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Sitting with Adjustable Ischial and Back Supports: Biomechanical Changes

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Study Design. The seat and back contact force, pressure distribution, lumbar lordosis, and low back muscle activities associated with a new seat design with adjustable ischial support and backrest were investigated using kinematic, kinetic, electromyographic, and radiographic measurements.

Objectives. To investigate the biomechanical effects of adjusting ischial and backrest supports during sitting.

Summary of the Background Data. Sitting may induce posterior rotation of the pelvis, reduction of lumbar lordosis, and increases in muscle tension, disc pressure, and pressure on the ischium and coccyx, which may be associated with low back pain. A device that reduces the ischial load and maintains lumbar lordosis may help increase seating comfort and reduce low back pain.

Methods. Fifteen office workers with no known low back pain history were tested. Contact pressure distributions, reaction forces between the buttock-thighs and seat and between the back and backrest, load carried by the seat pan and backrest, sacral inclination, lumbar lordosis, intervertebral space of lumbar spine, and muscular activity in stabilizing the trunk were measured for sitting with and without ischial support and with adjustable back support.

Results. When the ischial support was relieved, the center of the force on the seat and on the legs of the chair, and the peak center of pressure on the seat, were significantly ($P < 0.002$) shifted forward toward the thighs. The total contact area on the seat pan and on the backrest was significantly decreased and increased, respectively ($P < 0.001$). The sacral inclination, total and segmental lumbar lordosis, and lumbar spine disc height were significantly increased for sitting upright with backrest, with the lumbar curve close to that during standing.

Conclusions. Sitting with reduced ischial support and fitted backrest to the lower spine altered the contact area, reduced peak pressure under the ischia, reduced muscular activity, maintained total and segmental lumbar lordosis, rotated the sacrum forward, and increased lumbar intervertebral disc heights, which could potentially reduce low back pain. [Key words: lumbar spine, lordosis, sacrum, disc, sitting pressure, low back pain, EMG] **Spine 2003;28:1113–1122**

Low back pain (LBP) is acute or chronic pain involving the lumbosacral, buttock, and/or thigh.[1] Discogenic LBP is aggravated by the sitting position, which is necessary in many occupations and daily activities. About 100 million workdays are lost annually in the United States due to LBP.[2] Despite improved knowledge and health care resources for spinal pathology, chronic disability resulting from nonspecific LBP is rising exponentially.[3] Although the causes of discogenic LBP are multifactorial and complex, sitting postures could increase stresses within the disc and contribute to disc degeneration and pain.[4,5] Two major occupational risk factors are static muscle load[1,6] and flexed curvature of the lumbar spine; both are involved in seated work tasks.[1,7,8]

During sitting, the head, arm and trunk weight is carried mainly by the ischial tuberosities and surrounding tissues.[9] High pressure at the tuberosities is closely associated with high load to the spine.[10] Marras *et al*[11] reported that a significant mechanical spine loading is associated with LBP resulting from trunk muscle coactivation. Ischial and lower back interface pressure vary with different sitting postures[12,13,14] and body positioning.[12,13,15,16,17] Koo *et al*[18] reported that repositioning of the lumbar support to redistribute the interface pressure and load is essential in preventing LBP associated with inappropriate sitting in a working environment. Therefore, a device that decreases the sitting pressure and load carried by the ischial tuberosity may decrease forces within the disc and associated degeneration and pain.

Physiologic lumbar lordosis in the standing position ranges from 40° to 60°,[19,20,21,22,23,24,25,26,27] with the lordosis occurring mainly at S1–L5 and L4–L5, and with the sacral inclination ranging from 30° to 40°.[19,23,28] Compared to standing or lying supine, sitting could cause the pelvis to rotate posteriorly, resulting in decreased sacral inclination and lumbar lordosis[19,26,29] and increased forces at the discs.[26,30,31] A number of investigators have reported interaction between LBP and biomechanical changes such as decreased lumbar lordosis,[4,32] malalignment of lumbar curvature,[5,23,24,33] and narrowing of disc spaces.[34] Williams *et al*[5] reported that use of a lumbar roll that increased lumbar lordosis re-

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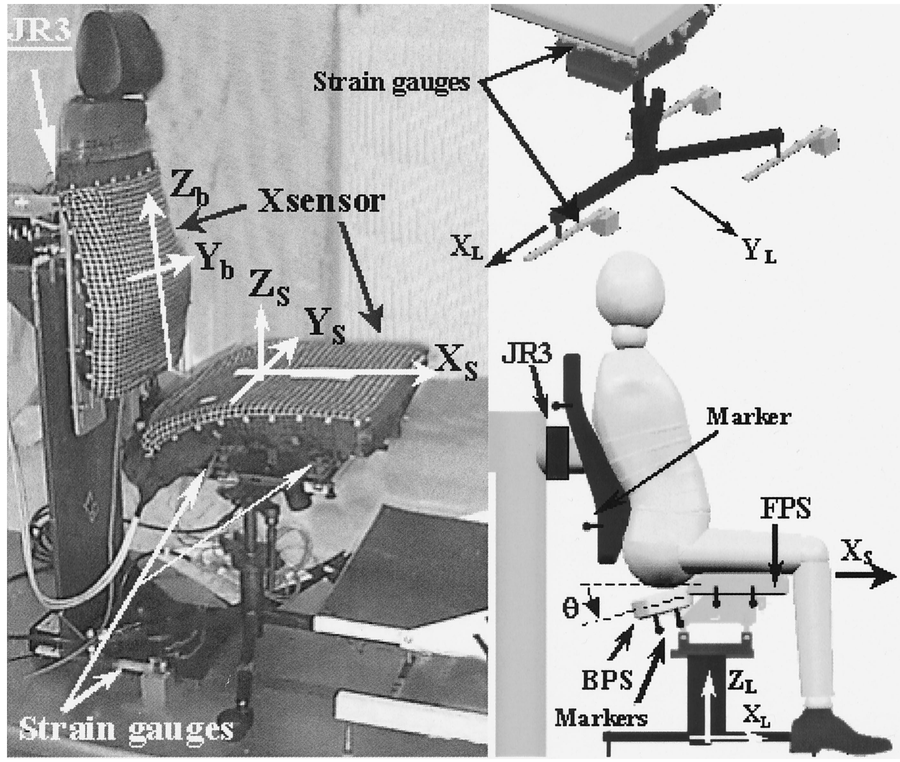

Figure 1. The seat of the chair consists of two parts, *i.e.*, the front part of the seat (FPS), which is fixed, and the back part of the seat (BPS), which can be tilted downward or upward by $\theta = \pm 18°$. The shape of the low back support can be adjusted for the individual subject using an inflatable air-filled cushion built into the lower backrest. The chair is equipped with three pairs of strain gauges on the chair legs and four pairs on the FPS, six-axis force sensors (JR3) mounted behind the backrest, and a pressure-mapping device (Xsensor) with two mapping pads on the seat and back support. Positions of the BPS, FPS, and back support were recorded using six active markers mounted on the BPS, FPS, and back support of the chair. The local coordinate systems of the legs, seat, and backrest are shown with the following axes: the X-axis points anteriorly and passes through the intersection of the legs, the Y-axis points to the left and perpendicular to the X-axis, and the Z-axis points superiorly.

duced LBP, and the chair backrest also helps increase the lumbar lordosis and decrease intradiscal pressure.[19,30,31]

Numerous chairs or cushions have been developed to reduce or redistribute the sitting pressure on the ischial tuberosities using custom-fit seat pans.[35,36,37,38] Others chairs are designed to maintain lumbar lordosis by adjusting back support[19,39] or using a forward tilted seat.[19,40] However, few chairs use adjustable mechanisms for both ischial release and lumbar support.

