SEATING ASSESSMENT AND PLANNING

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Wheelchair prescription is a nearly certain component of the management of a spinal cord injured patient. Though the increased occurrence of incomplete spinal cord injury dictates an increased need for gait training and orthotic management, it is still true that the primary mobility for the spinal cord injured population will be seated. This article addresses how to maximize the spinal cord injured patient's functional mobility with proper prescription of seating.

A two-part format enables this article to be more useful and practical for the reader. Part One focuses on the core subject (seating) and its critical components. Here seating as a therapeutic intervention is defined and the goals of seating are identified. The focus of Part Two is equipment, providing information on the different characteristics of equipment to assist the practitioner in selecting equipment to achieve their goals for seating.

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PART ONE

People who have a spinal cord injury (SCI) have issues with postural maintenance (because of motor weakness), skin protection (because of loss of sensation), and mobility (again because of motor weakness). All of these issues can be addressed by seating. Seating encompasses the base: the wheelchair, either power or manual, and the interface to the user, the cushion and the backrest. Significantly, seating, to be complete, also must encompass the set-up. The set-up is the arrangement of the equipment to provide for optimal stability and mobility of the spinal cord injured person. Seating (base, interface, and set-up) can and must be broken down into different categories to aid discussion; the two most obvious are seating for:

1. The individual with a lower level injury using a manual wheelchair and requiring maximal functional mobility as well as sufficient support from the seating system. Functional mobility includes not only the ability to maneuver the wheelchair but also the ability to freely move in and out of the wheelchair.
2. The individual with a higher level injury: using a power mobility base and requiring significant supports in the interface as well as a power system for pressure relief.

The final seating system for the individual will be based on the specific needs of the user. The rehabilitation professional is responsible for knowing those needs based on thorough neuromuscular, functional, and postural evaluation. For all seating there are the following goals:

1. To protect the skin integrity of the user
2. To allow optimal mobility of the user
3. To create or maintain normal anatomic alignment with particular attention to the spine

Obtaining normal alignment is the primary goal as this establishes the foundation for optimal skin protection and mobility. Postural alignment promotes even weight distribution across the seated surface and postural stability decreases forces of shear and aberrant pressures from malalignment. The seating set-up, in terms of arrangement of the wheelchair itself, can increase the mobility of the individual by establishing the balance and maneuverability of the wheelchair, but also can decrease the potential for injury to the upper extremity from poor push mechanics and joint positioning. What then is one trying to achieve with seating? Table 1 lists the alignment one hopes to achieve. Sagittal plane alignment is critical and, as seen in a later discussion, it must sequence first in seating priority. It is important to recall the normal sagittal plane curves that include a slight thoracic kyphosis and a posterior orientation of the sacrum.[8]

POSTURAL MAINTENANCE

Balance is a function of muscle strength and sensory feedback, including the vestibular system. When providing a seating system for the SCI patient it is important to understand balance and the impact of gravity on a person without antigravity muscular control. The SCI individual is missing vestibular reflexes below the level of SCI. They are also missing sensory feedback and muscular strength below the level of SCI. Yet, head righting reflexes remain strong and are a powerful factor in habitual posturing. Effectively, when working on seating, one is working within a closed kinematic chain from both ends; the seat surface contact to the pelvis and the righting reflexes impact on head positioning (head vertical, eyes horizontal).

A person without trunk innervation assumes a position of "C" sitting if placed in short sitting on a mat edge, and the individual can learn to balance without upper extremity support. To do so they posteriorly tilt their pelvis, which increases the base of support and flexes the entire spine except the high cervical spine, which moves into extension secondary to the eyes horizontal head righting reflex. The position is at end range spinal flexion with added stability from abdominal compression. If viewed from the sagittal plane, this equals kyphosis. A neutral pelvis with ischial weight bearing is in slight anterior tilt, with slight lumbar lordosis and thoracic kyphosis. Caution: if you seat a person

Table 1. DESIRED ALIGNMENT

Frontal Plane (Anterior View)	Sagittal Plane
Head midline—eyes horizontal	Ears over shoulder
Shoulders level	Mild cervical lordosis
Sternum vertical	Shoulders over hips
Rib to iliac crest equal	Slight thoracic kyphosis
ASIS level	Slight lumbar lordosis
Knees level	Slight posterior sacrum
	Slight anterior tilt to pelvis (no rotation)
	Thighs parallel to the seat
	Knees level

ASIS = anterior superior iliac spine.

with SCI and no trunk innervation on a seat with a seat plane parallel to the floor and an inside back to seat angle which is 90°, the result is they cannot remain erect. To prevent forward falling there are essentially three options:

1. Strap the chest to the backrest
2. Tilt the seat backwards
3. Scoot the buttocks forward in the seat

The first option provides stability, but this option restricts upper extremity and trunk mobility and respiration and is unacceptable to most wheelchair users. The second option will provide significantly improved stability from the situation with the seat parallel to the floor, but as the angle of the back to seat remains 90°, the resultant increased forward stability is gained at a loss of forward line of sight. This is self-corrected by flexion of the cervical spine with hyperextension of the C1 to C2, which is not an optimal long-term solution (and is a cause of complaints of neck pain, shoulder pain, and headaches). One manner of achieving the stability from tilting the seat backward is to adjust the lightweight folding wheelchair with a high axle plate ("dumping" the chair), but the result is again to direct the line of sight skyward and requires cervical compensation to adjust to a horizontal line of sight. A similar situation is seen when the patient is seated in a wheelchair that has an inside seat to back angle that is greater than 90° (reclined), and again there is compensatory exaggerated flexion and high extension in the cervical spine. The final option previously listed is the configuration one sees assumed by the paralyzed individual who has no inherent stability in the wheelchair set-up. This "C" sitting posture within the wheelchair has a significant negative impact on the patient's respiratory function, upper extremity mobility, and fit of the wheelchair. Table 2 lists the extent of the impact of this seated position. This is the seated posture and wheelchair set-up that is seen so prevalently in the SCI population who received their first wheelchairs in the 1970s or earlier, and many of these patients now have fixed kyphotic deformity. In addition to the poor posture resulting from sitting in a "hospital type" wheelchair, there are also the increased weight and high roll resistance of these wheelchairs and the poor joint mechanics for pushing that are created by the

