Comparison of Two Pelvic Positioning Belt Configurations in a Pediatric Wheelchair

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Accepted author version posted online: 05 Mar 2013. Published online: 14 Oct 2013.

To cite this article: Veronica Cimolin PhD, Martino Avellis PT, Luigi Piccinini MD, Claudio Corbetta PT, Andrea Cazzaniga Eng, Anna Carla Turconi MD & Manuela Galli Prof (2013) Comparison of Two Pelvic Positioning Belt Configurations in a Pediatric Wheelchair, Assistive Technology: The Official Journal of RESNA, 25:4, 240-246, DOI: 10.1080/10400435.2013.778916

To link to this article: http://dx.doi.org/10.1080/10400435.2013.778916

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Comparison of Two Pelvic Positioning Belt Configurations in a Pediatric Wheelchair

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Maintenance of stability for children in a wheelchair, particularly for those with spasticity, can be achieved through external stabilization components, such as pelvic positioning belts. Different kinds of pelvic belts exist on the market and one of the main characteristics is the different number of attachment points between the seat and the belt. As literature on this topic is limited to qualitative assessments, this study compared quantitatively 4-point versus 2-point pelvic positioning belts for the trunk fixation in 20 young patients with spasticity. Our data showed that 70% of the children required the use of pelvic belts on wheelchairs for stability and a better stability was observed with the 4-point belts than compared to the 2-point. Data generally showed in fact a higher percent of variation in terms of trunk flexion angle and knee joint angle with the 2-point belt than the 4-point belt, indicating increased submarining with the 2-point belt during sitting maintenance if compared to the 4-point belt ($p < 0.05$). According to our results, the 4-point belts seem to be the most effective configuration for patient stabilization, suggesting that its use prevents the thigh from submarining.

Keywords: ergonomics, kinematics, pelvic belts, spasticity, stability, wheelchair

Introduction

Pelvic stability refers to the ability of the trunk and hip/pelvic muscles to keep the spine and pelvis in optimal alignment during activity. If these structures are kept in an optimal alignment, then the muscles and joints of the lower limbs are able to work properly. If these structures are not kept in an optimal alignment, then the resultant poor joint and muscle function may lead to injury and pain in the spine and lower limbs. In the past years, clinicians, researchers, and the industry have devoted a considerable amount of attention to the design of wheelchair-based seating systems and their components in order to optimize pelvic stabilization in individuals with physical disabilities. Maintaining pelvic stability is essential to enable a person using a wheelchair to stay comfortably seated. The assumption that a stabilized pelvis is crucial for reaching and maintaining an adequate postural stability and for improving the functional performance is shared by most practitioners. As without seated stability, the upper extremities function is also restricted; achieving a stable pelvic position may enable not only a reduction of the repositioning need but also an improvement of upper extremity function (Trefler, 1984; Trefler, Hobson, Taylor, Monahan, & Shaw, 1993). Unstable pelvic invariability limits the comfort and security of wheelchair users not only during motor function and activities of daily living but also while sitting in wheelchair during travel in motor vehicles (Karg, Cotzin, Manary, & Fuhrman, 2011; Lacoste, Therrien, & Prince, 2009; Reid & van Roosmalen, 2005; Reid, Rigby, & Ryan, 1999; Ryan, Snider-Riczker, & Rigby, 2005; van Roosmalen, Reed, & Bertocci, 2005).

Wheelchairs are commonly used by non-ambulatory children with spasticity, such as with cerebral palsy or after traumatic brain injury, for mobility and to achieve postural support and comfort. However, there is concern in the use of wheelchairs for these patients, because a patient’s body often slides forward on the wheelchair seat. This situation leads to a sacral sitting posture and results in increased sacral shear stress, predisposing the patient to a sacral pressure sore, and requiring caregivers or parents to frequently reposition the child. In order to reduce this instability, external pelvic stabilisation components are generally used.

