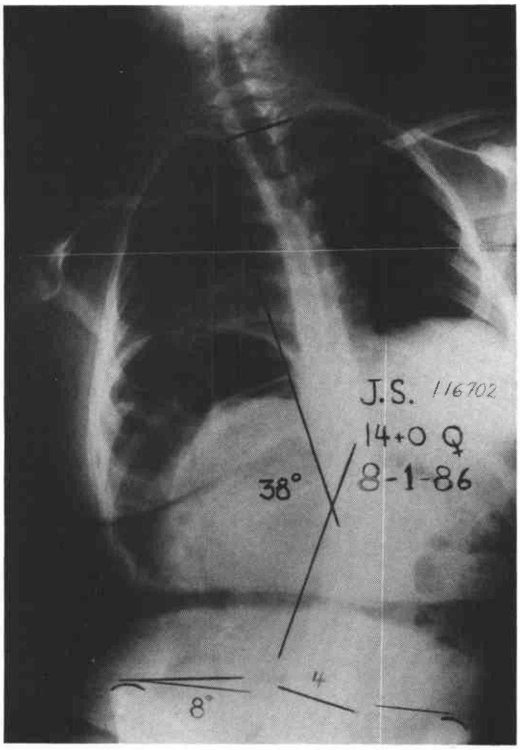


Figure 11a. This x-ray of J.S., a 14 year old girl with cerebral palsy, presented with a pelvic rightward tilt of 8° and a convex-right thoraco-lumbar scoliosis of 38°. Her shoulders were tilted 13° degrees toward the left. Her clinical appearance verified the features noted on the x-ray. She occupied her right arm almost constantly as a lateral prop.

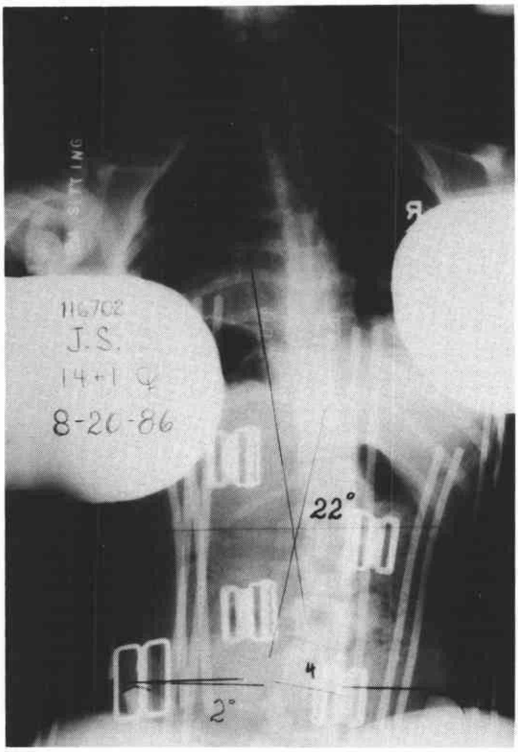


Figure 11b. J.S. was provided with a sitting support system consisting of soft corset worn under her clothing and a somewhat abbreviated S.S.O. Her system was almost identical to that provided to S.T. (see Figure 10b). This x-ray shows a pelvic tilt reduced to 2°, the scoliosis curve reduced to 22°, and her shoulders level. She liked the system because her hands were free and she found breathing easier.

boy with Duchenne muscular dystrophy; he was not wearing a corset.

A second example is given in Figure 9. The left and center x-rays show the progression which occurred in the eight months following fitting. During this period, the parents did not use the pelvic leveling procedure. The x-ray on the right was taken a short time after the center x-ray, with the only difference being the pelvic leveling procedure was performed before the last film. Note: once a spine deformity has become partially structural, the pelvis can be leveled only to the degree that the deformity is still flexible.

In summary, maintaining a level pelvis makes it easier to control the spine. Pelvic control and orientation in the frontal plane also relates strongly to the uniformity of pressures in weight bearing areas and minimizing the progressive deterioration of sitting comfort.

Let us now look at two examples where these stabilizing schemes have been simultaneously applied. Figure 10a is a photo of a 12 year old boy with muscular dystrophy, sitting as he was presented to us. Figure 10b shows the sitting support system properly applied. The corset is entirely independent; it is not attached to the seat. Figures 10c and 10d compare his A-P spine x-rays with and without the orthotic system. The lateral tilt of his pelvis is reduced from 30° to 14°. The Cobb angle of his scoliosis was reduced from 65° to 35°. Curve con-

Figure 12. Example of a Sitting Support Orthosis designed to accommodate a right hip extension contracture.

trol of this magnitude is not unusual as long as the deformity is still flexible. Figure 11a is the x-ray of J.S., a 14 year old girl with cerebral palsy. She presented a right thoraco-lumbar scoliosis of 38° and a rightward pelvic tilt of eight degrees. Her shoulders were tilted 13° to the left partly because she used her right arm for propping to avoid falling to the right. We provided her with a soft corset and the Gillette Sitting Support Orthosis. The Sitting Support Orthosis was to provide pelvic control and bilateral "propping" support. It had no head rest or anterior support. The x-ray taken just after fitting shows pelvic tilt reduced to two degrees (Figure 11b), the Cobb angle of the scoliosis reduced to 22°, and shoulders leveled. Both hands were free to function, and she said she could breathe deeper.

Figure 13. A diagram of a sitting posture caused by overactive hip extensors and inadequate thoracic extensors.

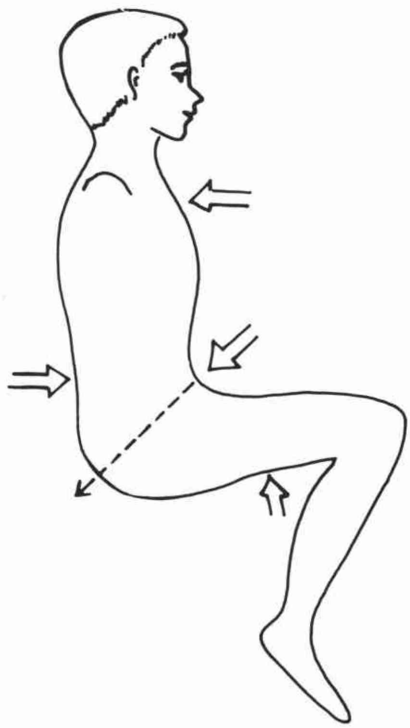


Figure 14. A diagram showing the thigh, pelvic, and lumbar forces essential to flex the hips, reduce pelvic posterior tilt, and restore lumbar lordosis. It also shows a fourth force, at the upper thorax, sometimes necessary to aid thoracic extension.