Table 2. IMPACT OF SACRAL SITTING IN WHEELCHAIR

- The back rest is now relatively higher, decreasing upper extremity mobility and further pushing into the normal thoracic curve, exaggerating the need to "slump" to maintain balance
- The seat depth is shorter, decreasing the support and control of the legs, and there is increased sacral skin pressure. The ischial tuberosities are now weight bearing through the gluteal muscle mass
- If the person uses armrests, they are now effectively higher
- The hand to rim position is changed and push mechanics are altered, requiring more extreme joint positions

posterior axle position. In this author's opinion, the prolonged use of these "hospital type" wheelchairs is a major cause of much of the upper extremity pain reported in the population of SCI individuals who have been injured 20 or more years.[6, 12]

WHEELCHAIR SET-UP

None of the above options are ideal. So how does one seat the individual who has no trunk innervation? The answer is to have a positive seat plane so that the seat-to-floor height is greater in front than in back, and a backrest perpendicular to the floor. This backrest adjustment can be achieved on all rigid frame manual wheelchairs. This position captures gravity to promote spinal extension and stabilizes the pelvis. A neutral pelvic position cannot be maintained without support; with a backrest and a positive seat plane (as found in a "squeeze frame"), however, one can maintain the pelvic position, essentially locking the pelvis between the backrest and the femurs. In addition to the backrest angle, the backrest needs to be short, usually just catching the lower 2 to 4 ribs. It is very important to recall the normal existence of a thoracic kyphosis. The backrest is a lumbosacral support and should act to facilitate dynamic posture and allow the thoracic kyphosis to extend posterior to, and above, the backrest. Figure 1 illustrates this method of seating. Sagittal plane stability is gained without the high cervical compensatory problems. If the patient is unable to use a rigid frame wheelchair, the same positioning can be achieved with an adjustable axle wheelchair (to create the positive seat plane) and an after market backrest adjusted to the perpendicular position. Careful titration is necessary to find the optimal seat plane for the individual; too narrow a posterior angle will cause sacral sitting. Careful evaluation of the patient's range of motion is necessary. At what degree of flexion of the hip does the pelvis begin to posteriorly tilt? One cannot have the inside angle of the back-to-seat tighter than the patient's anatomy allows. If this mistake is made the patient shifts their buttocks forward and posterior tilt results. When using a positive seat angle in the wheelchair it is important to not negate it by having the thighs down-sloped; the thighs must be parallel with the seat plane to lock in the pelvis. The result is the head positioned over the hips and the natural spinal curves maintained, establishing a stable position for dynamic mobility (see Fig. 1). This is the seating configuration for the SCI patient without trunk antigravity control who is an independent user of a manual wheelchair (C6 and below). After establishing the sagittal plane alignment by the orthotic set-up of the wheelchair it is wise to adjust the axle to a position that allows optimal push mechanics of the user. The goal is to reduce the forces required to push the wheelchair and to allow joint movement in a normal and comfortable range. The individual should be able to reach comfortably the front and rear of the pushrims at the axle height, which is achieved easily with the shoulder in, or slightly forward of, the

Figure 1. Ideal seating set-up includes: a positive seat plane; a short backrest perpendicular to the floor; a short seat depth that allows for thighs to be parallel to seat plane; and a foot support for keeping feet in dorsiflexion at the ankle.

vertical plane of the rear axle.[2, 5] Individuals with cervical injury and absent triceps function generally will have better push mechanics with the rear axle slightly more forward. The final wheel placement must work in terms of the stability of the wheelchair for the user.

When one moves to the higher injury level a need for a power pressure relief is added. This creates the requirement for a high backrest to support the individual when reclined. Additionally, the individual with a high level injury is typically dependent for transfers and, if a driver of a vehicle, it necessarily is from their wheelchair, which also requires more backrest and structure. It does not negate the need for normal anatomic sagittal plane curves; it simply changes how they can be achieved. Contoured backrest and lumbar supports are used for sagittal alignment. Wedge seating may be used to achieve a positive seat plane because one typically cannot change the seat plane in a power wheelchair. Wedge seating is still the best mechanism, with the footrest adjusted to support the thighs into flexion of the hips to lock the pelvis against the backrest. The inside seat to backrest angle should be acute and the upper backrest should be posteriorly placed to allow extension of the lumbar spine and a normal thoracic kyphosis. It is very important to provide normal postural alignment to allow maximal use of all innervated muscles for respiration, mobility, and function. As stated previously the reclined (obtuse inside angle of the seat to backrest) or the tilted back (tilting the entire seating system in space) positions are not recommended as these positions will overwork the cervical musculature to maintain a head vertical/eyes horizontal alignment. The individual with only cervical musculature innervated is limited significantly in their endurance to sitting if positioned without support for normal sagittal alignment.

It is important to recognize that seating which essentially is using the wheelchair and interface as an orthoses, must be accompanied by a maintenance range of motion program. Habitual sitting causes flexion contractures if not countered by stretching, and this can be hastened by seating, which captures a pelvis in a slight anterior pelvic tilt.

SEATING EVALUATION

The new SCI patient usually has a fairly flexible system without deformity or limitation; this is assuming, however, that none existed premorbidly. It is always best to base one's seating on a thorough postural evaluation of the patient. Table 3 lists the musculoskeletal and neurologic issues that one must consider when assessing the patient for seating. Muscle length is an important factor. In particular, shortened muscles or over-lengthened muscles certainly contribute to weakness especially in postural extensors. Shortened muscles limit the positions a person can assume, and it is necessary to realize that if one exceeds the range of the muscle the parts above or below (wherever the least stability is) will be affected. Bony blocks and restricted capsule limit range of motion in a similar manner. Passive range of motion is then a critical evaluation for seating. One must know the available range of motion (and the muscle length) of all of the joints involved in sitting; of particular interest are flexion and extension of the hips, flexion of the knee and straight leg raise (or hamstring length) and the lumbar spine, into anterior and posterior pelvic tilt and lateral flexion and rotation. Tone assessment is also a necessity for a seating evaluation. The passive