The purpose of this study was to investigate the biomechanical effects of tilting down the back part of seat (BPS) and adjusting the backrest. The hypotheses were the following: 1) when the BPS is tilted down, load on the ischial tubercles will be reduced and shifted to the thighs, and low back muscle activity will be reduced; and 2) an increase in lumbar lordosis, forward rotation of the sacrum, and larger disc height will be observed when the BPS is tilted downward in combination with a properly adjusted back support.

Methods

Subjects. Fifteen office workers (eight female and seven male, 30.4 ± 7.1 years old (mean ± SD), 60.1 ± 19.3 kg in weight, 169.1 ± 8.2 cm in height) with no prior history of LBP were tested. The study was approved by the Institutional Review Board. All subjects gave informed consent before the experiment.

Chair. A × 2 (Back Stretch Technology, Stockholm, Sweden) chair was used in the study. The front part of seat (FPS) is fixed, and the BPS can be tilted upward or downward within $\theta = \pm 18°$ (Figure 1). The shape and height of the back support can be adjusted using an inflatable cushion built into the lower backrest to fit to the shape of the lower spine. The seat height and depth can also be adjusted. A local coordinate system was defined for each part of the chair (legs, seat and backrest) with the X-axis, Y-axis, and Z-axis pointing to the anterior, left, and superior directions, respectively (Figure 1). The origins for the legs and seat coordinate systems were defined by the intersection of the chair legs on the floor and seat, respectively (Figure 1). The origin of the backrest coordinate system was defined as the center of the upper surface of the backrest.

Sitting Conditions. The following sitting conditions were tested in this study:

- Upright with backrest: the subject sat upright with the backrest accommodated to the natural curve of subject's lower spine, which kept the lower spine from sliding down
- Upright without backrest: sitting upright without using the backrest
- Relaxed: sitting relaxed with the trunk leaning backward against the backrest. The backrest supported the spine and shoulders
- Working: sitting with trunk leaning forward, using a desk as the armrest, with the elbow relaxed at approximately 90° flexion and wrists in a natural position

In order to calculate the center of force (CF) on the legs (CF_L) and on the seat (CF_S) of the chair under different sitting conditions, the chair was instrumented with strain gauges (Figure 1). Three pairs of strain gauges were mounted on three beams supporting the legs of the chair (Figure 1). Another four pairs of strain gauges were mounted under the FPS (Figure 1). The load measured under the FPS corresponded to the total load on the seat since the BPS was connected only to the FPS. The strain gauges were calibrated, and the experimental data were then transformed to forces using the calibration data. The

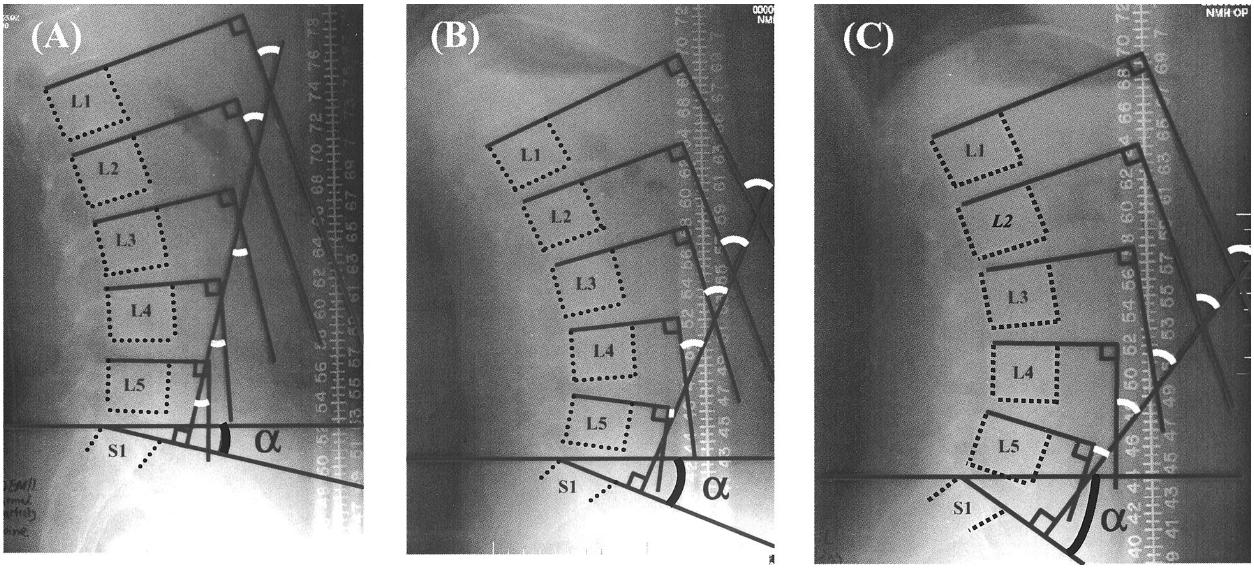

Figure 2. Representative sacral inclination (α) and total and segmental lumbar lordosis from one subject for sitting upright with fully fitted backrest with the back part of the seat (BPS) at level $\theta = 0°$ **(A)** and tilted down ($\theta = 18°$) **(B)**, and at the standing **(C)** postures. The α was the angle between the superior endplate of the S1 vertebra and the horizontal plane of the film that was parallel to the floor; The total (S1–L1) and segmental lumbar lordosis was measured using the Cobb method, *i.e.*, the angle between a line from endplate of the first lumbar vertebra (L1) and a line through the superior endplate of S1, and in similar fashion from L2 to S1, L3 to S1, L4 to S1, and L5 to S1.

