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Using pressure mapping intraoperatively to prevent pressure ulcers—A quasi-experimental study

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Abstract

Background and Aim: Patients undergoing surgery are at high risk of developing pressure ulcers. However, pressure ulcer prevention in the operating room department is demanding and restricted. New techniques, such as continuous pressure mapping that visualizes interface pressure, are now available. The aim of the study was to determine whether pressure mapping information of interface pressure intraoperatively leads to (1) more frequent intraoperative micro repositioning and a reduced amount of pressure on the sacrum area and (2) a lower frequency of pressure ulcer development.

Methods: A quasi-experimental ABA design was used. A total of 116 patients undergoing surgery were included. During the B phase, the need to consider repositioning the patient according to interface pressure readings was initiated.

Results: The result showed that there was significantly higher interface pressure in the A2 phase than in the B phase. Micro repositioning of the patient during surgery was performed in the B phase, but not in the A phase. The regression model showed that a higher BMI was associated with higher interface pressure. None of the patients developed hospital-acquired pressure ulcers up to Day 1 postoperatively.

Conclusion: Pressure mapping involves moving away from expert opinion and tradition towards objective assessment and flexibility and we see the benefits of using pressure-mapping equipment in operating room contexts. However, more research is needed in this area.

KEYWORDS

intraoperative care, perioperative care, pressure mapping, pressure ulcer, prevention

1 | INTRODUCTION

Patients undergoing surgery are considered to be at high risk of developing hospital-acquired pressure ulcers (HAPUs)[1] with a pressure ulcer development prevalence of 19%.[2] A HAPU is considered to be an adverse event and a quality indicator of nursing care.[3] Patients state that pressure ulcers significantly affect their lives negatively[4,5] and pressure ulcers are also associated with high healthcare costs.[6]

A pressure ulcer is defined as localized damage to the skin and/or underlying tissue, usually over a bony prominence, that is the result of pressure or pressure combined with shear forces.[1] Pressure and shear increase the risk of deformation of the soft tissue, which can lead to a lack of oxygen and cell death.[7] High levels of pressure to tissue for a short time or low levels of pressure for a long time can increase the risk of developing HAPUs.[1] Immobilized patients are therefore considered to be high-risk patients. During surgery, patients are immobilized and are therefore at risk of developing a HAPU.[1] Patients are also exposed to other risk factors associated with the type of surgery they are undergoing,[8,9] extended time in surgery,[10–13] general anesthesia,[9] major intraoperative blood loss,[12] periods of low diastolic blood -pressure,[14] and low number of nursing interventions.[9,15]

1.1 | Limitations and challenges in pressure ulcer prevention in the operating room

Positioning the patient intraoperatively to prevent pressure ulcers requires the operating room team to work collaboratively. Positioning needs to be decided according to the surgical and anesthetic teams' need for access to the patient, the patient's physical condition, the technical devices used during surgery, and the position the patient's tissues can tolerate.[16] Many surgical procedures require the supine position, which is associated with high-pressure points to the tissue over the scapulae, sacrum, and heels.[1,16] To reduce the risk of HAPU development during surgery, international guidelines state that teams should distribute pressure to the skin over a large body surface area, reposition the patient when possible, and pay particular attention to pressure points.[1] During surgery, any extensive repositioning is often impossible[16] but micro repositioning can be achieved depending on the patient's status.[1] Positioning and micro repositioning are mostly conducted based on assumptions that lower pressure will be achieved, however, to actually ensure that low pressure has been reached, international guidelines are now recommending pressure mapping during surgery.[1] Research on pressure mapping during surgery, however, is limited. A recent feasibility study of an operating room department showed that 55% of surgical patients had an interface pressure of >50 mmHg over the sacrum and that pressure varied considerably between patients. The study also revealed that the pressure mapping system supported pressure ulcer prevention. If the operating room team can monitor interface pressure, awareness, confidence, and consensus among the operating team can be increased.[17]