Table 3. MUSCULOSKELETAL PARAMETERS THAT IMPACT SEATING

- Muscle length
- Spasticity
- Muscle weakness
- Bony alignment
- Bony blocks
- Restricted capsule

resistance to movement is one issue, but the bigger issue for seating is often dynamic spasms in response to position change. This is especially true when using a power pressure relieving system. Response or reactivity to quick stretch is also important as this is how an individual's spasticity will react to uneven terrain. For the dynamic spasticity evaluation, observation is the key. Change the person's position; use the recline, have him or her drive around if in a power wheelchair or jump off curbs if in a manual wheelchair, and then observe. How does the spasticity react? Does it impact positioning? Upper extremity problems also impact seating. Noticeably the tight pectoralis muscles contribute to rounded shoulders and forward head posture; less obvious are the functional postures that are assumed because of limited upper extremity strength or mobility. This can be as simple as the lateral trunk shift for an individual using a hand drive control in a power wheelchair, or a more unusual pattern would be the postural abnormality of an individual with a unilateral limitation in elbow motion using a manual wheelchair. Leg length discrepancy is an overt postural issue in a standing person. In sitting, it matters too! In particular a problem occurs if the patient is bothered by the asymmetry of their knees/lap and shift to correct or level the knees. This will create a rotatory scoliosis as the individual compensates with counter-rotation above to return the eyes to forward. Finally, pelvic obliquity is a frontal plane abnormality that generally is assessed during a seating evaluation. But less recognized is the fact that the sagittal alignment of the pelvis will determine the impact of a pelvic obliquity. If the pelvis is neutral the weight-bearing surface is the ischial tuberosities, and in this position a pelvic obliquity has significant impact on the alignment of the spine. In a posterior tilt, however, the weight bearing occurs on the sacrum and the posterior condyles of the tuberosities, if at all, which negates a height difference normally seen with the obliquity. If the pelvis is in significant anterior tilt the weight bearing surface can become the pubic rami. Additionally, the architecture of the spine is such that the flexed spine allows for more lateral shift between segments without affecting the segments above or below, but in an extended spine the facets dictate that a lateral curvature be transmitted up and down the spine.

To determine postural support needed in the seating system a full postural evaluation must be done. The first key to doing a postural evaluation is to document what one sees. Get as much information as possible. One may have to synthesize the information after the patient is gone for the day. Correct information is what allows one to establish a plan for the next appointment. When the patient arrives, first document how they present in the wheelchair as they are. Next, get them out of the wheelchair and see how they present in short sitting on a mat (as firm as possible) with as little support as possible, not propped on their upper extremities. Comparing these first two pictures will give the impact of the wheelchair, or the environment of the patient. Next, do a supine evaluation; comparing this to sitting gives the impact of gravity (Table 4). Carefully document each assessment as the goal is to have

Table 4. THE STEPS TO A POSTURAL EVALUATION

Begin with how they present in their current wheelchair	Comparing here tells the impact of the wheelchair system
Next evaluation is short sitting on a mat edge	
Next evaluation is supine mobility assessments	Comparing here tells the impact of gravity

some objective parameters which can be recorded over time and compared. Table 5 is an outline of a complete postural evaluation.

Pressure Mapping

The most recent entry into the seating arsenal is the interface pressure mapping system. These are computer linked systems that will digitize the pressure information gained from sitting the patient on a thin flexible pad of sensors placed immediately under the individual and over their cushion. Some systems will have the ability to do the interface pressures of the seat back and seat together. The clinician then has a numerical description, three-dimensional representation, or a two-dimensional color gradient for the pressures generated by the individual while sitting in their system. It is imperative to note that this is an adjunct to a full seating evaluation; it cannot replace the postural evaluation. Pressure mapping is used best to confirm a suspected increased pressure because of malalignment, or as an educational tool; to help the patient accept improved alignment by showing them the changes in pressure on the computer screen. In the case of a known postural deformity or skin breakdown it is very useful to use a pressure mapping system first on the patient's current seating to get a baseline. Then after one makes interventions, do a pressure mapping again to ascertain that one has decreased the pressures on problem areas in the case of skin, or in the case of postural deformity without skin issues to insure that one has not increased pressure by the intervention. It is also nice, if one has the technology available, to get a baseline mapping of the newly injured individual in their seating at discharge for use in follow-up interventions if needed.

SEATING INTERVENTION

When one completes the postural evaluation, one then must synthesize the information. Determine whether one has a fixed or a flexible deformity. The flexible deformity can be corrected, often by support to the low side. The fixed deformity must be accommodated. It is sometimes possible, and advisable, to accommodate a fixed deformity by creating a counter curve at a mobile segment, especially in frontal plane

Table 5. POSTURE EVALUATION

Remember to record what is SEEN, not what one thinks should be seen

1. Observe short sitting in the wheelchair in the frontal plane:
   Anterior view
   - Shoulder height
   - Sternum orientation
   - ASIS height
   - Knee height
   - Hip position (rotation, add, abd)
   - Ankle position
   - Rib to iliac crest clearance

   Posterior view
   - Shoulder height
   - Scapular orientation
   - PSIS height
   - Spine for curvature
   - Ribs for humps
   - Posterior skin for signs of backrest pressure/shear

   Next in the sagittal plane:
   - Observe for curvature: lumbar, thoracic, cervical curves
   - Orientation of head to C spine

   Note the backrest height relative to a bony landmark (scapula)
2. Repeat all of the anterior and posterior observations in short sitting on a mat edge (the firmer the mat the better—if patient must be supported have it be very light support)
   Do not do sagittal plane evaluation because the person will C-sit into spinal flexion for stability—do not allow them to prop with arms.
   With the patient out of the wheelchair, note the parameters of the wheelchair set-up
   - Note the seat plane angle to the floor (slope-rise over run)
   - Note the angle of the seat to the backrest
   - Note the state of the upholstery (slung out? Worn or torn on the front aspect?)
   - Note the angle of the footrest drop relative to the seat plane
   - Note the width of the wheelchair relative to the supine width of the patient
3. Repeat all of the anterior observations in supine
4. Do a PROM evaluation (especially those tightened by sitting or impacting sitting) and leg lengths
5. Assess the flexibility in trunk
   - Lower trunk rotation
   - Lateral bending
   - Flexion and extension of the lumbar spine
6. Determine the flexibility of any deformity
7. Synthesize the findings and do empirical trials

ASIS = anterior superior iliac spine; PSIS = posterior superior iliac spine; PROM = passive range of motion.

deformity. It is most common to see a combination of fixed and flexible deformity. It is also critical to recall that in the body an area of hypomobility generally is compensated with an area of hypermobility above or below the limited segment. Additionally, the SCI patient who has internal hardware also has limitations dictated by the hardware, and potentially changes in the sagittal plane curves in the case of distracting hardware.