The most common intervention for pelvic stabilization is a pelvic belt. When the pelvic belt is properly placed and used in conjunction with a contoured seat cushion and/or a contoured backrest, the belt can assist in holding the pelvis in place. The resistance provided by the pelvic belt prevents the pelvis from submaring, which is defined as the slipping of the lap belt over the iliac crest of the pelvis consequently loading and injuring the abdomen (Adomeit & Heger, 1975) and, thus, makes it very difficult for the pelvis to slide forward (Chaves, Cooper, Collins, Karmarkar, & Cooper, 2007). Belt-to-chair attachment points and the angle at which the lap belt is attached are two very important...
elements that must be considered to increase safety and comfort. According to the literature (Chaves et al., 2007), the belt should be placed high across the thighs with a downward and slightly backward pull to prevent the pelvis from submarining. In this way, no belt pressure across the abdomen is created. The point of attachment of the lap belt should be less than 45 degrees, as this angle creates a downward pull across the thigh/abdomen area. The angle of the wheelchair lap belt should ideally be 60–90 degrees from the sitting surface. Different kinds of pelvic positioning belts that are commonly used include 2-point, 4-point belt, rigid pelvic stabilizers, and abdominal belt.

Although these systems are widely used, empirical evidence regarding the more effective pelvic belt for patients with disabilities and in particular for children with spasticity is not clear. To our knowledge, little clinical and research literature highlights the paucity of research evidence in this domain. The investigations were generally conducted on the stability of children in their wheelchair seating system, taking into considerations several aspects: the seat interface, the seat to backrest angle, the headrest, the pelvic belt, and other components. These assessments were mainly observational or based on interviews and questionnaire with patients, parents or therapists. Furthermore, the assessments are limited to physical variables, EMG activity, number of pathological movements, and qualitative aspects of sitting posture (Chaves et al., 2007; Crane, Holm, Hobson, Cooper, & Reed, 2007; Hatta et al., 2007; Ivancic, Cholewicki, & Radebold, 2002; Lacoste et al., 2009; Reid et al., 1999; Rigby, Reid, Schoger, & Ryan, 2001; Ryan et al., 2005).

However, literature about the assessment of different kinds of pelvic positioning belt systems for stability maintenance is not widely available, in particular focusing the attention on disabled children in their wheelchairs. Ivancic et al. (2002) assessed with EMG and trunk stiffness the effects of abdominal belts on the muscle-generated spinal stability and L4/L5 joint compression force. The evaluation was conducted on 10 adult subjects during perturbation with and without an abdominal belt in order to estimate the active spine stability and effective stability of the spine. In particular, the active stability was the stability of the lumbar spine achieved before perturbation as determined by the activities of the trunk muscles and forces acting on the spine, while the effective stability was the stability of the lumbar spine determined from the trunk kinematic response to perturbation. Data demonstrated that the presence of the belt influenced the passive stability of the lumbar spine, but not the active stability. In a review study, Chaves et al. (2007) reported that the 4-point belt system seemed to be as effective as a seatbelt when a wheelchair goes straight into a curb or falls straight off a curb, had no means of independent mobility, and, therefore, were transported by others. Patients using harnesses, such as a looped restraint and/or support, were excluded from this study. All participants were volunteers and their parents gave written consent to their child’s participation in this research, in accordance with the local IRB committee requirements.

Participants were evaluated at Movement Analysis Laboratory of Scientific Institute “Eugenio Medea - La Nostra Famiglia Association” in Bosisio Parini < (LC), Italy.

**Experimental Setup**

The patients were clinically assessed with the Gross Motor Function Measure (GMFM) and quantitatively assessed using 3D motion analysis. The GMFM is a standardized observational instrument designed and validated to measure change in gross

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Mean (st. dev.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gender (F/M)</td>
<td>7/13</td>
</tr>
<tr>
<td>Age (years)</td>
<td>6.95 (2.35)</td>
</tr>
<tr>
<td>Weight (Kg)</td>
<td>18.80 (4.18)</td>
</tr>
<tr>
<td>GMFM (%)</td>
<td>62.5 (16.63)</td>
</tr>
</tbody>
</table>
motor function over time in children with CP. It measures the child’s overall functional abilities and it consists of 88 items, divided into the following sections: (a) lying and rolling, (b) sitting, (c) crawling and kneeling, (d) standing, and (e) walking, running, and jumping. Each section contributes to the total GMFM score (range: 0–100; Russel et al., 1989). The GMFM demonstrates to be an excellent tool in the evaluation of children with CP and TBI (Linder-Lucht, 2007).

