Wheelchair Configuration and Postural Alignment in Persons With Spinal Cord Injury

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Objective: To determine whether postural alignment and shoulder flexion range differ for persons with spinal cord injury (SCI) seated in wheelchairs with standard configurations versus wheelchairs with posterior seat inclination and a low backrest set perpendicular to the floor.

Design: Prospective repeated-measures study.

Setting: Outpatient SCI clinic.

Participants: Fourteen subjects with C6-T10 motor-complete SCI.

Interventions: Subjects sat in 3 manual wheelchairs: standard setup E&J Premier (S1), standard setup Quickie Breezy (S2), and test configuration Quickie TNT (T) with posterior seat inclination and a low backrest set perpendicular to the floor.

Main Outcome Measures: Shoulder and neck alignment and pelvic tilt were determined from sagittal plane digital photographs at rest and with maximal vertical reach.

Results: At rest, T produced less shoulder protraction than either standard configuration (difference between the mean values, S1: 1.6cm, P=.048; S2: 1.2cm, P=.013). S1 and S2 showed a greater head-forward position than T (differences between the mean values, S1: 6.5°, P=.008; S2: 6.3°, P=.013). T allowed greater humeral flexion than S2 (difference between the mean values: 3.7°, P=.036) and greater vertical reach above the seat plane than either conventional configuration (differences between the mean values, S1: 4.7cm, P=.005; S2: 4.1cm, P=.002). The indirect pelvic tilt measurement showed a trend (P=.06) toward greater posterior pelvic tilt with S1 and S2.

Conclusion: The alternate configuration produces more vertical postural alignment and greater reach ability versus the standard factory setup wheelchairs.

Key Words: Rehabilitation; Shoulder; Spinal cord injuries; Spine; Wheelchairs.

OVER THE PAST 2 DECADES, research in biomechanics and ergonomics has led to considerable changes in the design of manual wheelchairs. The concept of the wheelchair as an assistive device for mobility is readily understood. Major design changes have been directed at improving this aspect of their function; examples include using lighter materials and increasing maneuverability in terms of roll efficiency and turn radius.[1]

The concept of the wheelchair as an orthosis is less well recognized and has not been studied in detail. An orthosis is an external device that provides stabilization, immobilization, or substitution for lost function. Wheelchairs can be considered orthoses because, when properly adjusted, they provide spinal stabilization and substitute for weak trunk musculature during static sitting and some functional activities. Some studies[2,3] have considered the effects of wheelchair configuration on spinal alignment; however, the primary focus has been on how spinal alignment affects seating interface pressures and the risk of pressure ulcers. A recent study[4] described individualized prescriptions for 4 individuals with tetraplegia who had problematic wheelchair seating and posture. Wheelchair configuration as it relates to balance and stability has been investigated, with findings that suggest that stability must be at the expense of alignment.[5] In general, minimal research has been directed at the postural support provided by wheelchairs and its effect on functional activities for persons with spinal cord injury (SCI).

This investigation was therefore undertaken to determine the effect of wheelchair configuration on seated posture in persons with SCI. The functional mobility of the shoulder is dependent on the spinal alignment of the individual, because the shoulder girdle is suspended on the thorax via the sternoclavicular joint and muscular attachment. If wheelchair configuration can change spinal alignment, then it should have a direct effect on the functional mobility of the person with SCI in terms of both reaching and wheelchair push mechanics.

The principal investigators for this study believe from empirical experience that a wheelchair configured in a specific manner improves the user's sagittal plane spinal alignment. For most of the past decade, patients with mechanical shoulder pain referred to the lead investigator (JDH) have received postural intervention by changing the wheelchair configuration as the foundation of physical therapy treatment.[6,7] The wheelchair configuration used has a posterior inclination of the seat (positive seat slope), a backrest that is perpendicular to the floor, and a backrest height that is set to meet the lowest ribs. This differs significantly from chair configurations previously investigated, which focus on rearward tilt or backrest recline.[5,8] The 2 conventional wheelchair configurations chosen for comparison have been commonly prescribed for individuals with SCI. The test wheelchair configuration is that described previously. The hypothesis was that the test chair would produce more vertical spinal alignment in the sagittal plane, decreased forward head position, and a greater active shoulder flexion range when compared with 2 wheelchairs with conventional configurations.