When correcting a deformity *never* counter the entire deformity. The extent of time that the deformity has existed and accommodations to it guide how aggressive intervention can be; the longer the person has lived with the deformity the more minimal the intervention. To determine the final seating do mock-ups and trials. Start at the base; align the pelvis first. The goal is to support the body into natural spinal curves, and this allows the individual to remain erect with minimal muscular work and minimal lateral supports or restrictive straps. Remember there is a driving force to maintain the eyes horizontal and the head vertical; the body aligns (appropriately or not) between the head and the weight-bearing platform. In the presence of an asymmetry there is increased work of the muscles to attain or hold the head position. This work can result in musculoskeletal pain. Table 6 lists common musculoskeletal presentations that may require seating interventions. It is important to realize that seating may not be *all* that is done to treat the patient, but if it is neglected the treatment will fail as the underlying cause or aggravant is not being addressed.

Table 6. THE MUSCULOSKELETAL PRESENTATION THAT MAY REQUIRE SEATING

- Headache
- Neck pain
- Shoulder pain
- Back or flank pain
- Pressure area or breakdown on posterior lower ribs
- Skin breakdown unilateral
- Complaint of "looking fatter even though I have lost weight"
- Increased spasticity

PART TWO

Equipment for seating is a dynamic field, and there is a very large amount of information to know if one was to know all of the available equipment and the variations of each. A lesser amount of knowledge is needed, however, to know the general characteristics of equipment.

MANUAL WHEELCHAIRS

This discussion begins with a review of a couple of points about the wheelchair market. At present there are many styles and designs of wheelchairs. This is the case even though there recently has been much activity in mergers and acquisitions in the durable medical equipment sector of business. It is important to realize that the basic chair design did not change at all until late in the 1970s and the early part of the next decade. The chrome folding "hospital type" wheelchairs were all that were available. When some Vietnam veterans came home and experienced dissatisfaction with the equipment they were given, some actually cut up their wheelchairs and modified them. They became the impetus for change. Many of the early wheelchair athletes began producing their own wheelchair lines.

The first lightweight wheelchairs were the same basic design but out of lighter material. Next came the axle plate and removable wheels, and then modular parts. The rigid frame wheelchair entered the market in the 1980s. This change was driven by wheelchair sports, or again by the wheelchair users. Slowly the rigid frame wheelchair has become recognized as a practical everyday wheelchair (that is, insurance began to pay for this style of wheelchair for everyday use). Tapers and tight footrest angles followed. During the 1970s a standard footrest drop angle was 55°, but now it is difficult to find a footrest angle of less than 70° (Fig. 2).

As the market has become more competitive there has been an increase in the "follow the leader" development. If one company produces a feature it is rapidly available, if not standard, on a product from

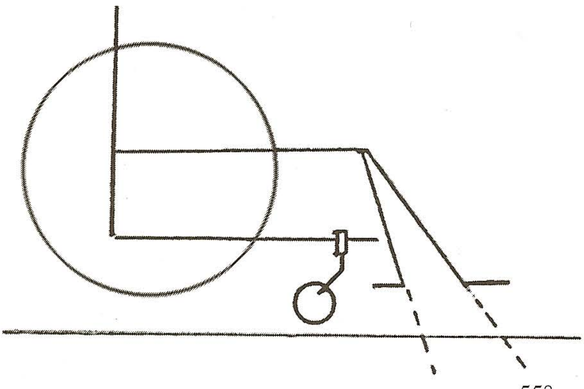

Figure 2. Footrest drop angles have been increasing, creating more flexion at the knee and dorsiflexion at the ankle.

all the other wheelchair companies. Tapers and tighter drop angles were driven by the competitive needs of wheelchair sports athletes, but the functional impact is the ability to get the wheelchair much closer for transfers and reaching by eliminating much of the front end and decreasing the turning radius of the wheelchair. End user suggestions and the market have improved wheelchairs significantly. Not all of the "hot" or glamour changes, however, are good for all patients. The rehabilitation professional must be wary and critically review new wheelchair features and advise the users on the merits or potential problems they offer. An example is the tapered footrest: placing the feet closer together causes the knees to fall apart and slightly externally rotate. The prevalence of this positioning has reduced significantly the use of adductor pummels and build-ups to prevent knocking knees, but it can cause lateral leg pressure, an aesthetically unpleasing effect, and the loss of a level lap for carrying. Also know that an extremely tight footrest drop angle can increase spasticity. In a patient who had knee pain before SCI this position of hyperflexion will create a noxious stimulus.

The classes of manual wheelchair that are appropriate for SCI patients are the "lightweight" and "ultralight" wheelchairs. Figure 3 illustrates some of the common components of these wheelchairs. "Lightweight" class wheelchairs are those weighing less than 36 pounds. "Ultralight" is a term that describes the daily use wheelchairs which had their origins in the sports chair. These wheelchairs are high performance and weigh less than 30 pounds. Most "lightweight" or "ultralight" wheelchairs will come standard with the end user adjustments for backrest height and footrest length. Most custom chairs (this would be a wheelchair that is built to specific measurements at the time of order) have no other end user adjustment. A step down from a custom wheelchair is to have an adjustable axle with the ability to move the

