Effects of unconsciousness during spinal immobilization on tissue-interface pressures: A randomized controlled trial comparing a standard rigid spineboard with a newly developed soft-layered long spineboard

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ABSTRACT

Background: Immobilization of the spine of patients with trauma at risk of spinal damage is usually performed using a rigid long spineboard or vacuum mattress, both during prehospital and in-hospital care. However, disadvantages of these immobilization devices in terms of discomfort and tissue-interface pressures have guided the development of soft-layered long spineboards. We compared tissue-interface pressures between awake and anaesthetized (unconscious) patients during immobilization on a rigid spineboard and a soft-layered long spineboard.

Methods: In this comparative study, 30 anaesthetized patients were randomized to immobilization on either the rigid spineboard or the soft-layered spineboard for the duration of their elective surgery. Tissue-interface pressures measured using an Xsensor pressure-mapping device were compared with those of 30 healthy volunteers who were immobilized sequentially on the rigid spineboard and the soft-layered spineboard. Redness of the sacrum was also recorded for the anaesthetized patients immediately after the surgery.

Results: For both anaesthetized patients and awake volunteers, tissue-interface pressures were significantly lower on the soft-layered spineboard than on the rigid spineboard, both at start and after 15 min. On the soft-layered spineboard, tissue interface pressure and peak pressure index (PPI) for the sacrum were significantly lower for anaesthetized patients than for awake volunteers. Peak pressures and PPI on the rigid spineboard were equal for both groups. Tissue-interface pressures did not change significantly over time. Redness of the sacrum was significantly more pronounced on the rigid spineboard than on the soft-layered spineboard.

Conclusions: This prospective randomized controlled trial shows that using a soft-layered spineboard compared to a rigid spineboard for spinal immobilization resulted in lower tissue-interface pressures in both awake volunteers and anaesthetized patients. Moreover, tissue-interface pressures on the soft-layered spineboard were lower in anaesthetized patients than in awake volunteers. These findings show the importance of using a soft-layered spineboard to reduce tissue-interface pressure, especially for patients who cannot relieve pressure themselves by changing position.

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Background

Spinal immobilization with long spineboards and cervical collars for extrication and transfer of trauma patients is a standard precaution in both prehospital and in-hospital protocols [1]. Especially for unconscious trauma patients, who are unable to maintain spinal alignment by muscular tone, these methods are considered essential to protect the spine from further injury. Although there is a general consensus that the patient should be removed from the spineboard as soon as reasonably possible,
the average time patients are reported to spend on a spineboard has been estimated to be around 1 h [2,3]. There is extensive evidence, however, that prolonged immobilization causes significant discomfort and pain, and on occasion may cause pressure ulceration over bony prominences, leading to prolonged hospital stay and increased cost of care [4–12].

Pressure ulceration occurs as a result of reduced perfusion due to prolonged pressure and/or shear injury to the tissues. Increased pressure can lead to compression of the dermal capillaries. When the pressure is relieved, reactive hyperaemia, clinically seen as a bright flush or reddened area that blanches under light pressure, can occur. At this stage of so-called blanchable erythema, damage to the underlying tissues has not yet occurred [13]. Shear injury occurs as the result of sliding, when the soft tissues are stretched relative to each other. The process of shear injury can occur quickly and the first signs of cell damage can be seen within minutes. In a recent study we demonstrated that when using a rigid spineboard, the maximum strains on the tissues can exceed the threshold for deformation damage [14]. Healthy conscious subjects may adopt pressure relieving strategies, involving position changes, to minimize the risk of exceeding this threshold at specific body regions. However, unconscious patients are thought not to adopt these strategies and may therefore be at higher risk of developing pressure induced tissue damage.

Therefore, this study investigated the hypothesis that when lying on a rigid spineboard, unconsciousness results in higher tissue-interface pressure compared to the awake status. In addition, a recent comparative study reported significantly lower interface pressures on a prototype spine board with soft, covered inlay [10]. Since the soft inlay may compensate for the lack of movement during unconsciousness, our second hypothesis was that there would be no difference in tissue-interface pressure between anaesthetized and awake status when lying on the soft-layered long spineboard.

Methods

Study design

We conducted a prospective, randomized, single-blinded, comparative study on tissue-interface pressures and redness of the skin using a standard rigid long spineboard and a soft-layered long spineboard in patients undergoing surgery under general anaesthesia. Tissue interface pressures were compared with those of a group of awake healthy volunteers. The study has been assigned ISRCTN96064657.