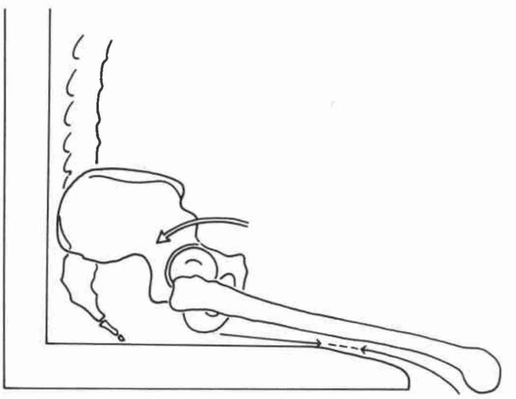


Figure 15. This diagram illustrates the skeletal alignment which actually occurs when someone with over-active hamstrings sits on a horizontal, lightly padded seat.

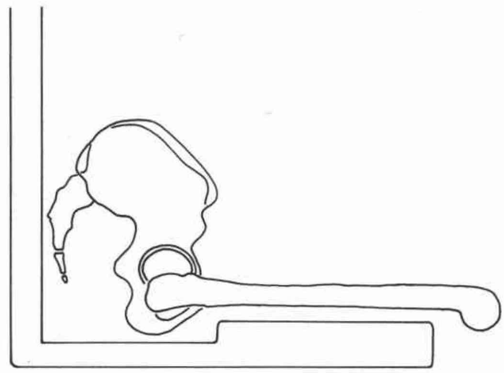
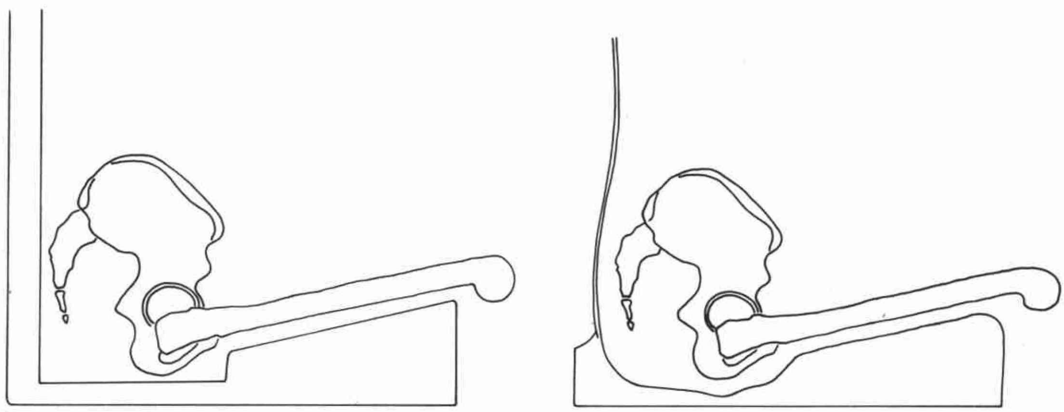


Figure 16. A depression under the pelvis is necessary to maintain horizontal thighs.



Figures 17a and 17b. These diagrams illustrate both the pelvic depression and the incline frequently needed in, (a) an upholstered seat and, (b) a contoured seat.

In cerebral palsy, we occasionally see a case of lateral pelvic tilt and scoliotic posture secondary to a unilateral hip extension contracture. A right hip extension contracture, if not accommodated, will cause the right side of the pelvis to be elevated. The pelvis will be tilted leftward and a compensatory convex left scoliosis will be produced. When we see this problem, it is usually an older child or adult. Figure 12 is an example of a rather extreme case of how the deformity was accommodated to minimize pelvic and spinal malalignment and stress.

In the sagittal view, we commonly see a posture dominated by the powerful, very active hamstring muscle group. The gluteals are often helping to resist adequate hip flexion for an ideal sitting alignment. To a greater or lesser degree, the pelvis is maintained in a posterior tilt position with weight bearing shifted posteriorly toward the sacrum. This pelvic alignment

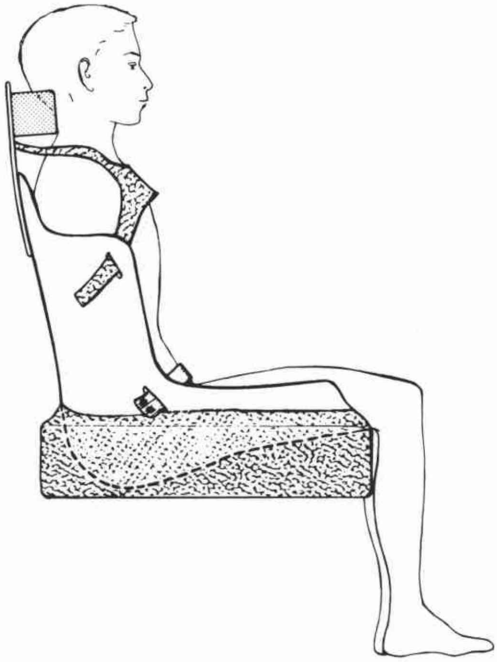


Figure 18. A diagram of the contoured plastic shell Sitting Support Orthosis (S.S.O.)

Figure 19. Anterior view of the child in his S.S.O. This photo illustrates how the thin polypropylene shell can achieve high bilateral thoracic support without interfering with arm position.

tends to reduce lumbar lordosis and convert it to a kyphosis (Figure 13). The loss of lumbar lordosis makes it more difficult for the thoracic extensors to maintain a vertical upper thorax. This explains why a flexible spine, maintained with a pelvic belt and lumbar bolster to restore lumbar lordosis, often produces better active alignment of the upper thorax and head. (We would caution you that different solutions are necessary for people with rigid hyperkyphosis.)

The three forces needed to maintain the position of the pelvis and lumbar spine are the thigh support, lap belt constraint, and lumbar support (Figure 14). Attention must be given to properly provide all three. The seat bottoms must be configured specifically to provide optimum thigh support. A flat horizontal seat bottom will never maintain hip flexion against active extension (Figure 15). The anatomy itself calls for a depression under the pelvis to bring the femurs to a horizontal position (Figure 16). More importantly, the hip flexion required to "break through" the extensor spasticity varies from child to child, but we usually find that some degree of seat bottom incline (pelvis to knees) is needed for the more severely involved children (Figures 17a and 17b).