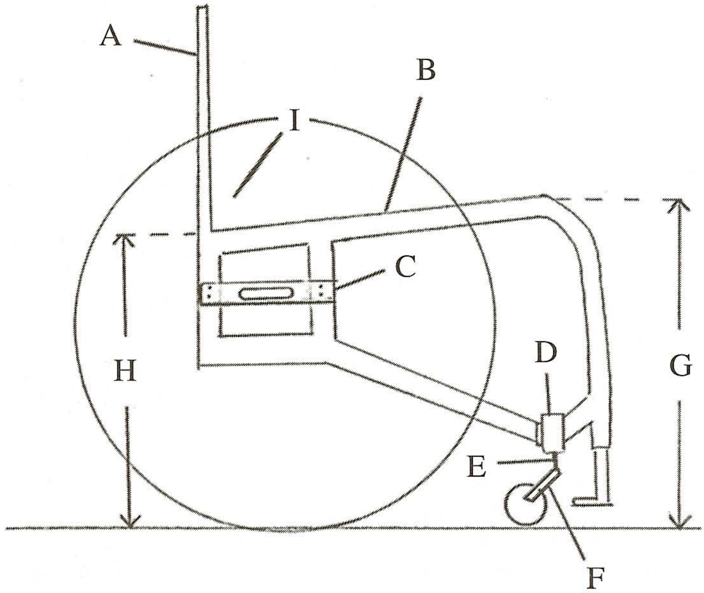

Figure 3. Components of the manual wheelchair: A = backrest; B = seat rail; C = axle plate; D = caster housing; E = caster stem bolt; F = caster fork; G = front seat to floor height; H = rear seat to floor height; I = inside back to seat angle.

axle forward or aft. Moving the axle forward makes the wheelchair easier to wheelie (a lighter front end) and creates a shorter turning radius (shorter wheel base). This also changes the hand to rim relationship, thus altering the push mechanics. Chairs that allow only forward and aft movement of the rear axle must have the axle mounted onto the frame in such a way that it is moved in a plane parallel to the floor. Because the plane is parallel there is no impact on other parts of the chair. These wheelchairs will have the caster housing permanently mounted or welded on to the frame. If the axle can be moved vertically up and down on the frame, however, there are caster adjustments that must follow.

Moving the axle up on the frame effectively lowers the rear seat to floor height, and if there is no change in caster size or fork the front frame height is higher, "dumping" the chair. This again makes the wheelchair easier to wheelie but does not shorten the wheel base (so jumping curbs is easier than with a short wheel base). This kind of axle adjustment is available on wheelchairs with axle plate mounting. After adjusting the axle in an upward or downward manner the caster housing must be adjusted so that the caster housing is perpendicular to the floor when the caster forks are positioned posterior (trail). It is important that this is adjusted after the axle position. If the caster housing adjustment is not done the wheelchair does not perform adequately, with increased rolling resistance and difficulty turning. The caster stem bearings also wear rapidly.

Axle plate adjustment changes the amount of wheel on which the individual pushes. With the axle placed low, the arc of push is smaller (shorter) and requires less joint motion. With the axle plate high, the arc is larger (longer), requiring greater joint motion (there is more wheel under the arm; the individual is "in the wheels"). The newest way to alter seating parameters is the squeeze frame; a hinge permits the seat plane itself to be moved up and down in the rear. This style of wheelchair requires the first type of axle mounting; camber tube or camber plugs with forward and aft axle adjustment only. The seat plane adjustment changes the individual's balance and also changes "how much wheel" they have without changing the wheel base or inherent stability of the wheelchair. The squeeze frame feature described previously is a feature of a rigid frame wheelchair only.

Another feature unique to rigid frame wheelchairs is the backrest angle adjustment. This is critical to seating. When the seat plane is "dumped" or "squeezed" so that there is a positive seat angle (a lower rear seat to floor height than the front floor to seat height), the backrest can be adjusted forward to be perpendicular to the floor (see Fig. 3). Adjusting the backrest to perpendicular is critical for the "locking" of the pelvis, which creates a stable postural base (see Fig. 1).

Camber (Fig. 4) can be adjusted by the end user on any of the higher end folding or rigid wheelchairs. In the case of camber tube or camber plug wheelchairs one needs to get a different part. The axle plate changes camber by changing the number of washers between the frame and the axle plate. More camber increases the side to side stability of a wheelchair, places the tops of the wheels in closer to the body for better push mechanics, and makes it quicker to turn; some users appreci-

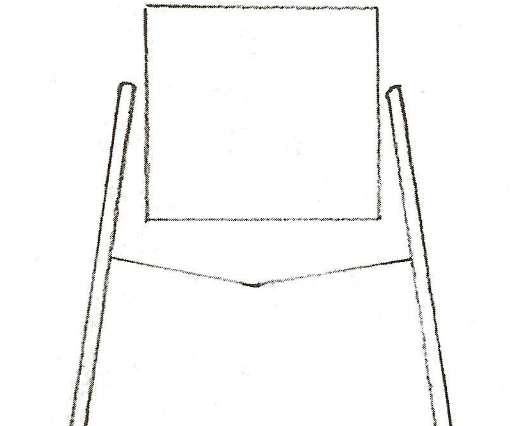

Figure 4. Cambered wheels.

ate the visual appeal. Camber also increases the footprint of the wheelchair, requires that one attends to toe in and toe out, increases the wear on the inside of the tires, and makes it more difficult to have a wheel lock, which can hold the wheelchair. A lot of camber also effectively lowers the frame into the wheels. Casters must be adjusted after camber change of more than 4°.