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METHODS

Participants

Subjects were recruited from the population receiving care through the Veterans Affairs Puget Sound Health Care System Spinal Cord Injury Service and from those attending an SCI educational forum. A study notice was mailed to patients followed by the service who reside in the greater Seattle, WA, area. All persons who contacted the investigators during a 3-month data collection period were screened for inclusion in the study. Inclusion criteria were as follows: SCI with an American Spinal Injury Association (ASIA) Impairment Scale[9] score of A or B; motor level between C6 and T10, inclusive; and age ≥18 years. Range of motion (ROM) and postural deformities that excluded participation were as follows: hip flexion range less than 110°, hip flexion contractures of greater than 20°, hamstring tightness with popliteal angle (inside tibia to femur angle measured with the hip at 90° of flexion) less than 135°, ankle dorsiflexion range less than neutral with knees flexed to 90°, and frontal plane postural deformity. The exclusion of individuals with hip flexion contractures was based on data showing that the hip flexors influence lumbar and pelvic sagittal plane alignment in neurologically intact persons until hip flexion is greater than 75°, indicating that tight hip flexors could affect seated alignment in paralyzed individuals.[10] Additional exclusion criteria included the following: inability to sit in a 45.7×40.6cm (18×16in) wheelchair because of body habitus; ankylosing spondylitis; current pressure ulcer; or any medical condition not allowing participation in transfers and sitting activities. The experimental protocol was approved by institutional review boards at the University of Washington and the VA Puget Sound Health Care System. Written, informed consent was obtained from all participating subjects.

Procedure

Each subject received a mat evaluation consisting of passive ROM measurements to determine that there were no exclusion criteria and a quick frontal plane postural check in their own wheelchair. During the mat evaluation, measurements were obtained from the individual's wheelchair to determine the seating characteristics of his/her personal seating system. After the mat evaluation, the subject was asked to transfer, or was assisted with a transfer, into 1 of the 3 test chairs. The order in which subjects were tested in the 3 chairs was randomly assigned for each subject. To control for postural differences secondary to wheelchair cushions, all subjects were tested with use of foam cushions of standard (10-cm) thickness.

The standard wheelchairs used in the study were a factory setup of an E&J Premier[a] (standard chair 1; S1) and a Quickie® Breezy 500[b] (standard chair 2; S2) (fig 1). Although the Breezy wheelchair does have seat plane angle adjustability, it does not allow for backrest angle adjustability, as does the intervention wheelchair. The S1 chair represents a design that has been commonly prescribed for more than 2 decades. S1 has a seat plane parallel to the floor (0° of seat angle), a backrest perpendicular to the seat plane (90° inside seat to backrest angle), and a 42.5-cm (17-in) backrest height. The S2 chair is a commonly prescribed basic lightweight wheelchair (classified under US Medicare billing code K0004). S2 has a very slightly positive seat angle (3.6°), a backrest perpendicular to the seat plane (90° inside seat to backrest angle), and a 42.5-cm (17-in) backrest height. The study intervention chair was a Quickie TNT[b] (test chair; T) set up to have the seat angle in the maximally tilted position (seat height of 48.3cm in the front and 38.1cm in the rear, with a positive seat angle of 14°) and the backrest set to be perpendicular to the floor, thus creating an acute inside angle (76°) between the backrest and seat plane. The height of the TNT backrest was also adjusted to contact the subjects' lower ribs and not to exceed the level of T10. The TNT chair was chosen for its ability to meet the above configuration needs; however, there are multiple chairs available that can meet these specifications.

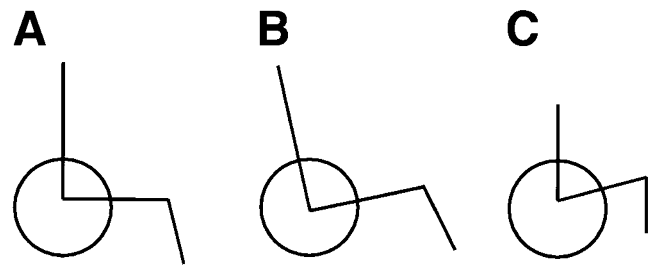

Fig 1. Schematic drawings of the significant angles in wheelchair configurations. (A) S1 and (B) S2 have the seat to back angle fixed at 90°. S2 can be tilted rearward with wheel adjustment. (C) Test wheelchair has acute angles at the seat to back and knees.