CF was separately calculated in the X and Y directions of the legs and seat coordinate systems, respectively, by finding an axis parallel to the X-axis or Y-axis where the total moment about the axis was zero. For example, the CF_S in X_S direction was calculated by finding an axis parallel to the Y_S-axis where the total moment about this axis was zero ($\Sigma M_Y = 0$).

A pressure-mapping device (Xsensor Pressure Mapping System, Calgary, Canada) with two mapping pads each with 36 × 36 cells was used to measure the pressure distribution on the seat and backrest. The total contact pressure area (TCA), peak contact pressure (PP), and center of pressure (COP) were calculated from the measured pressure distribution.

The backrest was mounted on a frame through a six-axis force sensor (JR3, Woodland, CA), which measured the forces and moments exerted on the backrest. Data from the six-axis force sensor were low-pass filtered and transformed to the backrest local coordinate system.

Positions of the BPS, FPS and backrest under different sitting conditions were recorded using a motion capturing system (Optotrak 3020; Northern Digital, Waterloo, Canada) with six active markers mounted on the FPS, BPS, and backrest of the chair (two markers on each segment) (Figure 1).

EMG activity in the back muscles was monitored by bipolar surface electrodes (Delsys, Boston, MA) with a built-in preamplifier (gain = 1000). The electrodes were placed 3 cm on the left (L) and right (R) sides of the spinous processes at L2 (L and R), L4 (L and R), T5 (R), and T12 (R) on the erector spinae along the muscle fiber orientation. A reference electrode was placed at the spinous process of C7. The EMG data were normalized to those under maximum voluntary contraction (MVC) when the subjects were asked to exert maximum lifting effort (using their back) in a deep squat position. A 2-minute rest period was used between the MVC trials.

Protocol. Subject sat on the chair seat with the BPS at the level position ($\theta = 0°$). The height and shape of the backrest were adjusted with the tip of the backrest located at L2–L4 of the lumbar vertebra. The seat depth was adjusted to make the seat pan short enough for knee clearance and the ischia located at the middle BPS. The thighs were approximately parallel to the floor, with the feet resting on a footrest.

Loads on the legs, seat, and backrest; interface pressure on the seat and backrest; chair position and tilting angle of the BPS; and EMG signals were recorded for the following conditions during 30-second long trials: 1) with ischial support: BPS at the level position ($\theta = 0°$), and 2) without ischial support: BPS tilted down to $\theta = 18°$ at about 5 seconds after the start of a trial. Three trials were recorded for each sitting condition.

Two sets of lateral sagittal plane radiographs of the lower spine, thigh, and pelvis were taken subsequently for both standing and sitting postures. The sitting postures included the upright with backrest sitting condition under the following four combinations of the backrest and ischial support: with partially or fully fitted backrest to the lower spine by inflating the cushion to approximately 30% and 100% of its capacity, respectively, and under each of these two conditions testing with or without ischial support.

The radiographic images of the lower spine, thigh, and pelvis were used to locate several bony landmarks and calculate the sacral inclination (α), lumbar lordosis, and disc height. The value 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 (Figure 2). Lumbar lordosis was measured using the Cobb method (Figure 2).[41] Total lumbar lordosis (S1–L1) was the angle between a line through endplate of the first lumbar vertebra (L1) and a line through the superior endplate of S1, and segmental lordotic measurements were made similarly from L2 to S1, L3 to S1, L4 to S1, and L5 to S1. Disc heights of S1–L5, L4–L5, L3–L4, L2–L3, and L1–L2 were obtained from the average of dorsal and ventral disc height using the Dabbs method.[42]

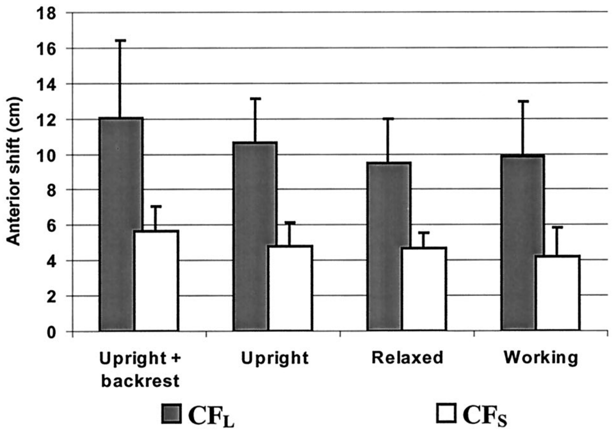

Figure 3. Changes of the center of force on the seat (CF_S) and legs (CF_L) of the chair for four sitting conditions: upright with backrest, upright without backrest, relaxed, and working. The CF_L and CF_S shifted forward in the anterior (X_L and X_S) direction (cm) when the back part of the seat (BPS) was tilted down to $\theta = 18°$.

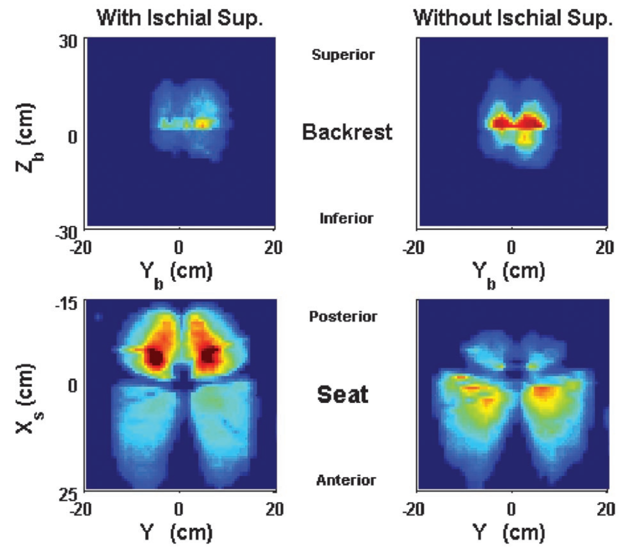

Figure 4. Representative pressure distribution on the seat (the lower row with X_S and Y_S pointing anterior and left, respectively) and backrest (upper row with Z_b and Y_b pointing superior and left, respectively) for the upright with backrest sitting condition. Left column: with ischial support when the back part of the seat (BPS) was at level $\theta = 0°$ position. Right column: without ischial support when the BPS was tilted down to $\theta = 18°$.

Statistical Analysis. Data collected were compared between sitting with the BPS at level ($\theta = 0°$) and downward tilting position ($\theta = 18°$). Using the SAS statistical software package (SAS Institute, Cary, NC), the paired *t* test was used to test for statistical differences in TCA, PP, COP, CF_S, CF_L, backrest load, EMG activity, sacral inclination, lumbar lordosis, and lumbar disc heights induced by tilting down the BPS. The significance level was set at 0.05.