Most other features of the wheelchair frame are specifications ("specs") delineated at the time of order and are not adjustable after purchase. An important "spec" is the "caster fork length." The front seat to floor height should be achieved with the shortest fork possible and, if necessary, a longer caster stem bolt. A much smaller caster spin radius is achieved with a shorter fork and a longer caster stem bolt. This decreases roll resistance to turning and improves the clearance of the caster and the feet. There also will be less up and down movement of the front of the chair in a wheelchair that has a relatively high axle placement. The decision on how small the casters themselves should be is dependent on the wheelie skills of the user and the environment in which the wheelchair primarily is used. Larger casters generally have a greater roll resistance but can negotiate more easily uneven surfaces. Other accessories and modular components that can be ordered for most wheelchairs include: armrests, push handles, antitip devices, straps, side guards, and handrims. A word of caution about handrims: it is no longer appropriate to use "quad knobs" or handrim projections. The reason is that they are very destructive to the hand and to any functional grasp. Hooking the projections with the thumb will stretch out the opponens, and hooking fingers lengthens the flexor tendons. They are also very unsafe for stopping or slowing the wheelchair. In the days when "quad knobs" were the device of choice wheelchairs weighed on average 60 to 70 pounds and had huge inertia. Wheelchair brakes were indeed brakes, and one taught the individual with quadriplegia to slow the wheelchair with a braking action on the brake extensions. Wheelchairs have gotten much lighter and so have their components, and the wheelchair brakes are now "wheel locks." This is an important distinction because they are not ever to be relied on for braking action. The lighter wheelchair with less roll resistance and the adjustability to set-up for optimal push mechanics makes "quad knobs" obsolete. The handrim of choice for the quadriplegic is foam-coated, or for those with some hand function, plastic-coated. This allows enough friction for push and allows slowing with inward pressure or biceps pull on the inside of the rim. It is not recommended to use plastic coating for anyone with wheelie skills as it decreases the ability to control the wheelchair in a wheelie. The handrim of choice for paraplegics is aluminum.

Folding Versus Rigid

Storage is the biggest issue for people who have been using a folding wheelchair. The rigid frame wheelchair will fit into a car using the space of one passenger; usually it is stowed in the passenger rear. Stowing a rigid wheelchair into a car requires that the wheels are removed (from a therapist's perspective this is good as the individual is now lifting a lighter package). The remaining box frame must be passed between the chest and the steering wheel, which is done with no trouble in a two-door car with a reclining seat. It can be done with more care in a four-door car but the seat must recline. The folding wheelchairs with an axle plate mounting system and quick release wheels usually require the removal of the wheels to stow behind the front seat folded, but can have the wheels left on if the stow technique is the cross chest method in a reclined seat. Stowing a rigid frame wheelchair into a trunk is usually difficult, and once the wheelchair is over 18 inches in width it is usually not possible. Stowing between the driver and the steering wheel also becomes difficult when the wheelchair is over 18 inches wide because the driver using it will be larger as well. However, a large individual should be in a rigid wheelchair as there is not a folding lightweight wheelchair that allows a body weight over 250 pounds. Back up wheelchairs that are spending most of the time in a closet are definitely easiest to store if they are folding.

Performance is also an issue when comparing rigid versus folding wheelchairs. The rigid wheelchair is easier to push; there is less roll resistance and less of the force of push is absorbed into the frame. But this also equals a rougher ride, the shock absorption of the folding cross frame is missing, so the same factor that makes it more efficient to push makes it more jarring over rough surfaces. In recent years suspension systems and shocks have been added to rigid frame wheelchairs in an attempt to smooth the ride. At this time the systems available do offer suspension but at some cost in increased roll resistance and weight. Rigid wheelchairs are stronger. When looking at a wheelchair it is important to recognize that the more working/adjustable parts the more potential for breaking parts. Who needs the high performance? Rigid wheelchairs came out of sports and for a while it was only the sports minded paraplegics and amputees who used such chairs. Yet it is truly the weakest pusher (the more marginally able to push manual wheelchairs) who need such a chair with the least roll resistance; this equals the cervical injuries, geriatric, and otherwise frail SCI persons. From the perspective of the wheelchair as an orthosis, the rigid frame wheelchair can be adjusted more specifically to fit the particular individual and to support their postural needs. For this reason it is strongly recommended as the frame of choice for the manual wheelchair using SCI patient.

POWER WHEELCHAIRS

It needs to be clarified that this section is on power "wheelchairs," not power mobility. There will be no discussion of power add-on systems (drive systems added-on to a manual wheelchair), scooters, or mobile standing units. The scooter is not an appropriate device for the SCI patient who requires postural control (seating) and mobility.

Power wheelchairs have seen significant changes since the late 1970s, while more dramatic changes have occurred in the 1990s. Power wheelchairs originally were available as essentially a standard cross-frame manual wheelchair with a power drive system mounted underneath. Power wheelchairs are still available with a cross frame, but this is now for the purpose of transportability. A folding frame wheelchair with a detachable battery pack allows for transportation in a car. These wheelchairs, however, are limited in what they offer for seating, with limited ability to adjust the sagittal alignment of the system. The folding power wheelchair does not allow for power pressure relief options nor any alternate drive control systems. Finally, as with the manual wheelchair, the folding power wheelchair is less durable.

To meet the needs of the patient with cervical SCI one needs to look at the nonfolding power base wheelchairs. These wheelchairs are now fairly modular; a seating system is selected to meet the patient's needs, and then mounted onto the power base that meets their lifestyle. The third component of the power wheelchair is the electronics.

The early power wheelchairs were belt driven with the ability to engage or disengage the motor. Most power wheelchairs now are direct drive and there is the ability to disengage the braking system but not completely disengage the gears. Power bases are now defining their market by being rear, front, or mid-wheel drive. The change to front or mid-wheel drive significantly improves the maneuverability of the wheelchairs by decreasing the turning radius, and increases the stability and traction of the wheelchair with the rider's body weight over the drive wheels. When selecting a power base one needs to know the type of battery used, the range (distance traveled on one charge), and the top speed available. The absolute weight of the base is also important, especially for lift access with public transportation and a heavy rider. Ground clearance is important depending on the environment of the user, and finally the wheel and caster options and suspension should be considered.