For all 3 wheelchairs, footrest positions were adjusted to align the thighs parallel to the seat plane. After the subject was positioned in the first wheelchair, markers were placed, and clothing and hair were pinned away from any markers. Clavicular marker placement was determined by bony palpation of the clavicle to its lateral terminus. The C7 spinous process was located by having the subject forward-flex his/her neck and then placing an adhesive pad directly over the C7 spinous process. A 5-cm long straw was then inserted into the adhesive pad to allow sagittal plane visualization of the marker.[11] During the pilot phase of the study, markers were also placed over pelvic bones for determination of pelvic alignment differences between chairs. However, the position of the wheelchair tires and wheels obscured these markers and prevented accurate measurements from being made. Therefore, indirect pelvic tilt measurements were made by using the effective thigh length measured from the anterior portion of the backrest cane to the forward-most knee position, with the line of measurement parallel to the seat plane.

A digital camera[c] was used for image capture. The camera was mounted on a tripod and positioned 213cm from the front of the camera to the shoulder of the subject, perpendicular to the sagittal plane. The height of the camera was set to 114cm to mid lens, as established during a pilot study, to allow a full view of the subject, including the arm, during the Functional Reach Test. A level was used to verify that the camera was level in all planes. Additionally, a plumb line was placed posterior to the subject to allow determination of the vertical plane on the digital photographs.

Once the markers were placed and clothing was arranged, the subjects received standardized verbal instructions for positioning in the wheelchair: "We would like you to position yourself in a comfortable manner. You need to assume a position in which you feel secure and in a manner that you will not fall forward or backward. You should not feel like you are being pushed forward by the backrest. You must not support yourself with your arms. We will guard you while you check out the limits of your stability. If you would like us to assist you in moving into a more comfortable posture, please instruct us in what you would like done. Finally, test your stability by reaching up in front of your face, thumb first, as high as you can. You should not have to hold on with your other arm for stability."

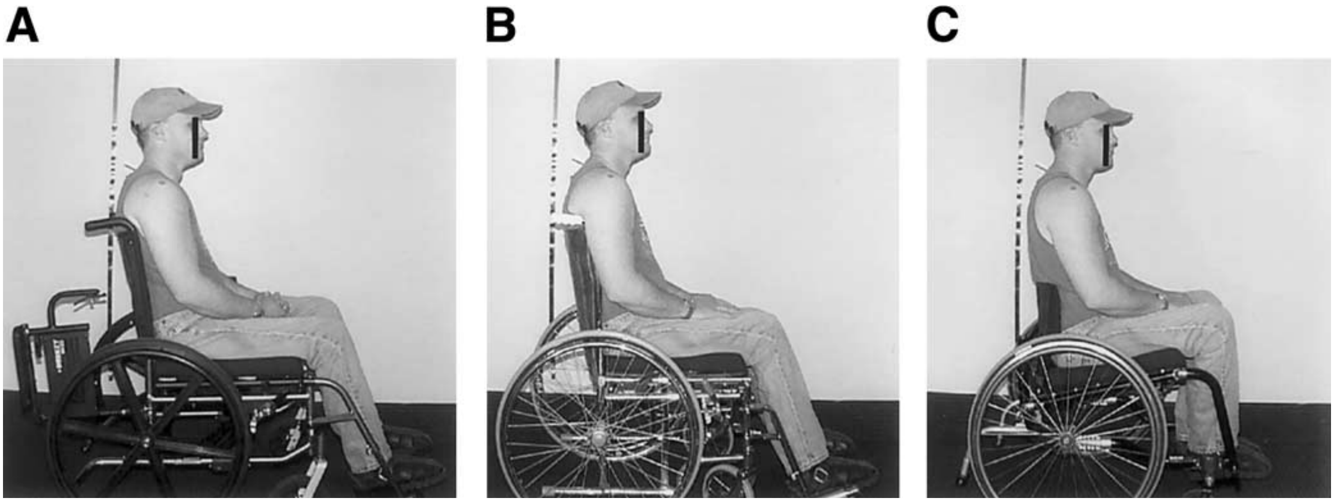

Fig 2. Subjects in a relaxed position in wheelchairs (A) S2, (B) S1, and (C) T.

Once the subjects felt that they had attained a relaxed position in the chair, a photo was taken with the subjects looking straight ahead (fig 2). A second photo was taken with the subjects asked to raise their right arm as high as they were able without using their left arm for stability (fig 3). Once the 2 photos were taken, the subjects transferred or were assisted in transferring to the second wheelchair, the markers and clothing were rechecked, and the procedure was repeated. The same procedure was followed for the photos in the third wheelchair.