1.2 | Pressure mapping as a tool in pressure ulcer prevention

Pressure mapping involves the patient lying on a pressure-sensing mat with thousands of sensors that measure the level of pressure between the patient and the surface they are lying on. The interface pressure between the body and the mat is shown in real time on a screen as a body silhouette in mmHg. Using pressure mapping when positioning the patient in bed or on the operating table makes it possible to control the amount of pressure experienced by the patient by making adjustments according to objective measurements rather than assumptions. Studies in experimental environments have shown that it is possible to reduce interface pressure when pressure mapping technology is available.[18,19] In a medical intensive care unit, the frequency of HAPUs decreased when nurses had access to pressure mapping equipment.[20] Moreover, in geriatric units, for example, pressure mapping equipment can be used to alert personnel of the need for repositioning and can also facilitate repositioning as personnel are provided with feedback on pressure points.[21]

Surgical patients are considered vulnerable and at high risk of developing HAPUs. Operating room teams need to tailor their pressure ulcer prevention plan to each patient's individual needs. Having access to information on body locations with high-pressure points could be one way of strengthening prevention work during surgery. Results from a feasibility study showed that using pressure-mapping equipment is possible in the operating room,[17] however, more knowledge is needed to conclude whether pressure on high-pressure points can be reduced using pressure-mapping equipment. Consequently, the aims of this study were to determine whether intraoperative pressure mapping can: (1) facilitate micro repositioning and reduce pressure on the sacrum area, and (2) reduce the frequency of pressure ulcer development.

2 | MATERIALS AND METHODS

2.1 | Design

A quasi-experimental ABA design was used. Phase A (A1) was baseline, phase B was the intervention, and phase A (A2) was return to baseline. Pressure mapping was used during all three phases, but was blinded for the operating room team in phases A1 and A2 and visible in phase B. The primary outcome was to investigate intraoperative micro repositioning and reduced interface pressure on the sacrum. The second outcome was to examine the frequency of pressure ulcer development.

2.2 | Setting

The study took place in a Swedish county hospital operating room department that performs both planned and emergency surgical procedures around the clock. The hospital has a catchment area of 170,000 people and carries out approximately 7500 surgeries per year. The operating room department has 11 operating rooms and performs gynecological, orthopedic, and general surgeries. All the beds in the hospital have high-resilience foam mattresses. The operating tables are equipped with 3-year-old standard polyurethane integral foam mattresses. The operating room team consists of an operating room nurse, an operating room nurse assistant, a nurse anesthetist, a nurse anesthetist assistant, one or two surgeons, and one ambulatory anesthetist. Responsibility for pressure ulcer prevention is shared between the nurses and assistant nurses. For standard pressure ulcer prevention (A1) guidelines stated that the following needs to be carried out: (a) skin assessment before and after surgery, (b) check to see the sheets on the operating table are smooth and dry, (c) position the patient according to the type of operation, (d) if possible, perform micro repositioning once each hour, and (e) document skin assessments and pressure ulcer prevention measures carried out intraoperatively in the patient's records.

2.3 | Sample

A convenience sample was used. Patients were selected according to the surgery schedule for the day and if they fulfilled the inclusion criteria. The sample size estimation and power calculation were based on mean, standard deviation, and effect difference from earlier research.[17] The comparison of the means was set at a significant level of 5%, 80% power, and a standard deviation of 15 mmHg. The difference in interface pressure over the sacrum between groups was estimated to be 10 mmHg and gave a minimum sample size of 37 patients per phases A1, B, and A2.

The inclusion criteria were: ≥18 years old, admitted during regular operating hours for general surgery, planned supine position on the operating table, estimated anesthetic time >60 min, and staying overnight in the hospital. Patients with surgeries that included x-rays, the use of an antislip mattress, or patients that could not give informed consent were excluded. There were additional dropouts due to operating times being shorter than 60 min, missing research protocols, and missing interface pressure recordings (Table 1).

2.4 | Pressure mapping

The pressure-sensing mat Xsensor ForeSite OR (sensor, X4 electronics, and ForeSite OR software) was the technical device used for pressure mapping in this study. It uses high-tech, semiconductor sensor technology to quantify and visualize pressure levels between two surfaces (the individual and the mat). It contains thousands of sensors that give direct visible information on interface pressure every 3 s. The pressure-sensing mat is connected to a computer with relevant software installed that records pressure in mmHg and time. The computer screen shows a body silhouette in real time using different colors and mmHg measurements. Blue indicates low pressure starting just above 0 mmHg and increasing pressure is shown in green, yellow, orange, and finally red, which indicates 100 mmHg of pressure. The pressure-sensing mat is placed on the operating table and covered with a standard surgical sheet.

