Reducing Low-Back Disorders Using a New Sitting Design

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List of Abbreviations and Definitions

AP: Average pressure.

BP: Buttock pain

BPS: Back part of the seat.

CL_{Base}: Center of load on the chair base stand

CL_{Seat}: Center of load on the seat of the chair

EMG: Electromyography

FPS: Front part of the seat

IT: Ischial tuberosity

LBP: Low back pain

PP: Peak pressure

TCA: Total contact area

TP: Total contact pressure

WO-BPS: A seat configuration of which the back part of the seat (BPS) is tilted downward at about 20° and the backrest is enhanced

Abstract

Occupational low·back pain (LBP) is alarmingly common, with a 100 million workdays lost in the United States each year. As the leading cause of disability in individuals less than 50 years old, LBP imposes a tremendous economic burden, with a direct treatment cost exceeding $25 billion in 1990 alone and the seated work tasks have a 25-76% prevalence of musculoskeletal discomfort. Although a number of occupational risk factors have been cited, the primary causes for work-related LBP include inappropriate curvature of the spine and pelvis induced by sitting, and sustained static muscle, ligament, and disc load caused by prolonged static sitting. Sitting induces backward rotation of the pelvis, reduction in lumbar lordosis, increased intervertebral disc pressure, tension in paraspinal muscles and ligaments in lumbar region, excessive pressure over the ischium and coccyx, and certainly the associated LBP.

This project investigated a new sitting concept for office chair to determine its potential beneficial effects to working individuals with sitting related LBP. This new seating system features an enhanced backrest, which is adjustable both in height and shape, providing various degrees of lumbar support, and a split seat pan, in which the back part of seat (BPS) can be dynamically tilted down with respect to the front part of the seat (FPS), providing adjustment of thigh and ischial support. Along with this new seating concept, a new sitting posture, **WO-BPS** sitting posture, was proposed by the investigators, which stands for using the protruded lumbar support on the backrest together with the released ischial support on the seat.

In this project, research was carried out not only through biomechanical and physiological test in laboratory and radiological imaging settings, but also through a 12-week subjective evaluation of the new office chair in practical working environment to collect feedbacks from individuals with sitting related low back complains.

Major findings from the project are:

- The proposed novel sitting concept, which combines adjustable ischial load relief and lumbar support enhancement, **effectively relieved LBP symptoms** in the majority of the LBP patients who participated in the study;
- The alleviation of the sitting related complains, the improvement of sitting posture, and the beneficial sitting load redistribution, are achieved **optimally by simultaneously using two interventions: the adjustable protruded lumbar support, and the tilted down back part of the seat** to achieve ischial load release;
- The alleviation of the LBP symptoms by using this sitting concept is attributed to the **significant sitting posture correction effect**, which results significant increased lumbar intervertebral disc height, forward rotation of the sacrum, increased lumbar lordosis, and **significantly decreased muscle effort** of paraspinal muscles in lumbar region;
- The alleviation of the LBP symptoms by using this sitting concept is attributed to the **significant load redistribution between the seat and backrest, and between the posterior and the middle portion of the seat pan**;
- The study chair also helped **effectively relieve buttock pain symptoms** in the majority of the LBP participants;

- Sitting in this study chair was found overall comfortable and **significantly increase sitting tolerance** in the majority of the participants;
- The new sitting concept, **WO-BPS** sitting posture, provided by the study chair, was found preferred by the majority of the participants.

In conclusion, the investigated new sitting concept has been confirmed to have significant postural correction effect to individuals with sitting related LBP; thus significantly reducing one of the primary causes of occupational LBP.

The investigators believe that this is the first seating system which provides sitting posture adjustment and correction by the combination of adjusting protruded lumbar support and the reduced ischial load.

Moreover, the posture adjustability and flexibility provided by the novel seating system offer ample options for the users to find the optimal sitting postural configuration best fits each individual's needs. Therefore, the investigators believe that, by introducing **an automatic posture adjustment mechanism** into current seating system, this seating concept would be transformed into a **dynamic seating device** which would have promising potentials to prevent prolonged static sitting, the other primary occupational cause for sitting related LBP, in individuals with occupations requiring long term sitting.

Encouraging findings on benefits of this seating concept on occupational LBP suggest further research and development effort be invested for improvement of the prototype and implementation of this new seating device in practical working space.

Proposed Specific Aims (from the original proposal)

A new seat design, of which the back part of seat (BPS) can be tilted downward (and upward if needed) with respect to the front part of the seat (FPS) and equipped with back support adjustable both in height and volume, introduces a new concept in more ergonomic sitting. The seat was initially developed in Sweden and the P.I. of this proposal was involved in the initial development and he has done further work at the Rehabilitation Institute of Chicago. It is found in our pilot study on healthy subjects that sitting with this lowered BPS brings forth a more evenly distributed contact pressure and a significantly reduced peak pressure under subject's ischia, and increases the total and segmental lumbar lordosis, a forwardly rotated the pelvis, and increases the lumbar intervertebral heights. Furthermore, tilting the BPS down and up alternately during prolonged sitting will increase the mobility of hip and spine and unload the lumbar spine, and shift the ischial load. The objective of this study is to quantitatively investigate the biomechanical and neuromuscular effects of applying the new sitting concept to a sample of patients with chronic LBP. The hypotheses and specific aims are as follows:

Hypothesis 1: When the BPS is tilted downward, load on the ischial tubercles and lumbar spine will be reduced and shifted to the thighs and the thoracic spine, respectively. As a result, low back muscle activities will be reduced.
Specific aim 1: Contact pressure distributions and forces between the buttock-thighs and seat, and between the back and backrest will be evaluated with and without ischial support, i.e. with the BPS at the level and tilted down positions, respectively. The pressure redistributions induced by tilting down the BPS will be evaluated through the pressure distributions and center of pressure at the seat and back using a pair of pressure mapping system, and the load shift at the seat and back will be measured by two six-axis force sensors mounted underneath the seat and behind the backrest, respectively. The muscular activities involved in stabilizing the trunk under these conditions will be investigated with surface EMG from the trunk extensor and flexor muscles.

Hypothesis 2: Increase in lumbar lordosis, forward rotation of the pelvis, and larger intervertebral heights will be observed when the BPS is tilted down to reduce ischial support.
Specific aim 2: Lateral view radiographs of the lower spine, pelvis and thigh will be taken with the subject sitting with and without tilting down the BPS and with adjustment of the low back support using an inflatable air-filled cushion built into the backrest. The influence of the backrest shape will be investigated when the backrest fits partially or fully to the lower spine for each sitting condition. The total and segmental lumbar lordosis, pelvis inclination, and intervertebral spaces of lumbar spine, will be measured and compared between different conditions.

Hypothesis 3: Sitting *alternately* between the postures with the BPS at level and tilted down positions will reduce the discomfort/pain associated with sitting. As a result, patients with LBP will better tolerate prolonged sitting.
Specific aim 3: The subjective evaluation and impressions gained from the use of such a sitting design for a period of ten weeks within two groups of chronic LBP patients with known pain history and current symptoms will be collected through questionnaires to identify the characteristics of the pain, including intensity, quality, location, radiation, aggravating and alleviating. The patients' subjective feelings on the new seating device with reduced ischial support and with partial or full support of the backrest to the lower spine will be evaluated in the two groups.

Highlights/Significant Findings

1. The proposed novel sitting concept, which combines adjustable ischial load relief and lumbar support enhancement, **effectively relieved LBP symptoms** and **increased their sitting tolerance** in the majority of the LBP patients who participated in the study ***(Proposed Specific Aim 3)***;

2. The alleviation of the sitting related complains, the improvement of sitting posture, and the beneficial sitting load redistribution, are achieved **optimally by simultaneously using two interventions: the adjustable protruded lumbar support, and the tilted down back part of the seat** to achieve ischial load release ***(Proposed Specific Aim 1 & 2)***;

3. The alleviation of the LBP symptoms by using this sitting concept is attributed to the **significant sitting posture correction effect**, which results significant increased lumbar intervertebral disc height, forward rotation of the sacrum, increased lumbar lordosis, and significantly decreased muscle effort of paraspinal muscles in lumbar region ***(Proposed Specific Aim 2 & 1)***;

4. The alleviation of the LBP symptoms by using this sitting concept is attributed to the **significant load redistribution between the seat and backrest, and between the posterior and the middle portions of the seat pan** ***(Proposed Specific Aim 1)***;

5. The study chair also helped **effectively relieve buttock pain symptoms** in the majority of the LBP participants ***(Proposed Specific Aim 3)***;

6. Sitting in this study chair was found **overall comfortable** and the new sitting concept, **WO-BPS** sitting posture, provided by the study chair, was found **preferred by the majority of the participants** ***(Proposed Specific Aim 3)***;

7. **An automatic posture adjustment mechanism,** which provides **dynamic** posture adjustment, would be beneficial to individuals with occupations requiring prolonged sitting ***(Finding beyond the proposed specific aims)***.

Translation of Findings

Findings in this project have significant impact on reducing hazards in working environment for the workers with occupational tasks requiring sitting for a long time, e.g. office workers and occupational vehicle operators. Work-related low back pain (LBP) has been reported as the leading cause of disability in US workforce. It has been agreed that two major occupational factors are the primary causes for work-related low back pain (LBP), abnormal spinal alignment during sitting and prolonged static sitting. This project was originally proposed to evaluate a new occupational intervention, a new sitting concept for office chair, in reducing the first major risk factor of the occupational LBP, the sitting-induced abnormal spinal alignment.

In finding that this new sitting concept helps significantly alleviate sitting-induced LBP and greatly increases sitting tolerance for individuals with established sitting-intolerance, it has been concluded that this beneficial effect has been achieved by **two combined mechanisms: using a protruded lumbar support, together with a reduced ischial (rear part of the buttocks) support**. Based on this finding, a new sitting posture, **WO-BPS** posture (initially stands for **W**ith**O**ut **B**ack **P**ortion of the **S**eat), is suggested by the investigators to individuals remained seated for long time when performing most of their occupational tasks.

Research in this project supported the above conclusion by providing evidences from 4 aspects:

1. **WO-BPS sitting posture created a new load-sharing pattern during sitting.** This posture shifted part of the sitting-induced lumbar spine load towards the thighs, and towards the upper back;
2. **WO-BPS sitting posture helped restore the lumbar spine curvature approximating the shape as seen in the standing posture** which is a posture when the spinal column is subjected to lower load than during regular sitting;
3. **In WO-BPS sitting posture, less muscular effort was needed to keep the trunk stable,** which reduced tension in muscles in lumbar region, thus prevented fatigue;
4. **Individuals who used this seating system for a period of 12 week in their office/home office environment experienced significant symptom alleviation,** which has helped them either returned to or kept regular job requirements.

In addition, the investigators also found a possible solution for reducing the second primary cause of work-related LBP, i.e. using **automatic dynamic seating device** to prevent prolonged static sitting in working environment.

By disseminating these findings, the PI and his colleagues expect to not only educate working population being aware of taking proper posture during their work-related sitting, but inspire further research and develop interest in implementing this new sitting concept in related working environment.

Outcomes/Relevance/Impact

Outcomes and relevance.

Main outcomes targeted in this project fall in 3 parts: biomechanical loading, physiological response, and subjective response from participants. All were related to sitting in the regular posture and a proposed new sitting posture.

Biomechanical loading during sitting: Outcomes in this group were load borne by the chair base, load borne by the seat, load borne by the backrest, pressure distribution on the seat, and pressure distribution on the backrest.

These outcomes recorded the biomechanical loading condition in sitting posture and helped to detect the difference in loading patterns between two sitting postures, **Normal** sitting and **WO-BPS** sitting.

Physiological response during sitting: Outcomes in this group were muscle efforts (surface EMG) from paraspinal muscles, spinal and sacral alignment in sagittal plane (radiological), and intervertebral disc height in lumbar spine (radiological). Radiological readings were also carried out in a standing posture.

These outcomes measured the physiological responses in sitting posture, and in standing posture for radiological outcomes. These measurements helped to better understand how the human body responded to different sitting postures, especially the two used in this project, **Normal** sitting and **WO-BPS** sitting. Radiological outcomes measured in the Standing posture also served as a reference reading determining the natural spinal alignment.

Subjective response from using the study seating system: Outcomes in this group were questions regarding the satisfaction and the alleviation/worsening of the symptoms in using the study seating system for a period of 12 weeks.

These subjective responses provided feedback from the participants with the first-hand experience of using such a seating system in their working environment. This helped the investigators to gauge the satisfaction/dissatisfaction of the participants in using the system. Mainly, it tested whether and how the proposed sitting concept worked in a practical environment different from that of a laboratory test.

Scientific Report

Background

LBP is acute or chronic pain of the lumbosacral, buttock, or upper leg areas [14]. LBP commonly reduces tolerance for prolonged sitting, required by many occupations and involved in routine daily activities. Occupational low back pain (LBP) is alarmingly common[27,46], with a 100 million workdays lost in the United States each year[44]. As the leading cause of disability in individuals less than 50 years old[16], LBP imposes a tremendous economic burden[87], with a direct treatment cost exceeding $25 billion in 1990 alone[96,97]. With the increasing workforce population, chronic disability from LBP is on the rise [95] with seated work tasks have a 25-76% prevalence of musculoskeletal discomfort[1,13,42,43,49,57,67,70,88,94]. In fact, occupations which require prolonged sitting have a 3.2 relative risk (95% confidence interval) of LBP within the first year of employment[93]. Although a number of occupational risk factors have been cited[11,20,35,47,53,55,60,62,75,100], the primary causes of LBP from occupational sitting are: 1) abnormal spinal alignment[2,3,5-8,11,18,19,23,25,28,32-35,38-41,45,51,52,56,61,68,70,74,78,82,84,86,98], and 2) prolonged static sitting[10-12,20,35,50,63,64,70-72,76,80,81,89-92].

In the standing posture, which was reported to have lower spinal loading than any seated posture[66], physiological spinal alignment is maintained, with a mean lumbar lordosis of 40° to 60° [7,15,21,22,40,41,48,56,83], and a mean sacral inclination of 30° to 40° [7,30,40]. However, sitting alters this spinal alignment through posterior rotation of the pelvis, resulting in both decreased lumbar lordosis[3] (up to 50%)[7,56] and sacral inclination[3,33,37], as well as increased forces at the intervertebral disc spaces[5,6,56]. A number of investigators have reported an association between decreased lumbar lordosis[28,29,45,79], malalignment of lumbar curvature,[40,41,52,98], and narrowing of disc spaces[33], with the development of LBP. It was concluded that aberrations of posture disturbed the distribution of stresses over the structures, thereby overloading some of them, causing strain, collapse and pain.

Prolonged static sitting is another major cause of sitting related LBP[10-12,20,35,50,63,64,70-72,76,80,81,89-92]. During sitting, upper extremity and truncal weight is carried by the ischial tuberosities and the surrounding tissues[77]. Elevated pressure at the ischial tuberosities is intimately associated with elevated spinal loads[99]. Sustained static load of lumbar viscoelastic tissues results in micro-damage of spinal collagen, and paraspinal muscle spasm [76,80]. Furthermore, metabolite accumulation from static load accelerates disc degeneration and herniation[70]. Solomonow et al., demonstrated that only a 20-minute constant load in static flexion results in creep of the viscoelastic spinal tissues, resulting in paraspinal muscular spasms and hyperexcitability [81]. Moreover, tissue oxygenation of the lumbar extensor musculature is reduced as a function of contraction intensity, even at levels as low as 2% of MVC (maximum voluntary contraction), causing concern for occupations requiring prolonged isometric contractions in the sitting position [63].

To improve spinal alignment and pressure distribution during sitting, numerous seating designs, such as lumbar supports,[7,68,84] forward tilted seat pans,[7,18,19] and custom-fitted seat pans[25,32,74,86], have been developed. Forward tilted seat pans improve lumbar lordosis[18,65]; however, Naqvi et al. reported that inclination as little as 5° results in neck pain[65]. Custom-fitted seat pans may reduce or redistribute pressure over the ischial tuberosities[9,24,25,32,74,86]; however, over time, progressive loss of this effect occurs with compression and distortion of the seating material[28]. It was found that use of a lumbar roll that increases lumbar lordosis decreased low back pain [98]. Koo et al. [69] reported that repositioning of the lumbar support to redistribute the interface pressure and load is essential to prevent LBP development associated with inappropriate sitting in a working environment. Although lumbar supports improve lumbar lordosis, decrease intradiscal pressure[5-7], and may reduce paraspinal muscle hyperactivity[84], there is concern regarding the effectiveness of using lumbar supports alone[11,59; 5,23]. Furthermore, fixed-height lumbar supports are unlikely to provide a comfortable or appropriate seat for the wide range of potential users[5,23].

Makhsous et al. demonstrated that lumbar supports combined with an ischial release mechanism had a significantly greater effect in decreasing ischial pressure and correcting postural alignment[58,59]. Pilot study[58] showed that sitting concept brought forth a more evenly distributed contact pressure and a significantly reduced peak pressure under subject's buttocks, as well as increases in total and segmental lumbar lordosis

Inspired by the literature review and the encouraging preliminary results, the PI and co-investigators believed that this novel sitting concept could provide an effective solutions to the occupational sitting related LBP. The functional relations of the seat and backrest needed to be further investigated in order to provide the optimal posture correction effect during sitting.

In this project, the investigators proposed to investigate the biomechanical benefits of this new sitting concept, which increased lumbar spine lordosis and redistributed ischial load during sitting. Furthermore, the investigators attempted to study the clinical benefits to the LBP patients when using chairs equipped with this sitting concept.

To the investigators' knowledge, there is no chair other than the proposed one, which implements the adjustable mechanism for either ischial release or lumbar support, not to say the combination of them.

It was also expected that proper clarification of the biomechanical effect of this sitting concept would help to implement it into broader application area involved prolonged sitting tasks, such as wheelchairs and car driver seats.

General Methodology

Participants

The investigation was performed on altogether 33 patients with chronic low back pain (LBP) but with no other musculoskeletal system injury or disease. A group of 10 healthy subjects with no musculoskeletal disorders were tested as controls.