The pelvic belt force is perhaps the most critical. The pelvic belt must be perfectly anchored: close to the body posterolaterally for good "wrap around" and at the correct level to achieve a good downward force component (Figures 18 and 19). The most common mistake is to anchor the lap belt too high. We have never seen one anchored too low. (We must remember that none of the hip/lumbar support forces function properly in service unless the caretakers know why and how to put the pelvis in position and snug up the pelvic belt. Without education and training of the users, our designs are worthless. We must train and retrain on every return visit.)

A fourth support force is sometimes needed in the area of the upper thorax or shoulders to maintain adequate thoracic extension. This is accomplished with a vest or shoulder straps which must be adjustable for grading the amount of support to fit the need, which may vary through the daily routine of activities.

Seating misalignment and deformity problems in the transverse plane are not uncommon among the severely involved cerebral palsy population. The problem consists of the pelvis being torqued right or left by deformities

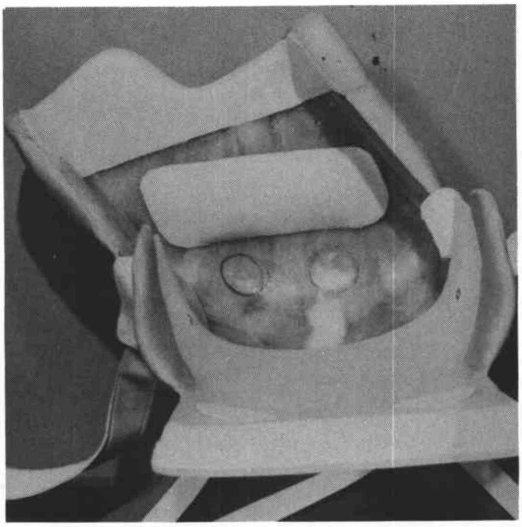


Figure 20a. Top view of a Sitting Support Orthosis for B.K., who, with a diagnosis of cerebral palsy, has a "windblown hips" deformity.

Figure 20b. Top view of B.K. sitting in the orthosis. Direction of the thigh section is designed to minimize the rightward torque of the pelvis and the corresponding spinal twist.

of one or both hips. A severe adduction contracture of the right hip will, for instance, cause a seated misalignment which includes leftward direction of the thighs (with respect to the pelvis), a rightwardly torqued pelvis, and an apparently (not actually) short right femur. This misalignment has been well diagrammed in an article by Mercer Rang, et al.[7] A severe abduction contracture of the left hip will cause a similar misalignment. These deformities are often referred to as "wind blown hips." We can see that when such a condition exists, forcing the thighs to be aligned straight forward will obligate the client to sit facing to one side, or the spine will be continuously twisted. In most cases, the direction of the thighs may be altered enough to avoid much of the spinal twist. Figure 20a is a photo of a top view of a Sitting Support Orthosis we provided for such a client. Figure 20b is the same view of the client in the orthosis.

It is of utmost importance, as we treat these clients, that we keep function and quality of life issues uppermost in our mind. Biomechanics and deformity prevention ideals often must be compromised to avoid undue impingement on any aspect of the child's development or function.

Client Evaluation

Seating evaluations at Gillette always include an orthotist, a therapist, and a physician in addition to the client, parents or caretakers, and, if available, a community therapist. The physical evaluation includes an assessment of orthopedic deformities, spastic reflex patterns, voluntary sitting capability, and other functional abilities. To assess sitting ability, two people manually control the child's thighs, pelvis and lower trunk. If, with this amount of stabilizing assistance, the child still cannot manage an upright sitting posture, we would grade voluntary sitting capability at non-existent to poor. If the child can, with that assistance, struggle to an upright sitting posture and maintain it for fifteen seconds, we would grade voluntary sitting capability at poor to fair. Better performance would be graded accordingly as better than fair.

A thorough interview of parents and others with the child is immensely valuable. We want to find out about the child's daily routine, mode of family transportation, what they feel are positive and negative features about their present

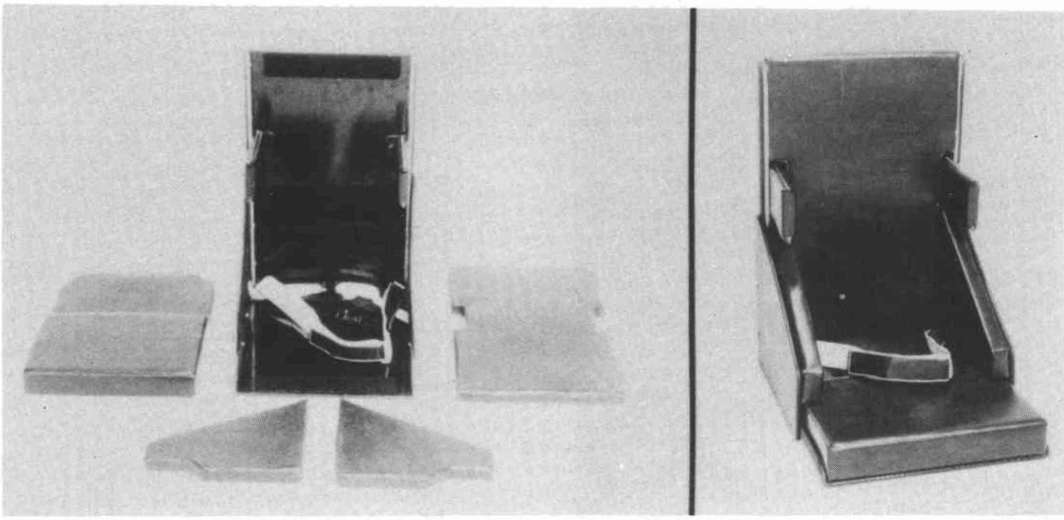


Figure 21. The current design for the Upholstered Sitting Support Orthosis combines an ABS frame and removable, firm upholstered components.