Results

The CF_L and CF_S were significantly ($P < 0.001$) shifted anteriorly (X_L, X_S) toward the thighs for all sitting conditions when the BPS was tilted down to $\theta = 18°$ (Figure 3). The highest anterior shift was found in the upright with backrest sitting condition for both CF_L (12.04 ± 4.36 cm) and CF_S (5.66 ± 1.41 cm). The right-left shift (Y_L, Y_S) of CF_L and CF_S was found to be less than 0.48 cm ($P > 0.240$).

One typical result of the pressure distribution on the seat and backrest of the chair for the upright with backrest sitting condition is given in Figure 4, with ischial support when the BPS was at level $\theta = 0°$ position (left column) and without ischial support when the BPS was tilted down to $\theta = 18°$ (right column). The first row shows the interface pressure distribution on the backrest in a frontal plane with the right-left axis (Y_b-axis) and inferior-superior axis (Z_b-axis). The second row shows the pressure distribution on the seat in a plane parallel to the floor with the posterior-anterior axis (X_S-axis) and right-left axis (Y_S-axis). When the BPS was tilted down, contact pressure on the seat pan distributed in a smaller area with a lower PP, and the pressure was shifted toward the thighs. Contact pressure on the backrest distributed in a larger area with a higher PP. For all subjects under the upright with backrest and relaxed conditions, the pressure distribution showed the same trend when the BPS was titled down $\theta = 18°$.

When the BPS was tilted down, the TCA was significantly ($P < 0.001$) decreased on the seat pan, and the largest change was observed for the upright with backrest position (-9.09 ± 4.99%). At the same time, TCA on the backrest was significantly ($P < 0.001$) increased by 29.96 ± 16.19% and 36.65 ± 20.57% for the upright with backrest and relaxed conditions, respectively (Table 1).

The peak of contact pressure on the seat pan was decreased significantly by 22.98 ± 19.00% ($P = 0.001$) and 19.22 ± 22.95% ($P = 0.010$) for the upright with backrest and upright without backrest conditions, respectively. The PP on the backrest was significantly ($P < 0.001$) increased 73.93 ± 60.67% and 112.78 ± 56.26% for the upright with backrest and relaxed conditions, respectively (Table 1).

Similar to the CF_S (Figure 3), the COP on the seat pan was significantly ($P < 0.002$) shifted anteriorly towards the thighs by 5.84 ± 4.20 cm, 7.66 ± 5.74 cm, 8.61 ± 4.79 cm, and 6.34 ± 5.27 cm for the upright with backrest, relaxed, upright without backrest, and working conditions, respectively (Table 1).

For all subjects, total load (F_{tot}) on the backrest showed a significant ($P < 0.001$) increase by 112.33 ± 41.93 N and 106.93 ± 46.27 N for upright with backrest and relaxed conditions, respectively. The load component in posteroanterior direction (F_{Xb}) was significantly ($P < 0.001$) increased by 111.63 ± 43.57 N and 106.19 ± 50.01 N for the upright with backrest and relaxed conditions, respectively, and it was 98.63 ± 4.12% and 97.12 ± 6.95% of the F_{tot} for the upright with backrest and relaxed conditions, respectively. Load component in right-left direction (F_{Yb}) was increased only by 2.69 ± 2.46 N ($P < 0.002$) and 2.88 ± 4.19 N ($P < 0.019$) for the upright with backrest and relaxed conditions, respectively. The vertical load component in inferosuperior di-

Table 1. The Total Contact Area, Peak Pressure, and Center of Pressure on the Seat and Backrest at Different Sitting Conditions With and Without Ischial Support

	Pressure parameters	Ischial support	Upright + Backrest	Relaxed	Upright − Backrest	Working
Seat	TCA (cm^2)	with	485.37 ± 46.20	490.21 ± 39.86	464.29 ± 109.29	489.93 ± 41.93
		without	442.52 ± 60.08	461.75 ± 51.69	446.67 ± 110.08	467.38 ± 49.56
	Change (%)		−9.09 ± 4.99	−6.00 ± 3.90	−4.02 ± 3.53	−4.72 ± 3.18
	P		<0.001	<0.001	<0.001	<0.001
	PP (kg/cm^2)	with	229.03 ± 54.99	221.46 ± 40.43	270.64 ± 47.76	222.63 ± 55.86
		without	175.19 ± 63.12	199.67 ± 59.18	216.42 ± 70.31	202.58 ± 69.19
	Change (%)		−22.98 ± 19.00	−8.41 ± 26.40	−19.22 ± 22.95	−5.13 ± 32.77
	P		0.001	0.131	0.010	0.188
	COP					
	Change (cm)	without	5.84 ± 4.20	7.66 ± 5.74	8.61 ± 4.79	6.34 ± 5.27
	P		<0.001	<0.001	<0.001	0.001
Backrest	TCA (cm^2)	with	76.18 ± 12.82	73.85 ± 17.78		
		without	97.93 ± 12.82	98.35 ± 16.21		
	Change (%)		29.96 ± 16.19	36.65 ± 20.57		
	P		<0.001	<0.001		
	PP (kg/cm^2)	with	143.88 ± 52.79	121.21 ± 48.69		
		without	230.00 ± 64.84	238.58 ± 52.22		
	Change (%)		73.93 ± 60.67	112.78 ± 56.26		
	P		<0.001	<0.001		

TCA, total contact area; PP, peak pressure; COP, center of pressure.
A positive COP indicates anterior shift of the PP toward the thighs (positive X_S). The relative changes between sitting with and without ischial support are given in terms of percentage (%) for each sitting condition. A positive value shows an increase in the corresponding data. The significant level (*P*) is given for the difference between sitting with and without ischial support.

rection (F_{Zb}) was changed by −3.68 ± 11.14 N (P = 0.138) and 8.08 ± 13.37 N (P = 0.030) for the upright with backrest and relaxed conditions, respectively.

As the BPS was tilted down, the EMG activity for sitting upright with backrest was significantly ($P <$ 0.049) decreased at all levels except at the T8 (R) level (Table 2). For sitting upright without backrest, the EMG activity was significantly ($P < 0.012$) decreased at all levels except at the T5 (R) level. Under the relaxed sitting condition, the EMG activity was significantly ($P < 0.03$) decreased at the L2 (L) and L4 (L). As for the working condition, it was significantly ($P < 0.045$) decreased at L2 (R), L4 (L and R), and T8 (R).

When the BPS was tilted down ($\theta = 18°$), the sacrum was rotated forward, as indicated by increasing α from 14.14 ± 10.84° to 24.95 ± 9.50° ($P < 0.001$) and from 14.04 ± 11.30° to 20.95 ± 11.22° ($P = 0.001$) for backrest fitted fully and backrest fitted partially, respectively (Table 3, Figure 2).