Participants recruitment and initial screening

Participants with LBP were all recruited by co-investigator Dr. Matthew Hepler, who is specialized in spinal disorders, from the outpatients of the Orthopaedics Department of Northwestern Memorial Hospital. Although several of the participants originally contacted the PI directly, they were all sent to Dr. Helper's office for screening. Only those with clear diagnosis of chronic LBP were included into the study. At the start of the study, all participants with LBP were evaluated with Oswestry (2.0) LBP Disability Questionnaire and 24-item Rolland-Morris Disability Questionnaire. Results of these scores are given in results section.

Study design

General description of the study design

The study in this project has two parts. One is the laboratory and radiological test, the other is a long-term take-home evaluation of the chair.

Load and muscle effort evaluation: In the laboratory experiment, load on sitting subject, on chair and muscle activities from the lower back were recorded continually for 1 hour. During this hour of sitting, the chair configuration was switched between 2 sitting postures every 10 minutes, i.e. **Normal** and **WO-BPS** postures (definitions follow).

Posture evaluation: In the radiological test, 3 lateral x-ray images were taken for the above mentioned postures and a **Standing** posture. The spinal lordosis and sacral tilting angle were measured in sagittal plan from these images.

Subjective evaluation: A chair was provided for each participant to take to his/her home or office to use for 12 weeks. Each week the subject filled a questionnaire form (see attached appendix A) regarding the therapeutic effect (alleviates or worsens the LBP, increases or decreases the sitting tolerance), and the chair function (meets the user's needs, adjustability, user friendly, etc).

The study chair and the posture definition

All data collection was carried out on the study chair which provides two major options for adjustability, one is the backrest, and the other is the seat. In addition to the general adjustment of the height of the backrest, the embedded air bladder in the backrest can be inflated and deflated to provide different degrees of lumbar support. The seat is divided into two parts, of which the back part of the seat (BPS) can be tilted down relative to the front part of the seat (FPS), to provide various degrees of ischial support.

Definition of the studied sitting postures provided by the study chair: Although the chair provides various configurations, the data collection was only carried out on two extreme configurations, i.e. **Normal** and **WO-BPS**.

- *Normal:* This configuration was chosen because it follows the concept of a regular chair with a flat seat and a flat backrest. It was achieved by keeping the BPS at the same level as the FPS, and deflating the lumber support bladder.

- ***WO-BPS:*** This configuration represents a new sitting concept with reduced ischial support plus enhanced lumbar support. This is the key posture the whole research was for (Fig. 1.). It was achieved by tilting down the BPS and inflating the lumber support bladder. Since the BPS is tilted down in this posture, much like the ischial support is removed to some degree, the posture was named as **WO-BPS**, stands for 'without BPS'. Although the adjustment of BPS and the lumbar bladder can be of many options, for standardizing the posture configuration and protocol, in the laboratory and radiological data collection for the **WO-BPS** posture, the BPS was tilted down to 20° relative to the FPS, and the lumbar bladder was inflated to the air pressure of 2.5 PSI above the atmosphere pressure. However, for the take-home evaluation, each subject chose the BPS tilting angle and the inflating status of the air bladder based on his/her own comfort expectation.

Methodology/Procedure by specific aims

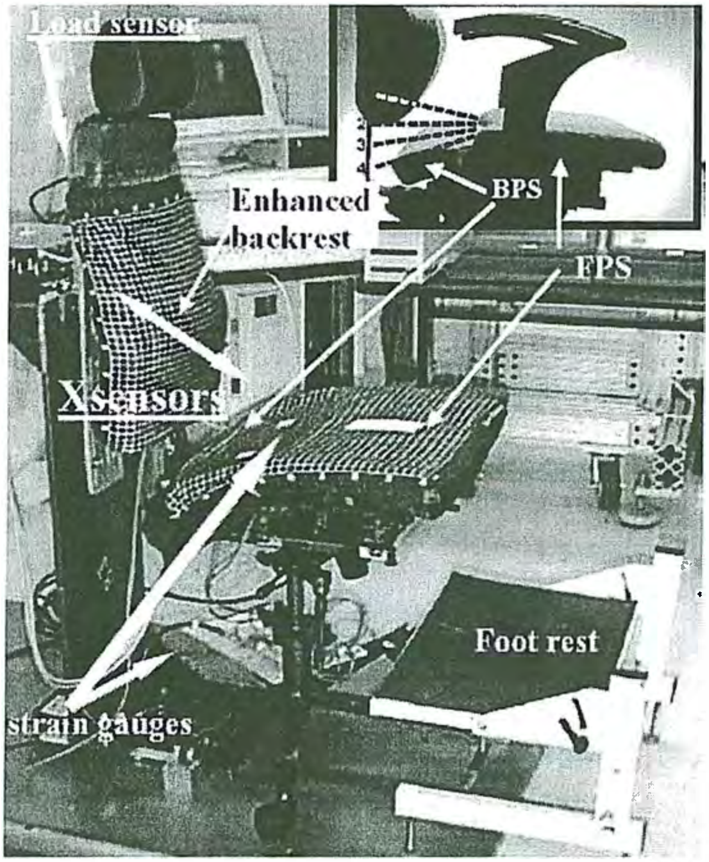
Specific aim 1 (SA1): **Laboratory evaluation of the loading condition and the muscle activity on the sitting subject, and the load taken by the chair in the Normal and WO-BPS postures.**

<u>Laboratory experimental setup</u>

<u>Laboratory Chair:</u> The chair used in ***Specific Aim 1*** was specially constructed for laboratory test, bearing the same sitting concept of the proposed study chair, i.e. with the adjustable backrest and the split seat pan and the adjustable BPS. The adjustment of the chair configuration was fully motorized with feedback control of the BPS tilting angle and the air pressure in the backrest air bladder. The control process was realized through a programmable logic controller (PLC) (Vision120, Unitronics Inc, MA) programmed with the manufacture provided software package, VisLogic®.

<u>*NOTE:* This automation of the experimental chair was not proposed in the original proposal, however, the PI found it necessary to achieve high reproducibility of the posture configuration, which is crucial to the data collection.</u>

<u>Load on the chair:</u> In order to find the load borne by the chair in a given sitting condition, the chair was instrumented with a 6-DOF force sensor (JR3 Inc., Woodland, CA) and 7 pairs of



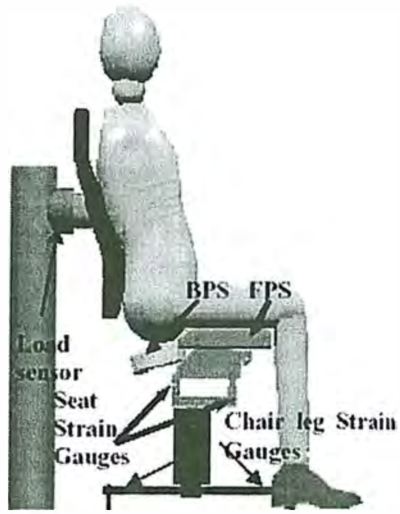


Fig. 1. Experimental setup for laboratory test (SA1). Left picture shows the actual experimental chair with Xsensor pressure mats on. It is shown in a WO-BPS configuration. The inset in the left figure demonstrates the adjusting angle of the BPS. Drawing above shows some details, also in WO-BPS posture.

strain gauges (Fig. 1 and 2).

- ***Load borne by the backrest:*** Load applied on the backrest when the subject was sitting in the chair was measured by the 6-DOF load sensor, which gave the readings of forces in 3 orthogonal directions and the moments about these axes.
- ***Total load borne by the chair:*** This total load was measured by 3 pairs of strain gauges, each installed on one leg of the chair stand (Fig. 2A).
- ***Load borne by the seat pan:*** Load exerted onto the seat pan was measured by 4 pairs of strain gauges installed between the seat pan and the chair stand (Fig. 2B)

NOTE: The method of measuring the load borne by the seat pan was different from what was originally proposed. It was proposed to measure the seat load by the second 6-DOF load sensor. However, at the starting stage of the project, the PI and his team found that installing a load cell between the seat and the chair stand would alter the structure of the chair stand and significantly challenged the stability of the chair. Besides, since the center of the load on the seat pan was also of interest, while the load cell had no capability to give that information, the PI and his team decided to change the setup of measuring the seat pan load to using 4 pairs of strain gauges installed between the seat pan and the chair stand. These 4 pairs of strain gauges were installed at the 4 corners on a rectangular frame right beneath the FPS of the seat pan, thus giving the capability to calculate the center of load on seat pan.

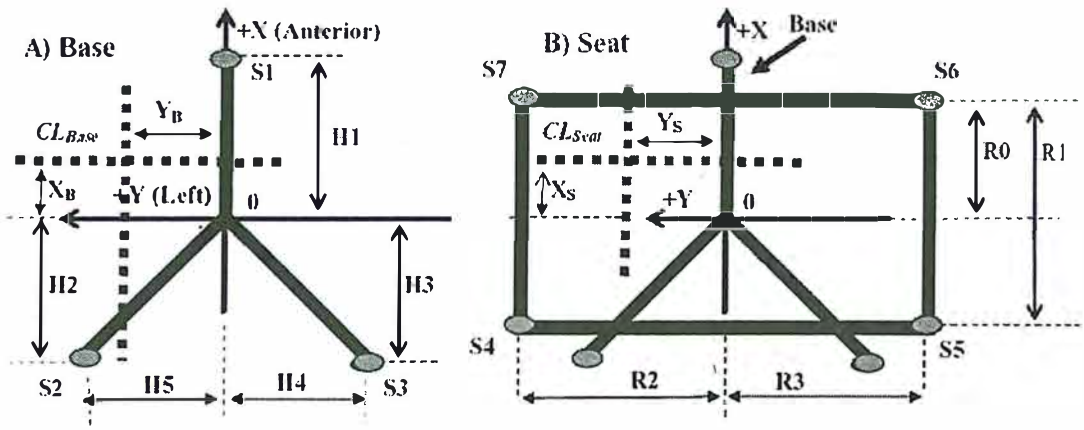


Fig. 2. Strain gauge location on the legs of the chair base and the frame of the seat. Strain gauge 1~3 were on the legs of the chair base; 4~7 were on the frame of the seat pan. X_B and Y_B define the location of Center of Load on the chair base (CL_{Base}); X_S and Y_S are for the location CL_{Seat}. Definition of the local coordinate system on the chair is shown above (also refer to the text for the definition).

Interface pressure on the seat and backrest: A pressure-mapping device (X2, Xsensor™ Technology Calgary, Canada) with two 36x36-cell mapping pads was used to measure the interface pressure between the seat and the subject's buttock-thigh and between the back support and the subject's back (Fig. 1, picture on the left).

Chair configuration and subject posture: As mentioned previously, the chair used in laboratory test was specifically constructed and the adjustment of the chair configuration was automated. The BPS position was continuously measured by a potentiometer. The air pressure inside the air bladder in the backrest was also read back from a pressure sensor inside the bladder. During the test, these two data were collected throughout the trial. Therefore, the chair configuration, though it was preset for each protocol, was also closely monitored. The subject was instructed to be relaxed and follow the change of the chair configuration.

NOTE: It was proposed in the original proposal that the chair position and the posture of the subject would be measured by a motion capturing system (Optotrak 3010, Northern Digital Inc., Ontario, Canada). However, the PI and the team modified the methodology to better fulfill the objectives of the specific aims and reduce unnecessary redundant measurement. In the current methodology, the Optotrak motion capture system was not used to measure the kinematics of the subject, nor for the chair. Reasons for this modification are:

- The chair was motorized with position feedback so the sensor on the chair accurately provided readings of the BPS position.
- Skin movement prevented accurate measurement of the pelvic rotation. In preliminary study, we selected very skinny subject to minimize the error. However, in current study, we targeted population with diverse body build. Also, the radiological imaging technique, which would be the methodology of ***Specific Aim 2***, would give precise measurement of the subject's posture in different chair configurations. Therefore, the PI and the team decided it was inaccurate and also redundant to use a motion capture system to measure the posture of the subject.

Back muscle activity: Surface EMGs were recorded bilaterally from the back paraspinal muscles at the level of T5, T8, L2, and L5, using a surface EMG system (Delsys Inc, USA). In thoracic region, the EMG electrodes were placed 3 cm lateral to thoracic spinous process. In lumbar region, they were 2 cm lateral to lumbar spinous processes (Fig. 3). With the subject in relaxed sitting position the spinous processes were marked and the exact sites for the electrodes were identified. A common reference electrode was placed at the spinous process of C7 (not shown in the figure).

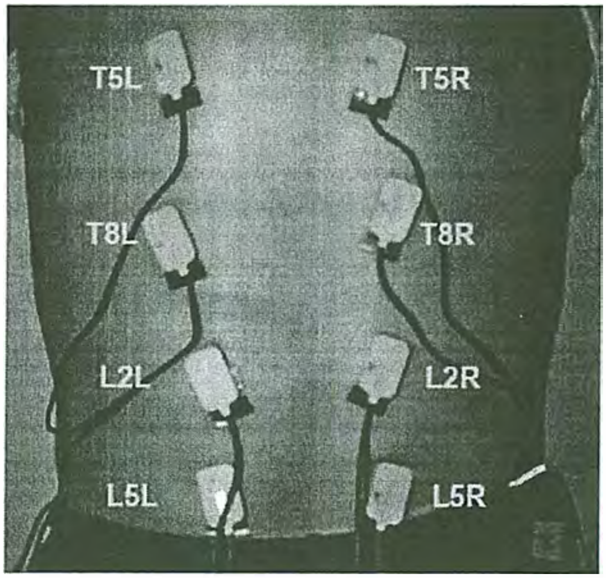


Fig. 3. Surface EMG electrodes on the back of a subject.

Experimental protocol

First, patient sit in a comfortable position on the seat with the chair configured as **Normal**. Then the height and shape of backrest were adjusted and the tip of the backrest was located at L2-L4 level of the lumbar spine. The seat depth was adjusted to make the seat pan short enough for knee clearance and with a waterfall front edge and with ischia locating as close as possible to the center of BPS. Thighs were approximately parallel to the floor and with feet resting firmly on the footrest.

With the subject sitting stable, a starting configuration of the chair was randomly chosen as either **Normal** or **WO-BPS**, and then the trial started. During the 1-hour trial, the chair configuration was switched from one to the other every 10 minutes. Data collection was performed continuously throughout the trial. The load on chair (both from load sensor and the strain gauges), the BPS tilting angle, and the air pressure inside the air bladder in the backrest were acquired at 100Hz. The EMG was sampled at 500 Hz. The pressure distribution on the seat and the backrest was recorded at a 1Hz frame rate.

NOTE: It was proposed in the original proposal that the data collection would be done at the **Normal** chair configuration and continued until several seconds after the chair was manually configured to the **WO-BPS** posture. Then the trial would be repeated 3-4 times. Since the chair configuration was automated, the data collection could be performed continuously without being disturbed by switching the configuration manually. Also, randomly choosing the starting posture made the data collection more reliable and robust to errors.

NOTE: It was proposed in the original proposal that the participants would be assigned to two sitting groups, 'Upright with proper adjusted backrest', and 'Upright with flat backrest'. Therefore, by changing the chair configuration from 'BPS level' to 'BPS down', it actually suggested data collection at 4 different postures, i.e. 'flat lumbar support + BPS level', 'flat lumbar support + BPS down', 'protruded lumbar support + BPS level', and 'protruded lumbar support + BPS down'. However, after the project started, the PI and the team re-examined the study design and the data from the first several subjects, and the feedback from the participants, it was found that collecting data from two of the postures, **Normal** and **WO-BPS**, which are 'flat lumbar support + BPS level' and 'protruded lumbar support + BPS down' would be more efficient and reasonable. The reasons are:

- When the subject took the 'flat lumbar support + BPS down' configuration, he/she would inevitably sink down along with the titled down BPS, which resulted in an awkward uncomfortable sitting posture, and the hypothesized ischial releasing effect of tilting down the BPS would not work. However, since some data collection had already done (mainly the EMG) with the 'flat lumbar support + BPS down' configuration, this part of the results will be reported in the Results section of this report;
- When the subject took the 'protruded lumbar support + BPS level' configuration, he/she would be pushed forward by the protruded lumbar support, which referred by the participants as uncomfortable and unstable;
- Moreover, it would be more efficient to do the comparison of the data collected in different sitting postures from the same subject. It would be less reasonable to assign different sitting posture to different subject.

Therefore, it was decided that there had been enough reasons to discard the two postures as 'flat lumbar support + BPS down' and 'protruded lumbar support + BPS level'. Final data collection was carried out only in the configurations of **Normal** and **WO-BPS**, in which the former represented a typical regular sitting concept and the latter used fully the proposed new sitting concept. However, since some data collection had already done (mainly the EMG) with the 'flat lumbar support + BPS down' configuration, this part of the results will be reported in the Results section of this report. Also, the participant would not be assigned to different groups taking different postures.

Data processing

A local coordinate system embedded on the chair was defined. The origin of this system was at the center of the upper surface of the seating pan. For backrest, the origin was at the center of the anterior surface of the backrest. X and Z-axis pointed to the anterior and superior, respectively. Y-axis pointed to the left laterally. Coordinate system is also shown in Fig. 2 and Fig. 5.

Load borne by the backrest: Raw data from the load cell were low-pass filtered at 30Hz cut-off and transformed into the above defined local coordinate system with components in the medial-lateral (Fy), the superior-inferior (Fz) and posterior-anterior (Fx) directions.

Load borne by the seat pan: Raw data from the 4 pairs of strain gauges were low-pass filtered at 30Hz cut-off and converted to measures of forces based on calibration data. Center of load on the seat pan (***CL_{Seat}***) was then calculated based on the force readings and the dimension of the frame on which the strain gauges were mounted (Fig. 2 & Equation 1).

