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Do different sitting postures affect spinal biomechanics of asymptomatic individuals?

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ABSTRACT

Background

Static sitting is thought to be related to low back pain. Of various common seated postures, slouched sitting has been suggested to cause viscoelastic creep. This, in turn, may compromise trunk muscle activity and proprioception, and heightening the risk of low back pain. To date, no research has evaluated immediate and short-term effects of brief exposures to different sitting postures on spinal biomechanics and trunk proprioception.

Research question

This study aimed to compare the impacts of 20 minutes of static slouched, upright and supported sitting with a backrest on trunk range of motion, muscle activity, and proprioception immediately after and 30 minutes after the sitting tasks.

Methods

Thirty-seven adults were randomly assigned to the three sitting posture groups. Surface electromyography of six trunk muscles during maximum voluntary contractions were measured at baseline for normalization. Pain intensity, lumbar range of motion, and proprioceptive postural control strategy were assessed at baseline, 20 minutes (immediately post-test) and at 50 minutes (recovery). Trunk muscle activity during sitting was continuously monitored by surface electromyography.

Results

While the slouched sitting group demonstrated the lowest bilateral obliquus internus/transversus abdominis activity as compared to other sitting postures ($F=4.87$, $p < 0.05$), no significant temporal changes in pain intensity, lumbar range of motion nor proprioceptive strategy were noted in any of the groups.

Significance

Sitting for 20 minutes of duration appears to have no adverse effects on symptoms or spinal biomechanics regardless of the posture adopted. Future research should determine if there is a point at which does slouched sitting causes significant changes in pain/spinal biomechanics in people both with and without low back pain.

1. Introduction

Low back pain (LBP) is one of the most prevalent musculoskeletal complaints among office workers [1]. Prolonged sitting is known to be associated with musculoskeletal discomfort in lumbar and buttock regions [2], which may predict future LBP [3]. Although some epidemiological studies/systematic reviews have suggested no significant associations between sitting duration or sitting postures and the development of non-specific LBP [4],[5],[6], other studies have revealed that sitting for prolonged periods of time in poor postures might increase the risk of LBP and lumbar discomfort [5],[7],[8],[9],[10]. As such, many people generally believe that prolonged sitting in a poor posture (e.g., slouched sitting) is related to the development of non-specific LBP [11],[12], while upright sitting and supported sitting with a backrest are relatively safer [13].

There is some support in the literature to justify these assumptions. Specifically, slouched sitting has been shown to cause full flexion of the lower three lumbar segments [14]. This level of flexion has the potential to induce creep and overloading of passive spinal tissues leading to LBP [15]. Research has demonstrated that 10 minutes of sitting in maximum lumbar flexion elicited creep in spinal tissues [16],[17], which manifested as increased ranges of motion (RoM) [18] due to the elongation of viscoelastic tissues under a constant load [19]. Creep may desensitize mechanoreceptors in spinal structures and alter spinal joint sense [20]. Hypothetically, deteriorated joint sense may consequently affect trunk proprioception, and prompt the central nervous system to rely more on proprioceptive inputs from ankles for postural control [21]. People relying on ankle-steered proprioceptive postural control strategy are known to have a higher risk of developing non-specific LBP in the future [21]. However, no studies have investigated the effect of slouched sitting on the relative proprioceptive weighting (reliance) of the trunk and ankle.

Additionally, trunk muscles play an important role in maintaining spinal stability, especially in different postures and tasks. Previous research has found that obliquus internus, transversus abdominis, and deep and superficial lumbar multifidus demonstrate significantly lower activity during slouched sitting than upright sitting in healthy individuals [23]. Therefore, decreased trunk muscle activity in slouched sitting may increase viscoelastic creep of passive tissues in static flexion. However, no studies have evaluated how trunk muscle activity during sitting may be related to ensuing changes in lumbar kinematics.

Importantly, since no biomechanical studies have investigated the recovery of spinal biomechanics following sitting in various postures, it remains unclear if any altered trunk RoM or proprioception induced by a short period of different sitting postures would recover after a comparable resting period. Therefore, the current study aimed to compare the effects of three common sitting postures (slouched, upright and supported sitting with a backrest) on pain, lumbar RoM, proprioception and trunk muscle activity immediately following 20 minutes of sitting and 30 minutes of recovery.