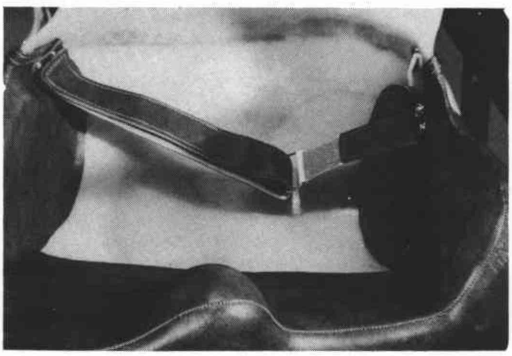


Figure 22. This photo shows the bilateral pelvic growth pads which can be removed later to accommodate an increased pelvic width.

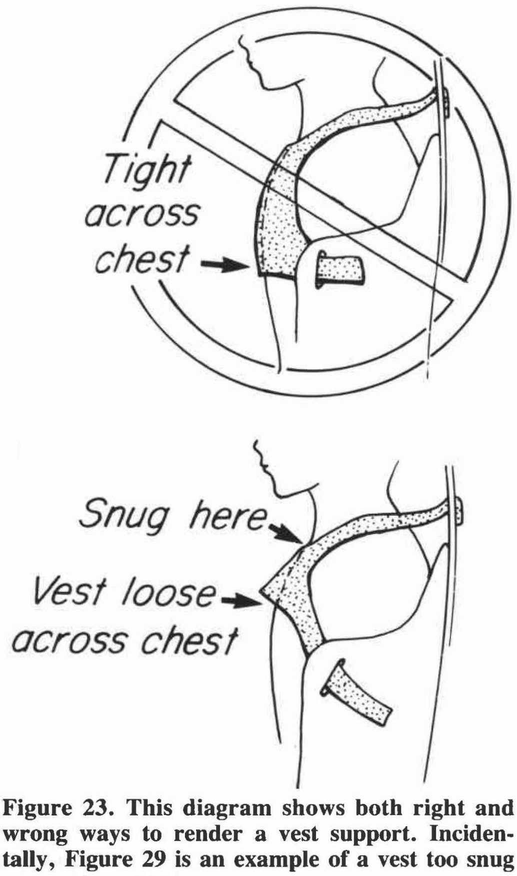


Figure 23. This diagram shows both right and wrong ways to render a vest support. Incidentally, Figure 29 is an example of a vest too snug across the mid-thorax.

equipment and routine, and the child's usual status compared to what we are observing. We also seek all concerns and ideas they may have for optimum seating. The interview should gradually become more of an educational session and finally a discussion of options. The child and parents or caretakers should, as much as possible, feel they were heard, were educated, and have participated in the decisions made on the seat, mobility base, accessories, etc.

Seating Design

We currently solve the majority of the seating problems we encounter with variations

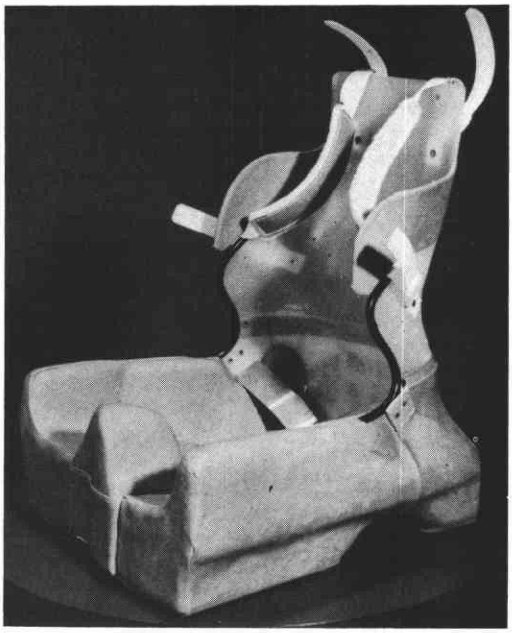


Figure 24. This is an example of an S.S.O. design utilizing the shoulder strap type anterior support. This S.S.O. also has a removeable pommel for easier entry and exit. It also has modifications to the base for recessing into the wheelchair.

on two basic designs. Both are custom made.

Although there have been many very significant design changes along the way, the Gillette style Sitting Support Orthosis (S.S.O.) has continued, from 1974 to the present, as a portable system utilizing a custom molded unpadded plastic shell mounted in a plastic foam base (Figures 18 and 24). We have provided approximately 1,100 of these Sitting Support Orthoses. Our present rate of S.S.O. production is about 140 per year.

In the early years, we also constructed upholstery and plywood seats. In 1983, we converted that rectangular design to one that used upholstered removeable components attached to the inside surfaces of a plastic seat frame as shown in Figure 21. (We first saw a design similar to Figure 21 at the Royal Ottawa Rehabilitation Center. In addition to our own changes, the present design incorporates features also learned from the Rehabilitation Engineering Center at Children's Hospital at Stanford.) To distinquish this design from the contoured plastic shell type S.S.O., we call it an

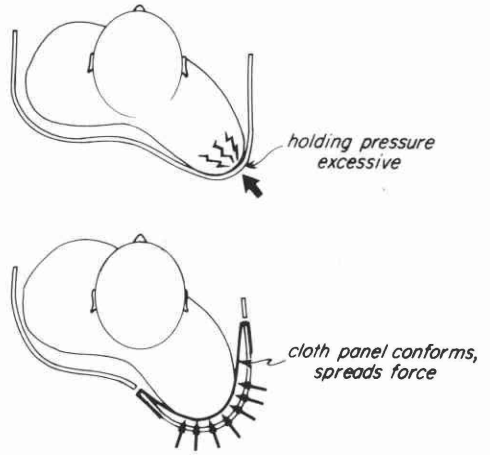


Figure 25. This diagram illustrates the difficulty in safely supporting spinal deformity prominences and how a denim fabric panel may be installed to provide a "wrapping-around" support which is more conforming. The flexible panel also accommodates some positioning errors and some movements without increasing the support pressures.

Figure 26. We call this the "over-shoulder, bend-down" type head rest. It is especially helpful for those children who consistently pull to one side as the head falls forward. Later, when they voluntarily extend the neck again, the extension is in place to guide the head toward mid-line.

Upholstered Sitting Support Orthosis (U.S.S.O.). We currently construct and fit about 200 of these units annually.