Load borne by the chair: Raw data from the 3 pairs of strain gauges were low-pass filtered at 30Hz cut-off and converted to measures of forces based on calibration data. Center of load for the whole chair (***CL_{Base}***) was then calculated based on the force readings and the dimension of the chair legs on which the strain gauges were mounted (Fig. 2 & Equation 1).

$$F_i = S_i \times c_i : \quad S_i = strain\ gage\ reading;\ c_i = calibration\ factor$$

$$F_{BaseTotal} = F_1 + F_2 + F_3 \ ; \quad F_{SeatTotal} = F_4 + F_5 + F_6 + F_7$$

$\underline{CL_{Base}}$

$$X-direction: \quad X_{Base} = \frac{F_1H_1 - F_2H_2 - F_3H_3}{F_{BaseTotal}}$$

$$Y-direction: \quad Y_{Base} = \frac{F_2H_5 - F_3H_4}{F_{Base\,Total}} \qquad \text{...... Equation (1)}$$

$\underline{CL_{Seat}}$

$$X-direction: \quad X_{Seat} = R_O - R_1\frac{F_4 + F_5}{F_{SeatTotal}}$$

$$Y-direction: \quad Y_{Seat} = \frac{R_2(F_4 + F_7) - R_3(F_5 + F_6)}{F_{Seat\,Total}}$$

Pressure on the seat and backrest: Raw data from the pressure mapping pads was used to calculate several pressure distribution parameters on seat and backrest, i.e. total contact area (TCA), peak contact pressure (PP), anterior-posterior location of the peak pressure shift (X_{PP}) on seat, superior-inferior location of the peak pressure on the backrest (Z_{pp}) and average pressure (AP).

NOTE: A new method to analyze the interface pressure on the seat has been added, in addition to the proposed methodology. Three evenly divided regions (A: anterior, M: middle, and P: posterior) were defined horizontally on the seat. The TCA, AP and PP were also calculated for each of the three regions. The rationale to add this new method of analyzing the interface pressure on the seat was for further quantifying pressure distribution characteristics on the seat for different sitting posture (chair configuration). It was shown preliminarily that the **WO-BPS** posture relieved the load from the ischia by sharing the load with thighs and back. Therefore, it would be helpful to have the new method in analyzing the interface pressure distribution.

Muscle activity: EMG data were first low-pass filtered at the 230Hz and then the envelope of the EMG signal was extracted for each trial.

NOTE: It was proposed in the original proposal that the EMG data would be calibrated to the Maximum Voluntary Contraction (MVC) data. However, since the EMG data would be compared only between those recorded in the 2 sitting postures from the same subject, there was no need to calibrate the data by MVC values. In addition, it was found that the LBP participants tended to complain that the MVC procedure induced their back pain.

Statistical analysis

Paired t-test with two tails was used to detect any posture effect on all the laboratory measurements. The significant level was setup as 0.05. The analysis was done with SAS software (SAS Institute, Cary, NC). Statistica (Stat Soft, Inc., Tulsa, OK) was used *post hoc* power analysis and sample estimation to check if the study design had enough power and sample size to detect the changes.

Specific aim 2 (SA2): **Evaluating the body posture in lumbar-sacrum region in the *Normal* and *WO-BPS* sitting postures by radiological imaging.**

Sagittal plane (lateral view) X-ray images were used to identify landmarks on the pelvis and lumbar spine to determine the pelvic inclination, lumbar lordosis and the intervertebral height. Besides the **Normal** and **WO-BPS** postures, a third posture, the **Standing** posture, was also used.

NOTE: In the original proposal, radiological evaluation of the posture was only proposed to perform in the **Normal** and **WO-BPS** postures. During the study, the PI and the team realized that it would be very informative to make a comparison of the posture data with those from the **Standing** posture, since the **Standing** posture is when the loads on the spine remains low, compared with any sitting posture [66]. Therefore, **Standing** posture was added to the experiment.

Experimental setup

An office chair with the proposed sitting concept was used for this experiment. Lateral X-ray images focusing on lumbar-pelvic region were taken for the seated subject while the chair was configured as the **Normal** and **WO-BPS** postures. Another image was taken when the subject was standing straight up allowing for physiological alignment of the spine.

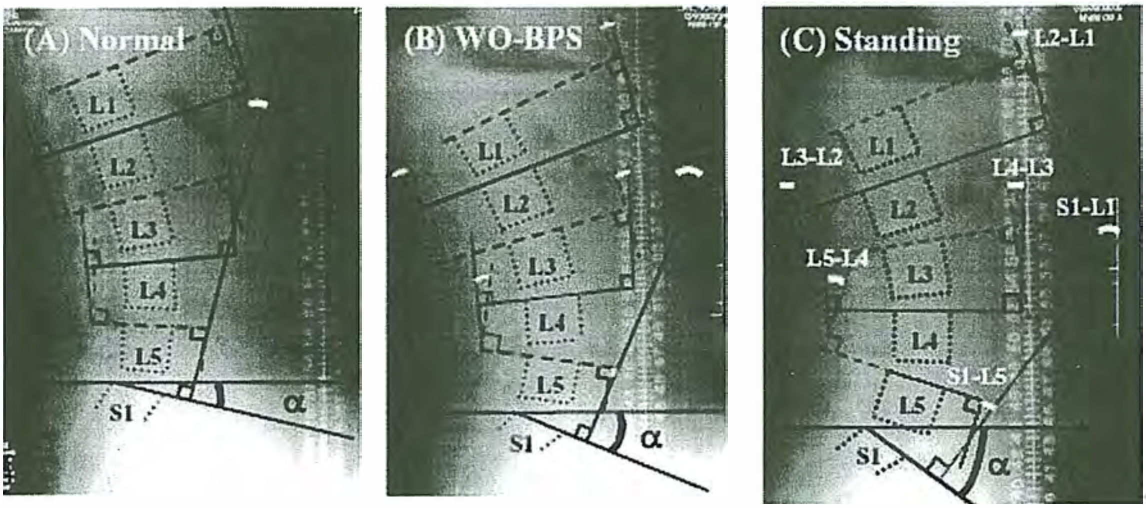


Fig. 4. The sacral inclination (α) and the lumbar lordosis were calculated by the traditional Cobb's technique. Measurement was done in the Normal (A), the WO-BPS (B), and the Standing (C) postures.

Data processing

Digital images of X-ray were loaded on computer screen and critical bony landmarks on lumbar spine, the sacrum, and the pelvis were digitized by custom made Matlab code. The sacral inclination, the lumbar lordosis (segmental and total), and the disc height were calculated, as demonstrated in Fig. 4.

The sacral inclination (α): It is used to describe the orientation of the buttocks. As shown in Fig. 4, α is defined as the angle between the sacral endplate and a horizontal line intersecting the top of the sacrum at the posterior corner. [7].

The lumbar lordosis: The curvature of the lumbar spine was described by the traditional Cobb's technique, which is commonly used for curvature analysis on lateral lumbar radiographs [36]. Total lumbar lordosis, i.e. the angle between a line through endplate of the first lumbar vertebra (L1) and a line through the endplate of the sacrum (S1), and segmental lordotic measurements were made in similar fashion from L2 to L1, L3 to L2, L4 to L3 and L5 to L4 (Fig.4C).

Disc height: Intervertebral disc height was obtained from the average of dorsal and ventral disc height according to the Dabbs method [17,26].

Statistical analysis

ANOVA with repeated measures was used to detect any posture effect on all the radiological measurements. After that, a paired t-test was performed on the data from each possible pair of posture to determine the statistical significance of posture induced difference. The significant level was setup as 0.05.

The analysis was done with SAS software. ANOVA with repeated measures from the 'Mixed' procedure was used. The repeated variable was 'posture'. T-test was also performed with SAS software.

Specific aim 3 (SA3): **Subjective evaluation of using the proposed office chair with adjustable ischial and lumbar supports.**

The subjective evaluation and impressions gained from the use of such a sitting design from LBP patients and health controls were collected through questionnaire for a period of 12 weeks.

During laboratory test, each participant had been trained to be familiar with sitting with released buttock load on a study chair and educated to adjust the BPS and lumbar support. When consented, a study chair was scheduled to be delivered to the participant's home or office, where he or she sits most of the time. Each participant filled a questionnaire weekly for 12 weeks.

Description of the questionnaire

The questionnaire used in this project has been redesigned with great improvement. The original questionnaire proposed in the proposal had 11 questions covering sitting comfort, pain and sitting tolerance. However, during using this questionnaire, the PI and the team found that some questions were formulated in a way that the participant could not come to an appropriate response. For example, the 2nd question was asking the participant whether he/she felt more natural sitting with this new concept chair, which was difficult to get a response. Therefore, the questionnaire has been totally redesigned with the help of professional consultant who is highly experienced on questionnaire design.

The new questionnaire is shown in appendix A. It maintained the same focus on the sitting comfort, pain characteristics, and sitting tolerance. For each question, there were 5 options for the participant to choose for the one most matching his/her opinion; each had a score from 1 to 5.

Major improvements are:

- More questions regarding how easy/difficult to use the new chair were added.
- The way of taking response from the participant was also changed. Two methods of gauging the participants' assessment of the chair were used.
    - ***Participant's agreement to statement:*** This method focused on participant's satisfaction of the chair by asking the participant to what degree he/she agreed a statement.
    - ***The frequency experiencing a stated situation:*** This other method paid more attention to how frequently a situation described in the questionnaire was experienced by the participant.

  These two methods were used for each of the questions regarding different aspect of using the chair.
- Detailed instructions were added to each section for easy completion of the questionnaire by the participant him/herself without the help of an interviewer.
- Clearly affirmed the participant that there was no right or wrong answer to any of the question.
- Participant's name was replaced with a participant code to protect their privacy.
- Five other free-answer format questions were added for optional response to collect more feedback from the first-hand users.

The newly designed questionnaire was used for the final data collection for all subjects who participated in the subjective evaluation part of the study.

Data processing

Responses from each subject to each question along the entire 12-week period were first examined before any statistical analysis. Responses were organized in 5 categories:

Category 1: Great improvement seen from the 1st week, but no further improvement/worsening ever since;

Category 2: Started from slight improvement, no improvement or even negative, gradually improved along the trial of 12-week usage of the chair;

Category 3: Kept no improvement, neither worsening, i.e. no effect at all;

Category 4: Worsened in any way.

This categorization is necessary for later statistical analysis. Categories 1 and 3 do not contribute to any statistical results since there was virtually no change along the trial. Categories 2 and 4 both contribute to the statistical results; however, the trends of change are in the opposite directions.

Since healthy controls did not have sitting related pain complains, questionnaires collected from them were only processed for those questions regarding overall sitting comfort and chair function and usage.

Statistical analysis

Table analysis for analyzing categorical data was used to obtain Cochran-Mantel-Hazenszel Statistics along the entire course of the 12 weeks. Data analysis was stratified by 'subject' with the row variable as the 'week', and the column variable as the 'score'. Week mean scores difference was examined. The significant level was setup as 0.05.

As mentioned above, since data in categories 1 and 3 do not contribute to statistical results, only data of categories 2 and 4 were performed statistical analysis. The analysis was done with SAS software. Table analysis from the 'Frequency' procedure was used.

Results of participants' information

General information

33 volunteers with complains of severe LBP and limited sitting tolerance participated in this study. All of them were diagnosed as chronic LBP and suffered from various degrees of disability due to their low back disorders. All subjects gave informed consent before participating in the study.

Of the 33 tested LBP participants, 8 of them had invalid data for laboratory and/or radiological test and were excluded from the final data processing (reasons follow), 28 of them also consented participating in the long-term take-home evaluation of the study chair. Among these 28 individuals, 4 were excluded from the final data analysis (reasons follow). Therefore, the final data set includes data from 25 LBP participants and 12 healthy volunteers as control for laboratory and radiological data, 24 LBP participants and 12 healthy controls for subjective evaluation.

Table 1. Participants' information

Group	Number	Gender	Age (year)	Weight (kg)	Height (cm)	Oswestry score	24-item Rolland-Morris score
LBP	25 Laboratory evaluation	15 female 10 male	41.3±12.1	72.1±12.6	168.0±8.5	18.4 ± 11.5 (N=15, sex life included)	8.0 ± 4.4 (N=22)
	24 Subjective evaluation	14 female 10 male	40.8±12.1	71.7±12.7	167.9±8.7	16.9 ± 9.6 (N=22, sex life not included)	
Control	10 Laboratory evaluation	2 female 8 male	30.5±7.8	80.6±13.2	175.5±9.1	N/A	N/A
	12 Subjective evaluation	4 female 8 male	32.3±8.3	78.5±13.3	174.5±8.5		

<u>Participants excluded from the final data set</u>

<u>Laboratory and radiological experiment:</u> 8 of the 33 tested LBP subjects were excluded from the final data analysis due to several reasons. 1 of them was found beyond the age range of participant inclusion criteria (at the time of test, this individual was actually 71 years old, which was 1 year older than the proposed inclusion criterion of 18-70). The others were excluded because of lack of all set of laboratory and radiological test data, i.e. for these 7 individuals, either they were not able to fulfill 2 visits for both lab and radiological test, or one or more measurements were missing from the test (4 different measurements should be performed in each of the lab test protocols, and 3 postures should be imaged during the radiological measurement) due to equipment failure or other factors.

Subjective evaluation of the new chair: 4 of the 28 participated individuals with LBP were excluded from the final analysis. 1 of them was the same individual found over the age range. Another individual was found to be of a very tiny body size which made her very difficult to fit in the chair, therefore, the data was not valid. The other two withdrew the long-term study due to personal reasons unrelated to the study (one job-relocation, the other was too busy to sit in his chair.).

Initial evaluation of the participants with LBP

Oswestry (2.0) LBP Disability Questionnaire

22 of the 25 participants with LBP who completed Oswestry Questionnaire had valid data. 7 of them opted not to answer the section 8 of this questionnaire, which was about their sex life. Average Oswestry score for participants with LBP was 18.4 ± 11.5 (N=15) for those with question of sex life answered and 16.9 ± 9.6 (N=22) for all LBP participants, including those chose not to answer the question of their sex life.

The average Oswestry score of our patient population shows that the participated LBP subjects for this project were generally among those with minimal disability due to their LBP. When looking into more details, 7 of the LBP subjects reported Oswestry score greater than 20 and less than 40, indicating that about 1/3 of our patient population experienced moderate disability due to LBP. One patient reported an Oswestry score as 40, which put him close to the edge of being classified as severely disabled by LBP [31,73].

Roland-Morris LBP Disability Questionnaire

22 of the 25 participants with LBP who completed Roland-Morris Questionnaire (RMQ) had valid data. Average RMQ score for participants with LBP was 8.0 ± 4.4 (N=22) for all LBP participants. The highest RMQ score was 17 for two of the subjects.

The average RMQ score of our patient population shows that the participated LBP subjects for this project were very likely to have LBP due to mechanical factors [73,85].

Results and Discussion

Results by specific aims

In most of the tables listing the results, P values for the comparison between the data from **Normal** and **WO-BPS** postures are given as 'P (N vs. W)'. Since two groups of participants were tested, a comparison for testing the group effect was also reported as 'group effect' in the tables and/or mentioned in the text. For giving a better overall assessment for the data collection and the study design, *post-hoc* power analysis and sample size estimation were also performed and reported for most of the measurements. This *post-hoc* sample size estimation was based on assumption that if 90% 'Power' was expected. 'Power' was calculated for both the healthy controls and LBP subjects assuming the α=0.05, and N=10 for healthy controls and N=25 for LBP subjects using a two-sided paired *t*-test. 'Effect size', i.e. changes able to detect assuming 90% power, and α=0.05, was calculated for healthy controls and LBP subjects using a 2-sided paired *t*-test. For radiological data, one-way ANOVA was performed to calculate the 'Power' and estimate the 'Sample Size'.

For statistical analysis done by ANOVA, generally, F value and degree of freedom (DF) are listed in the table. For those done by t-test, t values were given instead. For some of the over-complicated tables, t values and DF are ignored for the simplicity.

Specific aim 1 (SA1): **Laboratory evaluation of the loading condition and the muscle activity on the sitting subject, and the load taken by the chair in the *Normal* and *WO-BPS* postures.**

SA1-1. Loading conditions on the chair

The results of the load applied on the seat pan, the backrest and the chair base are shown in Table 2 and 3. Table 2 shows the load borne by the seat pan and the chair base measured by the strain gauges. From the strain gauge readings, the center of load on the seat (CL_{Seat}) and the center of load on the chair base stand (CL_{Base}) are also calculated for both the medial-lateral and anterior-posterior directions. Table 3 shows the load borne by the backrest measured by a 6-DOF force sensor in the medial-lateral, the superior-inferior and posterior-anterior directions. Since the changes induced through using the **WO-BPS** posture, relative to the values of the **Normal** posture, are those of concern, only these changes are listed in the tables.

Center of load on the seat and the chair base

From the results, it can be seen that, while sitting in **WO-BPS** posture, the center of load was shifted significantly ($P < 0.001$) forward (CL_{Seat-X} & CL_{Base-X}: center of load shift in X direction, i.e. posterior to anterior) from that in the **Normal** sitting posture, both on the seat pan and on the chair base. On the seat pan, this forward center of load shift was more than 4 cm for both LBP and Control groups, and on the base stand of the chair, this shift reached approximately 9 cm for both groups. Although it always has larger forward load shift in LBP group than that from Control, no significant group difference was found ($P > 0.05$).

The center of load shift in lateral (left-right) direction induced by the sitting posture change was very small. The CL_{Seat-Y} (center of load shift in Y direction, i.e. right to left) on seat pan for LBP and Control groups were -0.20 ± 0.05 cm and -0.25 ± 0.10 cm, respectively. Those (CL_{Base-Y})

on the chair base were -0.29 ± 0.13 cm and -0.26 ± 0.18 cm, respectively. Therefore, comparing with that in anterior-posterior direction, the center of load shift in left-right direction caused by using **WO-BPS** posture can be ignored.

Load on the seat and the chair base

Table 2 also shows that the load on the chair base decreased significantly (P < 0.001) from the value in the **Normal** sitting posture by more than 30 N, when the **WO-BPS** posture was taken. Similarly, the load borne by the seat pan shows a drop in the **WO-BPS** posture, from that of the **Normal** posture. However, this load decrease on seat pan in Control group, which had an average value about 4 N, did not show any statistical significance (P > 0.05), while this load

Table 2. Load parameter changes induced by WO-BPS posture. Part I: Load on the Seat and the Base.