2. Methods

2.1. Participants

Twenty-one males and 16 females (average age: 21.5 ± 2.0 years) with no current LBP or history of LBP that required sick leave in the last 12 months were recruited from The Hong Kong Polytechnic University (Table 1). Exclusion criteria included scoliosis, spinal surgery, vestibular dysfunction, lumbosacral or lower limb musculoskeletal pathology in the last 12 months, or neurological disorders. Participants provided written consent according to the experimental procedure approved by the Institutional Review Board.

2.2. Pain measure

Self-reported pain intensity was assessed by an 11-point numeric pain rating scale with anchors of 0 /"no pain" and 10/ "worst imaginable pain" [24]. Participants completed pain ratings verbally at baseline, and immediately after and 30 minutes after the sitting tasks.

2.3. Surface electromyography (sEMG)

The activity of bilateral obliquus internus/transversus abdominis (OI/TrA), obliquus externus (OE), and lumbar erector spinae (ES) were measured by sEMG. Biploar Ag/AgCl surface electrodes with a 10-mm active diameter (3M, Minnesota, USA) attached parallel to the muscle fiber direction with an inter-electrode distance of 20 mm (Table 2). A standardized skin preparation was performed to ensure skin impedance of ≤ 5000 Ω. The sEMG data were recorded at 1,500 Hz by a wireless sEMG system (Telemyo, Noraxon Inc., Phoenix, USA; CMRR 100 dB at 60 Hz) and digitized with the Desktop Direct Transmission System (Noraxon Inc., Phoenix, USA). Signals were processed with a Noraxon program, MR 3.10.2, to eliminate electrocardiography signals, notch filter at 50Hz to remove electrical noise, and digitally bandpass between 10Hz and 500Hz [25].

sEMG signals from each muscle were expressed as a percentage of maximum voluntary contraction (%MVC). Specifically, the root mean square (RMS) over 2-second windows throughout the sitting trial were calculated and normalized to corresponding RMS sEMG during MVC. To evaluate temporal changes in sEMG, the 20-minute sitting period was divided into three intervals of 400s and the mean normalized sEMG activity in each interval was calculated for analysis.

Two, 5-second, isometric MVC trials were performed for each target muscle against manual resistance with a 2-minute rest between trials. (Table 2). Following signal processing, RMS sEMG signals of each muscle during the middle 2 seconds of MVC was calculated. The highest RMS EMG amplitude of each muscle during MVCs was used for subsequent normalization.

2.4. Lumbar flexion/extension RoM

Lumbar kinematics were measured by a wireless 3D kinematic analysis system (MyoMOTION, Noraxon Inc., Phoenix, USA; reported static and dynamic accuracy of 1° and 2°, respectively) at a sampling frequency of 100 Hz. Two inertial measurement unit (IMUs) were attached to skin overlying the T12 and S1 spinous processes with double-side tape [26]. The relative lumbar angle was deduced from the orientations of these IMUs. A reference posture was taken with the participant in upright standing with the ear lobe aligned to the acromioclavicular joint and feet shoulder width apart. The participant was then instructed to perform full trunk flexion and extension twice and the average total RoM was used for analysis. The average lumbar flexion angle of an individual during a given sitting posture was expressed as the percentage of the maximum flexion angle.

2.5. Proprioception measurements

Center of pressure (CoP) displacement during standing was measured by a piezoelectric force plate (Kistler, Winterthur, Switzerland). A customized LabVIEW program collected data at 500 Hz using a data acquisition system for BioWare (Kistler Group, Winterthur, Switzerland) and low-pass filtered with a cut-off frequency of 5 Hz.

The relative reliance on trunk and ankle proprioceptive inputs for postural control was evaluated by muscle vibration. Muscle vibration stimulates muscle spindles to generate an illusion of muscle lengthening that may alter proprioceptive sense [27]. Two pairs of muscle vibrators (custom made with DC-max motors, Maxon motor Co., Ltd, Suzhou, China) were strapped to bilateral lumbar multifidus (LM) at the L5-S1 level and triceps surae (TS) [21]. The frequency and amplitude of vibration were set at 60 Hz and 0.5 mm respectively to optimize the illusion of muscle lengthening [27]. Vibration of LM in standing gives an illusion of posterior pelvic rotation, which causes an individual to shift CoP forward to avoid falling [21]. Conversely, TS vibration generates a forward leaning illusion, which causes a person to lean backward [21]. The magnitude of CoP displacement indicated the relative importance of proprioceptive signals of the vibrated muscles in informing the brain to maintain balance.