The S1–L1, S1–L2, S1–L3, S1–L4, and S1–L5 were significantly ($P < 0.042$) increased by tilting down the BPS (Table 3). The total lumbar angle was changed from 24.53 ± 21.31° to 32.63 ± 22.25° ($P = 0.010$) and from 38.94 ± 14.61° to 47.86 ± 11.89° ($P = 0.008$) for the partially and fully fitted backrest sitting conditions, respectively.

All the measured disc heights, S1–L5, L4–L5, L3–L4, L2–L3, and L1–L2, were significantly ($P < 0.011$) increased by lowering the BPS (Table 4). The lumbar vertebra heights (mm) of the L1, L2, L3, L4, and L5 are also given for both ventral and dorsal sides.

Table 2. Change in EMG Activity of Low Back Muscles When the BPS was Tilted Down (θ = 18°) Under Different Sitting Conditions

Sitting conditions	L2 (L)	L2 (R)	L4 (L)	L4 (R)	T5 (R)	T8 (R)
Upright + Backrest						
Change (mV)	−0.004 ± 0.004	−0.009 ± 0.016	−0.025 ± 0.040	−0.022 ± 0.042	−0.015 ± 0.029	−0.004 ± 0.031
P	0.003	0.028	0.026	0.048	0.048	0.346
Upright − Backrest						
Change (mV)	−0.012 ± 0.014	−0.023 ± 0.024	−0.023 ± 0.030	−0.020 ± 0.025	−0.003 ± 0.025	−0.013 ± 0.011
P	0.005	0.003	0.011	0.009	0.325	<0.001
Relaxed						
Change (mV)	−0.004 ± 0.005	−0.009 ± 0.025	−0.013 ± 0.020	−0.000 ± 0.018	−0.001 ± 0.008	−0.001 ± 0.013
P	0.010	0.098	0.020	0.485	0.386	0.356
Working						
Change (mV)	−0.015 ± 0.038	−0.024 ± 0.027	−0.042 ± 0.077	−0.032 ± 0.049	−0.016 ± 0.043	−0.012 ± 0.012
P	0.092	0.004	0.044	0.022	0.106	0.002

EMG, electromyograph; BPS, back part of seat; (L), left; (R), right.
EMG signals recorded at the left (L) and right (R) sides of the spinous processes at L2 (L&R), L4 (L&R), T5 (R), and T12 (R) levels on the erector spinae. A negative value indicates a decrease of EMG activity. The significant level (*P*) is given for the difference between sitting with and without ischial support.

Table 3. The Sacral Inclination (α), Total (S1–L1) and Segmental (S1–L2, S1–L3, S1–L4, S1–L5) Lumbar Lordosis for Standing and Sitting Postures

	Sitting Upright with Backrest				
	Backrest fitted partially (n = 6)		Backrest fitted fully (n = 9)		
Posture	With ischial support	Without ischial support	With ischial support	Without ischial support	Standing
Sacral inclination					
α	14.04 ± 11.30°	20.95 ± 11.22°	14.14 ± 10.84°	24.95 ± 9.50°	37.83 ± 3.50°
P		0.001		<0.001	
Total Lordosis					
S1–L1	24.53 ± 21.31°	32.63 ± 22.25°	38.94 ± 14.61°	47.86 ± 11.89°	53.95 ± 1.92°
P		0.010		0.008	
Segmental Lordosis					
S1–L2	25.26 ± 16.48°	33.06 ± 17.96°	36.04 ± 9.24°	42.92 ± 9.75°	51.01 ± 4.68°
P		0.015		0.005	
S1–L3	22.10 ± 12.92°	30.65 ± 15.61°	29.71 ± 6.14°	35.29 ± 10.88°	42.14 ± 6.14°
P		0.023		0.041	
S1–L4	16.31 ± 8.58°	24.62 ± 12.41°	21.15 ± 5.56°	27.53 ± 9.09°	31.35 ± 10.03°
P		0.024		0.025	
S1–L5	12.41 ± 5.96°	19.10 ± 6.45°	11.12 ± 3.88°	17.74 ± 4.79°	18.39 ± 7.22°
P		0.006		0.001	

The sitting posture tested was 'Upright with Backrest' under four different conditions: the backrest was partially or fully fitted to the lower spine, and under each condition the ischial support was either kept ($\theta = 0°$) or relieved by lowering the back part of the seat ($\theta = 18°$). The significant level (*P*) is given for the difference between sitting with and without ischial support.

Discussion

This study investigated quantitatively the biomechanical effects induced by adjusting ischial and back supports, including the contact pressure distributions, reactive forces between the buttock-thighs and seat and between the back and backrest, muscular activity in back muscles, sacral inclination, lumbar lordosis, and intervertebral space of the lumbar spine. It was found that sitting with this lowered BPS and adjusted backrest distributed contact pressure more evenly, significantly reduced peak pressure under ischia, reduced muscular activity, rotated the sacrum forward, increased total and segmental lumbar lordosis, and increased lumbar intervertebral disc height.

When the BPS was tilted downward by $\theta = 18°$ and the backrest was utilized, F_{tot} exerted on the backrest was significantly ($P < 0.001$) increased. The PP on the backrest was significantly increased, and it was significantly decreased on the seat; the largest change was found for the upright with backrest condition. The COP and CF_S were significantly shifted anteriorly to the thighs

Table 4. The Lumbar Spine Disc Heights (S1–L5, L4–L5, L3–L4, L2–L3, and L1–L2) for Standing and Sitting Postures, and the Lumbar Vertebra Heights of the L1, L2, L3, L4, and L5 for Both Ventral (V) and Dorsal (D) sides

	Sitting Upright with Backrest					
	Backrest fitted partially (n = 6)		Backrest fitted fully (n = 9)			
Posture	With ischial support	Without ischial support	With ischial support	Without ischial support	Standing	Lumbar height (mm)
Disc Height						L5
S1–L5 (mm)	13.47 ± 2.36	15.20 ± 2.28	11.35 ± 1.79	12.60 ± 2.26	13.51 ± 1.59	V: 33.08 ± 3.34
P		0.004		<0.001		D: 31.44 ± 2.11
						L4
L4–L5 (mm)	12.39 ± 1.20	14.06 ± 1.57	12.37 ± 1.68	13.57 ± 1.52	13.41 ± 0.75	V: 32.89 ± 4.78
P		<0.001		0.002		D: 32.03 ± 2.56
						L3
L3–L4 (mm)	11.77 ± 0.69	13.45 ± 0.91	11.38 ± 1.69	12.61 ± 2.16	13.84 ± 0.95	V: 33.51 ± 3.51
P		<0.001		0.004		D: 32.96 ± 2.11
						L2
L2–L3 (mm)	10.76 ± 0.92	11.99 ± 1.35	10.33 ± 1.36	11.51 ± 1.51	13.84 ± 3.97	V: 33.19 ± 3.29
P		0.010		<0.001		D: 32.71 ± 1.83
						L1
L1–L2 (mm)	10.55 ± 0.68	11.43 ± 0.96	9.75 ± 2.11	11.06 ± 2.13	11.69 ± 0.82	V: 31.51 ± 2.93
P		0.005		0.004		D: 32.82 ± 2.23

The sitting posture tested was Upright with Backrest under four different conditions: the backrest was partially or fully fitted to the lower spine, and under each condition the ischial support was either kept ($\theta = 0°$) or relieved by lowering the back part of the seat ($\theta = 18°$). The significant level (*P*) is given for the difference between the sitting with and without ischial support.

