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Biomechanical effects of a lumbar support in a mattress

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For many patients with chronic low back pain, the lack of sleep and sufficient rest period that allows some relaxation is a major obstacle to a good quality of life. During sleep periods, neuromuscular activity is at a minimal level. The major factor influencing the forces on the body, and particularly the spine, is gravity. The force of gravity is sufficient to deform soft tissues when the body is resting on a mattress. Thus, the goal of this study is to measure the contact pressure forces acting on the spine with and without an inflatable support in various experimental conditions. Our hypothesis is that a lumbar support will distribute the force of gravity more uniformly over the pelvic, lumbar and thoracic areas, maintaining the lumbar lordosis, in a supine posture.

In this study, 10 participants were tested when lying supine in six separate experimental conditions. These conditions varied according to the surface (no mattress, foam, mattress) and the fact that the support was inflated or not. The dependent variable measured was the contact pressure. It was measured using a pressure sensor mat (Tekscan™). When the cushion was inflated the distribution of contact pressure in the different areas (pelvic, lumbar and thoracic) was modified. The comparison of the mean forces revealed that when the cushion was not inflated, the pressure distribution was mainly localized in the pelvic area. After the cushion was inflated, a significant decrease of contact pressure in the pelvic region and a significant increase in the lumbar area were observed. Our results confirm the hypothesis that a lumbar support inserted in a mattress allows a more homogenous distribution of contact pressure over

Pour beaucoup de patients souffrant de lombalgies chroniques, le manque de sommeil et de périodes de repos suffisantes qui permettent une certaine détente constitue un obstacle important à une bonne qualité de vie. Pendant les périodes de sommeil, l'activité neuromusculaire est à un niveau minimal. Le principal facteur qui influence les forces s'exerçant sur le corps, et en particulier sur la colonne vertébrale, est la pesanteur. La seule force de gravité suffit à déformer les tissus mous quand le corps repose sur un matelas. Ainsi, l'objectif de cette étude est de mesurer les forces de contact agissant sur la colonne vertébrale, avec ou sans soutien gonflable, dans différentes conditions expérimentales. Notre hypothèse repose sur le fait qu'un soutien lombaire répartira la force de gravité de manière plus uniforme sur les régions pelvienne, lombaire et thoracique, maintenant la lordose lombaire en position couchée.

Cette étude a procédé à l'évaluation de 10 participants, en position couchée, dans six conditions expérimentales distinctes. Ces conditions variaient selon la surface (sans matelas, avec mousse, avec matelas) et selon que l'on dispose d'un soutien gonflable ou non. La variable dépendante mesurée était la pression de contact. Elle a été mesurée grâce à un tapis capteur de pression (Tekscan™). Quand le coussin était gonflé, la répartition de la pression de contact dans les différentes régions (pelvienne, lombaire et thoracique) était modifiée. La comparaison des forces moyennes montrait que lorsque le coussin n'était pas gonflé, la répartition de la pression était surtout localisée dans la région pelvienne. Après avoir gonflé le coussin, on observait une diminution

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the pelvic, lumbar and thoracic areas during supine posture. The use of an inflatable cushion favouring a transition of the contact pressure from the pelvic to the lumbar region could potentially limit unfavourable compressive and shearing forces acting on the lumbar spine.
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importante de la pression de contact dans la région pelvienne et une augmentation importante dans la région lombaire. Nos résultats confirment l'hypothèse selon laquelle un soutien lombaire inséré à un matelas permet d'obtenir une répartition plus homogène de la pression de contact sur les régions pelvienne, lombaire et thoracique lorsqu'on est en position couchée. L'utilisation d'un coussin gonflable favorisant une transition de la pression de contact, de la région pelvienne à la région lombaire, serait susceptible de limiter les forces de compression et de cisaillement défavorables agissant sur la colonne lombaire.
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KEY WORDS: lumbar support, mattress, lying posture, contact pressure.

MOTS CLÉS : soutien lombaire, matelas, position couchée, pression de contact.

Introduction

While there is general agreement among specialists that proper lumbar support is a fundamental requirement in seated posture, there is no consensus regarding the design of mattresses used by the general population with or without low back pain.[1] The literature on this topic is scarce and common recommendations are often based on empirical reports from subjects. In fact, a review of the literature reveals a lack of information on the biomechanics of lying and sleeping postures as well as the different types of support used while sleeping.[1–4] The mattress represents a wide body support surface on which prolonged and complete rest must be found. Nordin and Frankel,[5] recommend that a mattress should adapt to body curvature, remain flat, have a pleasant spring action, have good ventilation, and not be too warm or too cold. The first three criteria are related to the body support characteristics of the mattress and have a major influence on the spinal configuration during rest. For example, when lying on the side on a hard mattress, only the hip and the shoulder are supported and the spine is laterally flexed (i.e. convexity towards the mattress). A soft mattress will cause the hip and shoulder to sink creating a lateral bend of the spine away from the mattress.[1] In a supine position, the pelvis and lower thoracic spine are in contact with the mattress while the lumbar region is minimally supported.

