ORIGINAL ARTICLE

Effect of Different Sitting Postures on Lung Capacity, Expiratory Flow, and Lumbar Lordosis

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ABSTRACT. Lin F, Parthasarathy S, Taylor SJ, Pucci D, Hendrix RW, Makhsous M. Effect of different sitting postures on lung capacity, expiratory flow, and lumbar lordosis. Arch Phys Med Rehabil 2006;87:504-9.

Objective: To investigate the effect of sitting posture on lung capacity and expiratory flow (LC-EF) and lumbar lordosis.

Design: Repeated measures on 1 group of subjects in 4 postures.

Setting: Laboratory.

Participants: Seventy able-bodied volunteers.

Interventions: Postures were assumed randomly: normal, with full ischial support and flat lumbar support; slumped, with the pelvis positioned in the middle of seat while leaning against the backrest; against the back part of the seat without ischial support (WO-BPS), with partially removed ischial support and an enhanced lumbar support; and standing.

Main Outcome Measures: For LC-EF, forced vital capacity, maximum forced expiratory flow, forced expiratory volume in 1 second, and peak expiratory flow; and lumbar lordosis.

Results: All LC-EF measures in standing were significantly superior to those in slumped and normal sitting, and 4 measures were significantly higher than in WO-BPS. In slumped sitting, LC-EF significantly decreased from that in normal sitting. WO-BPS sitting significantly increased 4 of the LC-EF measures from those in the normal sitting. Lumbar lordosis was the highest in standing and progressively decreased in WO-BPS, normal, and slumped sitting.

Conclusions: Slumped sitting significantly decreased LC-EF and lumbar lordosis. Because it increases the lumbar lordosis and promotes LC-EF, the WO-BPS posture may be a better seating option for people sitting for a prolonged time.

Key Words: Lordosis; Lung volume measurements; Posture; Rehabilitation.

PEOPLE WITH SPINAL CORD INJURY (SCI) frequently experience a range of complications. Respiratory dysfunction,[1] pain,[2,3] muscle fatigue,[4] and pressure ulcers[5-12] are among the most common complaints. A major cause of morbidity and mortality in these people is long-term respiratory complication in the form of pneumonia or atelectasis,[5] with pneumonia being the leading cause of their deaths.[13] Many factors can contribute to poor lung function, including smoking habits, surgical history, hazardous occupational or environmental exposure, asthma, allergies, chronic obstructive pulmonary disease, and obesity. Additionally, the connection between posture and lung performance has proved significant.[1,6,14-16] Studies[1,15,16] with able-bodied subjects that compared sitting and standing postures support the hypothesis that pulmonary function is optimal while standing. In SCI populations, Chen[1] and Baydur[14] and colleagues found that the supine posture produced the best spirometric recordings. Because subjects with SCI are in a sitting posture for prolonged periods of time, it is important to know how different sitting postures affect pulmonary function. To date, this information has not been reported.

A new seating system that features adjustable ischial and lumbar support[17] has been developed to suggest a new sitting posture to mimic the spine's natural curvature in the stance, and provide better postural support for seated subjects.[18] This posture has been designated as the back part of the seat without ischial support (WO-BPS),[18] that is, the back part of the seat is tilted downward 20° and the enhanced lumbar support is used (fig 1). Because the WO-BPS's design imitates standing spinal alignment, it was expected that use of this model by able-bodied subjects would result in improved sitting posture and respiratory capacity.

We tested 2 hypotheses in this study: (1) body posture affects the lung capacity and expiratory flow (LC-EF); specifically, taking the LC-EF in the standing posture as a reference value, the kyphotic, or slumped, sitting posture may compromise LC-EF more than a normal sitting posture, and a sitting posture that approximates a standing condition may improve the LC-EF over that when in the normal sitting posture; and (2) the change in LC-EF induced by body posture can be correlated to spinal curvatures, that is, lumbar lordosis. To test these hypotheses and capture the variance in pulmonary indices across the different postures that most people assume, we examined the relation between the LC-EF and body posture, between lumbar lordosis and body posture, and between LC-EF and lumbar lordosis. The selected body postures included a standing posture and 3 different seated postures—slumped, normal, and WO-BPS sitting.