The first considerations for the seating system are the options for the seat itself. Often there is an upholstered seat available, but for the SCI patient an option of a seat and back combination that accepts the appropriate cushion and supports is a requirement. The ability to adjust the backrest height and an angle adjustable backrest are two features one should look for when selecting a power wheelchair for the SCI patient. An adjustable seat to floor height, especially one allowing a positive seat plane (front height higher than the rear) is also a feature available on some models, which improves the seating for the user. Some systems allow for increasing the width of the seat platform without replacing any components; this is a smart purchase for the first wheelchair prescribed postacute rehabilitation. Finally, the ability to tilt in space, recline, or a combination of both is a feature that allows pressure relief for the patient otherwise dependent in positional changes. Here one needs to note the maximum degree of tilt or recline and the stability of the wheelchair in the extreme position. Most systems that recline now have some antishear feature included in the mechanism. It is also important to evaluate the leg-rest system and whether elevation of the leg-rest is an integral feature of the pressure relief position change. Power pressure relief system should be selected depending on the needs of the user. The tilt in space systems allows for pressure relief without changing the position of the user; this has been the system of choice of many clinicians for persons with dynamic spasms that are triggered by positional change. Caution should be taken, however, to evaluate the spasticity and comfort of the user. In many cases the change in joint positions provided by an opening recline system can increase the comfort of the user and allow more hours of wheelchair use during the day. It is also important to look at the environment for use. The open recline system takes considerably more room to function.

Electronics are the final component when selecting a power wheelchair. This is the area of greatest change in recent years as the ability to program specific drive patterns, for example turn speeds and brake ramping, has become a standard feature. Additionally, many power wheelchair electronics have the ability to interface with environmental control units, as well as control the tilt or recline mechanism from the drive control. The standard drive control for most power wheelchairs is the proportional drive control, but most electronics now allow access for specialty switches. Description of the available switches and drive mechanisms is beyond the scope of this article. It is significant to realize, however, that postural stability provided by seating allows for consistent switch access, and the postural alignment provided by proper seating maximizes the switch options by allowing all possible mobility.

WHEELCHAIR SELECTION

The rehabilitation provider must consider what function the wheelchair serves. When looking at functional roles of the wheelchair and interface it is important to look at the amount of time spent in the wheelchair and the overall mobility of the user and his or her wheelchair. For example, will the wheelchair be put in and out of a vehicle several times a day, or what is the typical surface that the wheelchair is propelled over? If the individual is functionally able and has an easy independent transfer then the wheelchair is a mobility tool and it should be set up for maximized mobility. This individual would be expected to get out of the mobility device when driving his or her car, watching a movie, relaxing on the couch, and so forth, so his or her wheelchair can be very minimal. The user who is not independent in transfers, or who uses the wheelchair as his or her all day position, must have a chair that meets the needs throughout the day. For example, if one drives from his or her manual wheelchair he or she needs a higher backrest, and often the individual who stays in the wheelchair all day may request armrests. Power wheelchairs may provide the only mobility for a person who does not have access to lift equipped public transportation, and in this case the wheelchair must be selected for such features as durability, ground clearance, and range.

Proper selection of a wheelchair requires consideration of the needs of the user, both postural and functional, and the demands of the functions of the wheelchair. A particular wheelchair should be selected before measuring for the chair. If at all possible one should do wheelchair trials. Inpatients who are new to wheelchair use should try a wheelchair for a week, if possible, before deciding to purchase one. They should have the opportunity to try different makes and models and select the one that best meets their needs and their tastes. The trials should be guided by therapists and limited to the wheelchairs that meet the medical and environmental needs of the patient. Recognizing the shortened length of stay faced by most providers of SCI rehabilitation it may be necessary to defer the wheelchair selection to the outpatient team. It is critical to acknowledge that posture and balance are learned. The individual should be provided with a temporary wheelchair that does not hinder his or her ability to develop skills in these areas. If it is necessary to provide a temporary wheelchair it must be one that establishes the postural alignment of the patient and does not restrict their ability to move within their available range of balance.

HOW TO MEASURE FOR A WHEELCHAIR

Width

Most of the lightweight daily wheelchairs are measured from the outside frame width as the expectation is that the actual sitting surface extends over the rails; there are some exceptions; be sure that the measurement wanted by the manufacturer is known. For optimal seating one wants the width to be adequate but without any extra space that would allow lateral shifting of the pelvis. In many power wheelchair systems the effective seating surface is different from the actual measurement because of the method of armrest attachment.

Body Weight Considerations

When considering width one needs to consider body weight. People lose weight with traumatic injury and inpatient rehabilitation, but tend to gain postdischarge. Atrophy in the case of lower motor neuron injury is significant, but this is not evident immediately. It is not unusual to see a patient discharge from acute admission in a 17-inch wide chair and 2 years later require a 15-inch width. When measuring width go as narrow as possible unless weight gain is anticipated. The individual who weighed 210 pounds before injury and is 165 pounds now likely will get bigger. If the person already is atrophied and has no soft tissue over the trochanters one needs to be sure the width fits their hip measurement with clearance at each side. A person with more soft tissue who "spreads" can be contained without skin risk inside firm sideguards.

Tapers

One must consider if the seat will taper. There are tapers from the rear of the seat to the front, usually of 2 inches (sometimes one can specify). In the case of a taper be certain not to start too narrow. If the footrest tapers from the seat be wary of getting too narrow at the footrest. Atrophy does not affect the size of the feet so the individual with size 11 feet needs some space.

Seat Depth

This is a critical measurement, and it is critical for the manual wheelchair user to **not** go too long. Many manufacturers go to a longer frame once the seat depth is 17 inches and this impacts the turn radius of the wheelchair and environmental access. Too long of a seat depth creates a posterior tilt that has a major postural impact. Additionally, squeeze frame wheelchairs or tight foot drop angles require a shorter seat depth because of the increased knee flexion for clearance of the popliteal space. In contrast, too short of a seat depth will make lateral transfers more difficult especially when using a sliding-board and a 24-inch rear wheel. At 14 inches of seat depth there is very little room and one must transfer over the wheel rather than in front of it. Individuals who are dependent for transfers and positioning should be given a longer seat depth to maximize the distribution of pressure and support, but be certain that it is a length that allows popliteal clearance with a properly positioned pelvis. On some wheelchair seating systems the seat depth is changed by moving the backrest forward and backward. Increasing the seat depth in this way changes the center of gravity and can create instability; shortening the seat depth can weight the casters and decrease turn speed. It is also important to note the impact on the knee angle if the seat depth is adjusted in this manner.