There is good evidence that the use of a lumbar support is beneficial in the seated position. Backrests that support the lumbar region while seated reduce muscle activity and intradiscal pressure in the lumbar spine. The addition of a lumbar support, that increases lumbar lordosis, as well as the backward inclination of backrest will further reduce the load on the lumbar spine, measured in terms of pressure in the third lumbar disc.[5] Bendix et al.[6] showed that the design of backrests is important. In a controlled trial, they observed that a vertical backrest decreases the lumbar lordosis, whereas a more anteriorly curved backrest could improve the lumbar lordosis. These results suggest that an adequate configuration in the design of a lumbar backrest is essential. Coleman et al.[7] investigated the preferred settings for a lumbar support on adjustable office chairs. Their results highlighted the importance of proper adjustment of lumbar support. They showed that adjustment patterns chosen by subjects who had experienced long-term low back pain did not differ from those of control subjects. However, subjects with recent low back pain preferred chair settings that ensured maximal support of the lumbar spine. Once again, these observations suggest the importance of individual characteristics when it comes to the development of a new lumbar support device.

Very few studies have investigated the different biomechanical effects of mattress design and related sleeping postures. Gracovetsky,[1] in a theoretical paper, described the potential effects of different sleeping postures and mattresses on the spine. Most of his conclusions are based on the possible forces imposed to the spine in different conditions. Based on this, very little practical information can be used to improve the design of mattresses. Generally, the standard hard or extra firm mattress is recommended by most physicians and textbooks dealing with the subject, without any scientific evidence. In a survey of orthopedic surgeons, 95% believed that mattresses played a part in the management of low-back pain, with 76% recommending a firm mattress.[4] In this regard, the use of a soft mattress is discouraged by most physicians who regularly treat low back pain patients. People who have chronic low-back pain are more sensitive to the firmness of mattresses than healthy people.[2] Recently, Kovacs et al.[8] compared the firmness effect of a mattress on chronic non-specific low-back pain and found that the use of a mattress of medium firmness improved the clinical course of low-back pain in a higher proportion of patients than the use of a firm mattress. After observing a large reduction of symptoms in patients sleeping on a water bed, Garfin and Pye[9] speculated that a more uniform body support could help reduce turning and muscle activity during sleep.

When lying supine, loads on the spine are minimal. In fact, intradiscal pressure has been measured in this position by Wilke et al.[10] and is about 20% of the pressure measured in a relaxed standing position. However, with the body supine and the legs in a neutral position, the pull of the psoas muscle increases the load on the lumbar spine, increasing the lumbar lordosis.[5] In this position, contact pressure from a firm mattress is distributed to the pelvic and the lower thorax region. The lumbar region poorly supported, has to react to an increase in shear and compressive forces at the segmental level. Inadequate support of the lumbar spine during sleep could contribute to the development of low back pain. Lumbar support during sleeping could be even more important for subjects with chronic or recurrent low back pain.

Thus, the goal of this study is to measure the contact pressure acting on the spine with and without an inflatable lumbar support in various experimental conditions. Our hypothesis is that a lumbar support will distribute the force of gravity more uniformly over the pelvic, lumbar and thoracic areas, maintaining the lumbar lordosis, in a supine sleeping posture.

Methods

Participants

Ten subjects (5 men and 5 women; mean: age of 20 years old, range 22–31) from the Département de Chiropratique of the Université du Québec à Trois-Rivières participated in this experiment on a voluntary basis. They were all in good health and none reported any low back, thoracic or cervical pain.

Apparatus and procedures

The apparatus was composed of a pressure sensitive mat (Tekscan™ Matscan model 3150) that is designed to measure ground reaction vertical force or pressure applied to its surface. This pressure sensor mat measured 50.8 by 50 cm, which yielded a surface area of 2540 cm^2 with 2228 sensors. Thus, this gave us a resolution of 1.4 sensors for each cm^2. The mat was placed on a table and subjects were instructed to lie on it by placing their hips according to a specific reference point on the mat. In order to measure the effect of the inflatable cushion on the lower back, the surface of the mat was divided in three areas: pelvic, lumbar and thoracic. The width of these three areas was 30 cm along the X axis[11,12] which is parallel to the hips in order to use the largest surface of the pressure mat. The pelvic, lumbar and thoracic areas were respectively 15, 10 and 15 cm wide in the Y axis. The transition between the pelvic and lumbar areas was the posterior superior iliac spine (PSIS). This anatomical landmark corresponds to the L4–L5 vertebrae. For a subject of medium height (1,70 m), if we measure 10 cm above the iliac crest, this corresponds approximately to the level of the L1 vertebra and it defines the lumbar area. The area above the L1 vertebra and towards the head is the thoracic area.