METHODS

Participants

Seventy able-bodied people participated after giving their informed consent. Among them, 40 subjects (22 men, 18 women; mean age, 33.9±13.3y; mean weight, 73.3±20.3kg, mean height, 172.5±11.2cm) participated in the breathing test; 40 subjects (19 men, 21 women; mean age, 44.7±16.8y; mean

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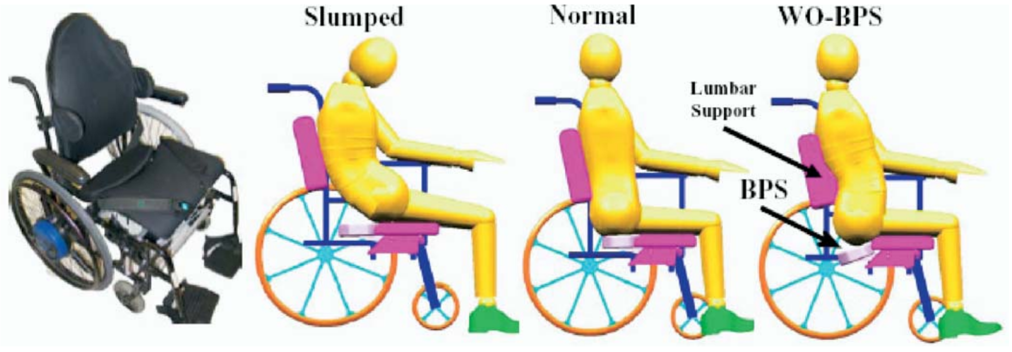

Fig 1. BPS of the wheelchair can be tilted downward 20°, and lumbar support added. Three sitting postures (ie, slumped, normal, WO-BPS) are shown here.

weight, 68.5±13.9kg; mean height, 168.0±11.2cm) took the radiologic measurement of lumbar lordosis in 3 body postures, that is, normal sitting, WO-BPS sitting, and standing. Ten subjects participated in both tests and 8 of the 10 (3 men, 5 women; mean age, 40.0±10.7y; mean weight, 72.4±17.2kg; mean height, 170.4±10.5cm) took an additional radiologic measurement of lumbar lordosis in the fourth (slumped sitting) body posture. All subjects had full range of motion (ROM) of the spine with no pain induced when assuming the testing postures. Exclusion criteria included the severe, fixed deformities of the pelvis and spine, which prevented conformity of the spinal column to the back of the chair. The study was approved by the institutional review board of Northwestern University.

Postures

The 3 sitting postures included WO-BPS, normal, and slumped sitting (see fig 1). In all seated postures, knees were flexed at 90° with feet fully supported. The WO-BPS posture included sitting with the buttocks all the way back into the seat while the BPS was tilted downward 20° with respect to the front part of the seat (see fig 1). There was a total back rest with a protruded lumbar support at the L4 area of the back. The normal sitting posture was defined as the BPS being level with the front part of the seat, with the lumbar support remaining flat. The slumped sitting posture was defined as the subject sitting in the chair, which was configured the same as in the normal posture, with the pelvis positioned in the middle of the seat, allowing it to significantly tilt posteriorly, with the trunk and spine assuming a long kyphotic posture against the backrest. The subject was instructed to keep his/her head statically flexed while performing the breathing test. This position was meant to mimic sitting without external posterior lumbar and pelvic support. The standing posture was defined as the subject standing upright, allowing for physiologic lumbar lordosis.