Table 5. The Sacral Inclination, Total and Segmental Lumbar Lordosis Results From Other Studies for Sitting and Standing Postures

Posture	Subjects (n)	Segmental Lordosis				Total lordosis (S1–L1)	Sacral inclination (α)
		S1–L5	S1–L4	S1–L3	S1–L2		
Standing							
Present study	9 N	18.4 ± 7.2°	31.4 ± 10.0°	42.1 ± 6.1°	51.0 ± 4.7°	53.9 ± 1.9°	37.8 ± 3.5°
Andersson[19]	8 N					59.8 ± 2.9°	38.0 ± 1.9°
During[28]	52 N						40.4° ± 8.8°
Itoi[23]	18 N					55.1 ± 2.9°	35.3 ± 2.2°
Stagnara[27]	100 N	21 ± 6°	36 ± 8°	47 ± 9°	54 ± 9°	56 ± 10°	
Chen[21]	16 N					50.4 ± 3.0°	
Chernukha[22]	199 N					46 ± 9°	
Propst-Proctor[57]	104 N	12°					
Saraste[58]	170 N			39°			
Mosner[56]	27 N				51.8 ± 8.8°		
Kimura[25]	8 N	20.8 ± 6.0°				57.3 ± 16.7°	
Wood[59]	50 N	22.0 ± 0.0°					
Gelb[55]	100 N	24°					
Bernhardt[20] (*L5–L1)	102 N	28°				*44 ± 12°	
Jackson[24]	100 N	24.6 ± 6.2°				60.9 ± 12.0°	
	100 LBP	21.5 ± 7.5°				56.3 ± 11.5°	
Lord[26]	109 LBP	18 ± 8°	31 ± 9°		47 ± 13°	49 ± 15°	
Fernand[54]	973 LBP				45.1 ± 0.8°		
Sitting							
Present study (Upright + Backrest)	9 N	17.7 ± 4.8°	27.5 ± 9.1°	35.3 ± 10.9°	42.9 ± 9.8°	47.9 ± 11.9°	25.0 ± 9.5°
Andersson[19]							
No back support	8 N					22.2 ± 5.9°	17.1 ± 4.1°
Back support	10 N					28.1 ± 3.1°	20.5 ± 2.4°
Lumbar support	10 N					46.8 ± 5.1°	28.3 ± 4.7°
Lord[42]	109 LBP	15 ± 7°	22 ± 8°		33 ± 13°	34 ± 15°	

n, # of subjects; *N*, healthy patient; LBP, low back pain patient.

for all sitting conditions (Figure 3, Table 1). All of these measurements for load and pressure redistribution on the seat and backrest indicated that load on the ischial tubercles was significantly decreased and shifted to the thighs, while load on the back support was increased, mainly with the load component in the posteroanterior direction (F_x) to maintain lumbar lordosis. Using this new sitting concept made the thighs take up more load over a larger surface area, with less load on the ischial tubercles.

Measurement of load and contact pressure redistribution are important in assessing tissue viability, as prolonged sitting can lead to pressure sore development,[43,44] increased disc degeneration, and LBP.[4,5] Repositioning of the lumbar support to redistribute the interface pressure and load is essential to prevent LBP. Furthermore, for patients who have limited mobility, body repositioning remains the only way to change their pressure distribution at the body-seat interface.[15]

Muscle activity was decreased in most of the sitting conditions when the BPS was tilted down, especially in the lumbar region. Relieving the ischial support may have made the pelvis rotate forward and relaxed muscles in the lumbar region more than in the thoracic regions. Another reason may be different amounts of pressure on the lumbar and thoracic regions during EMG recording for sitting conditions using backrest, especially for the relaxed condition. Under the relaxed sitting condition, the body did not show any significant change in muscle activity at the thoracic regions.

The upright with backrest sitting condition was found to be more efficient to change the pelvis and lumbar structures when the BPS was tilted down. The results from load and contact pressure redistribution on the seat and backrest (Table 1, Figure 3) indicated that this sitting condition gave the best results to reduce load on the ischial tubercles and lower spine. Thus, this sitting condition upright with backrest was used to evaluate changes in the lumbar spine and pelvis structures with the backrest fitted partially or fully to the lower spine using radiographs.

Tilting down the BPS maintained sacral inclination approaching that of the standing posture (Table 3). The total and segmental lumbar lordosis were also increased and resulted in an appearance in which the abdomen was particularly prominent and resembled closely that of the standing position (Table 3). The sacral inclination and lumbar lordosis results from other studies for sitting and standing are given in Table 5. A comparison between these results and the results from the present study confirmed the similarity (Table 5).

The benefit of lumbar lordosis was suggested in a postmortem study by Farfan *et al*,[45] who noted an association between decreased lumbar lordosis and increased disc degeneration at L5–S1, suggesting a protective effect for increased lumbar lordosis on the lumbosacral junction. Andersson *et al*[46] found lordosis to be inversely proportional to intradiscal pressure. Lumbar curvature affects disc pressure by changing the distribution of load between disc and apophyseal joints[47] and also by changing tension in the intervertebral ligaments.[48,49,50] The increased intradiscal pressure may also be the underlying factor for the association of decreased lordosis and LBP. In a study of osteoporotic patients by Itoi,[23] decreased lordosis was associated with increased LBP. Keegan,[4] in a study of the relation between lordosis and sitting, found the most important factor in LBP with prolonged sitting to be a decreased trunk-thigh angle with consequent flattening of the lumbar curve. Using a lumbar roll that increases lordosis has been found to decrease LBP.[5] With decreased lordosis, sitting pressure increases over the ischium and coccyx with resultant pain.[32] Others have also found distinct differences in lumbar lordosis when comparing LBP patients with healthy patients.[24,51]

All disc heights were significantly ($P < 0.011$) increased by lowering the BPS (Table 4). Extensive and consequent segmental lordosis may decrease intradiscal pressure. The effect of disc height on mechanical properties caused by compressive forces was investigated by Kimura *et al*,[25] who found that biomechanical axial stress for the intervertebral disc increased most at L4–L5 due to the decreased disc height in upright posture. The highest incidence of lumbar disc diseases was generally found at L4–L5.[52] The reason for the relatively high frequency of lumbar disc disease was connected to a relatively wide range of motion and high loads at L4–L5 and L5-S1 with lumbar flexion and extension.[53]