Participants 3D posture analysis was assessed in terms of kinematics, using an optoelectronic system (ELITE, BTS, Italy) and a synchronic video system (BTS, Italy). The optoelectronic system performs a real time processing of images from two (or more) video cameras to recognize in the field of view the presence of passive markers (with a diameter of 15 mm) that can be fixed onto proper anatomical landmarks of the individual; it then computes the individual’s 3D coordinates. The system was calibrated to assure good accuracy; the calibrated volume for this application was 2 m in length (x axis of the laboratory reference system), 2 m in height (y axis of the laboratory reference system) and 2 m along the z axis of the laboratory reference system. For the purpose of this study, passive markers were positioned at specific points of reference on participants’ bodies to represent the torso and lower limbs during the maintenance of a sitting position on the wheelchair; in addition six markers were positioned on the wheelchair (Table 2, Figure 1; Cimolin et al., 2009).

One wheelchair model was used with different measures (in particular two different measures of the same wheelchair model were used) to fit the anthropometric differences of the studied participants (Figure 2). The wheelchair has an armrest, a backrest, foostrests, and a foam cushion; no other components (head support, lateral thoracic, or pelvic/thigh supports) were used. At the beginning of testing, the geometries of the wheelchair were adjusted to a seat back angle of 100 degrees and a leg rest angle of 120 degrees. Children were asked to sit comfortably on the wheelchair, with free arm position, with feet on the support and their trunk close to the backrest. In particular, to standardize the initial position of the participants, the measurements of the primary joint angles of the lower limbs were fixed and maintained in all settings using a goniometer: 100 degrees at the hip, 110 degrees at the knee, and 130 degrees at the ankle joint.

After the familiarization by participants with the wheelchair, assessments were performed in three settings: (a) Setting 1: without belt; (b) Setting 2: with a 4-point pelvic belt [the belt was made by two neoprene pads fitted on the pelvis of the child, with two bands on each side fixed to the wheelchair frame (Figure 3a)]; and (c) Setting 3: with a 2-point pelvic belt [we used a similar belt, but with just one band in each side to fix it to the wheelchair frame (Figure 3b)].

The pelvic belts were arranged by the same operator with a downward and slightly backward pull to prevent the pelvis from

### Table 2. Anatomic segment and correspondent passive marker positions.

<table>
<thead>
<tr>
<th>Anatomic segment</th>
<th>Marker positions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Trunk</td>
<td>Right and left acromion; superior point of sternum</td>
</tr>
<tr>
<td>Lower limb</td>
<td>Right and left ASIS, right and left femoral condyle, right and left external malleolus, right and left 1st metatarsal head</td>
</tr>
</tbody>
</table>

![Fig. 1. Image of the markers position on the participant and on the wheelchair.](image1)

![Fig. 2. Image of the wheelchair model used in the present study (two different measures are shown) (color figure available online).](image2)

![Fig. 3. Schematic representation of the two pelvic belts used in this study (top view): (a) 4-point pelvic belt; (b) 2-point pelvic belt.](image3)
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To avoid the introduction of errors due to different operator to assure reproducibility of the acquisition technique and performances of the optoelectronic system in pre- and post-sessions of each setting with a break of 1 minute between each condition (Galli et al., 2011; Kuo, Tully, Galea, 2009; Rigoldi, Galli, Mainardi, Crivellini, & Albertini, 2011). After performing the path, before the post-session assessment, the participants maintained their position without repositioning themselves. Before each pre-session acquisition, the operator relocated the children in the initial position and checked with the goniometer the measurements of the primary joint angles (hip, knee, and ankle joints) to assure a similar starting position in all the assessed settings. All data acquisitions were conducted by the same experienced operator to assure reproducibility of the acquisition technique and to avoid the introduction of errors due to different operators.

Data Analysis

Starting from the XYZ coordinates of each marker, a 3D representation of the subject and the wheelchair was done. To quantify the kinematics’ participants during testing, we computed the markers’ trajectory and some lower limb angles, using SMART analyzer software (BTS, IT, 2006). For the purpose of this study, the parameters of interest were:

- Trunk flexion angle: calculated as the mean value of the angle defined by the markers placed on the acromion, the ASIS, and the knee in the sagittal plane, during testing (expressed in degrees);
- Knee joint angle: calculated as the mean value of the angle defined by the markers placed on the ASIS, the knee, and the ankle in the sagittal plane (expressed in degrees);
- Ankle joint angle: calculated as the mean value of the angle defined by the markers placed on the knee, the ankle, and the foot in the sagittal plane, during the testing (expressed in degrees).