LC-EF Measurement

The LC-EF measures evaluated were the forced vital capacity (FVC), maximum forced expiratory flow at 25%, 50%, and 75% of the FVC, respectively ($FEF_{25\%}$, $FEF_{50\%}$, $FEF_{75\%}$), average forced expiratory flow between the 25% and 75% FVC levels ($FEF_{25\%-75\%}$), forced expiratory volume in 1 second (FEV_1), and peak expiratory flow (PEF). An SBG spirometer[a] was used to measure each subject's LC-EF and the spirometric indices were calculated with the manufacturer-supplied software WinSpiro, version 2.35.[a] A demonstration of the LC-EF definitions can been seen in the typical flow volume loop plot in figure 2.

Wheelchair

A custom-instrumented wheelchair, designed to permit the BPS to be tilted downward, and with an enhanced lumbar support, was used to configure the sitting postures (see fig 1). The tilting angle of the BPS was controlled by a motor and had a ROM of 20° downward with respect to the front part of the seat. The depth, height, and width of the seat could also be adjusted to accommodate people of different sizes. The tilting angle of the BPS and the seat depth were measured with potentiometers. The height of the lumbar support was adjustable and its shape could be changed by pumping air into or from the bladder embedded in the backrest. Pressure sensors on the lumbar support were used to gauge its strength. The threshold was set between 50 and 60mmHg. The seat and backrest of the wheelchair were parallel to horizontal and vertical lines, respectively. A programmable logic controller[b] was used to control the pump and motor to change the posture from the normal to WO-BPS sitting posture, or vice versa.

Protocol

Each subject transferred into the wheelchair. The seat depth and height were adjusted in the normal sitting posture to make the seat pan short enough for knee clearance, to give the knee a waterfall front edge, and with the ischia located as close as possible to the center of BPS. The thighs were approximately parallel to the floor, with the feet resting firmly on a footrest. Subjects were told how to properly complete 1 trial, which consisted of: (1) deepest inhalation possible (without the spi-

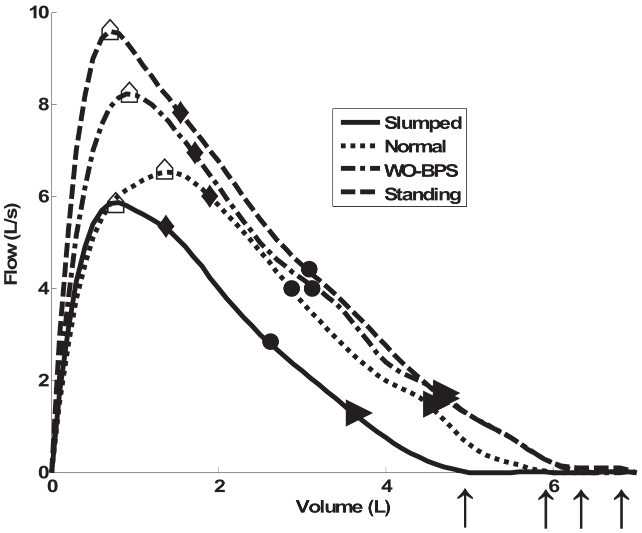

Fig 2. A typical flow volume loop from a subject for the slumped, normal, WO-BPS sitting, and standing postures. Legend: ⌂, PEF; ◆, $FEF_{25\%}$; ●, $FEF_{50\%}$; ▶, $FEF_{75\%}$; ↑, FVC.

rometer), (2) clamping of the nostrils, and (3) exhalation with maximal effort into the transducer tube of the spirometer. Exhalation continued until no more air flow was produced (at least 6 seconds in duration, or until the spirometer gave the auditory signal that the data collection was sufficient). Subjects were given time to practice the breathing protocol until they felt comfortable in the wheelchair and could reproduce, to the fullest extent possible, consistent trends on the flow-volume loop.

Three trials were then recorded for each of the 4 postures. The posture testing sequence was randomized according to a randomization schedule generated beforehand. A brief rest of 30 seconds between trials minimized the fatigue effect on the respiratory muscles.