It has been reported that a backrest with a protruded part to support the lumbar spine would result in an increase of the lumbar lordosis and the load on the back.[19,31] The present study supports such an observation. Furthermore, a much greater load reduction was observed in this study for proper lumbar support combined with the ischial tubercles load relief. However, the benefits of unloading the ischia were investigated during a short sitting time. The outcome needs to be evaluated for longer period of sitting with unsupported ischia with the concern that load shifted to the thighs may cause hip pain. Tilting the BPS down and up alternately is needed during prolonged sitting. Future study is needed to find the optimal tilting angle of the BPS and optimal period for tilting the BPS down and up during long periods of sitting.[54–59]

■ Key Points

- To reduce contact pressure and peak pressure under the ischia
- To reduce muscular activity
- To maintain total and segmental lumbar lordosis
- To maintain sacral inclination
- To prevent LBP associated with inappropriate prolonged sitting

References

1. Bernard BP. *Musculoskeletal Disorders and Workplace Factors*. Washington, DC: US Department of Health and Human Services; 1997.
2. Johanning E. Evaluation and management of occupational low back disorders. *Am J Ind Med* 2000;37:94–111.
3. Waddell G. Low back pain: a twentieth century health care enigma. *Spine* 1996;21:2820–5.
4. Keegan JJ. Alterations of the lumbar curve related to posture and seating. *J Bone Joint Surg Am* 1953;35:589–603.
5. Williams MM, Hawley JA, McKenzie RA, et al. A comparison of the effect of two sitting posture on back and referred pain. *Spine* 1991;16:1185–91.
6. Hedman TP, Fernie GR. Mechanical response of the lumbar spine to seated postural loads. *Spine* 1997;22:734–43.
7. Chaffin DB, Andersson GBJ. *Occupational Biomechanics*. 2nd ed. New York: Wiley; 1990.
8. Wilder DG, Pope MH, Frymoyer JW. The biomechanics of lumbar disc herniation and the effect of overload and instability. *J Spinal Disord* 1988; 1:16–32.
9. Schoberth H. Die Wirbelsäule von Schulkindern orthopädische Forderungen an Schulsitze. In sitting posture. In: Grandjean E, ed. *Sitzhaltung, Sitzschaden, Sitzmöbel*. Berlin, Germany: Springer Verlag; London, UK: Taylor; 1962.
10. Wu CS. Development of pelvic motion monitoring device and method. In: *Proceedings of Annual Meeting of the Kanto Chapter*. Tokyo, Japan: Ergonomics Research Society; 1991:69–70.
11. Marras WS, Davis KG, Ferguson SA, et al. Spine loading characteristics of patients with low back pain compared with asymptomatic individuals. *Spine* 2001;26:2566–74.
12. Henderson JL, Price SH, Brandstater ME, et al. Efficacy of three measures to relieve pressure in seated persons with spinal cord injury. *Arch Phys Med Rehabil* 1994;75:535–9.
13. Hobson DA. Comparative effects of posture on pressure and shear at the body seat interface. *J Rehabil Res Dev* 1992;29:21–31.
14. Koo TKK, Mak AFT, Lee YL. Posture effect on seating interface biomechanics: comparison between two seating cushions. *Arch Phys Med Rehabil* 1996;77:40–7.
15. Aissaoui R, Dansereau J, Lemire N, et al. Effect of repositioning on seat and back pressure measurements and posture of able-bodied subjects. *Proceedings of the International Conference of Wheelchairs Seating*. Dundee, Scotland: 1997.
16. Gilsdorf P, Patterson R, Fisher S, et al. Sitting force and wheelchair mechanics. *J Rehabil Res Dev* 1990;27:239–46.
17. Shileds RK, Cook TM. Effect of seat angle and lumbar support on seated buttock pressure. *Phys Ther* 1988;68:1682–6.
18. Koo TK, Mak AF, Lee YL. Evaluation of an active seating system for pressure relief. *Assist Technol* 1995;7:119–28.
19. Andersson GJB, Murphy RW, Ortengren R, et al. The influence of backrest inclination and lumbar support on lumbar lordosis. *Spine* 1979;4:52–8.
20. Bernhardt M, Bridwell KH. Segmental analysis of the sagittal plane alignment of the normal thoracic and lumbar spines and thoracolumbar junction. *Spine* 1989;14:717–21.
21. Chen YL. Vertebral centroid measurement of Lumbar Lordosis compared with the Cobb technique. *Spine* 1999;24:1786–90.
22. Chernukha KV, Daffner RH, Reigel DH. Lumbar lordosis measurement: a new method versus Cobb technique. *Spine* 1998;23:74–9.
23. Itoi E. Roentgenographic analysis of posture in spinal osteoporotics. *Spine* 1991;16:750–6.
24. Jackson RP, McManus AC. Radiographic analysis of sagittal plane alignment and balance in standing volunteers and patients with low back pain matched for age, sex, and size. *Spine* 1994;19:1611–8.
25. Kimura S, Steinbach GC, Watenpaugh DE, et al. Lumbar spine disc height and curvature responses to an axial load generated by a compression device compatible with magnetic resonance imaging. *Spine* 2001;26:2596–600.
26. Lord MJ, Small JM, Dinsay JM, et al. Lumbar lordosis: effects of sitting and standing. *Spine* 1997;22:2571–4.
27. Stagnara P, DeMauroy JC, Dran G, et al. Reciprocal angulation of vertebral bodies in a sagittal plane: approach to references for the evaluation of kyphosis and lordosis. *Spine* 1982;7:335–42.
28. During J, Goudfrooij H, Keessen W, et al. Toward standards for posture: postural characteristics of the lower back system in normal and pathologic conditions. *Spine* 1985;10:83–7.
29. Åkerblom B. *Standing and Sitting Posture: With Special Reference to the Construction of Chairs*. Stockholm, Sweden: Nordiska Bokhandeln; 1948.
30. Andersson BJG. *On Myoelectric Back Muscle Activity and Lumbar Disc Pressure in Sitting Postures*. Götenburg: GOTAB; 1974.
31. Andersson BJG, Örtengren R. Lumbar disc pressure and myoelectric back