TABLE 1 Number and reasons for exclusion of patients and number of included patients in phases A1, B, and A2.

			A1	B	A2
Excluded patients	Operating time < 60 min	*n*	0	1	1
	No research protocol	*n*	5	6	7
	No recordings of interface pressure	*n*	2	2	5
	Incomplete recording of interface pressure	*n*	0	0	2
Included patients total			43	43	30

2.5 | The ABA design

2.5.1 | Phase A1

During phase A1, standard pressure ulcer prevention measures were carried out. Pressure mapping was conducted without visible information on pressure points being available to the operating room team.

2.5.2 | Phase B

Three members from the operating room team and one of the researchers (ES) revised and adapted the standard pressure ulcer prevention guidelines to fit the intervention as follows:

1. Strive for as low interface pressure as possible on all body locations.
2. Before starting the surgery, come to a consensus with the entire operating team including the surgeon to reposition the patient every 4th hour if interface pressure is ≤65 mmHg and every second hour (or more frequently) if interface pressure is ≥65 mmHg.
3. If interface pressure rises during surgery, strive to reduce it through micro repositioning.
4. The operating room nurse assistant is responsible for noting the interface pressure at a minimum of 30-min intervals and for notifying the team if micro repositioning is needed.
5. Micro repositioning should only be carried out when the surgeon states that it is safe for the patient.

The operating room team had real-time information of interface pressure during the time the patient was on the operating table. After surgery, the patient was positioned in a bed in a way that relieved the points that had been exposed to high pressure during surgery. In the handover to the postoperative recovery unit, information regarding pressure points during surgery should be reported.

2.5.3 | Phase A2

Pressure mapping was conducted without visible information on pressure points to the operating room team. Twenty surgeries were performed with personnel mapping pressure according to the B phase.

2.6 | Information procedure to involved personnel

Before phase A1, those who were responsible for pressure ulcer prevention intraoperatively received information about the study at workplace meetings. They were informed about the pressure mapping system including how the device was to be placed on the operating table. They also had the possibility to test the technical devices on their lunch breaks on several occasions. The physicians received information about the study in connection with surgery. The personnel involved at the postoperative recovery unit received oral information on the study at two weekly staff meetings as well as written information. On the surgical ward, oral and written information on the study was given to the head nurse and written information was given to all staff. The research nurse, who assisted during the data collection, was introduced to all the departments involved at this time. Before phase B, information of the intervention was given to those responsible for pressure ulcer prevention in the operating room at their monthly workplace meeting.

2.7 | Data collection

A study-specific protocol was developed for data collection. In this protocol, the nurses responsible for patients in the operating room and postoperative recovery unit conducted the data collection. A research nurse conducted data collection on Day 1 post-operatively. In the study-specific protocol, patients' risk of developing pressure ulcers was calculated using the sub-scales “Activity” and “Mobility” from The Modified Norton Scale (MNS). The subscales were scored 1–4 with 1 indicating a total lack of function and 4 indicating full function.[22] Skin assessment was carried out when patients were moved from a bed to the operating table and from the operating table to a bed after 2 h in the postoperative recovery unit and on Day 1 after the surgery. If a HAPU was observed, it was categorized as 1–4. Category 1 was defined as normal skin with no visible changes and Category 4 as full-thickness tissue loss.[1] There was also the possibility to write additional information about the patient's skin condition in the protocol. Any pressure-relieving activities carried out were noted in the protocol, as well as what pressure-relieving material was used and where on the body it was placed. Micro repositioning/no micro repositioning during surgery was noted, as well as time, reason, and specific action. After surgery, data were collected from the patient's record including age, gender, BMI (body mass index), ASA classification (1–6) according to the American Society of Anesthesiologists surgery code,[23] anesthesia time in minutes, the amount of time the surgeon operated (surgery time) in minutes, time with a blood pressure <100 mmHg in minutes, bleeding in milliliters, and body temperature. Interface pressure in mmHg every 15 min was collected as the mean pressure of a square, $12.7 \times 12.7\ cm^2$, covering the highest pressure on the sacrum for each patient.