At a separate visit, lateral radiographic images (including the lumbar spine, pelvis, and thigh on a single image) were taken in the standing, normal, and WO-BPS postures for 40 subjects and in the standing, normal, slumped, and WO-BPS postures for 8 subjects to measure the sacral inclination (for the 40 subjects in the 3 postures), and the total and segmental lumbar spinal lordosis. The radiographic images of the lower spine, thigh and pelvis were used to locate several bony landmarks and calculate the total and segmental lumbar lordosis using the Cobb method.[19] As shown in figure 2, sacral inclination (α) was defined as the angle between the superior endplate of the S1 vertebra and the horizontal plane of the film, which was parallel to the floor. The total lumbar lordosis (S1-L1) was measured as the angle of intersection between a line extending from the superior endplate of the L1 vertebra and a line extending from the superior endplate of S1. Segmental lordotic measurements were made similarly from L2 to L1, L3 to L2, L4 to L3, and L5 to L4.

Data Analysis

After all subjects completed the breathing measurements, we selected their highest values among the 3 trials in each posture. The mean and standard deviation (SD) of the FVC, $FEF_{25\%}$, $FEF_{50\%}$, $FEF_{75\%}$, $FEF_{25\%-75\%}$, FEV_1, and PEF were then calculated across the subjects. To test the effect of posture on a subject's LC-EF, we used analysis of variance (ANOVA) with repeated measures with unstructured covariance, with the repeated variable being the posture (3 sitting postures, 1 standing posture). This analysis was first completed with the posture effect repeated over the 4 different postures to test the overall effect that posture had on the LC-EF. When significance was found, paired *t* tests were done to test posture effect on each of the LC-EF parameters between each possible pair of posture combinations (eg, normal sitting vs standing, slumped sitting vs WO-BPS sitting). Similar statistical analysis was performed on lumbar lordosis data to identify possible posture effect. Finally, in the group of 8 participants who took part in both the breathing test and the radiologic measurement in 4 body postures, we calculated the correlation coefficient between the changes of FVC and FEV_1 and the changes of lumbar lordosis data induced by the body posture. This was done to test the hypothesis that the LC-EF changes induced by body posture correlate with the change in lumbar spinal curvature. Statistical analysis was performed with SAS software.[c] The significance level was set at *P* equal to .05.

RESULTS

Lung Capacity and Expiratory Flow

Figure 3 shows a typical result for flow volume loop from 1 subject. It clearly shows that the subject's posture influenced the airflow during the subject's breathing test. This particular subject had the best LC-EF when in the standing posture, then in the WO-BPS sitting posture, followed by the normal sitting posture. The most compromised LC-EF resulted from the slumped sitting posture.

Table 1 summarizes averaged LC-EF results for all 40 subjects. Results from repeated-measures ANOVA showed that there was significant posture effect with *P* less than .001 on all the spirometric parameters.

All LC-EF data collected while subjects sat in the slumped posture revealed decreases relative to those in normal posture (FEV_1, $P=.002$; PEF, $P=.006$; all other measures, $P<.001$). The decrease of the LC-EF was in the range of 3.9% to 9.7%, with the $FEF_{75\%}$ having the largest. All spirometric parameters were also significantly smaller in the slumped posture than in the WO-BPS sitting ($P<.001$) and standing postures ($P<.001$).

Compared with the parameters in normal posture, LC-EF data collected while subjects sat in the WO-BPS posture show a concurrent increase for all the parameters. Four of the increases, FVC ($P=.037$), $FEF_{25\%}$ ($P=.025$), $FEF_{25\%-75\%}$ ($P=.005$), and $FEF_{50\%}$ ($P=.002$), were statistically significant. The increase of FEV_1, PEF, and $FEF_{75\%}$ were not statistically significant.