Statistical Analysis

All parameters were calculated for each pelvic belt configuration and for each session (before and after performing the path), then the mean value and standard deviation were considered to represent the behavior of the subjects during the different sessions and in different settings. We computed the percent of variation in parameter values between pre-session (PRE) and post-session (POST), according to the following formula:

\[
\text{Percent of Variation} = \frac{\text{Mean value}_{\text{POST}} - \text{Mean value}_{\text{PRE}}}{\text{Mean value}_{\text{PRE}}} \times 100
\]

As data were not normally distributed, the statistical analysis was conducted using non-parametric tests. In PRE, the kinematic data among the three settings were compared with Friedman ANOVA. Then, according to the repositioning need after performing the defined path (Group 1: patients without need repositioning and Group 2: patients with need repositioning), data among the three different settings as for the initial position and % of variation for each group were compared with Friedman ANOVA. In each subgroup of Group 2, the comparison between 2-point and 4-point belts was done with Wilcoxon test.

Finally, the level of impairment according to the GMFM value was compared with Kruskal-Wallis ANOVA among the three subgroups of the Group 2. Statistical significance was set at \( p < 0.05 \).

Results

All participants were able to perform the task without any difficulties and no interruptions occurred during test execution. For kinematic results, no statistical differences were found in the pre-session among the three settings; the initial position of the participants was maintained in all settings, and accordingly, measurements of the primary joint angles of the lower limbs (hip, knee, and ankle) were taken by the operator with a goniometer, as described earlier in the Experimental Setup section.

During the test, six patients (Group 1: 30%) needed no reposition after each post-session, showing a good stability without (Setting 1) and with the pelvic belts (Settings 2 and 3). On the other hand, 14 patients (Group 2: 70%) needed to be repositioned and required a submaring, and so to guarantee safety and comfort. In this study, we could not quantitatively insure that the same amount of belt tension was provided within and between subjects; however, during the preparation the operator interacted with the participants to determine the most comfortable position and the belt tension was adjusted to hold the child and resisted anterior and upward movement of the pelvis.

In each setting the children were evaluated in two sessions (pre- and post-session) performing a standardized path with the wheelchair driven by an operator. The operator was the same for each setting and for all children, and his walking velocity was standardized using a metronome to guarantee performance of the task in the same way within and among participants. The path was 250-m long and contained a rough surface (Figure 4), to make testing the effectiveness of the belt easier. Each test was repeated two times for each belt configuration.

All data acquisitions were performed with the subject in seated position quietly (relaxed and without any specific actions) for 30 seconds in the acquisition volume of the optoelectronic system in pre- and post-sessions of each setting with a break of 1 minute between each condition (Galli et al., 2011; Kuo, Tully, Galea, 2009; Rigoldi, Galli, Mainardi, Crivellini, & Albertini, 2011). After performing the path, before the post-session assessment, the participants maintained their position without repositioning themselves. Before each pre-session acquisition, the operator relocated the children in the initial position and checked with the goniometer the measurements of the primary joint angles (hip, knee, and ankle joints) to assure a similar starting position in all the assessed settings. All data acquisitions were conducted by the same experienced operator to assure reproducibility of the acquisition technique and to avoid the introduction of errors due to different operators.

Fig. 4. Detail of the rough surface contained in the path (color figure available online).
Subgroup A: 8 patients (aged: 5.37 ± 1.18 yrs.; weight: 49.8 ± 10.43 kg) who needed a reposition with the 2-point belt, but not with 4-point belt
Subgroup B: 3 patients (aged: 6.33 ± 1.53 yrs.; weight: 17.7 ± 3.1 kg) who needed a reposition with the 4-point belt and not with 2-point belt
Subgroup C: 3 patients (aged: 9.3 ± 2.5 yrs.; weight: 22.7 ± 4.7 kg) who needed to be repositioned both with 2-point and with 4-point pelvic belt.

The percent of variation of the computed parameters between the pre- and post-sessions of Group 1 and Group 2 and of each subgroup in each setting are reported in Table 3.