Recruitment of participants

A sample of 30 patients (25 men and 5 women) was recruited at the outpatient department of the Maastricht University Medical Center. Patients included were scheduled for open abdominal wall hernia repair under general anaesthesia, with an expected duration of less than 2 h. Patients with pressure ulceration either at time of inclusion or in the medical history, or with pain other than that due to the operation indication were excluded. Approval was obtained from the Medical Research Ethics Committee of the Maastricht University Medical Center. Written informed consent was obtained from all participants before they were enrolled in the study.

A power analysis was performed using the peak pressures found previously [10] on the standard rigid spine board and the soft-layered long spineboard in awake and healthy volunteers. The power analysis showed that if we included 12 patients in each of the conditions, we should be able to detect a 25% increase in peak pressure index (PPI, see below) between awake and unconscious patients on the soft-layered spine board (mean PPI 171 (SD 33)) with an alpha error of 0.05 and a beta error of 0.2.

Interventions

Two different support devices designed for prehospital trauma care were tested: a standard long spineboard (Ferno-Washington, Wilmington, OH), and a prototype soft-layered long spineboard. After induction of anaesthesia, patients were randomly assigned to one of the two devices. The pressure-mapping mat was placed on the device and the patient was then placed on the device. Pressure was recorded during the entire surgery. The control group consisted of awake healthy volunteers who were randomly put on each device for 15 min, with an interval between the devices of 5 min, while tissue-interface pressures were recorded continuously.

Measurements

Tissue-interface pressures were continuously measured using an Xsensor X2-6912 pressure-mapping device (Xsensor Technology, Calgary, Canada). This system consists of a thin, easily foldable full-body pressure-mapping pad, equipped with 6912 capacitive sensors. This pad was placed between the subject and the support surface, without folds. Pressure on the sensors generates a voltage difference, which increases linearly with the pressure. We connected the pad to a laptop computer with special Xsensor software (version 4.2), for real-time pressure recording.

Table 1

<table>
<thead>
<tr>
<th>Device</th>
<th>Anaesthetized</th>
<th>Anaesthetized</th>
<th>Awake</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number</td>
<td>15</td>
<td>15</td>
<td>30</td>
<td>–</td>
</tr>
<tr>
<td>Gender (M/F)</td>
<td>11/4</td>
<td>14/1</td>
<td>19/11</td>
<td>b</td>
</tr>
<tr>
<td>Age (years)</td>
<td>51.5 (16.2)</td>
<td>49.6 (18.9)</td>
<td>39.0 (11.1)</td>
<td>a,b</td>
</tr>
<tr>
<td>BMI (kg/m²)</td>
<td>24.3 (2.9)</td>
<td>24.2 (3.2)</td>
<td>24.7 (3.4)</td>
<td>n.s.</td>
</tr>
<tr>
<td>Type of surgery</td>
<td></td>
<td></td>
<td></td>
<td>n.s.</td>
</tr>
<tr>
<td>Hernia inguinalis</td>
<td>10/15</td>
<td>11/15</td>
<td>n.a.</td>
<td></td>
</tr>
<tr>
<td>Hernia epigastria</td>
<td>3/15</td>
<td>–</td>
<td>n.a.</td>
<td></td>
</tr>
<tr>
<td>Hernia umbilicalis</td>
<td>2/15</td>
<td>2/15</td>
<td>n.a.</td>
<td></td>
</tr>
<tr>
<td>Hernia inguinoscrotales</td>
<td>–</td>
<td>2/15</td>
<td>n.a.</td>
<td></td>
</tr>
<tr>
<td>Time on immobilization device (min)</td>
<td>63 (18)</td>
<td>65 (12)</td>
<td>n.a.</td>
<td>n.s.</td>
</tr>
</tbody>
</table>

n.a.: not applicable.

P: a = difference between anaesthetized rigid spineboard and awake rigid spineboard P < 0.05; b = difference between anaesthetized soft-layered spineboard and awake soft-layered spineboard P < 0.05; n.s.: not significant (P > 0.05).

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Directly after the surgery, visual inspection and semi-quantitative grading of the skin redness of the patient’s back was performed. Any redness was tested for being blanchable using a clear plastic disc, so as to distinguish between blanchable and non-blanchable erythema [15].

Outcome measures

Pressures were recorded continuously from the start of the anaesthesia until the end of the surgical procedure and reported as described previously [10]. Briefly, peak pressures (in mmHg) measured at the scapulae, the sacrum, and the heels were recorded continuously. The Peak Pressure Index (PPI) was calculated as a measure of pressure on a larger surface area [16]. PPI was defined as the area of $3 \times 3$ sensors ($14.5 \text{ cm}^2$ surface area) which included the sensor showing the peak pressure (one sensor = $1.61 \text{ cm}^2$) and which had the highest average pressure including this sensor. The area was defined based on the first recording. PPI was calculated solely for the sacrum, because this is the only body region with a relatively flat bony structure, whereas scapulae and heels have relatively pointy bony structures. Moreover, the sacrum is the body region with the highest risk of developing pressure ulcers [17–19].