FVC ($P=.042$), FEV_1 ($P=.030$), and PEF ($P=.010$) were significantly higher in the standing posture than in the WO-BPS posture. The rest of the spirometric indices showed a slight and

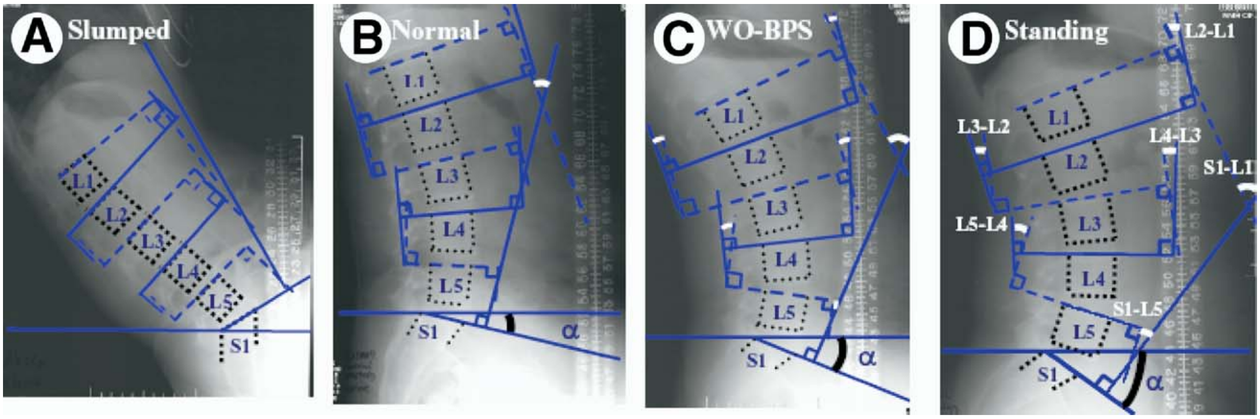

Fig 3. Lateral radiographic images. Representative lumbar lordosis from 1 subject in the (A) slumped, (B) normal, (C) WO-BPS sitting, and (D) standing postures.

Table 1: Average Airflow Measurements for 40 Subjects

Posture	FVC (L)	FEV_1 (L)	PEF (L/s)	$FEF_{25\%}$ (L/s)	$FEF_{25\%–75\%}$ (L/s)	$FEF_{50\%}$ (L/s)	$FEF_{75\%}$ (L/s)
Slumped	3.96±1.03	3.18±0.94	6.24±2.74	5.37±2.39	3.15±1.14	3.52±1.28	1.49±0.58
P^*	<.001	.002	.006	<.001	<.001	<.001	<.001
$t_{39}{}^*$	−3.862	−3.327	−2.902	−3.909	−3.645	−3.898	−3.764
$P^†$	<.001	<.001	<.001	<.001	<.001	<.001	<.001
$t_{39}{}^†$	−5.917	−4.258	−4.016	−5.613	−4.900	−4.942	−3.715
$P^‡$	<.001	<.001	<.001	<.001	<.001	<.001	<.001
$t_{39}{}^‡$	−6.519	−4.050	−4.526	−3.927	−4.061	−4.465	−4.041
Normal	4.13±1.01	3.31±0.90	6.55±2.77	5.79±2.26	3.38±1.11	3.77±1.24	1.65±0.57
$P^†$	.037	.121	.056	.025	.005	.002	.526
$t_{39}{}^†$	−2.159	−1.584	−1.974	−2.332	−2.958	−3.352	−0.640
$P^‡$	<.001	.001	<.001	.018	.035	.036	.084
$t_{39}{}^‡$	−4.344	−3.456	−3.877	−2.470	−2.183	−2.178	−1.776
WO-BPS	4.19±1.00	3.35±0.90	6.66±2.69	5.91±2.25	3.47±1.06	3.88±1.21	1.67±0.57
$P^‡$	.042	.030	.010	.257	.627	.544	.121
$t_{39}{}^‡$	−2.108	−2.260	−2.700	−1.151	−0.489	−0.612	−1.586
Standing	4.26±1.02	3.42±0.85	6.99±2.70	6.04±2.21	3.50±1.09	3.92±1.19	1.73±0.60
$P^§$	<.001	<.001	<.001	<.001	<.001	<.001	<.001
$F_{39}{}^§$	20.04	6.90	8.59	12.35	8.59	9.36	6.00

NOTE. Values are mean ± SD (N=40). LC-EF for the slumped, normal, WO-BPS sitting, and standing postures are given. Significance (*P*) and *t* or F value for comparison of each LC-EF parameter between postures is listed.