A more specific discussion of the design of the S.S.O. must start with noting that the main structure is an unpadded, thin plastic shell. Because of the thinness of the supporting shell, the seat is less bulky, less visible, and lighter than other seats. It allows us to provide close thoracic support up to the axillary level and wrap around the thorax, between the arms and chest, and well past mid-line, without impinging on the arms (Figures 18 and 19). When properly contoured, the shell can be left almost totally unpadded. The unpadded shell is easier to clean and requires less maintenance. The pelvic portion is contoured and sized to fit the hip/pelvic area quite close, but not snug. At fitting time, we leave adequate space to push our fingers between the gluteus medius and the seat bilaterally. About 18 months ago, we began providing room in the shell to install bilateral pelvic growth pads (visible in Figure 22), which are removed later as the pelvis grows wider.

There is complete freedom within the design to reduce the level and amount of support to match the client's need: it may not include a head support, vest, or shoulder straps, and bilateral thoracic support may be terminated at a lower level and leave more room for movement as appropriate.

Anterior upper thoracic support is provided by either a special vest (Figure 23) or shoulder straps (Figure 24). The shoulder straps are more efficient at keeping the thorax in an extended, upright posture. However, when the child has some arm function, we prefer to use the vest because it can be configured to impinge less on the anterior deltoid muscles. Note that the lower attachment points for the vest or shoulder straps should be in the sub-axillary area to provide good wrap-around and a posteriorly directed holding vector. Some commercially available seats anchor the shoulder straps to the lap belt. That design is seriously flawed because the shoulder straps then pull the lap belt up out of proper position and pull down on the shoulders.

When the S.S.O. is used for people with severe scoliosis or hyperkyphosis, the polypropylene shell accommodates to the contours of the deformity. However, sometimes our best efforts fail to create sufficiently precise contouring to spread pressure evenly over the entire rib prominence. Figure 25 diagrams how we sometimes solve that problem: an adjustable denim cloth panel is installed through vertical slits in the shell. The panel wraps around the prominence, conforming to the contour.

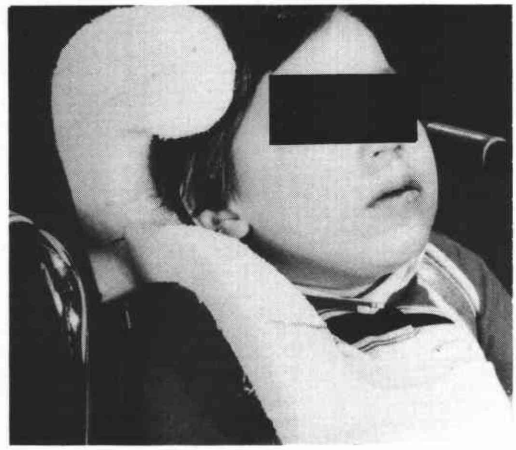


Figure 27. This is a variation which incorporates a cranial support above the ear for greater leverage if there is more forceful tendency to laterally flex the cervical spine.

Figure 28. If there is a tendency for the child's head to drop forward and she has very little or no ability to bring it back up, a firm, padded neck collar can sometimes give significant improvement. The collar is sometimes anchored to the S.S.O. behind the neck.

Head support varies from nothing to a simple occipital prop to a variety of designs, depending on the particular challenge presented. A few of the many designs we have contrived over the years are shown in Figures 26, 27, and 28. We do not have a good solution for the child who persists in actively bringing the head forward and down. In seating children with hydrocephalus, the sheer weight of the head presents special safety and weight bearing problems (Figures 29 and 30).

Figure 29. This headrest for a hydrocephalic child has a safety bar which hinges upward for entrance and exit.

Figure 30. This cradle type headrest is mounted so that it can be pivoted by means of a small wheel-crank. The child turns the wheel-crank to change weight bearing areas and to change the direction of her gaze.

We haven't the space to show and explain the wide variety of accoutrements which are variously added for shoulder protraction, arm positioning, etc. We work closely with the therapists so that they can help design the final configuration for best functional positioning.

As emphasized earlier, a seating program must consider the sitting functional environment. The seating orthoses we produce are removeably mounted in wheelchairs, strollers, buggies, and other bases as the circumstances indicate. Being portable, they are also utilized as car seats, or to place the child very near the floor to facilitate peer interaction (Figure 31). We have found that a seating program, to be effective, must address the full spectrum of life activities. It must also address related equipment in the sitting environment. Footrests, wheelchair upholstery, laptrays, and control boxes are some of the most common things which must be modified, moved, or completely replaced with special designs. It seems to us that the "standard" wheelchair was designed to be "slouched" into (Figure 32) rather than to be sat erect in. Those chairs are not adequate, as manufactured, for extended use by anyone. In spite of the newer, more enlightened designs coming along, those "standard" wheelchairs are still part of the scene and must be dealt with. When we sit a client erect on a firm seat, and then place that seat in a wheelchair, the client's shoulders are far from the center of the drive wheels (Figure 33). For clients who self-propel, the seat must be sized or shaped to sit between the upholstery mounting bars. The standard upholstery must be removed and replaced with straps so that the seat can be recessed down and back between the bars (Figures 34 and 35).

At semi-annual follow-up visits, we accommodate the child's growth by adjusting the size of the S.S.O. Thigh length is added as necessary. The bilateral pelvic growth pads are thinned or removed when appropriate. The back and sides of the shell can be heated to widen the shell width across the chest. Axillary extensions are welded on as necessary to accommodate increase in thoracic height. Head rests and the anchor points for vests and shoulder straps are also elevated as necessary. Presently, the basic S.S.O. shell is serving for an average of 37 months for children between three years and 14 years of age. We expect the use of the pelvic growth pads to push that service life even higher. For adults, the average useful life of S.S.O.s is much greater.

We recommend the S.S.O. for children who have non-existent to poor voluntary sitting capability. Other factors which would indicate a need for the S.S.O., in our program, would be significant orthopedic deformities (of the hips and spine) and moderate to severe spastic reflex patterns. Completed physical growth may also be an indication for the S.S.O., because the polypropylene shell is very durable. It requires less repair maintenance than the upholstered systems.

Provision of a good quality S.S.O. requires a relatively high level of specific orthotic skill and practice. This may be considered a disadvantage, but we feel the adaptability and quality which results more than justifies the necessary investment.

The structural components of the Upholstered Sitting Support Orthosis are made of ABS plastic. The upholstered firm inserts are removable to facilitate cleaning and adjustments for growth. Thoracic supports are thin (of metal) and can be easily adjusted to change height and spacing. The pelvic belt is used on every U.S.S.O. Lumbar bolsters, vests or shoulder straps, and head rests are used when appropriate. Figure 31 shows some of these design features. During therapy sessions, and for certain daily time periods, therapists or parents may wish to work specifically on improving upper trunk or head control. For this reason, shoulder straps and vests are designed for partial or complete loosening. Head rests can be easily removed from the unit (true of the S.S.O. as well as the U.S.S.O.).