Quantitatively, we observed that Group 1 showed no differences among the three settings, while the Group 2 revealed a significant main effect for settings \( p < 0.05 \) in terms of trunk flexion angle and knee joint angle (Figure 5). As for Group 2, Subgroup A showed percent of variation in terms of trunk flexion angle and knee joint angle statistically higher with the 2-point belt than the 4-point belt, indicating increased submaring with the 2-point belt during sitting maintenance if compared to the 4-point belt \( p < 0.05 \). The opposite results were obtained in Subgroup B, while no differences were found between the 4-point and 2-point pelvic belts in Subgroup C. No significant differences were found in terms of ankle index in any groups or subgroups; this may be due to the high variability of its values.

Furthermore, we assessed the presence of differences among the 3 subgroups of patients collected according to the level of impairment by the GMFM (Table 4): patients of Subgroup A (better stability with the 4-point belt less than the 2-point belt) were characterized by lower GMFM values than the other subgroups, which is significant from a statistical point of view \( p < 0.05 \). In addition, Subgroup A patients were younger and had lower body weights in comparison to Subgroup C \( p < 0.05 \); no significant differences were found with the Subgroup B \( p > 0.05 \). In particular, patient-by-patient analysis of data showed that all patients of Subgroup A (better stability with the 4-point belt less than the 2-point belt) were characterized by GMFM values below 60%.

**Discussion**

In the present study, we developed and applied an experimental setup in order to quantitatively compare the 2-point versus 4-point pelvic belts while sitting in a wheelchair in children with spasticity (i.e., CP and TBI). For these patients the major goal is to provide sitting stability through specialized seating devices aimed to stabilize the pelvis and avoid submaring of the patients. The pelvic belt is one of the most common forms of stabilization; however, families and clinicians express misgivings about effectiveness and the best type of pelvic belt, mainly because little evidence is available to guide professionals in the proper use of pelvic positioning belts and for which patient these restraints are indicated. To our knowledge, the majority of analyses are based on interviews and questionnaires, lacking empirical data (Chaves et al., 2007; Crane et al., 2007; Hatta et al., 2007; Ivancic et al., 2002; Lacoste et al., 2009; Reid et al., 1999; Rigby et al., 2001; Ryan et al., 2005).

The applicability and reliability of the proposed experimental setup was successfully tested in a sample of 20 young patients. No interruptions occurred during test execution and all participants concluded the acquisition sessions in all three settings. From data analysis of 3D kinematics, we observed that most of patients (70%) revealed a very low stability when no belt was present (in the third setting), evidencing a rolling down of the thigh without a pelvic belt. In this group (Group 2) the comparison between the two categories of pelvic positioning belts (2-point vs. 4-point) showed that most of the patients (8 out of 14 patients) revealed a better stability with the 4-point belt when compared to the 2-point (Subgroup A), as demonstrated by data about the trunk flexion angle and knee joint angle. A small number of participants revealed higher stability with a 2-point belt than compared to a 4-point (3 children) and no difference (3 children) between the two categories of pelvic belts.

**Table 3.** Percent of variation of the considered parameters for each group and subgroup with reported the number of children. Positive values are indicative of increasing values between post- and pre-sessions, negative values otherwise.

<table>
<thead>
<tr>
<th>% of variation</th>
<th>Group 1 (6 children)</th>
<th>Subgroup A (8 children)</th>
<th>Subgroup B (3 children)</th>
<th>Subgroup C (3 children)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Trunk flexion angle (%)</td>
<td>1.27 (2.28)</td>
<td>4.77 (3.86)*+</td>
<td>8.66 (2.52)*+</td>
<td>6.04 (4.92)*</td>
</tr>
<tr>
<td>Setting 1</td>
<td>2.52 (4.27)</td>
<td>12.40 (4.65)</td>
<td>2.82 (1.94)*</td>
<td>5.93 (4.97)*</td>
</tr>
<tr>
<td>Setting 2</td>
<td>2.09 (2.46)</td>
<td>15.82 (7.92)</td>
<td>17.73 (6.81)</td>
<td>10.73 (2.67)</td>
</tr>
<tr>
<td>Setting 3</td>
<td>1.56 (3.11)</td>
<td>6.77 (5.61)*+</td>
<td>9.99 (6.87)*+</td>
<td>10.72 (3.12)*</td>
</tr>
<tr>
<td>Knee joint angle (%)</td>
<td>0.72 (2.67)</td>
<td>14.59 (8.09)</td>
<td>4.84 (3.82)*</td>
<td>7.49 (4.14)*</td>
</tr>
<tr>
<td>Setting 1</td>
<td>0.21 (1.61)</td>
<td>13.82 (6.34)</td>
<td>13.60 (7.27)</td>
<td>14.89 (4.15)</td>
</tr>
<tr>
<td>Setting 3</td>
<td>14.36 (10.63)</td>
<td>14.29 (6.09)</td>
<td>19.09 (10.33)</td>
<td>10.63 (9.22)</td>
</tr>
<tr>
<td>Setting 2</td>
<td>12.54 (10.61)</td>
<td>17.28 (10.38)</td>
<td>13.38 (9.66)</td>
<td>11.45 (8.98)</td>
</tr>
<tr>
<td>Setting 3</td>
<td>21.26 (15.28)</td>
<td>22.26 (8.96)</td>
<td>20.97 (11.43)</td>
<td>15.07 (7.45)</td>
</tr>
</tbody>
</table>