Data Analysis

Distance and angle measurements for the quantitative postural assessment were determined from the digital photographs by a single investigator, who used a computer-aided design program.[d] The plumb line located posterior to the subject was used to reference all angle measurements. True wheel size was determined for each chair by using a tape measure, and the diameter of the rear wheel in the digital photograph was used to calibrate distance measurements. All listed measurements were taken from the resting position photograph, with the exception of the angle of humeral flexion (ARM) and the height of vertical reach, which were determined from the photograph showing maximal vertical reach. Measurements were defined as follows.

Shoulder position, a measure of shoulder protraction or retraction, was defined as the horizontal distance between the

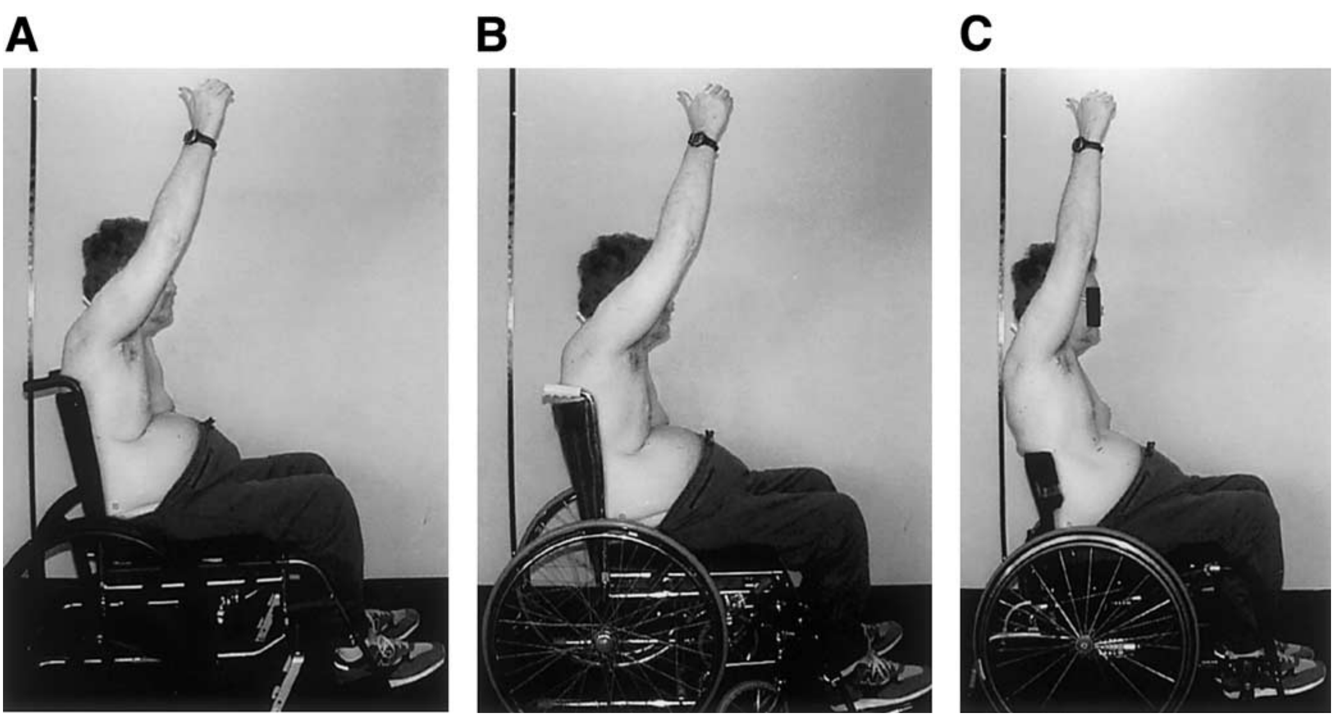

Fig 3. Subject performing the vertical reach without contralateral support, seated in wheelchairs (A) S2, (B) S1, and (C) T.