The inflatable cushion measured 64 cm long by 11.5 cm wide and was inflated using a manual pump similar to the ones used with a sphygmomanometer. The height of the fully inflated cushion was 5 cm with a pressure of 300 mmHg. This pressure value generated the largest displacement of the cushion with a small deformation when a subject lied on it. The placement of the inflatable cushion was standardised such that the apex of the cushion was always aligned with the L3 vertebra using the PSIS as an anatomical landmark. The subject was placed on the cushion in such a way that the iliac crest was aligned with the edge of the cushion.

Subjects were asked to lie supine in six separate experimental conditions. They were instructed to lie supine with eyes closed and to remain still for 30 seconds. The first condition was without any mattress and was the control condition. The second condition was with an 8 cm thick foam used over the mattress. This condition was included to verify the effect of the inflatable cushion with a commercially available device. The third condition was with a 14 cm latex mattress of medium density specially designed with a slot to receive the inflatable cushion. Finally all three conditions were repeated with the lumbar support inflated.

Data acquisition

The Tekscan (Matscan) hardware and software system was used to collect, calculate and display the mean contact pressure in each area. Data were recorded during 15 seconds at a sampling frequency of 20 Hz. This gave us a total of 300 frames for each experimental condition and each subject. The Tekscan software allows a color-coded display of the sensors pressure information in real time. Using the Tekscan software, we could also quantify the contact pressure for specific frame or set of frames at any moment. The dependent measure was the mean contact pressure in all three areas

Statistical analysis

The dependent variable was submitted to a repeated measure ANOVA (Surface x support). This analysis tested for the main effect of surface (no mattress, foam and mattress), the main effect of support (non inflated and inflated) and the interaction.

Results

The mean and standard deviations of the contact pressure for all six conditions and three areas are presented in Table 1. The main effect of cushion inflation yielded a significant increase of reaction forces for the lumbar area $(F1,9) = 70.028$ $p < 0.001$ and a significant decrease of contact pressure in the pelvic area $(F1,9) = 47.967$ $p < 0.001$. This force redistribution is illustrated in Figure 1. Generally, before the cushion was inflated, the pressure distribution was mainly localized in the pelvic area. After the cushion was inflated, a decrease of contact pressure in the pelvic region and increase around the cushion in the lumbar area was observed. In the pelvic and lumbar area the interactions were not significant.

Table 1
Mean contact pressure (SD) in newtons (N) for all conditions in the lumbar, pelvic and thoracic area

AREAS	CUSHION	
Lumbar	**Non inflated**	**Inflated**
No mattress	11.92 N (4.95)	174.19 N (25.24)
Foam (8 cm)	26.76 N (5.85)	41.62 N (8.64)
Matrress (14 cm)	53.63 N (12.71)	164.3 N (17.30)
Pelvic		
No mattress	448.86 N (31.56)	388.48 N (30.95)
Foam (8 cm)	79.71 N (11.72)	71.71 N (10.11)
Mattress (14 cm)	115.7 N (20.86)	94.05 N (17.61)
Thoracic		
No mattress	106.92 N (35.58)	60.8 N (26.11)
Foam (8 cm)	43.81 N (10.52)	43.33 N (10.02)
Mattress (14 cm)	107.77 N (27.78)	117.24 N (26.46)

In the thoracic area a significant interaction was observed $(F2,18) = 11.916$ $p < 0.001$. Post hoc analysis revealed that only the condition without mattress showed a significant decrease in contact pressure, when inflating the cushion (Tukey $p < 0.001$).

Discussion

The results of this study indicate a significant increase of contact pressure in the lumbar region when the support was inflated (Figure 1). These changes were coupled with a reduction of contact pressure in the pelvic and thoracic areas. The mechanical effect of cushion inflation is an anterior translation of the spinal process of L3 and therefore an increased lordosis. An increase in lordosis is presumably related to a decrease in intradiscal pressure (10, 13, 14, 15, 16). This could also reduce the shearing forces