The detailed procedure for assessing proprioceptive postural control has been reported elsewhere [21]. Briefly, the participant stood in an immobile but relaxed position barefoot on the force plate with feet 10 cm apart and arms hanging loosely at the sides. The feet position was marked on the force plate to standardize placement throughout repeated measurements. The participant was blindfolded by opaque goggles and tested under four conditions lasting for 1 minute each. The participant directly stood on the force plate in conditions 1 and 2, while the participant stood on foam placed upon the force plate in conditions 3 and 4. In conditions 1 and 3, muscle vibrators were used to stimulate bilateral LM [21]. In conditions 2 and 4, bilateral musculotendinous junctions of TS were stimulated by two muscle vibrators [21]. A 15-second muscle vibration was introduced after the first 15 seconds.

Postural data were analyzed by a customized MATLAB program (R2015a, MathWorks, Natick, MA, USA). The mean CoP displacement in the anteroposterior direction was estimated by the formula:

$$CoP = \frac{Mx}{Fz}$$

where Mx was the moments of force around the frontal axis, and Fz was the vertical ground reaction force. Average CoP position was estimated both over 15 seconds preceding and during a given muscle vibration. The difference in average CoP positions between the two conditions were used to estimate the Relative Proprioceptive Weighting (RPW) using the formula [21]:

$$RPW = \frac{TS}{LM} = \frac{abs\ TS}{abs\ TS + abs\ LM}$$

where *abs TS* and *abs LM* are the absolute values of average CoP displacement during TS and LM vibrations, respectively. A score of 1 indicates 100% reliance on TS proprioceptive signals for postural control while 0 implies complete reliance on LM proprioceptive signals for postural adjustment. Separate RPWs were calculated for stable (conditions 1 and 2) and unstable (conditions 3 and 4) surface conditions.

2.6. Experimental protocol

Each consenting participant provided demographic data, perceived LBP intensity, and performed MVCs of the six trunk muscles (Fig. 1). An examiner blinded to group allocation measured baseline lumbar flexion/extension RoM in standing and proprioceptive strategy using IMUs and the proprioception tests [21], respectively. Following these assessments, a research assistant uninvolved in the assessments opened a sequentially numbered opaque envelope containing a random number prepared by a person unrelated to the study, to randomly assign participants to the slouched, upright or supported sitting with a backrest group (thereafter called supported sitting). The slouched position was created by relaxing the trunk into flexion by rotating the pelvis posteriorly, while the upright position involved rotating the pelvis anteriorly to maintain a neutral lumbar lordosis with relaxed thorax [28]. Manual guidance and verbal feedback were given by the research assistant to achieve the upright sitting posture. The supported sitting position was maintained by leaning upper body against a backrest with a lumbar support of 2cm protuberance. All participants sat in the assigned postures on an adjustable office chair with hips and knees in 90° flexion. During this 20-minute trial, trunk inclination angles and trunk muscle activity were measured by IMUs and sEMG, respectively. This sitting duration was chosen because 20 minutes of maximum lumbar flexion exposure might induce viscoelastic changes in the lumbar tissues [17]. To maintain the prescribed postures throughout the trial, verbal feedback, was given if the IMU data showed postures deviated > 5º. Immediately following the sitting trial, the blinded examiner reassessed LBP intensity, lumbar RoM and proprioceptive postural control, and again at recovery (30 minutes post-trial). Participants lay supine on a therapy bench between reassessments.

2.7. Statistical analysis

Statistical analysis was conducted with alpha setting at 0.05 (SPSS v.20, IBM SPSS Statistics, Chicago, USA). Normality of all data was evaluated by Shapiro–Wilk tests. Mean lumbar RoM during sitting in all groups was analyzed by one-way analysis of variance (ANOVA). If a significant between-group difference was found, Tukey's post-hoc test was conducted. Pain intensity, sEMG of each muscle, lumbar flexion/extension RoM, CoP displacement, RPW were analyzed by separate 2-way repeated measures ANOVAs (sitting groups x time points). Post-hoc tests included simple effect tests and tetrad analyses with Bonferroni adjustment [29].

3. Results

There were no significant demographic differences among the three groups nor significant temporal changes in pain intensity during trials (Table 1).