Changes of load parameters	Control (N=10)	LBP (N=25)
CL_{Base-X} (cm)	8.86±0.93	9.87±0.55
P (N vs. W)	<0.001	<0.001
P of group effect	> 0.05	
t	-9.49	-17.57
DF	9	24
Power	100%	100%
Effect size	9.53	17.94
Sample size	3	2
CL_{Seat-X} (cm)	4.25±0.44	4.46±0.26
P (N vs. W)	<0.001	<0.001
P of group effect	> 0.05	
t	-9.71	-15.76
DF	9	24
Power	100%	100%
Effect size	9.66	17.15
Sample size	3	2
Load on base (N)	-32.47±5.21	-39.38±3.60
P (N vs. W)	<0.001	<0.001
P of group effect	> 0.05	
t	6.24	11.20
DF	9	24
Power	100%	100%
Effect size	-7.71	-10.94
Sample size	3	3
Load on seat (N)	-4.27±4.99	-11.93±2.63
P (N vs. W)	> 0.05	<0.001
P of group effect	> 0.05	
t	0.86	4.65
DF	9	24
Power	67%	100%
Effect size	-0.86	-4.53
Sample size	17	3

Table 3. Load parameter changes induced by WO-BPS posture. Part II: Load on the backrest.

Changes of load	Control (N=10)	LBP (N=25)
Lateral load (N)	-1.32±0.86	-0.74±0.68
P (N vs. W)	0.160	0.332
P of group effect	> 0.05	
t	1.53	0.99
DF	9	24
Power	99%	100%
Effect size	-1.53	-1.09
Sample size	7	11
Superior load (N)	-22.25±1.44	-24.17±1.93
P (N vs. W)	< 0.001	<0.001
P of group effect	> 0.05	
t	15.45	12.09
DF	9	24
Power	100%	100%
Effect size	-15.45	-12.52
Sample size	2	3
Posterior load (N)	66.79±5.57	66.65±3.46
P (N vs. W)	< 0.001	<0.001
P of group effect	> 0.05	
t	11.99	19.38
DF	9	24
Power	100%	100%
Effect size	-11.99	-19.26
Sample size	3	2
Total load (N)	69.66±5.57	68.01±4.16
P (N vs. W)	< 0.001	<0.001
P of group effect	> 0.05	
t	-12.51	-16.35
DF	9	24
Power	100%	100%
Effect size	12.51	16.35
Sample size	3	2

decrease on seat pan in LBP group presented a larger value (almost 12 N) and a statistical significance ($P < 0.001$). Same as the situation in the CL parameters, no significant group difference was found ($P > 0.05$) for the load magnitude changes on the seat pan and the chair base, though always a larger load decrease was found in LBP group than that from Control group.

Load on the backrest

Table 3 gives the load changes induced by sitting in the **WO-BPS** posture, relative to those from the **Normal** posture. It shows that the load on the backrest increased significantly ($P < 0.001$) from the value in the **Normal** sitting posture in the inferior and the posterior directions, when the **WO-BPS** posture was taken. The load increase in the inferior and posterior directions were in the scale of more than 20 N and 60 N, respectively. Similarly, the total load borne by the backrest shows a significant increase of nearly 70 N in the **WO-BPS** posture, from that of the **Normal** posture.

At the same time, the load borne by the backrest showed virtually no change in the lateral (left-right) direction ($P > 0.05$).

SA1-2. Interface pressure between the seat and the subject's buttock-thigh, and between the backrest and the subject's back

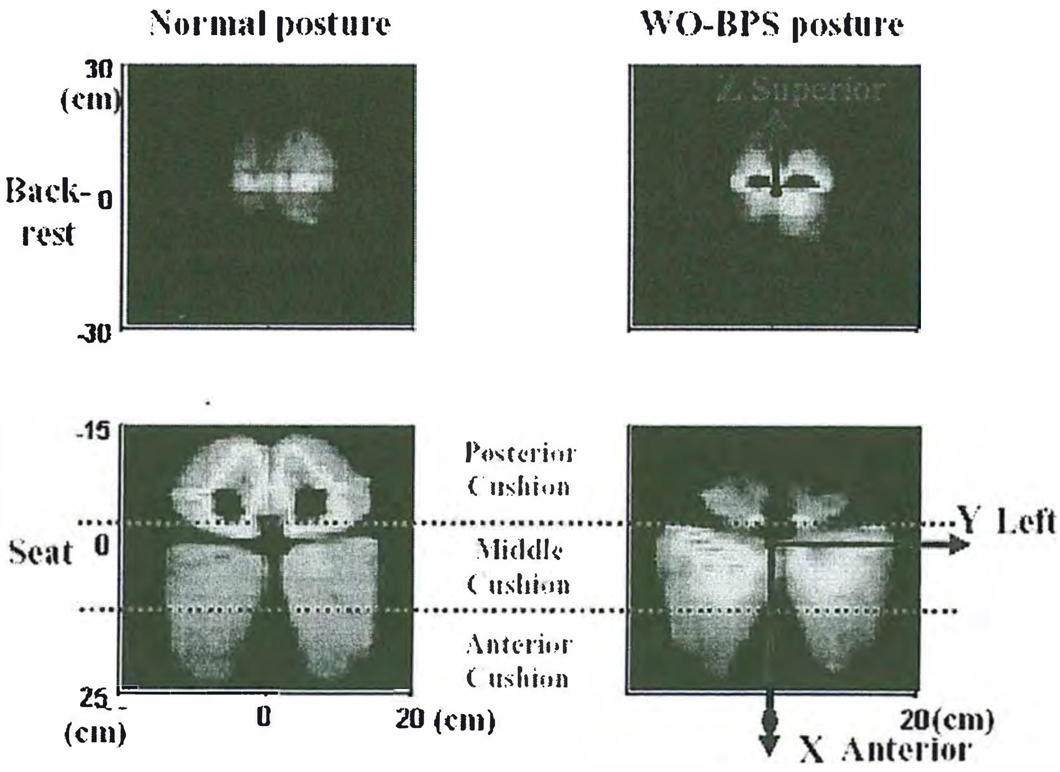


Fig. 5. Representative data of interface pressure from a subject. Upper row: interface pressure between the backrest and the subject's back. Lower row: interface pressure between the seat cushion and the subject's buttock-thighs. Left column: interface pressure recorded in Normal sitting posture. Right column: interface pressure recorded in WO-BPS sitting posture. Recordings were done in the same trial. For each posture, pressure maps from the backrest and the seat were recorded at the same time.

Representative results

A representative interface pressure recorded from a subject is shown in Fig. 5. In this figure, the axes of the local coordinate system are also plotted. Actual dimensions of the pressure maps are given. In the pseudo-colored pressure maps, the more towards the red color, the higher the contact pressure.

From this typical pressure map, it is clearly shown that in the **Normal** sitting posture, the

Table 4 Average changes (in percentage except the location of PP, mean ± SE) of parameters regarding interface pressure induced by WO-BPS posture. Part I: Interface pressure on the seat.

Changes of Pressure Parameters	Control (N=10)				LBP (N=25)			
	Whole Cushion	Anterior cushion	Middle cushion	Posterior cushion	Whole cushion	Anterior cushion	Middle cushion	Posterior cushion
TCA (%)	-12.59±2.41	-0.18±3.07	9.82±2.19	-37.85±6.35	-10.24±0.83	0.99±0.85	4.27±1.08	-30.33±2.63
P (N vs W)	<0.001	> 0.05	<0.001	<0.001	<0.001	> 0.05	0.002	<0.001
P group effect	> 0.05	> 0.05	0.002	> 0.05				
t	5.74	0.14	-5.69	6.94	12.50	-1.05	-3.55	14.16
DF	9	9	9	9	24	24	24	24
Power	100%	5%	100%	100%	100%	100%	100%	100%
Effect size	-5.22	-0.06	4.48	-5.96	-12.34	1.16	3.95	-11.53
Sample size	3	3059	3	3	3	9	3	3
AP (%)	1.52±2.81	17.01±3.13	43.49±3.74	-32.09±6.35	2.31±1.86	13.03±1.66	40.91±2.81	-31.41±4.68
P (N vs W)	> 0.05	<0.001	<0.001	<0.001	> 0.05	<0.001	<0.001	<0.001
P group effect	> 0.05	0.012	> 0.05	> 0.05				
t	-0.61	-5.66	-12.51	4.85	-1.16	-7.19	-16.66	5.98
DF	9	9	9	9	24	24	24	24
Power	33%	100%	100%	100%	100%	100%	100%	100%
Effect size	0.54	5.43	11.63	-5.05	1.24	7.85	14.56	-6.71
Sample size	38	3	3	3	9	3	3	3
PP (%)	-4.29±1.57	24.66±6.48	27.80±7.60	-17.87±4.76	2.40±3.55	26.68±4.64	40.85±8.82	-16.20±4.10
P (N vs W)	0.027	0.002	0.002	0.004	> 0.05	<0.001	<0.001	<0.001
P group effect	> 0.05	> 0.05	> 0.05	> 0.05				
t	2.64	-4.26	-4.26	3.93	-0.05	-5.42	-5.70	3.97
DF	9	9	9	9	24	24	24	24
Power	100%	100%	100%	100%	90%	100%	100%	100%
Effect size	-7.53	6.48	3.66	-3.75	0.68	5.75	4.63	-3.95
Sample size	3	4	4	4	25	3	3	3
Anterior location of PP (cm)	5.05±0.78				5.4±0.91			
P (N vs W)	<0.001				<0.001			
P group effect	0.029							
t	-6.44				-5.93			
DF	9				24			
Power	100%				100%			
Effect size	6.47				6.5			
Sample size	3				3			
Lateral location of PP (cm)	-0.28±1.33				-0.02±1.14			
P (N vs W)	> 0.05				> 0.05			
P group effect	> 0.05							
t	0.21				-0.45			
DF	9				24			
Power	10%				5%			
Effect size	-0.21				-0.018			
Sample size	240				34141			

Table 5 Changes (in percentage) of parameters regarding interface pressure induced by WO-BPS posture. Part II: Interface pressure on the backrest.

Changes of Pressure Parameters	CONTROL (N=10)	LBP (N=25)
TCA (%)	4.81 ± 4.24	4.56 ± 4.12
P (N vs W)	> 0.05	> 0.05
P group effect	> 0.05	
t	-0.86	-0.70
DF	9	24
Power	100%	100%
Effect size	1.13	1.11
Sample size	11	11
AP (%)	61.05 ± 15.45	44.10 ± 9.06
P (N vs W)	0.002	<0.001
P group effect	> 0.05	
t	-4.39	-23.27
DF	9	24
Power	100%	100%
Effect size	3.95	4.87
Sample size	3	3
PP (%)	10.80 ± 7.39	18.28 ± 10.19
P (N vs W)	> 0.05	> 0.05
P group effect	> 0.05	
t	-1.05	-1.48
DF	9	24
Power	100%	100%
Effect size	1.46	1.79
Sample size	8	6
Superior location of PP (cm)	1.19 ± 0.54	3.54 ± 0.55
P (N vs W)	> 0.05	<0.001
P group effect	> 0.05	
t	-2.21	-6.43
DF	9	24
Power	100%	100%
Effect size	2.30	6.44
Sample size	5	3
Lateral location of PP (cm)	-0.19 ± 0.76	-0.70 ± 0.39
P (N vs W)	> 0.05	> 0.05
P group effect	> 0.05	
t	0.24	1.78
DF	9	24
Power	11%	100%
Effect size	0.25	1.79
Sample size	171	6

buttocks of the subject were subjected to the highest pressure load, with the two highest pressure spots as the ischial tuberosities. When the subject took the **WO-BPS** posture, sitting contact pressure was shifted more towards the anterior part of the seat-buttock-thigh interface. At the same time, the sitting load was shared more by the back-backrest interface.

Average results

Average results of total contact area (TCA), average pressure (AP), peak pressure (PP), and the location of the PP are reported in Table 4 and 5, for the seat pan and the backrest, respectively. Similar to what was given for the loading data, since the changes induced through using the **WO-BPS** posture, relative to the values of the **Normal** posture, are those of concern; only these changes are given in the tables.

Average results on the seat cushion (Table 4)

When sitting in the **WO-BPS** posture, TCA on the seat decreased by more than 10% with statistical significance ($P < 0.001$) for both Control and LBP groups and AP showed virtually no change (less than 2.5% change with $P > 0.05$), compared with those in **Normal** posture. PP in Control group showed a small but significant decrease by about 4%, while PP for the LBP group experienced a slight increase (2.4%) with no statistical significance. The location of PP showed the same trend of being shifted forwardly towards the thighs in both LBP and Control groups. This anterior shift of the PP was about 5cm for both groups with statistical significance ($P < 0.001$) (Fig. 6). Similar to what was found for the load on the seat, the changes of the PP location in lateral (right to left) direction was substantially smaller than that in the anterior direction. They were -0.28 ± 1.33 cm and -0.02 ± 1.14 cm, respectively for Control and LBP groups. The lateral shift of the location of PP in neither of the groups showed statistical significance ($P > 0.05$).

Fig. 6 shows the anterior shift of the PP location on the seat and the CL_{Seat}. Although these two parameters are from difference measurement, contact pressure and load carried by the seat, respectively, they showed the same changing pattern when **WO-BPS** posture was used.

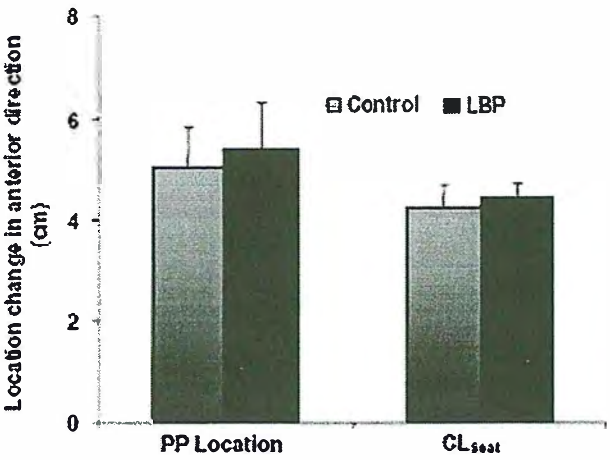


Fig. 6. Change of PP location and CL_{Seat} in anterior direction, induced by the WO-BPS posture.

Looking into more details of the interface pressure distribution on the seat pan, it is found that changes of the pressure distribution parameters within each seat region were not in the same trend. Details of changes in each seat region are described separately.

Anterior region of the seat cushion: In both Control and LBP groups, there was no changes for TCA (less than 1% of changes, both with $P > 0.05$) when comparing the readings in **WO-BPS** posture to that from the **Normal**. The AP significantly increased along with a substantial increase of the PP. All these increases showed statistical significance ($P < 0.01$). There was no difference between the groups, except for AP with an increase in Control group about 4% higher than that from the LBP group, with a statistical significance ($P = 0.012$).

Middle region of the seat cushion: In both Control and LBP groups, there was a significant increase for TCA (almost 10% in Control group and about 4% in LBP group, with $P < 0.001$ and $P = 0.002$, respectively) when comparing the readings in **WO-BPS** posture to that from the **Normal**. The increase of the TCA from the 2 groups showed statistical significant difference with the TCA increase from the Control group was more than twice as large as that of the LBP group. The substantial increase seen in AP readings reached more than 40% for both groups, with significance ($P < 0.001$). Although the PP in LBP group increased substantially more than the increase seen in Control group (40.85% for LBP vs. 27.80% for Control, both with statistical significance, $P < 0.001$ and $P = 0.002$, for LBP and Controls, respectively), no statistical significance was found between data from the two groups.

Posterior region of the seat cushion: In both Control and LBP groups, TCA, AP and PP were all seen significantly decreased when sitting in **WO-BPS** posture, compared to those from the **Normal.** The TCA was seen substantially decreased (more than 30% decrease) with significance ($P < 0.001$), with an absolute TCA decrease of 188.32±27.14 cm^2 for the Control group, and 148.19±10.46 cm^2 for the LBP group. The AP significantly decreased more than 30% ($P < 0.001$ for both groups). A significant decrease of the PP was seen in both groups more than 15%. No significant difference was found between the groups on any of the measurements ($P > 0.05$).

__Average results on the backrest (Table 5)__

Compared with those in **Normal** posture, when sitting in the **WO-BPS** posture, TCA on the backrest increased by about 5% but with no statistical significance ($P > 0.05$) for both Control and LBP groups. AP in both groups showed substantial and significant increase (44.10% for LBP and 61.05% for Control, both with statistical significance, $P < 0.001$ and $P = 0.002$, for LBP and Controls, respectively). Although PP in both groups showed an average more than 10% increase, the increase of PP from that in the **Normal** posture was found with no statistical significance ($P > 0.05$). The location of PP showed the trend of being shifted upward towards the thoracic region of the back in both LBP and Control groups. However, this upward PP shift showed statistical significance only in LBP group with $P < 0.001$. Similar to what was found for the load on the seat, the changes of the PP location in lateral (left-right) direction was so small and so insignificant that it could be ignored. They were -0.19 ± 0.76 cm and -0.70 ± 0.39 cm, respectively for Control and LBP groups. The lateral shift of the location of PP in neither of the groups showed statistical significance ($P > 0.05$).

SA1-3. Muscle effort to stabilize the trunk during sitting in the *Normal* and *WO-BPS* postures.