As a clinical measure of these tissue-interface pressures, the redness was scored post-operatively semi-quantitatively as absent, diffuse or clearly defined, and further categorized in terms of blanchable or non-blanchable.

Fig. 1. (a) Tissue-interface pressures on the heel. Mean peak pressures and standard deviation for the heel for rigid spineboard (grey bars) and soft-layered spineboard (striped bars). (b) Tissue-interface pressures on the scapula. Mean peak pressures and standard deviation for the scapula for rigid spineboard (grey bars) and soft-layered spineboard (striped bars). (c) Tissue-interface pressure on the sacrum. Mean peak pressures and standard deviation for the sacrum for rigid spineboard (grey bars) and soft-layered spineboard (striped bars). (d) Tissue-interface peak-pressure index on the sacrum. Mean peak pressure index and standard deviation for the sacrum for rigid spineboard (grey bars) and soft-layered spineboard (striped bars).

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Data collection and processing

Statistical analysis was performed using the Statistical Package for Social Sciences (SPSS, IBM), version 20.0.0.1. Pressures are presented as mean ± SD. Analysis of tissue-interface pressures involved repeated-measures analysis of variance with correction of the degrees of freedom using the Greenhouse–Geisser estimates of sphericity when Mauchly’s test indicated that the assumption of sphericity had been violated, using time as the within-group factor and treatment as the between-group factor. Post hoc group comparisons at the different time points were only performed when the overall repeated-measures tests were statistically significant. All scores were tested for normality using the Kolmogorov–Smirnov test. Parametric variables were compared using Student’s t-test, while non-parametric variables were compared using the Mann–Whitney U statistic. Nominal variables were compared across independent groups using the chi-squared test or Fisher’s exact test. Homogeneity of variance was assessed using Levene’s test. Level of significance was set at P < 0.05.

Results

Patients

Characteristics of anaesthetized subjects and awake controls are described in Table 1. No differences in demographics or baseline characteristics were found between the patients randomized for rigid spineboard or soft-layered spineboard. Participants in the patient group were on average older and more often male than in the awake volunteers group. No relationship was found between pressure values and age or gender.

Discussion

This study showed that unconscious subjects placed on a soft-layered spine board had lower tissue-interface pressures than conscious subjects, while no differences between these two groups were found when using a rigid spine board. Patients under anaesthesia and awake controls both had significantly lower tissue-interface pressures on the soft-layered spineboard than on the rigid spineboard.

Despite a growing body of evidence that immobilizing patients on a rigid spineboard can cause a number of adverse effects such as aspiration, respiratory problems, pain, and pressure ulceration [6,10,20–25], the use of spineboards is expected to continue in practice. In addition to efforts to increase awareness in order to limit the use of spineboards, more tissue-protective devices for spinal immobilization have been developed to minimize the risks of pain and pressure ulcer development. However, evidence showing how these products compare with traditionally used rigid spineboards is scarce. In an earlier study [10] we compared the tissue-interface pressures between the rigid spineboard and the soft-layered spineboard in healthy, awake volunteers. It was unknown, however, whether these results for conscious healthy subjects could be translated to the target group of patients incapable of moving to relieve pressure, such as unconscious patients or patients with spinal cord injury. In this study we therefore looked at anaesthetized patients as a proxy for these patient categories. The average duration of the surgical procedure was about one hour, which is in practice equal to the average time a trauma patient is immobilized on a spineboard [2,3].

Table 2

Redness at the sacrum, anaesthetized patients.

<table>
<thead>
<tr>
<th>Redness at the sacrum</th>
<th>Rigid spineboard</th>
<th>Soft-layered spineboard</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>No redness</td>
<td>1</td>
<td>9</td>
<td>10</td>
</tr>
<tr>
<td>Diffuse redness</td>
<td>5</td>
<td>6</td>
<td>11</td>
</tr>
<tr>
<td>Clearly defined redness</td>
<td>9</td>
<td>0</td>
<td>9</td>
</tr>
<tr>
<td>Total</td>
<td>15</td>
<td>15</td>
<td>30</td>
</tr>
</tbody>
</table>

Chi² = 15.49, P < 0.01.