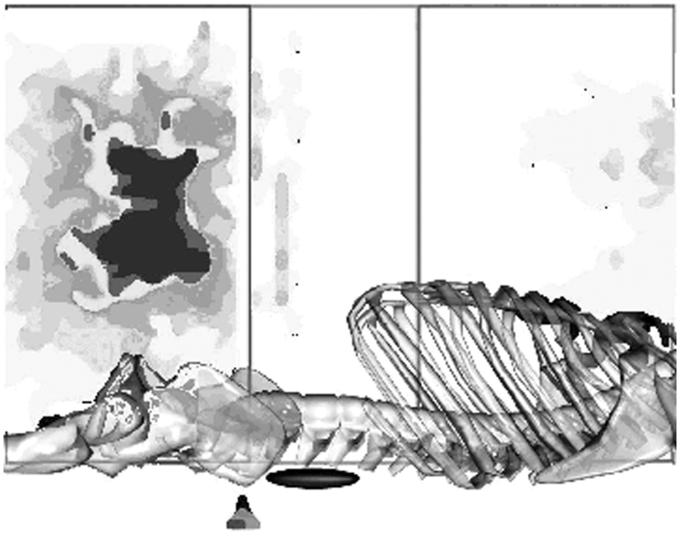

Figure 1a Illustration of the overall effect of contact pressure redistribution in all three areas analyzed without the lumbar support inflated for one subject and one trial. The darkest area represents the highest contact pressure recorded. A lateral view of the skeleton was superimposed on the contact pressure measurement to illustrate the location of the inflatable cushion and the subject's specific position. The triangle illustrates the PSIS landmark.

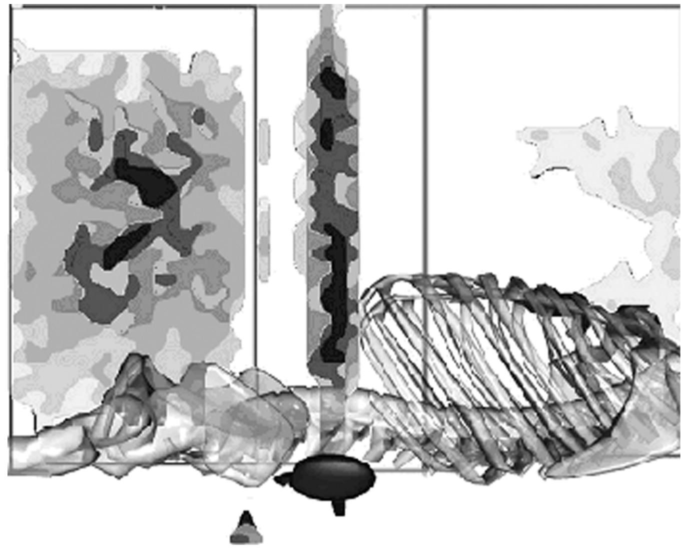

Figure 1b Illustration of the modification in the intensity of contact pressure in all three areas analyzed with the lumbar support inflated for the same subject and the same trial. One can observed the reduction of contact pressure in the pelvic area and the increase of contact pressure in the lumbar area.

elicited by gravity when the subject is in a supine position. Our results also point out that when the inflatable support is closer to the spine (no mattress) the vertical force rearrangement is greater. Thus, the vertical force redistribution is affected by the thickness and firmness of the support surface.

Most health professionals, when recommending a mattress, suggest a hard or extra firm mattress instead of a soft one. This is based on the fact, that this type of mattress is better to conserve lumbar lordosis. However, a very firm mattress will decrease contact surface and therefore increase contact pressure. The major advantage of an inflatable lumbar support is to maximise the trade-off between stiffness of the mattress and restoring the lumbar spine lordosis. This could produce the most interesting biomechanical effects allowing a maximal contact surface and optimal lordosis for every individual using a commercial[14] available device that is placed over the mattress.

Coleman et al.[7] showed that specific adjustment patterns (adjustable office chairs) were related to the anthropometric data of each individual and confirmed the importance of specific characteristics when it comes to the development of a new lumbar support device. Thus, for this reason, an inflatable cushion represents a versatile equipment to personalise lumbar support and increase the quality of resting periods. Moreover, as mentioned earlier, people with chronic low-back pain require a finer adjustment of their mattress firmness than healthy people. Harrison et al. determined that the lumbar lordosis is not curvilinear but has a more elliptic form.[11] They also showed modifications of lumbar lordosis configuration in subjects with low back pain. Based on this work, the design of the cushion should be investigated in order to optimize surface contact and therefore contact pressure.

A small sample size of healthy individuals was selected for this study and only a short term mechanical effect was analyzed. Future studies should investigate clinically important outcome in normal and symptomatic populations.

Conclusion

Our results confirm the hypothesis that a lumbar support inserted in a mattress allows a more homogenous distribution of contact pressure over the pelvic, lumbar and thoracic areas during supine posture. The use of an inflatable cushion favouring a transition of the contact pressure from the pelvic to the lumbar region could potentially limit unfavourable compressive and shearing forces acting on the lumbar spine.

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