Representative results

A representative surface EMG recording from a subject in one trial is shown in Fig. 7. In this figure, the EMG data is plotted with respect to the time and the time points when the posture was switched are indicated by arrows. It is clear from the figure that the muscles in lumbar region (L2 and L5 levels) on both the left and right sides exerted less effort in the **WO-BPS** posture in

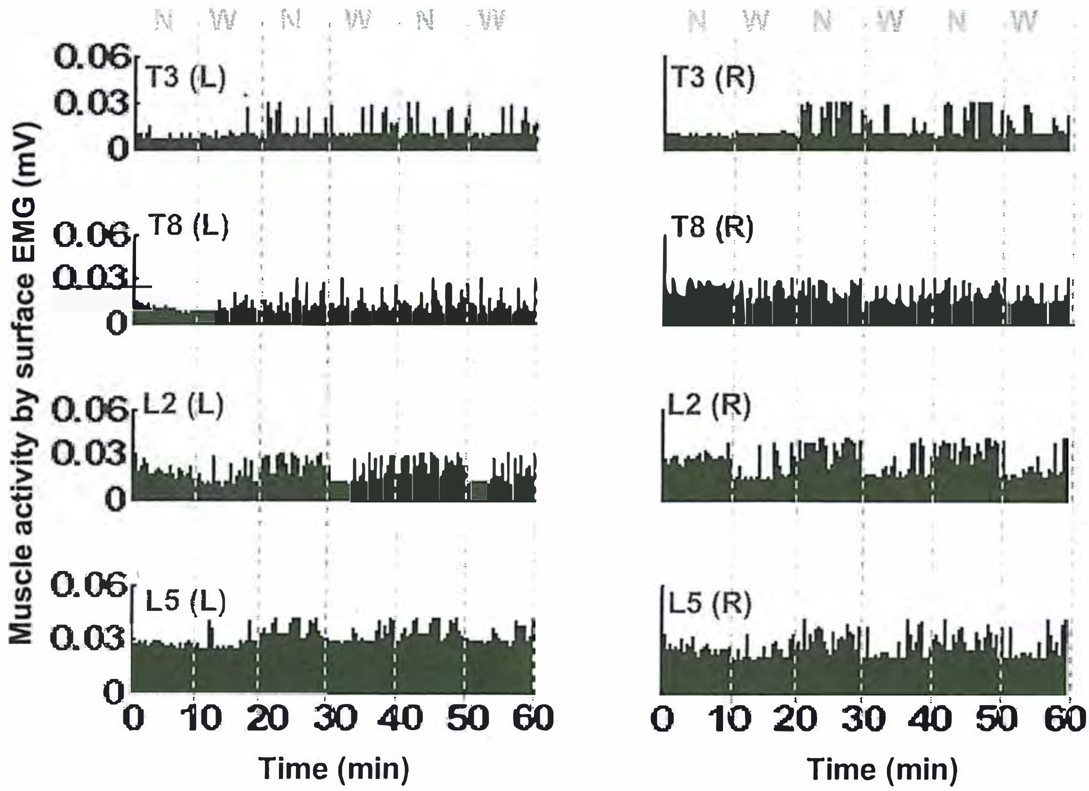


Fig. 7. A typical result showing that posture changes induced muscle activity changes, measured by surface EMG from paraspinal muscles at 4 levels. The data were plotted from a 60-min trial of a subject. The posture change was at a 10-min interval. N — Normal posture; W — WO-BPS posture; R—Right side; L—Left side.

stabilizing the trunk.

Average EMG results (Table 6)

Compared with those in **Normal** posture, when sitting in the **WO-BPS** posture, muscle activities in lumbar region were significantly decreased to a substantially lower level on both left and right side of the back, in both Control and LBP groups (Table 6). The largest such decrease was seen as about a 24% decrease in lower lumbar region on the right side in Control group. The lumbar paraspinal muscle activity changes induced by changing the sitting posture from **Normal** to **WO-BPS** are plotted in Fig. 8.

Table 6. Average changes (in percentage, mean ± SE) of surface EMG from the back muscles induced by WO-BPS posture.

Subject	Control (N=10)	LBP (N=25)	Control (N=10)	LBP (N=25)
Muscle	Left		Right	
Change (%)				
L5	-13.05 ± 2.73	-9.77 ± 2.48	-23.68 ± 6.34	-9.94 ± 2.67
P (N vs. W)	<0.001	< 0.001	0.002	<0.001
t	-4.76	-3.94	-3.96	-3.72
DF	9	24	9	24
P of group effect	> 0.05		0.007	
Power	100%	100%	100%	100%
Effect size	-4.78	-3.94	-3.74	-3.72
Sample size	3	3	4	4
L2	-15.18 ± 7.15	-6.55 ± 2.14	-17.15 ± 7.39	-9.93 ± 3.92
P (N vs. W)	0.026	0.003	0.018	0.009
t	-2.24	-3.06	-2.46	-2.54
DF	9	24	9	24
P of group effect	> 0.05		0.031	
Power	100%	100%	100%	100%
Effect size	-2.12	-3.06	-2.32	-2.53
Sample size	5	4	5	4
T5	-5.58 ± 5.34	9.29 ± 6.79	14.18 ± 15.25	12.09 ± 8.24
P (N vs. W)	> 0.05	> 0.05	> 0.05	> 0.05
t	-1.11	1.37	0.98	1.47
DF	9	24	9	24
P of group effect	> 0.05		> 0.05	
Power	84%	100%	74%	100%
Effect size	-1.04	1.37	0.93	1.47
Sample size	12	8	15	8
T8	-2.45 ± 6.21	3.00 ± 5.85	-2.52 ± 7.37	3.60 ± 3.88
P (N vs. W)	> 0.05	> 0.05	> 0.05	> 0.05
t	-0.42	0.512	-0.36	0.93
DF	9	24	9	24
P of group effect	> 0.05		> 0.05	
Power	20%	69%	16%	99%
Effect size	-0.39	0.51	-0.34	0.93
Sample size	70	42	92	15

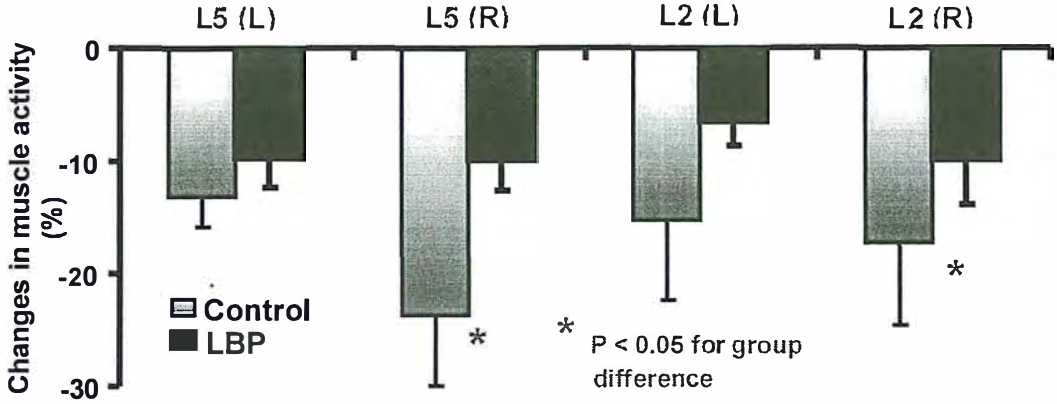


Fig. 8. Posture induced muscle activity changes (in percentage, i.e. ($EMG_{WO\text{-}BPS}$ – EMG_{Normal})/EMG_{Normal} × 100%) measured from paraspinal muscles in lumbar region. All changes in lumbar region were found with statistical significance (P < 0.05, for details; Refer to Table 6).

The decreases of the muscle activities in lumbar region appear to be in larger magnitude in Control group than those in LBP group. For Control group, the decreases of activities in lumbar paraspinal muscles were in the range of 13% to 24%. However, in LBP group, these decreases were only able to reach to about 6% to 10%. Interestingly, significant difference between groups was only found on the right side (P = 0.007 and 0.031 for L5 and L2 levels, respectively).

In paraspinal muscles at thoracic levels, the changes in muscle activities were found in no statistical significance between two sitting postures (P > 0.05), neither between the two groups (P > 0.05).

EMG results for adopting released ischial support ONLY (Table 7)

As stated in the proposal, laboratory test was planned for a posture with 'flat lumbar support + BPS down' configuration, without engaging the protruded lumbar support (Refer to the

Table 7. Average changes (in percentage, mean ± SE) of surface EMG from the back muscles induced by releasing ischial support ONLY.

Subject	Control (N=10)	LBP (N=20)	Control (N=10)	LBP (N=20)
Muscle	Left		Right	
Change (%)				
L5	26.23±9.34	15.07±5.38	39.12±10.55	16.94±6.05
P*	0.001	> 0.05	0.009	0.040
L2	13.57±7.83	20.97±6.38	8.53±5.49	13.86±4.57
P*	0.035	> 0.05	<0.001	> 0.05
T5	11.66±5.16	12.38±7.23	3.53±7.55	6.72±3.47
P*	<0.001	> 0.05	<0.001	> 0.05
T8	9.50±8.49	8.76±4.17	8.89±7.49	5.37±3.93
P*	0.003	> 0.05	0.001	> 0.05

statement in Methodology). 10 healthy controls and 20 LBP patients were tested in this posture. Not all LBP patients were tested in this posture because of the reason provided in the Methodology section.

Averaging results of surface EMG in this BPS-down-ONLY posture are shown in Table 7. Different from what was seen in the changes induced by **WO-BPS** posture (Table 6), this BPS-down-only posture caused general increase in muscle activities in the paraspinal muscles in both lumbar and thoracic regions. In Control group, this increase of muscle activity was seen with statistical significance at all tested level. However, in LBP group, most of the increased muscle activities showed no statistical significance ($P > 0.05$), except at L5 level on the right side.

<u>Highlight findings in Specific Aim 1:</u>

1. **WO-BPS posture shifted the center of mass anteriorly to the thighs (Table 2).**
2. **Overall load on the chair was redistributed between the seat and backrest.**
3. **WO-BPS posture significantly redistributed contact pressure on the seat.**
4. **WO-BPS posture significantly decreased muscle effort of paraspinal muscles in lumbar region.**
5. **Using released ischial support alone did not help to reduce the muscle effort in lumbar muscles.**

<u>*Specific aim 2 (SA2):*</u> **Evaluating the body posture in lumbar-sacrum region in the *Normal* and *WO-BPS* sitting postures by radiological imaging.**

The body posture in lumbar-sacrum region was evaluated by bony curvature of the lumbar spine and the sacrum, i.e. sacral inclination and lumbar spine lordosis. In addition, intervertebral

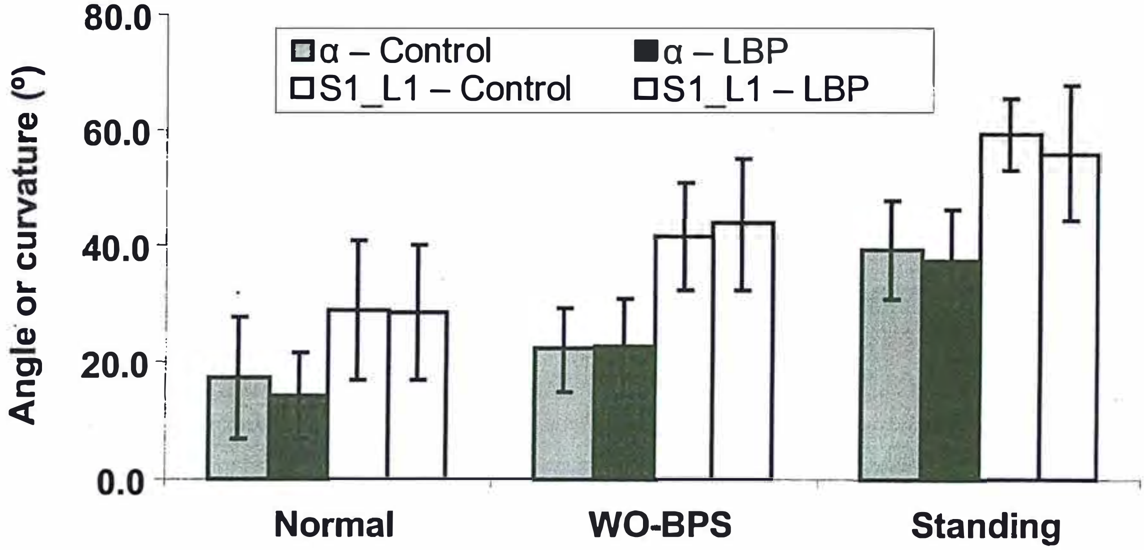


Fig. 9. Effect of the body posture on lumbar-sacral curvatures. Sacral inclination (α) and the total lumbar lordosis (S1- L1) are plotted for both Control and LBP groups in 3 body postures. Detailed data and the results of statistical test are given in Table 7.

disc height in these postures is also given as a measure of the disc loading/unloading.

SA2-1. Sacral inclination and lumbar spine lordosis

The results of the sacral inclination and lumbar lordosis are shown in Table 8 for 2 sitting postures (**Normal** and **WO-BPS**) and a **Standing** posture for both Control and LBP groups. On top of all statistical tests, an overall evaluation of the effect of posture changes on these parameters is given by 'P (overall)', which is the P value obtained through ANOVA with repeated measures (in the sense that the measurement was repeated in 3 body postures: **Normal, WO-BPS**, and **Standing**). This P value gives a general idea on whether the body posture plays a role in affecting the lumbar-sacral curvature. From Table 8, it is seen that the body posture did affect all the measurements of lumbar-sacral curvature significantly ($P < 0.001$), except for the segment of L1-L2 in Control group.

For showing the trend of lumbar-sacral curvature changes induced by the body posture, sacral inclination and the total lumbar lordosis are plotted in Fig. 9 for both Control and LBP groups. It is clearly seen in Fig. 9 that body posture affected these two measurements substantially. For the sequence of the body posture as from **Normal** to **WO-BPS** and then to **Standing**, sacral inclination and the total lumbar lordosis were increased successively. In **Normal** posture, the lumbar-sacral region had the least curved profile, while in the **Standing** posture, this part of the body was in the most curved condition. The **WO-BPS** posture, although it is a sitting posture, brought the lumbar-sacral curvature towards that of a **Standing** posture.

In Table 8, more details are given for each of the lumbar-sacral curvature measures. In **WO-BPS** sitting posture, all lumbar lordosis (total and segmental) measures and the sacral inclination were significantly larger than those in the **Normal** sitting posture ($P < 0.05$; Detailed P values refer to Table 8). Despite the substantial increase of lumbar-sacral curvature in **WO-BPS** sitting, which prevented the lumbar-sacral flatness seen in the **Normal** sitting, the lumbar-sacral spinal profile still was less curved than that in the **Standing** posture with statistical significance ($P < 0.05$; details see Table 8), except the segmental lordosis of L1-L2 in Control group ($P > 0.05$).

Table 8. The sacral inclination (α), total (S1-L1) and segmental (L1-L2, L2-L3, L3-L4, L4-L5) lumbar lordosis for standing and sitting postures. (mean ± SD)

Posture	Normal Sitting		WO-BPS Sitting		Standing	
Group	Control (N=10)	LBP (N=25)	Control (N=10)	LBP (N=25)	Control (N=10)	LBP (N=25)
Sacral inclination:						
α	17.2 ± 10.5°	14.2 ± 7.3°	22.2 ± 7.1°	22.5 ± 8.4°	39.4 ± 8.5°	37.4 ± 8.6°
P (overall)	<0.001	<0.001				
P (N vs. W)	0.008	<0.001				
P (vs. Standing)	<0.001	<0.001	<0.001	<0.001		
P of group effect	> 0.05		> 0.05		> 0.05	
Power	100%	100%				
Sample size	2	2				
Total Lordosis:						
S1-L1	28.8 ± 11.9°	28.6 ± 11.5°	41.6 ± 9.3°	43.7 ± 11.3°	59.3 ± 6.1°	56.0 ± 11.9°
P (overall)	<0.001	<0.001				
P (N vs. W)	<0.001	<0.001				
P (vs. Standing)	<0.001	<0.001	<0.001	<0.001		
P of group effect	> 0.05		> 0.05		> 0.05	
Power	100%	100%				
Sample size	2	2				
Segmental Lordosis:						
L1-L2	2.2 ± 2.2°	3.3 ± 1.6°	4.1 ± 3.3 °	4.2±1.9°	4.4 ± 3.2°	5.6 ± 3.2°
P (overall)	> 0.05	<0.01				
P (N vs. W)	0.026	0.008				
P (vs. Standing)	0.028	<0.001	> 0.05	< 0.001		
P of group effect	> 0.05		> 0.05		> 0.05	
Power	100%	100%				
Sample size	6	6				
L2-L3	3.9 ± 3.4°	4.6 ± 2.7°	7.1 ± 2.8°	7.2 ± 3.6°	8.3 ± 3.2°	8.8 ± 4.5°
P (overall)	<0.001	<0.001				
P (N vs. W)	<0.001	<0.001				
P (vs. Standing)	0.001	<0.001	0.037	0.001		
P of group effect	> 0.05		> 0.05		> 0.05	
Power	100%	100%				
Sample size	3	3				
L3-L4	4.4 ± 2.7°	5.4 ± 3.8°	6.8 ± 2.7°	8.5 ± 3.9°	11.6 ± 2.0°	11.6 ± 4.0°
P (overall)	<0.001	<0.001				
P (N vs. W)	<0.001	<0.001				
P (vs. Standing)	<0.001	<0.001	0.001	< 0.001		
P of group effect	> 0.05		> 0.05		> 0.05	
Power	100%	100%				
Sample size	2	3				
L4-L5	5.8 ± 4.4°	8.6 ± 5.1°	8.6 ± 4.5°	11.7 ± 6.0°	17.1 ± 2.4°	14.6 ± 5.8°
P (overall)	<0.001	<0.001				
P (N vs. W)	0.017	<0.001				
P (vs. Standing)	<0.001	<0.001	<0.001	0.009		
P of group effect	0.037		0.025		> 0.05	
Power	100%	100%				
Sample size	3	5				

SA2-2. Disc height in lumbar-sacral region

The results of the disc height in lumbar-sacral region are shown in Table 9 for 2 sitting postures (**Normal** and **WO-BPS**) and a **Standing** posture for both Control and LBP groups.