The U.S.S.O. is most appropriate for children with poor-to-fair voluntary sitting capability, minimal orthopedic deformities, and less severe spastic reflex patterns. The easy size-adjustability of this design gives it some advantage over the S.S.O. for younger, rapidly growing children. For children under two years, we often utilize one of the commercial infant seat or car seat frames to which we can add support bolsters, lap belt, etc. (Figure 36).

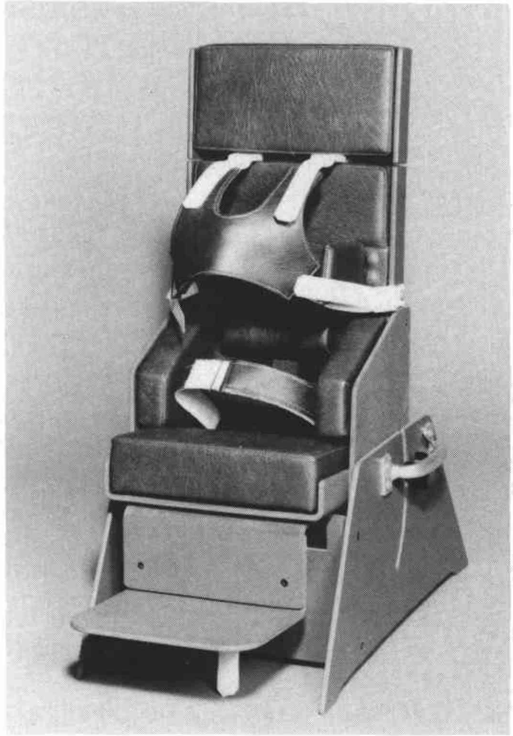


Figure 31. Both types of seating orthoses can be mounted in this type of base for use at near-floor levels for greater interaction with other young children. The base allows a variety of recline angles. This photo also shows many of the components which may or may not be part of a U.S.S.O. provided for a specific child.

Fabrication

Much about the fabrication of these orthoses can be inferred from the photos and design information given earlier. Some information on fabrication of the "Gillette" S.S.O. has been discussed in earlier articles on that orthosis.[2,9] However, there are some serious errors in the S.S.O. fabrication process we made in the very beginning. Other orthotic labs might repeat those errors unless we reiterate a couple of the procedural steps and more clearly explain the rationale for those steps.

The polypropylene shell is obtained by covering a pattern developed from an impression of the child. To obtain the impression, we position the child, on a supporting fixture (Figure 37) in a face-down, hips-flexed, knees-flexed configuration (Figure 38). We use the weight relieving (horizontal) trunk alignment, support under the knees, and a waist belt for the precise purpose of achieving an impression which does

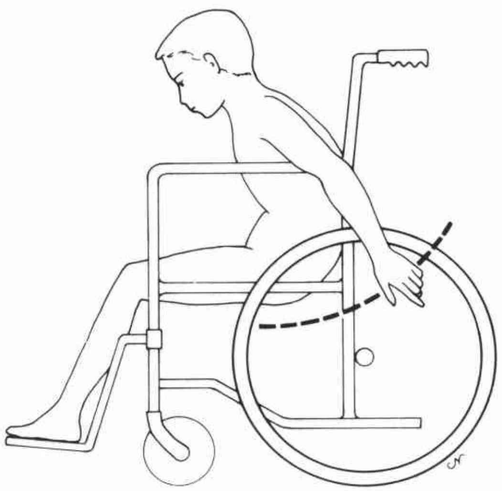


Figure 32. The "hammock" style upholstery on standard wheelchairs encourages a "slouched" sitting posture. That posture is almost necessary for a good hand-on-wheel power stroke.

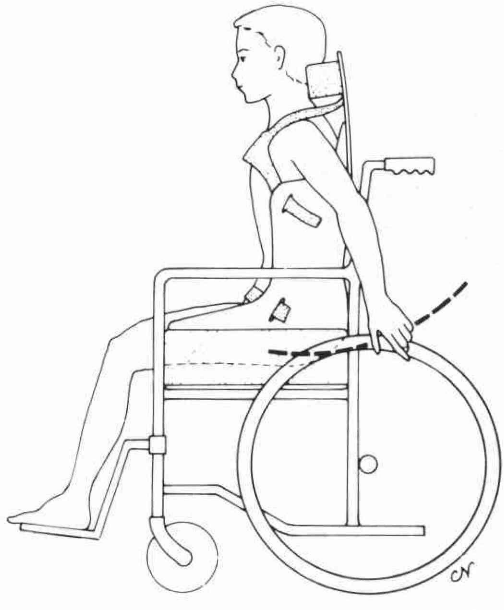


Figure 33. If the client sits erect in a seat orthosis which rests on the upholstery mounting bars, the shoulders are elevated. The hand-on-wheel power stroke is unacceptably shortened. Also, the excessively high forward position of the center-of-gravity causes the client/wheelchair combination to be dangerously susceptible for forward upset.

not possess the poor alignment characteristics we are trying to avoid. The support under the knees allows us to locate the pelvis as directly as possible in alignment with the spine. For the child with tight hamstring muscles, a waist belt on the fixture helps reduce lumbar kyphosis and perhaps achieve a little lumber lordosis, if possible. The contrasting diagrams in Figures 39a and 39b illustrate the critical role of knee support. The hip flexion angle of the fixture can be varied and is adjusted according to the amount of hip flexion we want in the seat shell. On the positive model, plaster is added to create the bulges and contours needed to avoid pressure on bony prominences (Figure 40). Plaster is added across the back of the upper thorax to give room for extension. Figures 41a and 41b are posterior and lateral views of a positive model fully modified and ready for covering. The resulting polypropylene seat shell is mounted in a polyethylene foam base (Figure 42). Final trim lines, lap belt and vest attachment points, head-rest placement, etc. wait until the child comes for fitting.