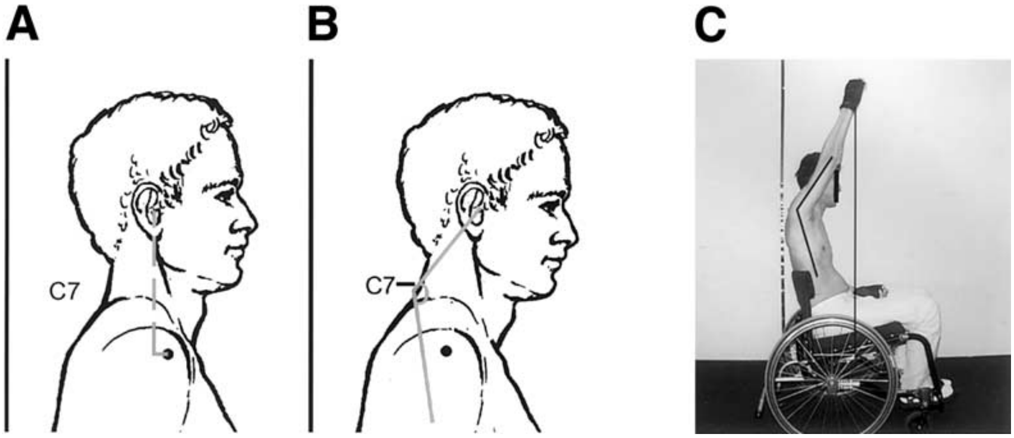

Fig 4. Diagrams of measurements for (A) shoulder position, (B) head position, and (C) ARM and height of vertical reach.

clavicular marker and a vertical line through the ear tragus (fig 4A). The vertical line through the tragus was designated the zero point, with positive numbers indicating that the clavicular marker was forward of the tragus and negative numbers indicating that the clavicular marker was behind the tragus. A greater value for shoulder position indicates greater shoulder protraction. Trunk angle inclination in the sagittal plane was defined as the angle created between the plumb line and a line bisecting the length of the trunk.

Head position, a measure of head-forward position, was defined as the angle between a line bisecting the trunk and a line connecting C7 and the ear tragus (fig 4B). A greater angle indicates less head-forward positioning. Prior studies[11,12] defined this angle in relation to a plumb line rather than the angle of the trunk; however, those subjects were measured in a standing position, whereas in our study the subjects were seated. In standing position, the trunk angle would be expected to correspond closely with the plumb line. In sitting, our subjects were noted to have trunk angles that varied considerably from vertical, so we chose to reference the C7 to tragus line to the trunk angle. Forward head position can be a function of cervical flexion or protrusion; with the maintenance of a forward line of sight, there is often a combination of both. In this study, we were not concerned with determining where the motion occurred, but, rather, the alignment of the head relative to the trunk.

The effective length of the thigh was measured from the anterior portion of the backrest to the forward-most knee position, with the line of measurement being parallel to the seat plane. Thigh length was used as an indirect measurement of pelvic tilt in the sagittal plane. Increased posterior pelvic tilt produces increased length for this measurement. Backrest upholstery can sling and create an effectively longer seat depth than that measured at the backrest cane, and this is more apparent in folding wheelchairs. However, the extent of the sling can change with positioning in the wheelchair, and, therefore, the point of reproducible measurement is the backrest cane.

ARM was determined from the angle between a line bisecting the trunk and a line bisecting the humerus. Height of vertical reach was measured as the distance from the radial styloid to a horizontal line originating at the junction of the seat pan and the backrest (fig 4C).

Intrarater reliability for measurements taken from the photos was evaluated with the coefficient of repeatability. This value represents the range from the mean within which 95% of repeated measures will fall; this is considered to be a better representation of variability than correlations.[13] The repeatability of the distance and angle measurements from the digital photographs was determined to be acceptable for study purposes. Distance measurements showed coefficients of repeatability of ≤10mm. Angle measurements showed coefficients of repeatability of ≤2.7°, with the exception of trunk angle, for which the value was 4.4°.

Nonparametric tests were used for the analysis because of the nonnormal data distribution. These included the Friedman test for comparisons among the 3 chairs, with use of the Wilcoxon signed-rank test for comparisons between pairs of chairs when the Friedman test indicated the presence of a significant difference. All statistical analyses were performed with SPSS statistical software, version 10.0.[e] A *P* value of less than .05 was considered significant.

RESULTS

Seventeen individuals volunteered to participate in the study. One was excluded because of hip flexion contractures, and a second was excluded because of frontal plane deformity resulting from prior ischiectomy. We were unable to adequately visualize all skin markers on 1 of the 15 subjects who underwent the study procedure, and his data were excluded from the analysis. Demographic information for the 14 subjects who completed data collection is presented in table 1.

Subjects showed more neutral postural alignment at the shoulder and neck in the test chair configuration (T) compared

Table 1: Subject Characteristics

Variable	Data
Age (y)	42±13
Time since injury (y)	14±11
Height (cm)	178±8
Weight (kg)	78±17
Motor level	
Cervical	4
Thoracic	10
ASIA score	
A	12
B	2
Sex	
Male	12
Female	2

NOTE. Values are mean ± standard deviation (SD) or n.