Backrest Height

An adjustable backrest is stronger when it is telescoped and not set at the highest setting, so a tall backrest set at the lowest setting is a better choice than the medium backrest set at the highest setting. Backrest height is measured from the seat at the side rail and should be placed well below the scapula for a manual wheelchair pusher, generally catching the lowest 2 to 4 ribs. Slightly higher for new injuries usually is recommended. Note: if one cannot bring the backrest to perpendicular the actual height must be higher. The power wheelchair user who is using a tilt or recline pressure relief system requires a taller backrest to support him or her in the posterior position. In this case the backrest should be measured to come to at least mid-scapula to avoid irritation with the inferior angle of the scapula on the top edge of the backrest. Additionally, a headrest should be provided for support when reclined.

CUSHIONS

The importance of starting the seating system at the base was stressed in the first part of this article. The base is the wheelchair frame and the set-up (arrangement) of that frame. Adjacent to that and the actual interface to the user is the cushion. The cushion is selected to provide comfort, skin protection, and positioning. In terms of seating, the positioning is the most critical. A cushion that has no inherent positioning, however, can be used quite successfully if it allows the set-up of the wheelchair to provide the orthotic control of the user and does not interfere. In contrast to that, if a cushion is selected that has significant contours and those contours conflict with the orthotic support provided by the wheelchair set-up, one can have an unsuccessful system. Comfort is not considered a primary issue with SCI users as generally they are insensate. In the individual with partial or heightened sensation, however, comfort is a key consideration. The postural support of the cushion also can make a significant difference in the musculoskeletal comfort of the user.

The wheelchair cushions marketed to the SCI individual compete aggressively on skin protection. There are cushions that claim greater pressure relief and others lower shear. It is necessary to state that there is not one *best* cushion. The cushion selected for the individual is the one that meets his or her needs and works in the wheelchair system selected. There are some cushions that are easier to modify or to which postural lifts can be added; these tend to be better for the user who has postural deformity that needs correction or support. Heat and moisture is another factor that directly relates to skin protection; some of the cushions retain heat between the cushion and the user whereas others allow air circulation.

There are other factors to consider when selecting a cushion. The first is maintenance. Some cushions require vigilant maintenance for proper adjustment. Some are more durable than others and some more readily cleaned. It is important to consider the cognitive ability and the attention to detail of the user when selecting a cushion. Another important issue is the functional mobility of the user. The cushion selected can impact directly the ability of the individual to independently transfer in and out of his or her wheelchair. An air cushion may not provide enough stability for a person with marginal transfer skills, whereas a postural control cushion may not allow the forward movement that precedes a transfer activity. The weight of the cushion has an impact on function as well; the user in a power wheelchair is not likely to be concerned with the weight of the cushion, but the manual wheelchair user must push that extra weight as well as lift the cushion out of the wheelchair to stow it into a car. Finally, there are aesthetics. It is reasonable that part of the criteria for selection is the user's acceptance of the cushion's appearance.

Backrest options are manufactured by most of the same companies that provide cushions. The cushion and backrests often are offered as "systems." It is often necessary to use such an after-market backrest in a power wheelchair as the ability to arrange the wheelchair itself as an orthosis is limited by the other functional demands, such as power pressure relief. The after-market backrest can be used to provide the support for the normal sagittal plane postural curves. In a manual rigid frame wheelchair, it usually is not necessary to use an after-market backrest as adjustment of the wheelchair itself can provide the postural support.

CONCLUSION

Equipment selection should be based on the individual needs of the user, yet it is the rehabilitation professional who is responsible for knowing those needs. The rehabilitation professional must base those needs on a thorough neuromuscular and postural evaluation of the user and integrate these findings with an understanding of the functional use of the wheelchair. Once one has determined what one requires from the equipment, a knowledgeable rehabilitation vendor can provide specific equipment to meet those needs. Final set-up and check-out of the seating system should be done just as one would a prosthetic leg or lower extremity orthosis. Goals are set for the seating system, and once it arrives one must check to ascertain that those goals have been achieved.

In conclusion, seating is a major intervention and prevention as well as health promotion tool for patients with SCI. It is important to recognize the need and advocate for the quality of seating for one's patients. Seating done correctly takes a commitment of therapist resources and increased expenditure in the initial equipment; it is a very valid investment, however, that improves the function, mobility, and comfort for one's patients. The bottom line is when one sits better, one feels better.

References

1. Bergen AF: The prescriptive wheelchair: An orthotic device. *In* O'Sullivan SB, Shmitz TJ (eds): Physical Rehabilitation Assessment and Treatment, ed 3. Philadelphia, F. A. Davis, 1994, pp 685–705
2. Boninger ML: Research into the cause and prevention of upper extremity pain in

manual wheelchair users. *In* Programs and Abstracts of the American Spinal Injury Association Annual Meeting, 1998
3. Burnham RS, May L, Nelson E, et al: Shoulder pain in wheelchair athletes. The role of muscle imbalance. Am J Sports Med 21:238–242, 1993
4. Cooper RA: High tech wheelchairs gain the competitive edge, IEEE engineering. Medicine and Biology Magazine 10:49–55, 1991
5. Cooper RA: Wheelchair Selection and Configuration. NY, Demos Medical Publishing Inc, 1998
6. Goldstein B, Young J, Escobedo EM: Rotator cuff repairs in individuals with paraplegia. Am J Phys Med Rehabil 76:93–111, 1997
7. Hallenborg S: Wheelchair needs of the disabled adult. *In* Jackson-Klykken O (ed): Therapeutic Considerations for the Elderly. New York, Churchill Livingstone, 1987
8. Kendall HO, Florence KP, Boynton DA: Posture and Pain. Malabar, FL, Krieger Publishing Co Inc, 1981
9. Maddox S: Front and mid-wheel drive a new era arrives for power chairs. New Mobility 9:52, 1988
10. Mayall JK, Desharnais G: Positioning in a Wheelchair, A Guide for Professional Caregivers of the Disabled Adult, ed 2. Thorofare NJ, Slack, 1995
11. Minkel J: Principles of positioning the seated person with neuromuscular dysfunction. *In* Program and Abstracts of Prosthetic/Spinal Cord Injury Clinical Practices in a Changing Environment, Las Vegas, 1997
12. Wylie EJ, Chakara TM: Degenerative joint abnormalities in patients with paraplegia of duration greater than 20 years. Paraplegia 26:101–106, 1988

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