3.1. sEMG during sitting

No significant interactions nor temporal changes in sEMG activity of the trunk muscles were found among the three sitting postures. However, a significant between-group difference in bilateral OI/TrA activity was found (Fig. 1). Post-hoc tests revealed that left OI/TrA activity in slouched sitting and supported sitting was significantly lower than that of upright sitting (P<0.05) (Fig. 1). Similarly, mean sEMG value of right OI/TrA in slouched sitting was significantly lower than that in upright sitting or supported sitting (P=0.04) (Fig. 1). Overall, the lowest sEMG activity of bilateral OI/TrA was found during slouched sitting.

3.2. RoM during sitting

The mean lumbar RoM during slouched, upright and supported sitting were 44.4 % ± 4.74 %, 9.5 % ± 2.50 % and 14.8 % ± 6.01 % of the participants' maximum lumbar flexion RoM, respectively. The one-way ANOVA revealed that the lumbar flexion angle in sitting significantly differed among groups (P<0.05). Post-hoc tests found lumbar flexion angle during slouched sitting was significantly larger than other sitting postures (P<0.05).

3.3.2. Lumbar active RoM

There was no significant interaction between time and group in lumbar RoM (P=0.26, η^{2_2}= 0.08). Similarly, there was no significant temporal change in lumbar active RoM in any of the groups (P=0.28, η^2=0.04) nor between-group difference in mean lumbar active RoM

(P=0.66, η^2=0.03).

3.4. RPW

The solid surface findings revealed no significant interaction effect (P=0.50, η^2=0.052) nor time effect (P=0.052, η^2=0.09) but a significant between-group effect ($P<0.01$, η^2=0.30) on RPW. Post-hoc tests showed that RPW of upright sitting group was significantly higher than that of supported sitting group ($P<0.01$) (Fig 2). Conversely, the RPW results on foam surface showed no significant interaction (P=0.43, η^2=0.06), time (P=0.82, η^2=0.006) nor between-group effect (P=0.61, η^2=0.03).

4. Discussion

This study has evaluated the impact of three common seated postures on spinal biomechanics immediately after 20 minutes of sitting and a 30-minute recovery. Slouched sitting elicited the lowest bilateral OI/TrA muscle activity during sitting. Likewise, right OI/TrA sEMG activity during supported sitting was significantly lower than during upright sitting. Compared to upright and supported sitting groups, participants in slouched sitting maintained the greatest lumbar flexion angle during sitting. The three sitting postures had no significant impact on LBP intensity, lumbar active RoM nor RPW, except that the upright sitting group displayed significantly higher RPW than supported sitting. Overall, there were no temporal changes in lumbar symptoms or lumbar biomechanical factors immediately following 20 minutes of sitting intervention, and 30 minutes of recovery.

Sitting posture can influence trunk muscle activity. Significantly lower activity of bilateral OI/TrA in slouched sitting compared to upright sitting concurred with previous observations [30],[31]. It has been suggested that posterior passive lumbar tissues may take up the load of the upper body and maintain the position against gravity at mid to end-range flexed spinal postures [14],[31]. The increased passive support in slouched sitting may reduce the activation of OI/TrA for lumbar stabilization [32]. It is not known if these low levels of muscle activity could be a problem in terms of spine health. This differs from situations of supported sitting where the backrest shares part of the upper bodyweight. For example, we found the right OI/TrA activity in supported sitting was also significantly lower than the levels in upright sitting. However, the negative biomechanical impacts of low trunk muscle activity during supported sitting should be considered minimal as the potential for viscoelastic creep would be reduced.

While prior studies [16],[17],[18],[22] have shown that creep of lumbar tissues occurs after 10 to 60 minutes of sitting in lumbar flexion and persist 50 minutes following 20 minutes of full lumbar flexion [17], our study found no temporal changes in lumbar active RoM after slouched sitting. The discrepancy may be ascribed to the small lumbar flexion angle in our slouched sitting group. Our participants sat slumped in approximately 44.4% of full lumbar flexion for 20 minutes, whereas participants in previous studies maintained maximum flexion for 20 minutes [17] or > 70% of full lumbar flexion for 30 or 60 minutes [16],[33]. However, since a self-selected slouched sitting posture (like ours) has much lower percentage of full lumbar flexion, the generalizability of prior findings should be interpreted with caution. Also, since creep is a time dependent variable, there is the potential that longer durations of typical slouched sitting may induce these changes; therefore, future studies should determine the combined effects of lumbar sitting angles and time on the resulting lumbar RoM.