**P* (*t*) is the significance difference as compared with normal posture.

†*P* (*t*) is the significance difference as compared with WO-BPS posture.

‡*P* (*t*) is the significance difference as compared with standing posture.

§*P* (F) is the significance of repeated-measures ANOVA for posture effect.

insignificant increase from that in WO-BPS sitting posture ($P>.050$).

Total and Segmental Lumbar Lordosis

Typical lateral radiographic images from 1 subject, together with the measurement method of lumbar lordosis, are shown in figure 2. The subject maintained the largest lumbar lordosis and sacral forward inclination in the standing posture. With the subject seated, both total and segmental lumbar lordosis decreased, as did sacral inclination; this decrease was progressive from WO-BPS to normal. The slumped sitting posture demonstrated a close to flat lumbar spinal curvature and induced a backward rotation of the pelvis.

The average results of lumbar lordosis are shown in table 2 for 40 subjects who were measured in 3 body postures (normal sitting, WO-BPS sitting, standing). Overall posture effect was significant ($P<.05$) for all lumbar lordosis measures. A comparison of all lumbar lordosis measures between each possible pair of body postures (ie, normal sitting vs WO-BPS sitting, normal sitting vs standing, WO-BPS sitting vs standing) was statistically significant ($P<.005$), except for L3-L2 and L2-L1 between WO-BPS sitting versus standing. Among the 3 body postures, normal posture carried the smallest value of sacral inclination, angle of lumbar spine curvature, and segmental lumbar lordosis. The largest difference in lumbar lordosis was in the total lordosis in normal sitting, a 47.3% decrease from the value in standing posture ($P<.001$). In the 8 subjects who were tested in an additional sitting posture (ie, slumped posture), we found a similar change trend in lumbar spine curvature induced by changing body posture. The slumped posture assumed the flattest

Table 2: Total and Segmental Lumbar Lordosis in 2 Sitting Postures and 1 Standing Posture

Posture	Sacral Inclination (deg)	S1-L1 (deg)	S1-L5 (deg)	L5-L4 (deg)	L4-L3 (deg)	L3-L2 (deg)	L2-L1 (deg)
Normal	16.0±8.4	30.2±13.6	13.4±63	8.9±8.1	5.0±5.2	2.8±4.5	0.1±4.0
P^*	<.001	<.001	.002	<.001	<.001	<.001	.001
$t_{39}{}^*$	−7.197	−9.403	−3.292	−3.919	−6.590	−5.548	−3.465
$P^†$	<.001	<.001	<.001	<.001	<.001	<.001	.001
$t_{39}{}^†$	−14.133	−10.547	−7.494	−5.793	−10.481	−8.003	−3.431
WO-BPS	22.8±8.9	43.3±11.8	15.3±6.1	11.4±8.5	7.8±4.7	6.5±4.3	2.2±4.1
$P^†$	<.001	<.001	<.001	.001	<.001	.104	.845
$t_{39}{}^†$	−10.397	−6.673	−5.811	−3.233	−6.059	−1.665	−0.197
Standing	38.8±9.2	57.3±11.3	20.4±6.8	15.6±7.0	11.4±4.2	7.5±4.7	2.4±5.1
$P^‡$	<.001	<.001	<.001	<.001	<.001	<.001	.002
$F_{39}{}^‡$	101.82	63.92	28.11	24.01	59.59	32.51	7.45

NOTE. Values are mean ± SD (N=40). The total (S1-L1) and segmental lumbar lordosis were measured using the Cobb method. Significance (*P*) and *t* or F value for comparison of each lumbar lordosis parameter between postures are listed.

**P* (*t*) is the significance difference as compared with the WO-BPS posture.

†*P* (*t*) is the significance difference as compared with the standing posture.