Tissue-interface pressures

In both awake volunteers and anaesthetized patients, peak pressures for scapula and sacrum and peak pressure index (PPI) at the sacrum were significantly lower on the soft-layered spineboard than on the rigid spineboard (Fig. 1a–d). Peak pressures at the heel were similar for both devices for awake volunteers, and were significantly lower for patients under anaesthesia on the soft-layered spineboard than for the healthy volunteers. Peak pressures and sacrum PPI on the soft-layered spineboard were significantly lower for anaesthetized patients compared to awake volunteers (P < 0.01). Peak pressures on rigid spineboard did not differ between anaesthetized patients and awake volunteers (P > 0.05). No significant changes in pressure were seen during the course of the pressure measurements (P > 0.05).

Redness

Redness was assessed for anaesthetized patients only (Figs. 2 and 3). There was a clear difference in redness on the sacrum after surgery, with significantly more patients without any redness at all on the soft-layered spineboard and significantly more volunteers with clearly defined redness on the rigid spineboard (Table 2). In all cases the redness was blanchable and had disappeared at the 2 h postoperative follow up assessment.

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Earlier studies showed that the use of a rigid spineboard leads to discomfort and high tissue-interface pressures [6,9,10,16,21]. We have also previously demonstrated that using a rigid spineboard led to a considerably higher maximum tissue strain than the threshold at which deformation damage can occur [14]. These high tissue-interface pressures are therefore a significant risk factor for the development of pressure ulcers [26], which are both debilitating for the patient [27–29] and costly for the hospital [4,8,30]. We found equally high tissue-interface pressures for both awake volunteers and anaesthetized patients using the rigid spineboard, with values comparable to those from earlier studies [6,10,16]. The tissue-interface pressures experienced by the unconscious patients on the rigid spineboard remained comparable to those for the awake subjects. In addition, tissue-interface pressures on the soft-layered spineboard were significantly lower for the unconscious patients than for the awake volunteers. Both these observations are remarkable, as they did not confirm our initial hypothesis that both spineboards would lead to an increase in pressures. The data from our study suggest that each board has a ceiling effect. The rigid spineboard reaches this ceiling almost immediately, while the tendency of the pressure to increase on the soft-layered spineboard suggests that its ceiling effect is reached later. Although the former may be speculative, the bottom line remains that the risk of tissue damage by pressure-induced tissue deformation is reduced by using the soft-layered spineboard compared to the rigid spineboard.

After removal from the spineboard, reactive hyperaemia occurred, indicating that there had been a period of relative hypoperfusion. This was especially noticeable with the rigid spineboard, with 9 out of 15 patients showing clearly defined redness, compared to 0 out of 15 patients on the soft-layered spineboard. There is a trade-off between pressure and time regarding pressure-induced tissue damage with higher pressures causing tissue damage sooner than lower pressures [31,32]. In our study the pressures did not lead to permanent damage to the soft tissue; the redness had disappeared in all patients at the follow up assessment of the skin two hours after the end of the surgery. The patients remained haemodynamically stable during the procedure and had only low-risk comorbidities. Tissue hypoperfusion leading to tissue ischaemia and cell necrosis occurs more rapidly in hypotensive patients because of compromised microcirculation caused by poor perfusion [25]. Especially patients with shock or spinal cord damage combined with altered conscious levels are at increased risk of hypotension, so immobility, time or pressure-related risk factors should be reduced.

A number of comments need to be made on the interpretation of our observations. First, although weight and body mass index of the participants were representative of those in the general Dutch population, age and gender were not completely comparable between healthy volunteers and the patients undergoing surgery and anaesthesia. Second, our study was single-blinded, as the researcher who performed the pressure measurements and redness evaluations knew which device the volunteer was lying on. However, pressure measurements were objected by using the Xsensor pressure mapping device. Redness was objectified by testing blanchableness using a clear plastic disc. Photos were taken to enable classification of the redness afterwards. The redness of the skin was also judged by an independent, blinded observer with no knowledge of the allocation of the patients. Kappa was 0.811 and differences of opinion were resolved through discussion. Furthermore, visual inspection of the skin was undertaken as an indicator of tissue damage. Although hyperaemia was rated in a significant number of patients, we do not know how this relates to tissue ischaemia and cell necrosis. Further studies should therefore focus on the relation between local tissue-interface pressures and indicators of tissue damage.

In conclusion, this randomized study found tissue-interface pressures to be significantly lower for the soft-layered spineboard than for the rigid spineboard, for both awake volunteers and anaesthetized patients. Furthermore, tissue-interface pressures using the soft-layered spineboard were lower for the anaesthesitized patients than for the awake volunteers. Redness of the skin of the sacrum was significantly less on the soft-layered spineboard than on the rigid spineboard. These findings show the importance of using a soft-layered spineboard for tissue-interface pressure reduction, and may be of importance for trauma patients with a reduced level of consciousness.

**Conflict of interest**

The authors state there are no conflicts of interest. No external funding was received for this study.

**References**


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