The molded "Chailey Heritage" supportive seat,[8] which also utilizes vacuum dilatancy to obtain an impresson, creates a positive model, and vacuum forms the seat materials over that

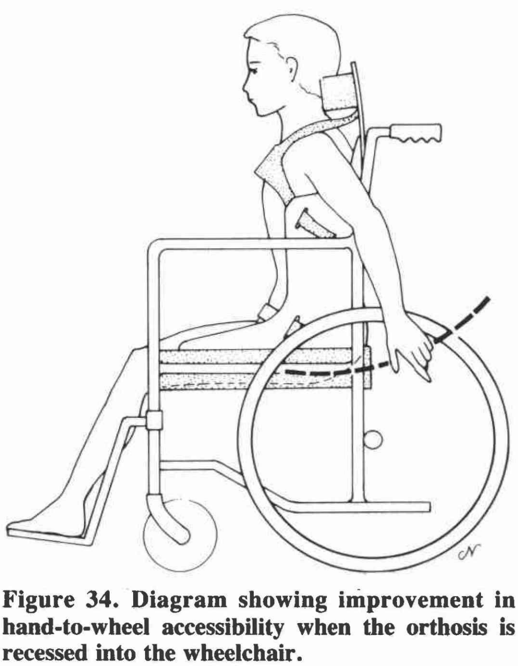


Figure 34. Diagram showing improvement in hand-to-wheel accessibility when the orthosis is recessed into the wheelchair.

Figure 35. This photo shows an example of how to shape the base of a seat and use straps instead of standard upholstery to recess the seat into the wheelchair for better access to the wheels.

Figure 36. For children under about two years of age, we can save expense by building appropriate sitting support into one of the commercial infant or car seats.

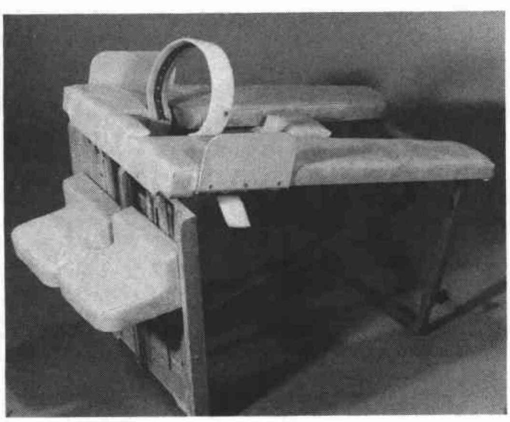
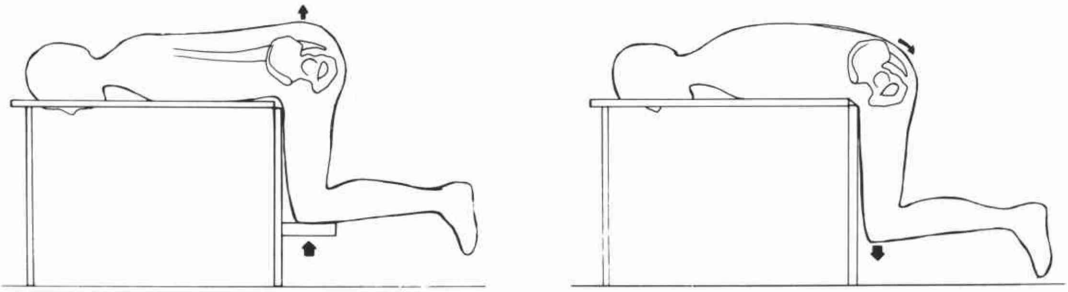


Figure 37. This is the positioning fixture which helps us obtain an impression with the alignment characteristics we hope to achieve in the finished S.S.O. The hip flexion angle can be varied. The knee supports are moved to the proper position for each child's impression. The waist belt helps to reduce lumbar kyphosis.

Figure 38. When we have achieved optimum alignment of the child on the fixture, bony prominences and landmarks are covered with masking tape and outlined with lipstick. A bag of polystyrene beads is packed around the child and when a vacuum is drawn on the bag it becomes a firm impression which may be removed and filled with molding plaster.



Figures 39a and 39b. These diagrams illustrate the critical value of proper support under the knees during the impression-taking process.

model. With the exception of those general similarities, the procedures, materials, and design of the Chailey Heritage seat is very different from the Sitting Support Orthosis developed at Gillette Children's Hospital.

Fabrication of the U.S.S.O. does not require a pattern and is therefore free of the potential problems inherent in obtaining and modifying a model.

Figure 40. Plaster is added to the positive model as appropriate to provide pressure relief in the locations of bony prominences (lipstick marks transferred from the masking tape to the plaster vacuum bay were re-marked with indelible pencil on the bag to get the transfer to the plaster positive).

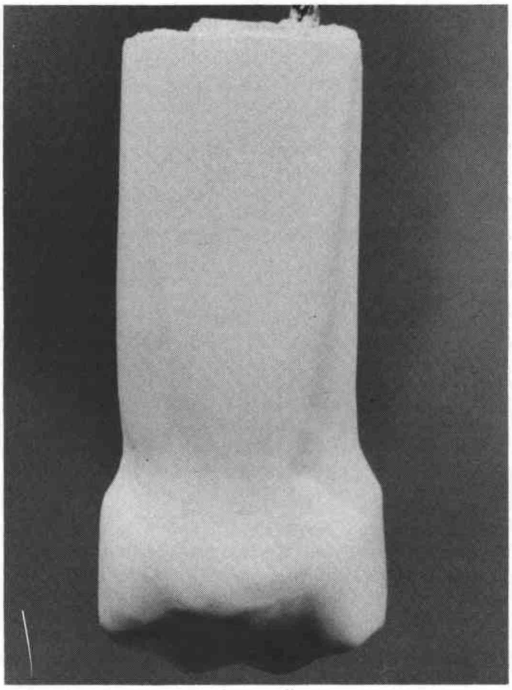
Conclusions

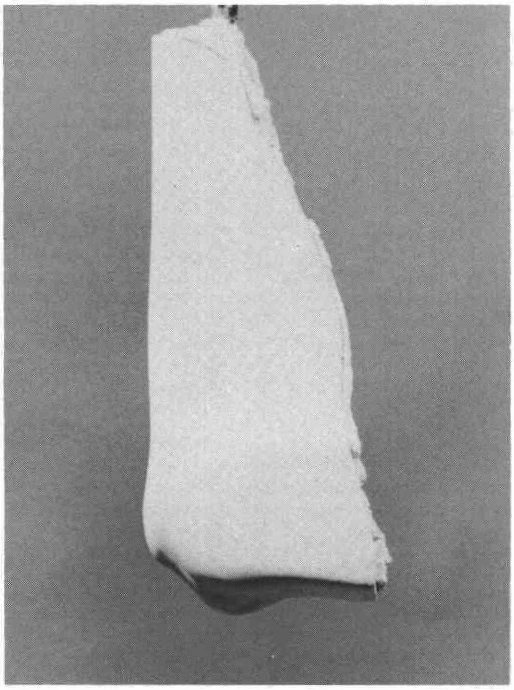
This paper has dealt most heavily with biomechanics and design, but many other programmatic components have been mentioned. Devices do not solve seating problems. A program is required. A truly successful seating program, one that approaches the fundamental goals discussed at the beginning of this paper, must contain at least the following components:

1. Involvement of all appropriate and available professional disciplines.
2. Comprehensive discussion with, and education of, the client (when possible), the parents and/or other caretakers, and other available community-based professionals.
3. Attention to finding and solving the family-specific functional (including play, recreation, and transportation) problems and opportunities.
4. Provision of effective equipment with thorough instructions on its use.
5. Tenacious follow-up to uncover and solve the inevitable problems and opportunities brought on by growth and functional changes; to obtain feedback necessary to the efficient evolution of the program; and to reinforce, as necessary, the education of the users.

Acknowledgments

The important roles of some individuals and institutions have been cited earlier and will not be repeated here. Our experience with Duchenne Muscular Dystrophy has come





Figures 41a and 41b. Posterior and lateral views of a finished molding pattern for an S.S.O. shell.

primarily through Dr. Lowell (Hap) Lutter, chief of the Growth and Development Clinic at Gillette, and orthopedic surgeon for the Muscular Dystrophy Clinic at Fairview Hospital. The seating systems were provided at Gillette by Team Leaders, Mark Payette and David Wilkie, and the people they supervise. Those people include (currently, and in the recent past) Tracy Lillehaug, Joe Bieganek, Dannel Friel, John Spielman, Katie Voss, Lee Hegfors, Bruce Tew, Wendy Schifsky, Rick Weber, Paul Swanlund, Paul Lemke, and Marcia Munson. Gene Berglund is orthotic group manager at Gillette. Former Therapy Supervisors, Diane Twedt and Jan Headley were very involved and important during the early years of the program. Gillette therapists significantly involved with the program currently (or in the recent past) include Rebecca Lucas, Lynn Bowman-Bathke, Cindy Theisen, Patricia Mathie, Gail Graff, Marilyn Kochsiek, and Ellen Kratz.

Over the years, we have been privileged to work with many outstanding individuals and institutions in various communities in our referral area. Five institutions which have been especially cooperative and capable are the Cambridge Regional Human Services Center (formerly Cambridge State Hospital), People's Child Care Residence, Homeward Bound, Brainerd State Hospital, and Moose Lake State Hospital.

We have significantly learned from (in addition to centers cited earlier) the professionals associated with seating programs at the Rehabilitation Engineering Center of the University of Tennessee, the Hugh MacMillan Center in Toronto, and the Winnipeg Rehabilitation Center for Children.

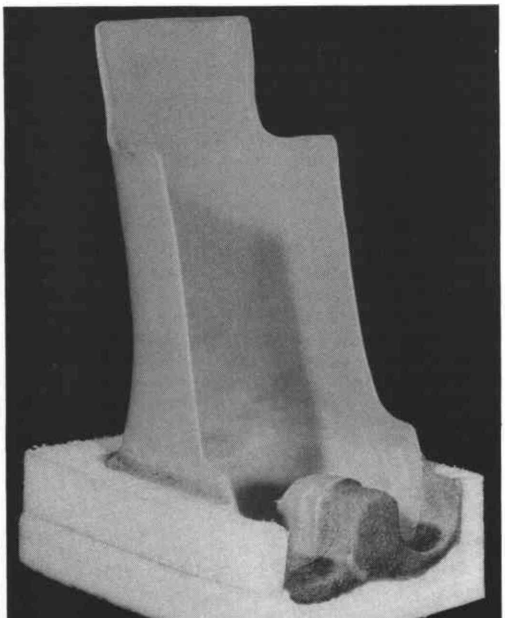


Figure 42. The polypropylene S.S.O. shell is matted to a polyethylene foam base by using foam-in-place material. The foam is shaped and becomes the distal portion of the thigh support.

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David C. Wilkie, B.F.A., is an Adaptive Equipment Team Leader at Gillette Children's Hospital.

References

[1] Bowker, John H. and Reed, "A Vacuum Formed Plastic Insert for Neurologically Handicapped Wheelchair Patients," *Inter-Clinic Information Bulletin,* 12:10, July, 1973, pp. 7–12.

[2] Carlson, J. Martin and Payette, Mark, "Seating and Spine Support for Boys with Duchenne Muscular Dystrophy," Program and Proceedings of the Rehabilitation Engineering Society of North America, Memphis, Tennessee, June, 1985.

[3] Carlson, J. Martin and Winter, Robert, "The Gillette Sitting Support Orthosis," *Orthotics and Prosthetics,* 32:4, December, 1978, pp. 35–45.

[4] Crandall, Stephen H. and Dahl, Norman C., "Stability of Equilibrium," *An Introduction to the Mechanics of Solids,* McGraw-Hill, 1959, Chapter 9, p. 420.

[5] Morris, J.M., Lucas, D.B., and Bresler, B., "Role of the Trunk in Stability of the Spine," *The Journal of Bone and Joint Surgery,* 43-A:3, April, 1961, pp. 327–351.

[6] Nachemson, Alf L., Andersson, Gunnar, B.J., and Schultz, Albert B., "Valsalva Maneuver Biomechanics: Effects on Lumbar Trunk Loads of Elevated Intra-abdominal Pressures," *Spine,* 11:5, June, 1986, pp. 476–479.

[7] Rang, M., Douglas, G., Bennet, G.C., and Koreska, J., "Seating for Children with Cerebral Palsy," *Journal of Pediatric Orthopedics,* 1:3, 1981.

[8] Ring, N.D., Nelham, R.L., and Pearson, F.A., "Moulded Supportive Seating for the Disabled," *Prosthetics and Orthotics International,* 2:1, April, 1978, pp. 30–34.

[9] Winter, Robert B., and Carlson, J. Martin, "Modern Orthotics for Spinal Deformities," *Clinical Orthopedics.* 126:5, July–August, 1977, pp. 74–86.