‡*P* (*t*) is the significance of repeated-measures ANOVA.

lumbar curvature, with the lumbar lordosis as 14.5°±8.0°, 11.6°±7.6°, 3.8°±6.6°, 2.9°±5.1°, –1.3°±3.3°, and –2.4°±5.7° for S1-L1, S1-L5, L5-L4, L4-L3, L3-L2, and L2-L1, respectively. The total lumbar lordosis increased progressively through normal sitting, WO-BPS sitting, and standing postures. Specifically, slumped posture lead to a significant further decrease (44.2%, $P=.013$) in the total lumbar lordosis from the measure in normal posture. This is a 75.5% ($P<.001$) decrease of the value in standing posture. At the same time, 3 of the segmental lumbar lordosis showed a significant flattening effect while subjects were sitting in normal posture, compared with those standing. Slumped sitting, however, did not show any significant further flattening of the spinal curvature at each segmental level, compared with normal sitting ($P>.05$).

Correlation Between LC-EF and Total and Segmental Lumbar Lordosis

We calculated correlation coefficients between the changes in FVC and FEV_1 and the changes in lumbar lordosis induced by different body postures. Among the 12 pairs of correlations, the change of FVC correlated significantly with the change of the total lumbar lordosis (S1-L1: $R=.75$, $P=.004$). Besides, both FVC ($R=.69$, $P=.021$) and the FEV_1 ($R=.64$, $P=.046$) correlated significantly with the segmental lumbar lordosis of S1-L5.

DISCUSSION

We investigated quantitatively the biomechanic effects on the LC-EF of different sitting postures and the standing posture on the LC-EF. Results show that posture significantly influenced all spirometric parameters in tested subjects.

The flow-volume loop (see fig 2) is widely used in clinical practice to assess lung function for the condition of airways and the strength of the respiratory muscles. The PEF reflects and measures the rate of flow from the large airways; it is also affected by the strength of the thoracic and abdominal muscles and the degree of muscular effort generated by the subject.[20] The FVC is the total volume of air exhaled with maximal effort. $FEF_{25\%}$, $FEF_{25\%-75\%}$, $FEF_{50\%}$, and $FEF_{75\%}$ are the flow rates at the corresponding percentage point of the FVC exhaled, and indicate the status of small to medium airways.

As mentioned, Lalloo et al[16] concluded that all spirometric indices, with the exception of PEF, increased in the standing posture compared with the sitting posture. Chen et al[1] found that the vital capacity of an able-bodied subject was enhanced in the standing posture, which Druz and Sharp[21] attributed to an increase in the activation of the ribcage inspiratory muscles and the diaphragm in the upright posture. Taking into consideration the stiffened abdomen, the activated muscles act to move the ribcage more effectively and promote ribcage expansion. Also, in supine postures, the diaphragm aids in providing greater compliance with the abdomen over the ribcage.[22] Our study corroborates these results because it demonstrates that subjects showed overall better lung function in the standing posture than in the slumped, normal, and WO-BPS sitting postures. More specifically, standing posture enabled the subjects to perform significantly better on every spirometric index than in the slumped and normal sitting postures except for the $FEF_{75\%}$ in normal sitting. This indicates that subjects could achieve larger lung volume during inspiration, perform more efficient expiratory muscle contraction, and experience less air flow obstruction within airways of all sizes when in a standing posture. When compared with WO-BPS sitting posture, standing posture is only significantly superior on FVC, FEV_1, and PEF. This implies that, in the WO-BPS sitting posture, it is possible to achieve the condition of airflow in airways that is similar to those provided in the standing posture.

Our results agree with those of previous studies that found that the LC-EF in the standing posture is better than in the seated postures. We were unable to find, however, any studies that sought to determine the influence of different seated postures on LC-EF.

Our subjects had the lowest average spirometric indices while in slumped sitting; the differences in these indices between the slumped posture and other sitting postures showed statistical significance. The slumped posture may compress organs and impede diaphragm movement more than the other seated postures. Another possible reason that slumped posture gives the lowest LC-EF readings may be the position of the head in this posture. Hellsing[23] has shown that the size of the free airway is affected by the head flexion and extension.[2] On the other hand, significant increases in FVC and FEF markers indicate lung volume and air flow improvements in the WO-BPS sitting posture over those in normal posture.