muscle activity during sitting, II: studies on an office chair. *Scand J Rehabil Med Suppl* 1974;6:115–21.
32. Drummond DS, Breed AL, Narechania R. Relationship of spine deformity and pelvic obliquity on sitting pressure distributions and decubitus ulceration. *J Pediatr Orthop* 1985;5:396–402.
33. Kostuik JP, Hall BB. Spinal fusion to the sacrum in adults with scoliosis. *Spine* 1983;8:489–500.
34. Frymoyer JW, Newberg A, Pope MH, et al. Spine radiographs in patients with low back pain: an epidemiological study in men. *J Bone Joint Surg Am* 1984;66:1048–55.
35. Cooper RA, Dvorznak MJ, Rentschler AJ, et al. Displacement between the seating surface and hybrid test dummy during transitions with a variable configuration wheelchair: a technical note. *J Rehabil Res Dev* 2000;37:297–303.
36. Ferrarin M, Andreoni G, Pedotti A. Comparative biomechanical evaluation of different wheelchair seat cushions. *J Rehabil Res Dev* 2000;37:315–24.
37. Rosemeyer B. Eine Methode Zur Beckenfixierun im Arbeitssitz. *Z Orthop* 1972;110:514.
38. Takechi H, Tokuhiro A. Evaluation of wheelchair cushions by means of pressure distribution mapping. *Acta Med Okayama* 1998;52:245–54.
39. Parent F, Dansereau J, Lacoste M, et al. Evaluation of the new flexible contour backrest for wheelchairs. *J Rehabil Res Dev* 2000;37:325–33.
40. Burandt U. Radiography of the position of the pelvis and vertebal alumb while seated on a forward tilted surface. *Ergonomics* 1969;12:356–64.
41. Cobb JR. Outline for the study of scoliosis. In: Thomson JEM, Blount WP, eds. *American Academy of Orthopaedic Surgeons: Instructional Course Lectures*. Ann Arbor, MI: JW Edwards;1948:261–75.
42. Dabbs VM, Dabbs LG. Correlation between disc height narrowing and low back pain. *Spine* 1990;15:1366–9.
43. Bader DL. The recovery characteristics of soft tissues following repeated loading. *J Rehabil Res Dev* 1990;27:141–50.
44. Colin D, Saumet JL. Influence of external pressure on transcutaneous oxygen tension and laser doppler flowmetry on sacral skin. *Clin Physiol* 1996;16:61–72.
45. Farfan HF, Huberdeau RM, Dubow HI. Lumbar intervertebral disc degeneration. *J Bone Joint Surg Am* 1972;54:492–510.
46. Andersson GJB, Örtengren R, Nachemson A, et al. The sitting posture: an electromyographic and discometric study. *Orthop Clin North Am* 1975;6:105–20.
47. Adams MA, Hutton WC. The effect of posture on the role of the apophysial joints in resisting intervertebral compressive forces. *J Bone Joint Surg Br* 1980;62:358–62.
48. Adams MA, Hutton WC. The effect of posture on the lumbar spine. *J Bone Joint Surg Br* 1985;67:625–9.
49. Adams MA, McNally DS, Chinn H, et al. Posture and the compressive strength of the lumbar spine. *Clin Biomech* 1994;9:5–14.
50. Hukins DWL, Kirby MC, Sikoryn TA, et al. Comparison of structure, mechanical properties, and functions of lumbar spinal ligaments. *Spine* 1990;15:787–95.
51. Harrison DD, Cailliet R, Janik TJ, et al. Elliptical modeling of the sagittal lumbar lordosis and segmental rotation angles as a method to discriminate between normal and low back pain subjects. *J Spinal Disord* 1998;11:430–9.
52. Wisneski RJ, Garfin SR, Rothman RH, et al. Lumbar disc disease. In: Herkowitz HN GS, Balderston RA, et al, eds. *The Spine*. Philadelphia, PA: WB Saunders; 1999.
53. White AA, Panjabi MM. *Clinical Biomechanics of the Spine*. Philadelphia, PA: JB Lippincott; 1990.
54. Fernand R, Fox DE. Evaluation of lumbar lordosis. A prospective and retrospective study. *Spine* 1985;10:799–803.
55. Gelb DE, Lenke LG, Bridwell KH, et al. An analysis of sagittal spinal alignment in 100 asymptomatic middle- and older-aged volunteers. *Spine* 1995;20:1351–8.
56. Mosner EA, Byran JM, Stull MA, et al. A comparison of actual and apparent lumbar lordosis in black and white adult females. *Spine* 1989;14:310–4.
57. Propst-Proctor SL, Bleck EE. Radiographic determination of lordosis and kyphosis in normal and scoliotic children. *J Pediatr Orthop* 1983;3:344–6.
58. Saraste H, Brostrom L-A, Aparisi T, et al. Radiographic measurement of the lumbar spine: A clinical and experimental study in men. *Spine* 1985;10:236–41.
59. Wood KB, Kos P, Schendel M, et al. Effect of patient position on the sagittal plane profile of the thoracolumbar spine. *J Spinal Disord* 1996;9:164–9.

Point of View

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It is reported in the literature that the stresses in lumbar intervertebral discs and muscles alter with alteration in the sitting posture as well as with the introduction of back support. Very well planned and executed investigation has explored this issue. Consideration has been given to collect kinematic, force, EMG, and radiograph data simultaneously at the lower lumbar spine to perform biomechanical investigation. Designing a special seat created specific alterations in the lumbar lordosis, and the upper body static load shifted from ischial tubercles to the thighs in a sitting posture. In this design, one can make adjustments in the back and ischial supports; this in turn makes alterations in the lordosis, sacral inclination, and muscle activities. Fifteen subjects of no known low back pain history were enrolled in this study. Quantitative biomechanical measurements were made for sitting with and without ischial support and with adjustable back support, and statistical analyses were performed.

When sitting upright with the back support but no ischial support, the loads were transferred to thighs and back support. The loads in the back support increased, and at the same time, the pressure under the thighs in the seat became more uniform. The total contact area on the seat pan and on the backrest was significantly decreased and increased, respectively, $P < 0.001$. Since there was no seat under the tubercles, the pressure concentration was eliminated. In addition, the pelvis was induced to rotate forward to maintain the lordosis. Farfan *et al*[1] report that pelvis rotation plays an important role in altering the loads in the lumbar spine. Sitting upright with backrest and without ischial support created a desirable condition to reduce the loads on the lower spine and muscle activities.

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The seat in the current design is 40 cm (medial-lateral) × 25 cm (anterior-posterior) with a 15-cm addition of the ischial support. The authors planned to perform the study for an optimal tilt angle of the seat back part support (BPS) and sitting for long duration in this posture. A continuous and smooth alteration in the BPS will be desired. To make this type of design practical, it will be desirable to develop indicators of reduction in the lower lumbar loads such as an optimum anterior shift in center of pressure.

References

1. Farfan HF, Huberdeau RM, Dubow HI. Lumbar intervertebral disc degeneration. *J Bone Joint Surg [Am]* 1972;54:492–510.