Table 2: Comparison Among 3 Wheelchair Configurations

	Wheelchair Configuration			Comparisons	
	S1	S2	T	S1 vs T (*P* value)	S2 vs T (*P* value)
Shoulder position (cm)	−1.6±3.6	−2.0±3.4	−3.2±3.5	.048	.013
Head position (deg)	110.8±12.3	111.0±12.0	117.3±9.4	.008	.013
ARM (deg)	128.1±22.2	127.5±24.7	131.2±27.4	NS	.036
Height of vertical reach (cm)	93.6±16.2	94.2±17.5	98.3±17.4	.005	.002
Trunk angle inclination (deg)	12.9±3.0	14.1±4.0	8.9±5.6	.011	.001
Thigh length (cm)	53.8±5.8	53.8±3.8	52.7±4.3	NS	.019

NOTE. Data for chairs are mean ± SD. *P* values are for the Wilcoxon signed-rank test.
Abbreviation: NS, not significant.

with the 2 standard chairs (S1, S2). Less head-forward positioning, as measured by the head position angle, was seen with the T chair configuration than with either the S1 or S2 configurations (table 2). The T configuration produced less shoulder protraction than either of the standard chair configurations, as measured by the shoulder position distance. Shoulder position measurement has an inherent weakness in that it could reflect a difference in head position rather than shoulder position. However, taken in conjunction with the head position measurements, the difference in shoulder protraction becomes apparent. The T chair had less forward head position and a larger negative shoulder position measurement (indicating shoulders behind the head). Additionally, trunk angle was significantly lower with T than with either S1 or S2, indicating more upright trunk positioning with the T chair.

The indirect pelvic tilt measurement showed a trend toward greater posterior pelvic tilt with the S2 chair compared with the T chair (table 2). The Friedman test indicated a difference ($P=.06$) among the 3 chairs, whereas the Wilcoxon signed-rank test indicated a difference ($P=.019$) between the S2 and T chairs.

The T chair configuration allowed a significantly greater amount of active humeral flexion (ARM) than the S2 configuration, but the humeral flexion was not significantly greater than with the S1 configuration (table 2). However, subjects were able to reach to a greater height (vertical reach) above the wheelchair seat base with the T chair than with either the S1 or S2 chairs. Using the T configuration, subjects were able to reach a mean of 4.7 and 4.1cm higher above the seat base than with the S1 and S2 chair configurations, respectively.

DISCUSSION

The concept of discussing an ideal sitting posture for the able-bodied population is somewhat unclear, because sitting is not a normative position for locomotion. Sitting is, in fact, usually a transitional phase or a position of rest. Many positions are used by able-bodied persons for task-specific activities, including squatting and sitting positions.[10] It is the workplace, and, in particular, the office environment, that has brought a focus on sitting posture. The importance of this discussion has centered on comfort and specifically the prevention of low back pain.[14] More recently, posture as a predictor or causative agent in upper-extremity repetitive stress disorders has been investigated. Recent review articles conclude that a sitting posture with an anterior pelvic tilt and decreased lumber flexion is the more favorable posture.[14,15] Black et al[16] associated increased posterior pelvic tilt with lumbar flexion and increased forward head and shoulder positioning, and these postural features have been associated with chronic neck and shoulder pain.[11]

The SCI population differs from the able-bodied population in that the sitting position is not transitory but rather the position of locomotion and interaction with the environment. In the absence of trunk musculature, the individual with SCI is more at the mercy of gravity, and with a posterior pelvic tilt, the mass of the head and upper trunk will facilitate trunk flexion. People with SCI who have paralyzed trunk musculature can learn a functional unsupported position of balance. This is accomplished with a posterior pelvic tilt and full spinal flexion, with high cervical extension, known as C sitting.[8,17] This is a functionally stable position of balance, which allows bimanual activity.[18] In a study of patients with severe neurologic disability who require wheelchairs, Pope[19] found that the "predominant posture" mirrors C sitting. This suggests that the wheelchair is not providing support for postural alignment and may in fact be creating the need for the individual to assume this position of balance to function.[17] Researchers looking at balance and chair configuration have confirmed that the tilted or reclined chair imposes a posterior tilt of the pelvis.[5] Kyphosis and scoliosis occur to a greater degree in persons with tetraplegia than in controls, and these postural deformities have been shown to develop early after injury.[20]