2.8 | Data analysis

Statistical analyses were performed in IBM SPSS version 21 for Windows (SPSS IBM) and in R version 3.1.0 (R Foundation for Statistical Computing). Numerical results are presented as percentage, mean, standard deviation, median, and range. The statistical significance level was set at $p < 0.05$. ANOVA analysis was used to test for demographic differences between phases A1, B, and A2 regarding age, BMI, and anesthesia time. Chi-square analyses were used to test for differences between phases regarding gender and ASA classification. ANOVA analysis was used to test for differences in interface pressure between phases A1, B, and A2, and an independent two-sample *t* test assuming equal variance was used to test for differences in interface pressure between phases A1 and B. A multiple linear regression model was conducted with the dependent variable as mean pressure over the sacrum and independent variables as BMI, anesthesia time, and number of times micro repositioning was performed.

2.9 | Ethical considerations

The study was approved by the Regional Ethical Review Board, Dnr 2018/118. It followed the ethical principles for scientific work as described in The Declaration of Helsinki and the national and local ethical guidelines.[24] Before surgery, all participants received both oral and written information about the study, including that their participation was on a voluntary basis. All patients gave written informed consent.

3 | RESULTS

3.1 | Demographic data

A total of 116 patients participated in the study. The participants had a mean age of 60.9 years and the mean anesthesia time was 135 min. Thirty-five patients were assessed into ASA 1, 59 patients into ASA 2, and 22 patients into ASA 3, and their mean BMI was 27.3. In MNS, the variable “Activity” was preoperatively 4 for all of the patients except for one who scored 2. The variable “Mobility” was also scored 4 for all of the patients except one who scored 3. Nine patients had a mean of ≥65 mmHg over the sacrum. There were no statistical significances between the three phases regarding age ($p = 0.550$), gender ($p = 0.307$), ASA ($p = 0.797$), BMI ($p = 0.885$), and anesthesia time ($p = 0.06$). The demographic data are presented for each of the phases A1, B, and A2 in Table 2.

3.2 | Intraoperative micro repositioning, interface pressure, and pressure ulcers

No patients in phase A1 nor A2 received any micro repositioning. In phase B, there were 17 patients (40%) who were micro repositioned on 42 occasions (Table 3). The median interface pressure over the

TABLE 2 Demographic data for the patients in phases A1, B, and A2.

		A1	B	A2
Patients	*n*	43	43	30
General anesthesia	*n*	43	42	30
Regional anesthesia	*n*	0	1	0
Age	Mean (SD)	58.4 (20.4)	62.9 (18.7)	61.5 (18.1)
Gender, men	*n* (%)	8 (18.6)	14 (33)	9 (30)
ASA 1	*n* (%)	14 (32.6)	14 (32.6)	7 (23.3)
ASA 2	*n* (%)	22 (51.2)	21 (48.8)	16 (50)
ASA 3	*n* (%)	7 (16.3)	8 (18.6)	8 (26.7)
BMI	Mean (SD)	27.6 (5.6)	26.9 (5.9) 2 missing	27.3 (5.4)
Surgery, min	Median (range)	73 (28–245)	82 (31–393)	70.5 (16–355)
Anesthesia, min	Media (range)	136 (72–314)	142 (101–559)	126 (50–453)
Blood pressure systolic, min < 100 mmHg	Median (range)	72.5 (0–235) 1 missing	65 (0–285) 1 missing	45 (0–240) 1 missing
Blood loss, mL	Median (range)	70 (0–450) 2 missing	50 (0–6400) 1 missing	50 (0–2900) 1 missing

TABLE 3 Intraoperative micro repositioning and offloading pressure, phases A1, B, and A2

Reposition and offload of pressure		A1 *n* = 43	B *n* = 43	A2 *n* = 30
Patients receiving repositioning	*n* (%)	0	17 (40)	0
Performed repositioning	*n*	0	42	0
Performed repositioning, sacrum	*n*	0	18	0
Patients with offloading of sacrum	i	0	0	0
Performed repositioning of heels	*n*	0	14	0
Patients with offloading of heels	i (%)	35 (81.4)	36 (83.7)	21 (70)

sacrum for the time the patients spent on the operating table varied between 22.4 and 113.2 mmHg (Table 4). When comparing differences in the interface pressure between the three phases, there was statistically significant ($p = 0.001$) higher pressure in phase A2 compared to phase B. The Multiple Linear Regression model showed a significant positive association between patients' BMI and interface pressure, that is, a high BMI was associated with high interface pressure ($p < 0.001$; Table 5). None of the patients had developed any HAPU by Day 1 postoperatively. When the patients were moved from the operation table to the bed blanchable erythema over the sacrum was observed in six patients (14%) in phase A1, five patients (14%) in phase B, and five patients (13%) in phase A2. All patients had normal skin on Day 1 postoperatively.