Table 9. The lumbar spine disc heights (S1-L5, L4-L5, L3-L4, L2-L3 and L1-L2) for Normal, WO-BPS and Standing postures for the Health and LBP subjects. (mean ± SE)

Posture	Normal Sitting		WO-BPS Sitting		Standing	
Group	Control (N=10)	LBP (N=25)	Control (N=10)	LBP (N=25)	Control (N=10)	LBP (N=25)
Disc Height (mm):						
S1-L5	12.2 ± 0.6	10.2 ± 0.6	12.1 ± 0.6	10.8 ± 0.6	11.6 ± 0.8	10.9 ± 0.6
P (Overall)	> 0.05	> 0.05				
P (N vs. W)	> 0.05	0.034				
P (vs. Stand)	> 0.05	> 0.05	> 0.05	> 0.05		
P of group effect	0.027		> 0.05		> 0.05	
Power	46%	98%				
Sample size	27	17				
L4-L5	12.4 ± 0.5	10.2 ± 0.5	12.0 ± 0.5	10.8 ± 0.5	12.3 ± 0.6	11.2 ± 0.4
P (Overall)	> 0.05	> 0.05				
P (N vs. W)	> 0.05	0.006				
P (vs. Stand)	> 0.05	<0.001	> 0.05	0.005		
P of group effect	0.005		0.048		> 0.05	
Power	30%	100%				
Sample size	42	6				
L3-L4	11.8 ± 0.4	9.5 ± 0.5	12.2 ± 0.4	10.1 ± 0.4	11.9 ± 0.4	10.3 ± 0.5
P (Overall)	> 0.05	<0.001				
P (N vs. W)	> 0.05	<0.001				
P (vs. Stand)	> 0.05	<0.001	> 0.05	> 0.05		
P of group effect	0.005		0.005		0.034	
Power	38%	100%				
Sample size	32	9				
L2-L3	10.8 ± 0.4	9.3 ± 0.4	10.9 ± 0.5	9.5 ± 0.4	10.7 ± 0.3	9.9 ± 0.4
P (Overall)	> 0.05	> 0.05				
P (N vs. W)	> 0.05	> 0.05				
P (vs. Stand)	> 0.05	0.010	> 0.05	0.019		
P of group effect	0.023		0.029		> 0.05	
Power	99%	100%				
Sample size	6	11				
L1-L2	9.7 ± 0.6	8.4 ± 0.3	9.9 ± 0.5	8.7 ± 0.3	9.5 ± 0.4	8.8 ± 0.4
P (Overall)	> 0.05	> 0.05				
P (N vs. W)	> 0.05	0.008				
P (vs. Stand)	> 0.05	0.030	> 0.05	> 0.05		
P of group effect	0.017		0.027		> 0.05	
Power	48%	99%				
Sample size	25	15				

Similar to Table 8, an overall evaluation of the effect of posture changes on these parameters is given by 'P (overall)'. This P value gives a general idea on whether the body posture plays a role in affecting the disc height. From Table 9, it is seen that the body posture did not affect the disc height in lumbar-sacral region in Control group ($P > 0.05$); however, it did affect most of the disc height measurement in LBP group ($P < 0.05$, details refer to Table 9). For LBP group, the smallest values of disc height were seen always in the **Normal** sitting posture at all levels with the largest values were generally from the readings in the **Standing** postures at all levels. Compared with the values in the **Normal** sitting posture, significantly larger readings were seen in the **WO-BPS** posture at S1-L5, L4-L5, L3-L4, and at L1-L2 levels. At the same time, at 3 of these levels (S1-L5, L3-L4, and at L1-L2), no significant difference was found between the measurements from the **WO-BPS** sitting posture and the **Standing** posture. Therefore, in LBP group, it is seen that the **WO-BPS** sitting posture, significantly increased the intervertebral disc height in the lumbar-sacral region, from that in the **Normal** sitting posture, and brought it close to, or almost same as the value in the **Standing** posture.

Highlight findings in Specific Aim 2:

1. **WO-BPS posture resulted in significant forward rotation of the pelvis.**
2. **WO-BPS posture significantly increased lumbar lordosis.**
3. **WO-BPS posture significantly increased disc height.**

Specific aim 3 (SA3): Subjective evaluation of using the proposed office chair with adjustable ischial and lumbar supports.

During a 12-week trial, subjective evaluation and impressions gained from practically using such a sitting design in office or home-office environment were collected through questionnaire (Appendix A) from LBP patients (N=24) and health controls (N=12).

Subjective responses to all questions in the questionnaire from the LBP group were processed (refer to methodology section) and the categorized results are summarized in Table 10 & 11 for the two measuring methods, 'Participants' agreement to a statement', and 'The frequency having experienced a stated situation', respectively.

A quick comparison of Table 10 & 11 came to an impression that the results measured by these two methods generally agreed with each other and showed a very similar pattern. Therefore, in following description when a specific number is mentioned, it is come from Method 1 (Table 10), unless stated clearly from which method it was obtained.

For control group, only responses to those questions regarding the overall comfort and chair function were processed (refer to methodology section) and the categorized results are summarized in Table 12 for both measuring methods, 'Participants' agreement to a statement', and 'The frequency having experienced a stated situation'.

SA3-1. General responses characterized in categories

Table 10. Summary of the LBP participants' response (total N = 24) to long-term subjective evaluation questionnaire of using the study chair. Method 1: Participants' agreement to the statement.

Brief descriptions of the categorization criteria are given. Refer to Methodology section for detailed criteria. The number of participants whose response fell into each category is reported. For category 2, the average 12-week improvement (mean ± SD) is also given in percentage relative to the score of the week 1. P values were for the 'week mean score differ' from the Cochran-Mantel-Hazenszel Statistics (refer to Methodology section).

Category		**1** (Improve from week 1, keep feeling good in the same way)	**2** (Keep gradual improving along the trial time)			**3** (No effect at all)	**4** (Worsened)
Number of response		**N**	**N**	**Final improvement (%)**	**P***	**N**	**N**
Overall comfort (Sitting tolerance, pain, comfort)	Comfortable	11	11	37.1± 26.7	< 0.001	2	0
	I have less pain	8	16	31.7± 10.2	< 0.001	0	0
	I can keep my balance by myself	18	6	31.9± 17.0	< 0.001	0	0
	I can sit longer	11	10	29.2± 16.3	< 0.001	3	0
Low back pain (LBP)	The length of time of my LBP is shorter	7	13	33.3± 17.4	< 0.001	3	1
	Intensity of my LBP is relived	5	15	45.0± 36.6	< 0.001	2	2
	Area of my LBP is smaller	9	12	45.1± 35.1	< 0.001	3	0
Buttock pain (BP)	The length of time of my BP is shorter	6	9	33.3± 13.2	< 0.001	7	1
	Intensity of my BP is relived	5	10	35.8± 22.9	< 0.001	9	0
	Area of my BP is smaller	6	9	38.0± 16.7	< 0.001	8	1
Chair function	Easy to use	9	15	63.3± 82.8	< 0.001	0	0
	Easy to care for	17	7	28.6± 19.8	< 0.001	0	0
	I can do my usual activities without difficulty	14	7	22.6 ± 17.8	< 0.001	3	0

Generally, the majority of the LBP participants reported improvement (categories 1 & 2) over

Table 11 Summary of the LBP participants' response (total N = 24) to long-term subjective evaluation questionnaire of using the study chair. Method 2: The frequency of having experienced a stated situation.

The number of participants whose response fell into each category is reported. For category 2, the average 12-week improvement (mean ± SD) is also given in percentage relative to the score of the week 1. P values were for the 'week mean score differ' from the Cochran-Mantel-Hazenszel Statistics (refer to Methodology section).

Category		1 (Improve from week 1, keep feeling good in the same way)	2 (Keep gradual improving along the trial time)			3 (No effect at all)	4 (Worsened)
Number of response		N	N	Final improvement (%)	P*	N	N
Overall comfort (Sitting tolerance, pain, comfort)	Comfortable	12	11	34.8 ± 26.6	< 0.001	0	1
	I have less pain	6	15	32.2 ± 37.2	< 0.001	3	0
	I can keep my balance by myself	20	4	12.5 ± 14.3	< 0.001	0	0
	I can sit longer	13	8	28.1 ± 18.3	< 0.001	3	0
Low back pain (LBP)	The length of time of my LBP is shorter	8	11	28.5 ± 22.3	< 0.001	5	0
	Intensity of my LBP is relived	8	14	35.7 ± 16.8	< 0.001	2	0
	Area of my LBP is smaller	6	13	40.4 ± 21.2	< 0.001	5	0
Buttock pain (BP)	The length of time of my BP is shorter	7	9	32.1 ± 15.5	< 0.001	6	1
	Intensity of my BP is relived	4	10	33.3± 13.4	< 0.001	9	1
	Area of my BP is smaller	4	10	47.5 ± 25.8	< 0.001	9	1
Chair function	Easy to use	10	13	46.2 ± 42.7	< 0.001	1	0
	Easy to care for	21	3	16.7 ± 14.4	< 0.001	0	1
	I can do my usual activities without difficulty	16	4	20.8 ± 14.4	< 0.01	3	0

their preexisting complains about the LBP, buttock pain (BP) and sitting intolerance. The improvement can be in two patterns as defined in the Methodology section as categories 1 and 2. Participants whose response was classified as in category 1 felt immediate symptom improvement as soon as starting using the chair and then kept the same rating along the 12-week trial, either as 'moderate improvement' indicated by selecting 'Agree' (scored as 4) to the question, or as 'great improvement' by 'Strongly agree' (scored as 5). Responses in category 2 characterize those participants who kept improvement for several weeks, either continuously or intermittently, all the way along the 12-week trial, no matter what score they started with. Apparently, although moderate or great improvement was seen from participants who gave category 1 responses, their data would not show any statistical changes. Therefore, statistical analysis was only performed on the data from category 2. On the other hand, category 4 responses would have contributed to statistically analysis, had there been more responses (no more than 2 participants responded as 'worsened' for any statement).

A small amount of participant reported 'no effect' (category 3) using the study chair. More responses as 'no effect' were seen in questions related to the characteristics of 'Buttock Pain'.

Details of category 2

As described above, responses in category 2 showed moderate or great improvement continuously or intermittently along the trial; therefore, a statistical analysis would help for characterizing the responses from these participants. Seen in Table 10, 11, and 12, besides the number of responses, an improvement measure (final improvement in %) and corresponding P value are given for responses to each of the questions. The final improvement was calculated for each participant as ($Score_{week12}$ – $Score_{week1}$)/ $Score_{week1}$ × 100%, to justify a percentage change over the initial status when the 12-week trial was done. The P value was from the Cochran-Mantel-Hazenszel Statistics for the 'week mean score differ' for the data from all 12 weeks.

For LBP participants, seen in Table 10 & 11, all the improvements in category 2 showed statistical significance with $P < 0.001$, except for the response to the last statement regarding the difficulties of doing usual activities in the chair, measured by Method 2 (Table 11 last row), which had a P value as < 0.01. Besides the responses pertaining to chair function, the most improvements were seen in the LBP symptoms of participants, reached a final improvement at 33.3%, 45%, and 45.1% for decreasing the length of time, the intensity and the area of the LBP, respectively (Table 10). While measured by Method 2, these improvements were 28.5%, 35.7%, and 40.4%, respectively (Table 11), slightly lower than those observed by Method 1. Overall comfort was also rated as continuously improved by close to or more than 30%, except for the balance perception measured by Method 2 (Table 11), which had a value of final improvement as 12.5%. Buttock pain was seen continuously decreased in more than one third of the participants.

Response to questions about chair function showed interesting results. In LBP participants, the 'easiness to use' showed the highest improvement among all questions, reached 63.6% over the 12-week trial time and with a large standard deviation as 82.8% (Table 10). With Method 2, it had the second largest improvement as shown by 46.6% (Table 11). In Control group, similar pattern was seen, with the second highest improvement observed (Table 12). By examining the data, it was found that there were 4 LBP participants (3 for Method 2) and 2 Control subjects chose to answer 'Strongly disagree' or 'Disagree' in week 1 (for Method 2, the 3 participants answered as 'Never' of 'Rarely' for the same question) when asked their opinion about the statement 'This chair is easy to use' (or when asked about the frequency of experiencing this situation for Method 2). However, through continuous improvement over the entire trial time, their answers finally reached to 'Agree' or 'Strongly agree' (in Method 2, they were 'Most of the time' and 'Always', respectively), which, for some of the participants, generated dramatically high final improvement scores as 200%.

Table 12 Summary of the healthy control participants' response (total N = 12) to long-term subjective evaluation questionnaire of using the study chair.
Both Method 1 and Method 2 are included.

The number of participants whose response fell into each category is reported. For category 2, the average 12-week improvement (mean ± SD) is also given in percentage relative to the score of the week 1. P values were for the 'week mean score differ' from the Cochran-Mantel-Hazenszel Statistics (refer to Methodology section).

Category		**1** (Improve from week 1, keep feeling good in the same way)	**2** (Keep gradual improving along the trial time)			**3** (No effect at all)	**4** (Worsened)
Number of response		**N**	**N**	**Final improvement (%)**	**P***	**N**	**N**
Method 1: Participants' agreement to the statement							
Overall comfort (Sitting tolerance, pain, comfort)	Comfortable	3	8	80.2 ± 44.5	**< 0.001**	1	0
	I can keep my balance by myself	10	2	25.0 ± 0.0	**> 0.05**	0	0
	I can sit longer	1	3	25.0 ± 25.0	**> 0.05**	8	0
Chair function	Easy to use	3	8	60.4 ± 30.5	**< 0.001**	1	0
	Easy to care for	4	7	32.1 ± 19.5	**0.002**	1	0
	I can do my usual activities without difficulty	8	3	27.8 ± 4.8	**0.021**	1	0
Method 2: The frequency of having experienced a stated situation							
Overall comfort (Sitting tolerance, pain, comfort)	Comfortable	4	7	70.2 ± 37.2	**< 0.001**	1	0
	I can keep my balance by myself	10	2	25.0 ± 0.0	**> 0.05**	0	0
	I can sit longer	2	5	45.0 ± 11.2	**0.002**	5	0
Chair function	Easy to use	3	7	52.4 ± 35.9	**< 0.001**	1	1
	Easy to care for	7	4	45.8 ± 24.1	**0.002**	1	0
	I can do my usual activities without difficulty	10	2	50.0 ± 23.6	**> 0.05**	0	0

SA3-2. Responses to specific concerns

Subjective responses to the questionnaire were classified, by the nature of the questions, into 4 different groups of concerns, Overall comfort (consisted of 4 questions), Low back pain (3 questions), Buttock pain (3 questions), and Chair function (3 questions). This concept of grouping responses is also applied to the layout of the Table 10 ~ 12.

Overall comfort

Very few participants (both LBP and Controls) commented that sitting in this chair made no difference in sitting comfort/tolerance (no more than 3). Only 1 LBP participant thought this chair was less comfortable than other chairs (Table 11). However, her answer was not consistent when assessed by Method 1 and 2. Almost half of the participant felt immediate more comfort and improved sitting tolerance as soon as they started to use the study chair. While in Control group, 8 participants did not think their sitting tolerance was improved, very likely because they had not had problem with sitting tolerance. One third (8) of the total LBP participants reported having less pain right at the time they started using the chair, and the other two third (16) progressively had less pain over the 12-week trial. Most of the participants (18) did not have problem to keep balance in the study chair, and the rest of them improved their balance in the chair over the trial time.

LBP

The majority of the LBP participants experienced less intensive, smaller area and shorter time of their preexisting LBP symptoms. Very few of them reported that sitting in this chair made no difference for their LBP (no more than 3). One patient thought her time experiencing LBP was increased when using this chair. 2 participants (including the one reporting increased LBP time) reported that their LBP was more intensive after using the chair.

Among those having improvement over their LBP symptoms, more than half had the progressive improvement pattern over the 12-week trial. The rest observed immediate improvement and kept the status.

BP

Comparing with the number reporting improvement over the LBP symptoms, fewer LBP participants reported improvement over their BP symptoms; however, this number was still around two third of the total participants. More than half of the participants experienced less intensive, smaller area and shorter time of their preexisting BP symptoms. About one third of the total participants reported that sitting in this chair made no difference for their BP (7~9 subjects chose 'no effect'). One patient (the same who reported worsening of her LBP symptoms) thought her time and the body area experiencing BP were increased when using this chair.

Among those having improvement over their LBP symptoms, more than half had the progressive improvement pattern over the 12-week trial. The rest observed immediate improvement and kept the status.

Chair function

The majority of the participants found the chair was easy to use and easy to care for. No participant reported any difficulty to perform his/her usual activities while using this study chair. As mentioned above in 'Details of category 2', almost two third of the participant greatly improved their skills of using this chair over the trial time.

SA3-3. Optional feedback and suggestions for the seating system

Besides the above formulated questions, 5 free-answer questions were listed in the questionnaire for optional responses. They are regarding the design of the overall seating system, as well as how eager the user would want one. Feedbacks and suggestions are organized below.

Advantages: what the users like?

18 of the 24 LBP participants commented on what they liked about the seating system. 17 of the 18 responded that the chair was ***extremely comfortable*** to sit in. The feature appraised the most by the users is the enhanced lumbar support, which was mentioned by 17 of the 18 respondents. The ischial release which relieves the pressure on the buttocks was picked by 16 of the 18 as something they liked.

Most of the participants valued the pain-relieving effect of the seating system, which was commented by 14 of them. 12 of them specifically mentioned that the pain-relief effect for their back pain. Pain-relief effect was also reported from body area other than back, such as leg, neck, and shoulder.

Many of the responses also focused on the posture correcting effect this chair offered. 9 of them explicitly valued that the chair forced them to sit correctly. 8 of them also appraised the adjustability and increased mobility the chair provided. They commented that the chair made them conscious of sitting correctly.

Need improvement: what the users dislike and what are the suggestion for improvement?

All 24 participants provided their opinions on what they did not like about the seating system and/or what improvement they would like to see. 10 of them answered that nothing they did not like.

Most of the improvement suggestions were about the physical design of some parts of the chair. 6 of them thought that although the chair provided lots of adjustability, the way of realizing these adjustments needed to be improved. They thought that there were too many knobs and handles and all those handles were at the bottom of the chair which made them confused about the function for each of them. Also the participants commented that sometimes it was difficult to remember changing the posture settings. 11 of them would like an automatic control of posture adjustment to make changing of the setting easier and preventing sitting in one posture for prolonged time.

3 participants complained about the maneuverability of the chair because the wheels did not roll well, especially not on carpet. 5 of them wanted to make the chair lighter.

4 replied that at times the head/neck rest was a bit uncomfortable.

Several participants expressed their concerns of getting a different size of the chair, either in different heights, or in different widths. Those chairs provided in the current project were of only one size.

Easiness to use: any problems while using the seating system?

20 of the 24 LBP participants commented on whether it was easy to use the chair. 15 of them responded that using this chair was generally fine. 10 of them mentioned they had problems adjusting the chair in the first 2~3 weeks and after that they were fine, which corresponding well with the results presented in Table 10 ~ 12 regarding the great improvement seen in the skills of using the chair.