We suggest that the test wheelchair configuration creates improved postural alignment in the sagittal plane. Recent attempts to promote anterior pelvic tilt with a forward inclination of the seat have been unsuccessful.[21] Our belief is that a pelvic stabilizing system is created with a posterior inclination of the seat plane (positive seat plane), with the backrest perpendicular to the floor and relatively short. The backrest functions as a lumbar support to maintain anterior pelvic tilting. The acute angle of the backrest to seat creates a space for the posterior sacrum. The femurs, which are parallel to the seat plane, prevent the pelvis from tilting forward. The seat inclination also helps maintain the ischium in the rear of the seat by blocking the pelvis from moving anteriorly. The pelvic stabilizing system recommended here incorporates 3 points of control and passive mechanical supports. By providing postural support for the pelvis and lower trunk, a position of increased erectness can be maintained even with muscle paralysis. In this study, the test chair showed altered posture in the following ways: decreased forward head position, decreased shoulder protraction, decreased posterior pelvic tilt, and improved height of overall reach.

Outcomes in this study were limited to measurements of sagittal plane alignment, and we did not assess functional activities or the ability to propel the wheelchair. The increased slope of the seat plane may create difficulty with transfers, particularly for patients with tetraplegia; however, our experience shows that with training, nearly all manual wheelchair users can master transferring independently out of this wheelchair configuration. Our reach measurement does indicate that there could be a functional advantage to this spinal posture. In testing reach, we had subjects reach without supporting themselves with the contralateral arm. In this way, we determined that the subject had a stable position of balance; however, we did not test the limits of stability. Each subject sat in each wheelchair only once; therefore, the repeatability of the self-positioning of each subject in a wheelchair was not tested.

Subjects included only patients with motor-complete SCI. Prior research[17,22] shows that lumbar supports affect seated posture differently in individuals with SCI than in those without SCI. It is unknown how the test chair configuration would affect posture in patients with motor-incomplete SCI or in those without paralysis. The average magnitude of the postural improvements with the test chair was relatively small. However, due to the need to standardize the testing protocol, no individualization of the test chair configuration was performed. If we had individualized the test wheelchair configuration, the magnitude of the improvements may have been larger. Additionally, if we had selected only subjects who had severe postural abnormalities in conventional chair configurations, the magnitude of the improvement with the test chair may have been larger. Several of the measurements used in our study had to be modified from their original use to allow testing while subjects were seated in a wheelchair. Seated pelvic tilt has been measured previously by using a modified chair with a partial backrest,[21] but we chose to use conventional wheelchairs with standard backs for our measurements. We were unable to visualize all pelvic markers when subjects were seated in the wheelchair, and this necessitated the use of an indirect measurement of pelvic tilt. The shoulder position measurement would need to be refined in further studies to eliminate the confounding codependence between the head position and the shoulder position.

Our study was limited to persons with ROM adequate for sitting in the test wheelchair. Persons with long-term SCI often have ROM limitations and, therefore, these seating recommendations may have limited value for persons with long-term SCI. The backrest in the test manual wheelchair was low by design, and this limits its application to those individuals who can or do use a manual wheelchair and do not require a high backrest for power recline or tilt function or drive a motor vehicle from their wheelchair. However, conceptually, we suggest that the same sagittal plane contours (ie, a thoracic posterior contour that is above and posterior to the lumbar contact, and a posterior recess for the sacrum) are applicable to power-wheelchair users.

Further research is needed to observe the sagittal alignment of persons with high tetraplegia or those who use a power wheelchair. In this study, we chose a test parameter of a 14° positive slope (10-cm difference between the front seat to floor height and the rear seat to floor height over a 40-cm seat depth). It would be important to compare this slope with a greater or lesser degree of slope, particularly in light of the industry move toward suspension wheelchairs that limit the adjustability of wheelchairs, in most cases to a 5.08-cm (2-in) difference from front to rear. This may not be sufficient to promote the sagittal plane spinal alignment. Research is also needed to determine the effect of this type of wheelchair configuration on the risk of pressure ulceration. This study used a 10-cm foam cushion for all tests, and it is known that persons with SCI do not routinely use this type of cushion. It would be important to consider the interaction of this wheelchair configuration with the commonly prescribed cushions. Investigators researching push mechanics may want to examine the effect of seated postural alignment on push mechanics.