It is not surprising to find no significant temporal changes in RPW (postural control strategy) in all sitting groups given the lack of post-sitting creep in spinal tissues (including LM). Our

RPW findings differed from prior research. Dolan and Green [34] found that a 5-minute slouched sitting increased the trunk reposition errors. However, since their study did not measure lumbar active/passive RoM before and after slouched sitting, the observed increase in post-sitting trunk reposition errors might be unrelated to creep. Importantly, since trunk reposition sense is confounded by an individual's ability to pay attention and/or to recall a trunk position consciously [35], this assessment is not a direct measurement of trunk proprioceptive control, which involves subconscious processing [35]. Accordingly, our results highlight that a short period of slouched sitting is unlikely to affect trunk proprioception.

Interestingly, participants in the upright sitting group relied more on ankle-steered postural control strategy (RPW>0.5) than those in the supported sitting group. Claeys et al. [21] revealed great variability in proprioceptive postural control strategy among asymptomatic individuals (95% confidence interval of RPW ranging from 0.44 to 0.94). Since the estimated mean RPW of participants in the upright sitting (0.76) and supported sitting groups (0.54) lay within the 95% confidence interval, the observed difference might only reflect coincidental variations in RPW of participants in the two groups.

Our results demonstrate that a short duration of static sitting in different postures does not appear to alter spinal biomechanics of asymptomatic individuals. While many epidemiological studies/reviews have suggested no association between sitting duration/posture and LBP [4],[5],[6], various occupational health advice have advocated office workers to regularly change posture to avoid static loading to the body/intervertebral discs [7],[36],[37]. Active break with postural change from sit to stand as well as back exercise have been recommended to reduce LBP, lumbar discomfort, back muscle fatigue and mental fatigue [7]. Importantly, breaks and sufficient postural variation can improve contraction, motivation, and good musculoskeletal health [38] without affecting work productivity among office workers [7]. In fact, a 2-minute break for every 20 minutes of sitting is known to reduce the postprandial glucose and insulin responses in adults [39]. Given that the 20-minute sitting duration has no significant adverse effects on lumbar discomfort or lumbar biomechanics among asymptomatic individuals regardless of sitting postures, this sitting duration appears to be safe. Since people sit for much longer durations than 20 minutes, future research needs to investigate the maximum sitting duration, in various spine postures, that can be tolerated without adversely affecting spinal biomechanics in people with and without LBP. Future studies should also investigate the optimal combination of sitting and break durations to help develop ergonomic recommendations/standards for office workers.

The current exploratory study has several limitations. Firstly, while our sample size was comparable to similar studies [34],[40], it was relatively small. However, from our observed effect size, 22 participants per group would detect statistically significant differences in lumbar ES activity between slouched and upright sitting groups, thus minimizing this limitation. Future studies may consider using a repeated measures design with participants serving as their own controls in order to increase the sensitivity with which differences may be detected between postural conditions. Secondly, since there is redundancy in trunk muscle recruitment [41], spatial variability in muscles activity may have been missed. Future research should use high-density sEMG electrode arrays [42] to monitor temporal and spatial changes in trunk muscle activity during sitting. Finally, because the current study only recruited asymptomatic participants, future studies should compare our findings with patients with LBP so that appropriate sitting recommendations can be given to office workers with and without LBP.

To conclude, this is the first study to evaluate the effect of three common sitting postures on back symptoms, trunk muscle activities, RoM and proprioception. Our findings show that 20 minutes of slouched sitting, upright sitting, and supported sitting have no adverse effects on LBP nor spinal biomechanics. However, it is not known whether longer durations of sitting may impact these outcome measures. Future research should investigate the effects of different sitting and break durations on people with and without LBP so as to formulate proper ergonomic recommendations/standards for office workers.

Contributors

AW: Conception and design of the study, analysis and interpretation of data, revising and final approving the article. TC, AC, HC, KK, AL, PW: acquisition of data, analysis and interpretation, drafting, revising and final approving the article. DD: conception and design of the study, interpretation of the data, revising and final approving the article.

Conflict of interest statement

The authors declare that there are no financial or personal relation with people or organizations that have inappropriately influenced this work.

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