Highlight findings in Specific Aim 3:

1. **Using the study chair, which features the WO-BPS posture, effectively relieves LBP symptoms in the majority of the LBP patients, in a 12-week trial.**
2. **The study chair also helps effectively relieve buttock pain symptoms in the majority of the participants, in a 12-week trial.**
3. **Sitting in this study chair was found overall comfortable and significantly increase sitting tolerance in the majority of the participants, in a 12-week trial.**
4. **The new sitting concept, WO-BPS sitting posture, provided by the study chair, was found preferred by the majority of the participants.**
5. **It is found that some improvement is necessary in the design of the chair. An automatic feature which can switch the chair configuration was suggested by users.**

Discussion

The proposed objectives for this project were two folds. First, the applicants proposed to investigate the biomechanical benefits of the new sitting concept (**WO-BPS**), which enabled both ischial load relief and lumbar lordosis increase. Second, the applicants attempted to study the clinical benefits to the LBP patients when appropriate combination of lumbar and seat support were used to increase lordosis and decrease the sitting pressure and load carried by the ischial tuberosities.

In the course of the current project, research pertained to the objectives, thus the proposed specific aims, were conducted, hypotheses have been verified and some new findings have been brought forth. Besides publications of the findings of this sponsored research, new ideas of further implementing this new sitting concept (**WO-BPS**) in preventing/relieving chronic LBP have been formed from the research data.

The major finding is that the biomechanical and physiological benefits of the proposed **WO-BPS** sitting concept have been confirmed in a group of chronic LBP patients and health controls, as the PI and the team expected. Findings from the healthy controls have already been reported in a peer-reviewed journal paper [59].

From the research data, we believe that the benefits of the **WO-BPS** posture to the LBP population are achieved through its combination of enhanced lumbar support and reduced ischial load. This combination enables a comprehensive load redistribution and body posture correction effect for seated individual. This conclusion is supported by the following specific findings:

1. ***Overall load on the chair was significantly redistributed between the seat and backrest.*** Total load on the backrest increased significantly ($P<0.001$, Table 3) while the load on the chair base significantly decreased ($P<0.001$, Table 2). Refer to Fig. 1 of the experimental setup, load on backrest and chair base were measured by separate mechanism. The only connection between them was the body of the seated subject. Therefore, this load changing pattern, i.e. increase on backrest and decrease on the chair base, reflects the load redistribution between the seat and the backrest. In the **WO-BPS** posture, the enhanced lumbar support and the released ischial support create a different load-sharing pattern for the sitting load. The backrest takes more loads in **WO-BPS** posture, in both posterior and inferior directions. At the same time, the decrease of ischial load implies that there is less compressive load to the inferior end of the spinal column. These phenomena suggest that the lumbar spine is subjected to less compression during **WO-BPS** sitting.
2. ***WO-BPS posture significantly redistributed contact pressure on the seat.*** On the seat-buttock-thigh interface, the significant and substantial decrease of pressure (both AP and PP) in the posterior seat cushion was accompanied by the similar magnitude substantial increase of the pressure in the middle and the anterior regions (Table 4). This suggests that, compared with that in the **Normal** sitting posture, the thighs bear more and the ischia bear less sitting load in the **WO-BPS** posture. This is also corroborated by the finding that the **WO-BPS** posture significantly shifted the center of mass anteriorly to the thighs.

3. ***WO-BPS posture significantly decreased muscle effort of paraspinal muscles in lumbar region.*** EMG activity significantly ($P<0.05$) decreased at both lumbar levels, but not at the thoracic levels. It suggested that in **WO-BPS** posture, the lumbar paraspinal muscles are more relaxed than in the **Normal** posture. The PI and the team believe that this muscle-relaxing effect of **WO-BPS** posture attributes to the combination of enhanced lumbar support and released ischial support, featured by the **WO-BPS** configuration. First, the enhanced lumbar support provides more load support to the lumbar region, thus, reducing the muscle effort required to support the trunk. Second, the release of ischial support in **WO-BPS** posture, causing forward pelvic rotation, relaxed the lumbar paraspinal muscles.
4. ***WO-BPS posture resulted in significant forward rotation of the pelvis and increased lumbar lordosis***. The **WO-BPS** posture maintained sacral inclination and lumbar lordosis approximating those at the standing posture. This forward pelvic rotation and increased lumbar spine lordosis can only be achieved by the combination of the protruded lumbar support and the tilted down of the BPS. As stated in the **Methodology**, we found that using the released BPS alone made the seated subject sank his/her buttocks down along with the BPS' tilting down, resulting no pelvic forward rotation and still flattened lumbar spine profile. We also found that using protruded lumbar support alone pushed the seated subject in a forward direction, giving the subject a feeling of instable condition. Only in **WO-BPS** posture, the seated subject was fitted to a posture which not only had an optimal spinal alignment and reduced spinal load, but also comfortable.

In addition, measurement of lumbar disc height confirmed that sitting in the **WO-BPS** posture applied lower load on those discs in the lumbar region. It has commonly been observed that individuals with chronic LBP have difficulty in adopting a mid or neutral position of the lumbar spine[54], and that balance may be impaired[4]. Different from that most of the data in this study do not show any significant difference between the LBP group and the healthy controls, there was significant group difference in the measurement of the lumbar disc height in sitting postures. Referring to Table 8, disc height at all lumbar-sacral levels was found significantly ($P < 0.05$) larger in the Control group than from the LBP group, in **Normal** sitting posture. The difference can be as large as 2.3 mm. When the **WO-BPS** posture was taken, the intervertebral disc height at S1-L5 level had no significant group difference ($P > 0.05$). The other 4, maintained with significant smaller disc height in LBP group ($P < 0.05$). This fact suggested that, although the **WO-BPS** posture helps the LBP patients assume a posture with a better physiological spinal alignment, optimal spinal profile may not readily achieved in individuals suffered from chronic LBP by a short time sitting in **WO-BPS** posture.

Measurement of load and contact pressure redistribution are important investigation tools to evaluate the biomechanical effects of sitting, as elevated spinal loads are commonly observed in the seated position [20]. Callaghan and McGill found that the sitting posture exerted significantly higher low back compressive loads than standing. As elevated ischial tuberosity pressures from sitting are intimately associated with elevated spinal loads and spinal collagen damage, a seating device which can decrease ischial tuberosity pressures may help decrease and/or prevent LBP[77] [77 81]. The results of this study demonstrate the beneficial effects of the **WO-BPS** sitting posture in both healthy controls and LBP subjects in improving overall pressure parameters, as both groups had a significantly reduced load on the ischial tuberosities, while redistributing load anteriorly towards the thighs, over a larger surface area.

Many investigators have reported the negative effect of the seated position on increased paraspinal muscle activity[5,6,35,56]. The seated position results in sustained static load of lumbar viscoelastic tissues, resulting in spinal collagen micro-damage, paraspinal muscle spasm [80], and a transient neuromuscular disorder [76]. Marras *et al*[61] reported that a significant mechanical spine loading is associated with LBP resulting from trunk muscle coactivation. Thus, decreasing paraspinal muscle activity may also help minimize LBP. In this study, for both the healthy control and LBP groups, a change in sitting from the **Normal** to the **WO-BPS** position, significantly decreased EMG paraspinal muscle activity at the lumbar levels ($P<0.05$). Since the **WO-BPS** position had no significant effect on EMG at the thoracic level, we do not believe that the **WO-BPS** position has a negative effect by shifting lumbar muscular activity superiorly to the thoracic level.

A very interesting finding regarding the muscle activity is that the muscle effort for stabilizing trunk was generally increased from that of a **Normal** sitting posture when the subjects took the BPS-down-ONLY posture, which was a posture using only a tilted down BPS without engaging the protruded lumbar support. Although statistical significance for this increase was only found in Control group not in LBP group, it is alarming that using the reduced ischial support alone might not provide beneficial effect to the lumbar spine.

Another important aspect of this project is the subjective evaluation of the proposed new sitting concept. This 12-week take-home study generated vast amount of useful information regarding the effect, the function and the usage of the study chair.

We found that, in general, the majority of the participants (both LBP and Control) were fond of the new chair, mainly for the ability of providing two new adjustments, the adjustable enhanced lumbar support and the tilted down BPS, which were not seen in any other office chairs. Moreover, these two new features were able to adjust to the user's need, i.e. how protruded the lumbar support was, and how much tilted down the BPS was, were all subject to the use's own needs. Seat depth adjustment and the backrest height adjustment were also appreciated by the users. Major benefits documented by the participating users are:

1. ***Using the study chair, effectively relieved LBP symptoms in the majority of the LBP patients.***
2. ***The study chair also helped effectively relieve buttock pain symptoms in the majority of the participants.***
3. ***Sitting in this study chair was found overall comfortable and significantly increase sitting tolerance in the majority of the participants.***
4. ***The new sitting concept, WO-BPS sitting posture, provided by the study chair, was found preferred by the majority of the participants.***

Of the findings from the subjective evaluation, the most important one is that using this chair concept was found able to alleviate the existing LBP symptoms in participating LBP patients and this improvement was seen in quite a few of the patients from the very beginning of using the chair. Referring to the results of initial evaluation of the participants, it was found that our LBP group had the initial Roland-Morris score in the range suggesting having LBP due to mechanical factors. Therefore, this kind of immediate pain alleviation may come from the immediate posture correction effect from the **WO-BPS** configuration.

Perhaps because this study chair provides a new sitting posture which has not seen in any other chairs, about half of the participants reported that they needed time to get used to the **WO-BPS** posture. Since the **WO-BPS** posture is a concept of a combination of protruded lumbar support and released ischial support, and both of them can be adjusted, there should be an optimal **WO-BPS** posture to each user's needs. Therefore, the investigators believe that one reason for users needing time to get used to the new posture might be that they actually need the time to finally find their own optimal configuration of the lumbar support protrusion and the BPS tilted down angle.

Besides the findings which confirmed the beneficial effects of the **WO-BPS** posture to the LBP individuals, new ideas also have been formulated through this project. As prolonged static sitting is another major cause of LBP, [10-12,20,35,50,63,64,70-72,76,80,81,89-92], the investigators of this project started to bring the concept of dynamic posture change to the office chair.

In literature, several strategies and seating devices have been reported to prevent prolonged static sitting. Although periodic alternation between sitting and standing has an overall improved effect in LBP prevention than prolonged sitting[10,64,70-72,89,91], continuous spinal loading occurs in each position with minimal dynamic movement, providing minimal rest/change on muscular activation levels[20]. Furthermore, as work requirements and demands of most occupations preclude routine, periodic alternations between sitting and standing, the practicality of this approach is a concern. Adjustable seating devices improve overall comfort relative to fixed seating devices[12,35], with spinal shrinkage measurements demonstrating a larger stature gain with chairs equipped with a moveable seat and backrest compared to chairs with a fixed seat and back rest[92]. However, there is concern whether manually adjustable seat designs effectively facilitates movements[11,20]. In a study measuring EMG muscle activity of subjects permitted to independently change sitting position during prolonged sitting, McGill et al. showed no clear difference in muscle activation patterns from subjects required to remain in a static position [20]. This finding may suggest that individuals may not have the ability or knowledge to adopt the most effective postural position[2], as it is commonly observed that individuals with chronic LBP have difficulty in adopting a mid or neutral position of the lumbar spine[54], and that balance may be impaired[4]. Furthermore, individuals tend to shift postures after they experience LBP, which may be too late to benefit from postural changes, as creep of the spinal structure and paraspinal muscle spasm occurs after only 20 minutes of static flexion[80].

Although numerous ergonomic seating devices and strategies improve overall comfort for the seated individual, none of these devices have been capable of both: 1) restoring normal spinal alignment, and 2) preventing prolonged static sitting.

However, research practice and the results from this project have provided the investigators the triggering idea of an automatic dynamic seating device, which could potentially be the first seating concept reducing the above mentioned two primary occupational causes of sitting related LBP.

During the laboratory test of this current project, the posture change between the **Normal** and **WO-BPS** was automated and realized by motor-compressor system controlled by a Programmable Logic Controller (PLC). During the 1-hour trial, the posture would be switched every 10 minutes. At the beginning, this automation was for optimizing the repeatability of the posture configuration to make sure the data collection was done at standard **Normal** and **WO-BPS** posture, for later carrying out comparison between these two postures. However, the investigators found that this **dynamic** posture change was appreciated by most of the participants. Then the investigators started to implement the dynamic posture adjustment idea in the subjective evaluation part of the study.

Different from the laboratory test, which collected data from either **Normal** or **WO-BPS** posture with standard setup; this take-home evaluation gave the participants the freedom of adjusting the chair to their needs. The investigators also provided information to the participants that prolong static sitting in any posture might cause problems.

Feedback from the participants showed that the majority of them valued the idea of postural change. Some of them suggested that they would like to see an automatic control of postural changing to prevent sitting in one posture for prolonged time.

Therefore, the PI is thinking to adopt an automatic control mechanism into this office chair, in the sense to help minimize the second major cause of LBP, the prolonged static seating.

Moreover, the investigators also found that proper trunk support is crucial to relax the muscles in lumbar region. Besides the already implemented lumbar support, a sacrum support is also needed in stabilizing the trunk, since the pelvis serves as the base for the whole trunk and upper limbs for movement to accomplish activities of daily living and functional skills in seated posture. An unstable pelvis will inevitably impair the movement of the trunk and therefore, hamper the functional performance of a seated individual. Also, when **WO-BPS** posture is taken, the released ischial support may put the pelvis in a less stable condition. Therefore, a sacrum support is in the investigators' consideration for further research.

Conclusion

Research carried out in this project successfully accomplished the work related to the proposed objectives. First, the investigators have confirmed the predicted biomechanical benefits of the new sitting concept (**WO-BPS**), which releases ischial sitting load, as well as, increases lumbar lordosis. Second, results from this research have explored the clinical benefits to the LBP patients when appropriate combination of lumbar and seat support were used to increase lordosis and decrease the sitting pressure and load carried by the ischial tuberosities. Major conclusions are:

1. The proposed novel sitting concept, which combines adjustable ischial load relief and lumbar support enhancement, **effectively relieved LBP symptoms** in the majority of the LBP patients who participated in the study;

2. The alleviation of the sitting related complains, the improvement of sitting posture, and the beneficial sitting load redistribution, are achieved **optimally by simultaneously using two interventions: the adjustable protruded lumbar support, and the tilted down back part of the seat** to achieve ischial load release;

3. The alleviation of the LBP symptoms by using this sitting concept is attributed to the **significant sitting posture correction effect**, which results significant increased lumbar intervertebral disc height, forward rotation of the sacrum, increased lumbar lordosis, and significantly decreased muscle effort of paraspinal muscles in lumbar region;

4. The alleviation of the LBP symptoms by using this sitting concept is attributed to the **significant load redistribution between the seat and backrest, and between the posterior and the middle portion of the seat pan**;

5. The study chair also helped **effectively relieve buttock pain symptoms** in the majority of the LBP participants;

6. Sitting in this study chair was found overall comfortable and **significantly increase sitting tolerance** in the majority of the participants;

7. The new sitting concept, **WO-BPS** sitting posture, provided by the study chair, was found preferred by the majority of the participants;

8. **An automatic posture adjustment mechanism,** which provides **dynamic** posture adjustment, would be beneficial to individuals with occupations requiring prolonged sitting.

List of Publications

Journal

Makhsous M, Lin F, Hendrix RW, Hepler M, Zhang LQ: [2003] Sitting with adjustable ischial and back supports: Biomechanical changes. Spine, 28: 1113-1121

Conference

Makhsous M, Lin F, Hendrix RW, Hepler M, Zhang LQ: [2003] Biomechanical effects of altering ischial and back-support using a new sitting design. 49^{th} Annual Meeting of Orthopaedic Research Society. New Orleans, Feb. 2-5.

Inclusion of gender and minority study subjects.

Please see attached PHS-2590.

Inclusion of children.

Children were not included in this project as research subjects since they are unlikely to have low back disorders related to long time sitting.

Materials available for other investigators.

Following materials will be available to other researchers on our updated website: http://www.smpp.northwestern.edu/BOSSM/Preventing%20LBP.html.

Questionnaire for assessing sitting comfort:

33 questions to identify the characteristics of the pain, including intensity, quality, location, radiation, aggravating and alleviating, sitting comfort, and sitting tolerance.

A summary of results, including tables and figures

Research methodology for sitting biomechanics

Experimental setup and hardware configuration will be on the website. Software for collecting and analyzing data will be available upon request.

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Appendix A:

Pressure Seating Evaluation Survey

Participant Code:__________________ **Date:**____________________

Weeks Using the Sitting Device: 2 4 6 8 10 12

Approximately how many hours do you sit daily on this chair during a day? ___

How much of your sitting time was with this device?

☐ 0% ☐ 20% ☐ 40% ☐ 60% ☐ 80% ☐ 100%

INSTRUCTIONS: The following statements are designed to gauge your satisfaction with the Pressure Distribution Seating System. After you read or hear a statement, please respond by choosing the scale option that best describes your feeling about the item. There are no right or wrong responses, so please choose the response that most closely matches how you feel about the statement you read or heard. For items 1-14, the response choices range from Strongly Disagree to Strongly Agree. Once you have determined your response, write or say your choice aloud and the interviewer will record your answer.

Perceived Effectiveness Items	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
1. The seating system is easy to use.	1	2	3	4	5
2. The seating system is comfortable.	1	2	3	4	5
3. The seating system is easy to care for.	1	2	3	4	5
4. I have less pain when I use the seating system.	1	2	3	4	5
5. I can keep my balance myself when I sit on the seating system.	1	2	3	4	5
6. I am afraid I will fall when using the cushion system.	1	2	3	4	5
7. I can sit in my chair longer when I use the seating system.	1	2	3	4	5

8. The length of time my Low-back pain is shorter with the seating system.	1	2	3	4	5
9. Intensity of Low-back pain is relived with the seating system.	1	2	3	4	5
10. Area of Low back pain is smaller after using the seating system.	1	2	3	4	5
11. The length of time my Buttock pain is shorter with the seating system.					
12. Intensity of Buttock pain is relived with the seating system.	1	2	3	4	5
13. Area of Buttock pain is smaller after using the seating system	1	2	3	4	5
14. I can do my usual activities without difficulty when using the seating system.	1	2	3	4	5

INSTRUCTIONS: The following statements are designed to gauge how often you experience certain conditions with the Pressure Distribution Seating System. After you read or hear a statement, please respond by choosing the scale option that matches the frequency with which you experience the given statement. There are no right or wrong responses, so please choose the response that most closely matches how often the statement is true for you. For items 15 – 28, the response choices range from Never to Always. Once you have determined your response, write or say your choice aloud and the interviewer will record your answer.