CONCLUSION

It is known that neck and shoulder pain are common in the SCI population, and in this population, shoulder pain is associated with functional limitations and disability.[23,24] The association between posture and upper-quadrant musculoskeletal pain is well established in the able-bodied population. Specifically, Greenfield et al[11] established the correlation with forward head positioning and shoulder pain. If the same association holds true in the SCI population, it seems imperative that wheelchair prescription do more than provide a mobility device. The orthotic posture-supporting properties of the wheelchair must be recognized and wheelchairs specifically prescribed and adjusted to meet the needs of the user. In this study, the wheelchair with a positive seat slope (14°), acute inside backrest angle, and relatively low backrest (meeting the lowest ribs) was superior to standard wheelchairs in supporting postural alignment.

References

1. Cooper RA. Manual wheelchairs. Wheelchair selection and configuration. New York: Demos Medical; 1998. p 199-226.
2. Hobson DA. Comparative effects of posture on pressure and shear at the body-seat interface. J Rehabil Res Dev 1992;29:21-31.
3. Shields RK, Cook TM. Effect of seat angle and lumbar support on seated buttock pressure. Phys Ther 1988;68:1682-6.
4. Bolin I, Bodin P, Kreuter M. Sitting position—posture and performance in C5-C6 tetraplegia. Spinal Cord 2000;38:425-34.
5. Janssen-Potten YJ, Seelen HA, Drukker J, Reulen JP. Chair configuration and balance control in persons with spinal cord injury. Arch Phys Med Rehabil 2000;81:401-8.
6. Goldstein B, Young J, Escobedo EM. Rotator cuff repairs in individuals with paraplegia. Am J Phys Med Rehabil 1997;76:316-22.
7. Hastings JD. Seating assessment and planning. Phys Med Rehabil Clin North Am 2000;11:183-207.
8. Zacharkow D. Essential wheelchair modifications for proper sitting posture. Wheelchair posture and pressure sores. Vol 6. Springfield (IL): CC Thomas; 1984. p 18-38.
9. American Spinal Injury Association and International Medical Society of Paraplegia. International standards for neurological and functional classification of spinal cord injury, revised 1996. Chicago: ASIA; 1996.
10. Keegan JJ. Alterations of the lumbar curve related to posture and seating. J Bone Joint Surg Am 1953;35:589-603.
11. Greenfield B, Catlin PA, Coats PW, Green E, McDonald JJ, North C. Posture in patients with shoulder overuse injuries and healthy individuals. J Orthop Sports Phys Ther 1995;21:287-95.
12. Braun BL, Amundson LR. Quantitative assessment of head and shoulder posture. Arch Phys Med Rehabil 1989;70:322-9.
13. Bland JM, Altman DG. Statistical methods for assessing agreement between two methods of clinical measurement. Lancet 1986;1:307-10.
14. Pynt J, Higgs J, Mackey M. Seeking the optimal posture of the seated lumbar spine. Physiother Theory Pract 2001;17:5-21.
15. Harrison DD, Harrison SO, Croft AC, Harrison DE, Troyanovich SJ. Sitting biomechanics part I: review of the literature. J Manipulative Physiol Ther 1999;22:594-609.
16. Black KM, McClure P, Polansky M. The influence of different sitting positions on cervical and lumbar posture. Spine 1996;21:65-70.
17. Hobson DA, Tooms RE. Seated lumbar/pelvic alignment. A comparison between spinal cord-injured and noninjured groups. Spine 1992;17:293-8.
18. Minkel JL. Seating and mobility considerations for people with spinal cord injury. Phys Ther 2000;80:701-9.

19. Pope PM. A study of instability in relation to posture in the wheelchair. Physiotherapy 1985;71:124-9.
20. Boninger ML, Saur T, Trefler E, Hobson DA, Burdett R, Cooper RA. Postural changes with aging in tetraplegia: effects on life satisfaction and pain. Arch Phys Med Rehabil 1998;79:1577-81.
21. Janssen-Potten YJ, Seelen HA, Drukker J, Huson T, Drost MR. The effect of seat tilting on pelvic position, balance control, and compensatory postural muscle use in paraplegic subjects. Arch Phys Med Rehabil 2001;82:1393-402.
22. Shields RK, Cook TM. Lumbar support thickness: effect on seated buttock pressure in individuals with and without spinal cord injury. Phys Ther 1992;72:218-26.
23. Turner JA, Cardenas DD, Warms CA, McClellan CB. Chronic pain associated with spinal cord injuries: a community survey. Arch Phys Med Rehabil 2001;82:501-9.
24. Ballinger DA, Rintala DH, Hart KA. The relation of shoulder pain and range-of-motion problems to functional limitations, disability, and perceived health of men with spinal cord injury: a multifaceted longitudinal study. Arch Phys Med Rehabil 2000;81:1575-81.

Suppliers

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