The results of lumbar lordosis in this study are, in general, consistent with other published studies.[24-28] In parallel with subjects' improved respiratory performance in the WO-BPS sitting posture over performances in the normal and slumped postures, total and segmental lumbar lordosis of the WO-BPS sitting posture were significantly larger in comparison with those of the normal and slumped sitting postures, with the lowest lumbar lordosis recorded in the slumped posture. Although there is no evidence in the literature that changes in lumbar lordosis and kyphosis have significant influence on lung function, we think that these significant differences in lumbar lordosis in different postures may account for the changes in pulmonary capacity between the postures we tested. The adjustments to spinal alignment may change the volume of air available to the lung and/or influence the efficacy of contraction of the diaphragm and other respiratory muscles. The correlation test performed on results from the 8 subjects who participated in both spirometric and radiologic protocols showed a statistically significant correlation between lumbar lordosis and those spirometric indices that relate to lung volume and expiratory muscle function (FVC, FEV_1). As shown in lateral radiographs of the normal spine, there are 4 naturally formed curvatures, the cervical, thoracic, lumbar, and sacral. A shape change in any one of these curvatures will cause compensatory changes in the others to help maintain balance and conserve muscular energy.[29] Therefore, an increase in spinal lordosis in the lumbar region is likely to induce a decrease in thoracic kyphosis, thus giving the ribcage greater room to expand during inspiration. This may explain the correlation that exists between the increased FVC and FEV_1, and the increased total and segmental lumbar lordosis found in our study. Considering that this correlation test was done on data from only 8 subjects, however, a larger sample size may be necessary to reliably detect any correlation between respiratory performance and the lumber spine curvature.

Although there was an obvious trend of a decrease in lumbar lordosis as the body posture changed from the standing to WO-BPS, normal, and slumped in the group that was measured in 4 body postures, changes of some of the lordosis markers did not show statistical significance, for example, all segmental lumbar lordosis between slumped and normal ($P>.05$), and L5-L4 between the normal and WO-BPS postures ($P=.788$). In the group that was tested in 3 body postures (normal sitting, WO-BPS sitting, standing), all lumbar lordosis parameters showed significant changes in conjunction with body postures ($P<.005$; see table 2), except L3-L2 and L2-L1, when compared with WO-BPS sitting and standing postures. This is probably because of the relatively smaller sample size in the 4-posture group. For example, based on the current data, it was estimated that the sample size should be 42 to be able to detect significant difference for S1-L5 between the slumped and normal postures with 90% power.

Given that the slumped posture was detrimental to both spinal alignment and respiratory function in our able-bodied subjects, we are conducting similar studies of SCI subjects with different level of injuries to determine whether a similar phenomenon exists in that population. Because respiratory dysfunction is a major cause of mortality and morbidity among SCI subjects, further research into this problem is necessary.

It must be noted that our study tested the posture effect on the LC-EF and lumbar lordosis in consecutive posture changes over a short time in able-bodied subjects. It is necessary to investigate the posture effect, especially for the author-defined WO-BPS sitting posture, over a longer period of time by full-time wheelchair users with SCI. The other limitation of this study is the relatively small sample size, especially the group of 8 subjects who took both breathing test and lumbar lordosis measure. As noted, statistical significance may have been achieved if the sample size had been larger. Also, we must point out that this study did not test the effect of simply changing the lumbar support without removing the ischial support, which is among its major limitations.

CONCLUSIONS

The slumped posture has significantly lower values of LC-EF and a significantly decreased amount of the lumbar lordosis than the normal and WO-BPS sitting postures and standing posture in able-bodied subjects. Because it increases the lumbar lordosis and promotes lung function, the WO-BPS sitting posture may be a better seating option for people who sit for extended periods of time. Further study with an SCI population is needed to determine the influence of various sitting postures on the LC-EF and lumbar lordosis.

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