* \( p < 0.05 \), if setting 1 or setting 2 is different from setting 3; \( +p < 0.05 \), if setting 1 is different from setting 2.

The unit of measure is % (percent of variation of angles).
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Fig. 5. Graph representing the percent of variation of the trunk flexion and knee joint angle parameters for each subgroup of Group 2. *p < 0.05, if setting 1 or setting 2 is different from setting 3; +p < 0.05, if setting 1 is different from setting 2.

<table>
<thead>
<tr>
<th>Group 2 (14 children)</th>
<th>Group 1 (6 children)</th>
<th>Subgroup A (8 children)</th>
<th>Subgroup B (3 children)</th>
<th>Subgroup C (3 children)</th>
</tr>
</thead>
<tbody>
<tr>
<td>GMFM, % (0−100)</td>
<td>70.8 (7.7)</td>
<td>49.9 (10.4)*</td>
<td>70.1 (5.1)</td>
<td>72.0 (13.9)</td>
</tr>
</tbody>
</table>

*p < 0.05, if Subgroup A is different from Subgroup B and Subgroup A is different from Subgroup C.

In summary, this study has shown that the 4-point pelvic positioning belt seems to be an effective device for improving the functional performance of children with spasticity that are seated in a wheelchair, and in particular in those patients with lower GMFM values. The sample of patients considered in this study was not large; for this reason, a cut-point of 60% was identified in terms of GMFM assessment at which use a 4-point pelvic belt is recommended. All patients with a GMFM assessment below 60% this value presented in fact better stability with the 4-point belt. The configuration of the 4-point pelvic belt likely allows a greater area surrounding the thigh, which prevents the thigh from submerging, as our data showed. More investigations are needed with a larger number of patients to confirm this observation, but it could be considered a preliminary indication.

Moreover, the obtained results demonstrated that instrumental data and data processing procedures used in the present study can provide a useful tool for better understanding of how the concept of pelvic positioning belts in wheelchair use may
affect and influence the position and the stability of individuals with spasticity, integrating qualitative information obtained by questionnaires and therapists experience. These results could be interesting from two different perspectives: first, for improving the functional performance of children with spasticity that are seated in a wheelchair during motor function and activities of daily living; second, for ensuring a proper postural belt fit when a child is being transported in a motor vehicle while seated in their wheelchair (Lacoste et al., 2009; van Roosmalen et al., 2005).

The main limitation of this study is the small number of participants that due to the complexities of sitting problems in patients with spasticity resulted in a limited strength of the clinical and statistical findings. Moreover, this study was conducted with attention focused on the sagittal plane, considering only submargining of the participants. As not only pelvic tilt (rotation in the sagittal plane) but also pelvic obliquity (rotation in the frontal plane) and pelvic rotation in the transverse plane are the three movements that clinicians try to control to allow an upright, stable, and functional position on the wheelchair, further investigations should be conducted in frontal and transverse planes. However, this study proposes an instrumented method to assess and compare quantitatively two different kinds of pelvic positioning belts commonly used to improve stability and safety of individuals with severe instability in sitting position on the wheelchair and it represents the first attempt of applying this method to children with disabilities. Further studies should be conducted on larger groups of patients with wider levels of motor disorders, both pediatric and adult, to confirm the obtained results of this study. At present, no comparison with literature was possible as, to our knowledge, no quantitative analyses on this domain are present. Finally, further research may be conducted comparing other categories of belts, with different angle inclinations, in order to identify the most effective for specific motor disorders.

References