Perceived Frequency Items	Never	Rarely	Half of the time	Most of the time	Always
15. The seating system is easy to use.	1	2	3	4	5
16. The seating system is comfortable.	1	2	3	4	5
17. The seating system is easy to care for.	1	2	3	4	5
18. I have less pain when I use the seating system.	1	2	3	4	5

19. I am able to balance myself when I sit on the seating system.	1	2	3	4	5
20. I am afraid I will fall when using the cushion system.	1	2	3	4	5
21. I can sit in my chair longer when I use the seating system.	1	2	3	4	5
22. The length of time my Low-back pain is shorter with the seating system.	1	2	3	4	5
23. Intensity of Low-back pain is relived with the seating system.	1	2	3	4	5
24. Area of Low back pain is smaller after using the seating system.	1	2	3	4	5
25. The length of time my Buttock pain is shorter with the seating system.	1	2	3	4	5
26. Intensity of Buttock pain is relived with the seating system.	1	2	3	4	5
27. Area of Buttock pain is smaller after using the seating system	1	2	3	4	5
28. I can do my usual activities without difficulty when using the seating system.	1	2	3	4	5

29. What did you like about using this seating system?

____

____

____

______

30. What did you dislike about using this seating system?

31. Did you have any problems while using this seating system?

32. If you were able to get this seating system would you do so? Why or why not?

33. Are there any changes we should make to this seating system? If yes, please describe.

Form Approved Through 9/30/2007

OMB No. 0925-0001

Department of Health and Human Services
Public Health Services

Final Progress Report

Review Group	Type	Activity	Grant Number
			OH007737

Total Project Period
From: 9/30/02 Through: 4/30/05

Requested Budget Period
From: NA Through: NA

1. TITLE OF PROJECT
Reducing Low-back Disorders Using a New Sitting Design

2a. PRINCIPAL INVESTIGATOR OR PROGRAM DIRECTOR
(Name and address, street, city, state, zip code)
Mohsen Makhsous
Rehabilitation Institute of Chicago
345 E. Superior Street, Room 1406
Chicago, IL 60611

3. APPLICANT ORGANIZATION
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2b. E-MAIL ADDRESS
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4. ENTITY IDENTIFICATION NUMBER
36-328711

2c. DEPARTMENT, SERVICE, LABORATORY, OR EQUIVALENT
Sensory Motor Performance Program

2d. MAJOR SUBDIVISION
Rehabilitation Institute Research Corporation

5. TITLE AND ADDRESS OF ADMINISTRATIVE OFFICIAL
Joan Ciapas, Associated Director for Research Admin
345 E. Superior Street, Room 1408-B
Chicago, IL 60611

E-MAIL: jciapas@northwestern.edu

6. HUMAN SUBJECTS
☐ No
☒ Yes

6a. Research Exempt
☒ No ☐ Yes

6b. Human Subjects Assurance No.
FWA00001549

If Exempt ("Yes" in 6a):
Exemption No.

6c. NIH-Defined Phase III Clinical Trial ☒ No ☐ Yes

If Not Exempt ("No" in 6a):
IRB approval date 2/6/05
☒ Full IRB or
☐ Expedited Review

7. VERTEBRATE ANIMALS
☒ No
☐ Yes

7a. If "Yes," IACUC approval Date

7b. Animal Welfare Assurance No.

8. COSTS REQUESTED FOR NEXT BUDGET PERIOD
8a. DIRECT $0
8b. TOTAL $0

9. INVENTIONS AND PATENTS
☒ No ☐ Yes If "Yes," ☐ Previously Reported ☐ Not Previously Reported

10. PERFORMANCE SITE(S) *(Organizations and addresses)*
Rehabiliation Institute of Chicago
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Sensory Motor Performance Program
Chicago, IL 60611

11a. PRINCIPAL INVESTIGATOR OR PROGRAM DIRECTOR *(Item 2a)*
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11c. NAME AND TITLE OF OFFICIAL SIGNING FOR APPLICANT ORGANIZATION *(Item 14)*
NAME Joan C. Ciapas
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12. Corrections to Page 1 Face Page
N/A

13. PRINCIPAL INVESTIGATOR/PROGRAM DIRECTOR ASSURANCE: I certify that the statements herein are true, complete and accurate to the best of my knowledge. I am aware that any false, fictitious, or fraudulent statements or claims may subject me to criminal, civil, or administrative penalties. I agree to accept responsibility for the scientific conduct of the project and to provide the required progress reports if a grant is awarded as a result of this application.

SIGNATURE OF PI/PD NAMED IN 2a. *(In ink. "Per" signature not acceptable.)*

DATE 7/12/05

14. APPLICANT ORGANIZATION CERTIFICATION AND ACCEPTANCE: I certify that the statements herein are true, complete and accurate to the best of my knowledge, and accept the obligation to comply with Public Health Services terms and conditions if a grant is awarded as a result of this application. I am aware that any false, fictitious, or fraudulent statements or claims may subject me to criminal, civil, or administrative penalties.

SIGNATURE OF OFFICIAL NAMED IN 11c. *(In ink. "Per" signature not acceptable.)*
Joan C. Ciapas

DATE 7/12/05

Principal Investigator/Program Director (Last, First, Middle): Makhsous, Mohsen, PhD

PROGRESS REPORT SUMMARY	GRANT NUMBER R21 OHO7737	
	PERIOD COVERED BY THIS REPORT	
PRINCIPAL INVESTIGATOR OR PROGRAM DIRECTOR Mohsen Makhsous, PhD	FROM 9/30/02	THROUGH 4/30/05

APPLICANT ORGANIZATION
Rehabilitation Institute Research Corporation

TITLE OF PROJECT (Repeat title shown in Item 1 on first page)
Reducing Low-back Disorders Using a New Sitting Design

A. Human Subjects (Complete Item 6 on the Face Page)
Involvement of Human Subjects ☒ No Change Since Previous Submission ☐ Change

B. Vertebrate Animals (Complete Item 7 on the Face Page)
Use of Vertebrate Animals ☒ No Change Since Previous Submission ☐ Change

SEE PHS 2590 INSTRUCTIONS.

Occupational low back pain (LBP) is alarmingly common, with a 100 million workdays lost in the United States each year. The primary causes for work-related LBP include inappropriate curvature of the spine and pelvis induced by sitting, and sustained static muscle load caused by prolonged static sitting.

This project investigated a new sitting concept for office chair to determine its potential beneficial effects to working individuals with sitting related LBP. This new seating system features an enhanced adjustable protruded lumbar support, and a split seat pan, in which the back part of seat (BPS) can be dynamically tilted down with respect to the front part of the seat (FPS), providing adjustment of thigh and ischial support. Along with this new seating concept, a new sitting posture, **WO-BPS** sitting posture, was proposed by the investigators, which stands for using the protruded lumbar support on the backrest together with the released ischial support on the seat.

Research was carried out through biomechanical and physiological test in laboratory and radiological imaging settings, as well as through a 12-week subjective evaluation of the new office chair in practical working environment to collect feedbacks from individuals with sitting related low back complains.

Major findings from the project are:

- The proposed novel sitting concept **effectively relieved LBP symptoms** in the majority of the LBP patients who participated in the study;
- Alleviation of sitting related complains was achieved **optimally by simultaneously using two interventions: the adjustable protruded lumbar support, and the tilted down back part of the seat**;
- This sitting concept showed **significant sitting posture correction effect**, which resulted significant increased lumbar intervertebral disc height, forward rotation of the sacrum, increased lumbar lordosis, and **significantly decreased muscle effort** of paraspinal muscles in lumbar region;
- This sitting concept showed **significant load redistribution between the seat and backrest, and between the posterior and the middle portion of the seat pan**;

In conclusion, the investigated new sitting concept has been confirmed to have significant postural correction effect to individuals with sitting related LBP; thus significantly reducing one of the primary causes of occupational LBP. The investigators believe that this is the first seating system which provides sitting posture adjustment/ correction by the combination of protruded lumbar support and the reduced ischial load.

Moreover, since the novel seating system offer ample options for the user to find the optimal sitting postural configuration, the investigators believe that, by implementing **an automatic posture adjustment mechanism**, the seating device would have promising potentials to prevent prolonged static sitting, the other primary occupational cause for sitting related LBP.

Principal Investigator/Program Director (Last, First, Middle): Makhsous, Mohsen, PhD

Inclusion Enrollment Report

This report format should NOT be used for data collection from study participants.

Study Title: Reducing Low-back Disorders Using a New Sitting Design

Total Enrollment: 37 **Protocol Number:** Northwestern Univ. IRB 1209-001

Grant Number: R21 OHO7737

PART A. TOTAL ENROLLMENT REPORT: Number of Subjects Enrolled to Date (Cumulative) by Ethnicity and Race

Ethnic Category	Sex/Gender			
	Females	Males	Unknown or Not Reported	Total
Hispanic or Latino	4	3		7 **
Not Hispanic or Latino	15	15		30
Unknown (individuals not reporting ethnicity)				
Ethnic Category: Total of All Subjects*	19	18		37 *
Racial Categories				
American Indian/Alaska Native				
Asian	4	5		9
Native Hawaiian or Other Pacific Islander	0	0		0
Black or African American	2	2		4
White	13	11		24
More Than One Race				
Unknown or Not Reported				
Racial Categories: Total of All Subjects*				37 *

PART B. HISPANIC ENROLLMENT REPORT: Number of Hispanics or Latinos Enrolled to Date (Cumulative)

Racial Categories	Females	Males	Unknown or Not Reported	Total
American Indian or Alaska Native				
Asian				
Native Hawaiian or Other Pacific Islander				
Black or African American				
White				
More Than One Race				
Unknown or Not Reported	4	3	0	7
Racial Categories: Total of Hispanics or Latinos**				7 **

* These totals must agree.
** These totals must agree.

Form Approved Through 9/30/2007
OMB No. 0925-0001

Department of Health and Human Services **Final Invention Statement and Certification** *(For Grant or Award)*	DHHS Grant or Award No. 5 R21 OH007737

A. We hereby certify that, to the best of our knowledge and belief, all inventions are listed below which were conceived and/or first actually reduced to practice during the course of work under the above-referenced DHHS grant or award for the period

9/30/02 through 4/30/05.

original effective date — *date of termination*

B. Inventions (Note: If no inventions have been made under the grant or award, insert the word *"NONE"* under Title below.)

NAME OF INVENTOR	TITLE OF INVENTION	DATE REPORTED TO DHHS
Mohsen Makhsous, PhD	none	
(Use continuation sheet if necessary)		

C. First Signature —The person responsible for the grant or award is required to sign (in ink). Sign in the block opposite the applicable type of grant or award.

TYPE OF GRANT OR AWARD	WHO MUST SIGN *(title)*	SIGNATURE
Research Grant	Principal Investigator or Project Director	[signature] 7/11/05
Health Services Grant	Director	
Research Career Program Award	Awardee	
All other types (*specify*):	Responsible Official	

D. Second Signature — This block *must* be signed by an official authorized to sign on behalf of the institution.

Title	Name and Mailing Address of Institution
Associate Director for Research	
Typed Name: Joan C. Ciapas	
Signature: Joan C. Ciapas — Date: 7/11/05	

HHS 568 (Rev. 9/2004)

FINANCIAL STATUS REPORT

(Short Form)

date transmitted *job number* *date accepted*

1. Federal Agency and Organizational Element to Which Report is Submitted NATIONAL INSTITUTE OF HEALTH	**2. Federal Grant or Other Identifying Number Assigned by Federal Agency** 5 R21 OH007737-02	OMB Approval Number 0348-0039	Page 1 of 1 pages

3. Recipient Organization (Name and complete address, including ZIP code)
Rehabilitation Institute of Chicago
Grants Administration
345 East Superior Street Rom 1408A
Chicago, Illinois 60605

4. Employer Identification Number 1-363728711-A1	**5. Recipient Account Number** 03.80842	**6. Type of Report** FINAL	**7. Basis** X Cash __ Accrual

8. Funding / Grant Period From: (Month, Day, Year) 09/30/2002	To: (Month, Day Year) 04/30/2005	**9. Period Covered by this Report** From: (Month, Day, Year) 09/30/2004	To: (Month, Day, Year) 04/30/2005

10. Transactions:	**I. Previously Reported**	**II. This Period**	**III. Cumulative**
a. Total outlays	72,500.00	72,500.00	145,000.00
b. Recipient share of outlays	0.00	0.00	0.00
c. Federal share of outlays	72,500.00	0.00	0.00
d. Total unliquidated obligations **			0.00
e. Recipient share of unliquidated obligations			0.00
f. Federal share of unliquidated obligations			0.00
g. Total Federal share (Sum of lines c and f)			145,000.00
h. Total Federal funds authorized for this funding period			145,000.00
i. Unobligated balance of Federal funds (Line h minus line g)			0.00

11. Indirect Expense	**a. Type of rate** Provisional	xx Predetermined	__ Final	__ Fixed
	b. Rate 45%	**c. Base** 50,000.00	**d. Total Amount** 72,500.00	**e. Federal Share** 22,500.00

12. Remarks: *Attach any explanations deemed necessary or information required by Federal sponsoring agency in compliance with governing legislation.*

13. Certification: I certify to the best of my knowledge and belief that this report is correct and complete and that all outlays and unliquidated obligations are for the purposes set forth in the award documents.

Typed or Printed Name and Title Joan Ciapas, Associate Director, Grants Administration	**Telephone (Area code, number)** (312) 238-1265
Signature of Authorized Certifying Official Joan Q. Ciapas	**Date Report Submitted** 07/11/2005

NSN 7540-01-218-4387 269-201 Standard Form 269 (REV 4-88)

Prescribed by OMB Circulars A-102 and A-110

20029674

Title: Reducing Low-back Disorders Using A New Sitting Design
Investigator: Mohsen Makhsous
Affiliation: REHABILITATION INSTITUTE RESEARCH CORP
City & State: Chicago, IL
Telephone: (312) 238-4824
Award Number: 5R21OH007737-02
Start & End Dates: 9/30/2002-9/29/2005
Total Project Funding: $145,000.00
Program Area : Musculoskeletal Disorders: Low Back

Final Report Abstract:
Occupational low back pain (LBP) is alarmingly common, with a 100 million workdays lost in the United States each year .As the leading cause of disability in individuals less than 50 years old, LBP imposes a tremendous economic burden, with a direct treatment cost exceeding $25 billion in 1990 alone and the seated work tasks have a 25-76% prevalence of musculoskeletal discomfort. Although a number of occupational risk factors have been cited, the primary causes for work-related LBP include inappropriate curvature of the spine and pelvis induced by sitting, and sustained static muscle, ligament, and disc load caused by prolonged static sitting. Sitting induces backward rotation of the pelvis, reduction in lumbar lordosis, increased intervertebral disc pressure, tension in paraspinal muscles and ligaments in lumbar region, excessive pressure over the ischium and coccyx, and certainly the associated LBP.
This project investigated a new sitting concept for office chair to determine its potential beneficial effects to working individuals with sitting related LBP. This new seating system features an enhanced backrest, which is adjustable both in height and shape, providing various degrees of lumbar support, and a split seat pan, in which the back part of seat (BPS) can be dynamically tilted down with respect to the front part of the seat (FPS), providing adjustment of thigh and ischial support. Along with this new seating concept, a new sitting posture, WO-BPS sitting posture, was proposed by the investigators, which stands for using the protruded lumbar support on the backrest together with the released ischial support on the seat.
In this project, research was carried out not only through biomechanical and physiological test in laboratory and radiological imaging settings, but also through a 12-week subjective evaluation of the new office chair in practical working environment to collect feedbacks from individuals with sitting related low back complains.
Major findings from the project are:
The proposed novel sitting concept, which combines adjustable ischial load relief and lumbar support enhancement, effectively relieved LBP symptoms in the majority of the LBP patients who participated in the study;
The alleviation of the sitting related complains, the improvement of sitting posture, and the beneficial sitting load redistribution, are achieved optimally by simultaneously using two interventions: the adjustable protruded lumbar support, and the tilted down back part of the seat to achieve ischial load release;
The alleviation of the LBP symptoms by using this sitting concept is attributed to the significant sitting posture correction effect, which results significant increased lumbar

intervertebral disc height, forward rotation of the sacrum, increased lumbar lordosis, and significantly decreased muscle effort of paraspinal muscles in lumbar region;
The alleviation of the LBP symptoms by using this sitting concept is attributed to the significant load redistribution between the seat and backrest, and between the posterior and the middle portion of the seat pan;
The study chair also helped effectively relieve buttock pain symptoms in the majority of the LBP participants;
Sitting in this study chair was found overall comfortable and significantly increase sitting tolerance in the majority of the participants;
The new sitting concept, WO-BPS sitting posture, provided by the study chair, was found preferred by the majority of the participants.
In conclusion, the investigated new sitting concept has been confirmed to have significant postural correction effect to individuals with sitting related LB~; thus significantly reducing one of the primary causes of occupational LBP.
The investigators believe that this is the first seating system which provides sitting posture adjustment and correction by the combination of adjusting protruded lumbar support and the reduced ischial load.
Moreover, the posture adjustability and flexibility provided by the novel seating system offer ample options for the users to find the optimal sitting postural configuration best fits each individual's needs. Therefore, the investigators believe that, by introducing an automatic posture adjustment mechanism into current seating system, this seating concept would be transformed into a dynamic seating device which would have promising potentials to prevent prolonged static sitting, the other primary occupational cause for sitting related LBP, in individuals with occupations requiring long term sitting.
Encouraging findings on benefits of this seating concept on occupational LBP suggest further research and development effort be invested for improvement of the prototype and implementation of this new seating device in practical working space.

Publications:

20029217 Makhsous M, Lin F, Hendrix RW, Hepler M: Sitting with Adjustable Ischial and Back Supports: Biomechanical Changes. Spine, 28:1113-1121.
Makhsous M, Lin F, Hendrix RW, Zhang LG; (2003) Biomechanical Effect of Alttering Ischial and Back-Support Using a New Sitting Desigh. 49th Annual Meeting of Orthopaedic Research Society. New Orleans, Fe. 2-5, 2003.