4 | DISCUSSION

The results from this quasi-experimental study showed that there was significantly higher interface pressure after the intervention when pressure mapping was no longer present. Micro repositioning of the patients during surgery was only performed during the intervention when pressure mapping was available. The regression model showed that a higher BMI was associated with higher interface pressure. None of the patients had developed any HAPUs by Day 1 postoperatively.

The results of the study showed a significantly lower interface pressure during the intervention when pressure mapping was available. Studies in other contexts have also shown that lower

TABLE 4 The interface pressure at sacrum in mmHg for each phase A1, B, and A2 and total.

Interface pressure		A1	B	A2	Total all groups
Sacrum, mmHg	Median (range) min–max	38.8 (48.9)	37.9 (89.8)	44 (47.9)[a]	40.6 (90.7)
		22.4–71.3	23.4–113.2	30.3–78.1	22.4–113.2

[a]Differences between groups: $p = 0.001$ (ANOVA analysis).

TABLE 5 Regression model, dependent variable was interface pressure in mmHg at sacrum.

	t	95% CI	*p* Value
BMI	4.817	0.575–1.278	<0.001
Frequency of reposition	1.805	−0.245–5.226	0.074
Anesthesia time	−1.256	−0.050–0.011	0.212

Abbreviations: BMI, body mass index; CI, confidence interval.

interface pressure is possible to achieve when nurses use pressure mapping when positioning a patient in bed.[19,25] No decrease in interface pressure was seen when going from standard pressure ulcer prevention to the intervention with pressure mapping. An explanation for this could be the focus that was put on pressure ulcer prevention before the start of the study. Personnel were provided with information about pressure ulcer prevention and the pressure mapping equipment was demonstrated and tested by the personnel. We believe this might have increased pressure ulcer prevention activities, so it is questionable if this phase (A1) is a true reflection of standard pressure ulcer prevention measures. During the intervention, focus was put on preventing pressure ulcers using pressure mapping. However, when pressure mapping was removed after the intervention, we believe the focus on pressure ulcer prevention declined and the increased interface pressure and lack of micro positioning was actually a truer reflection of standard pressure ulcer prevention procedures.

During the intervention, one nurse was responsible for observing interface pressure and when necessary informing the rest of the operating team that micro repositioning was needed, which resulted in micro repositioning being carried out during surgery. When pressure mapping was removed after the intervention phase of the study, these procedures were not carried over. The use of pressure mapping has previously been shown to facilitate teams in reaching consensus regarding if, and when, micro repositioning should be performed.[17] Reaching consensus in the operating team is a key strategy in preventing the development of pressure ulcers.[26] Therefore, to increase patient safety, pressure mapping could be used as a tool to facilitate consensus in the operating room team regarding if and when micro repositioning needs to be performed. It has been argued that the patient's fragile situation during surgery implies that unnecessary interruptions should be avoided, but it is important to disseminate knowledge about how minute changes in a patient's position can lead to increased blood flow[27] and that international guidelines recommend micro repositioning during surgery.[1] The latter, however, is a statement based on expert opinion, not research. For this reason, more research involving pressure mapping is necessary to understand which nursing actions can decrease interface pressure intraoperatively and how these actions should be carried out. Currently, there is no objective way of evaluating if interface pressure is as low as possible in clinical practice, which means that nurses have to trust their own assessments.

The results showed that a higher BMI was significantly associated with higher interface pressure. This is interesting as when we look at the risk assessment scales, obesity is not included as a risk for developing pressure ulcers.[22,28,29] However, there are some studies that suggest that obesity is a risk factor for developing HAPUs.[30–32] If this is the case, there is a need to identify a cutoff point, that is, magnitude of pressure in relation to the risk of pressure ulcer development. Results from an intensive care unit showed that patients with an interface pressure >60 mmHg for more than 56% of their time spent in an intensive care unit developed HAPUs.[33] There is a lack of knowledge concerning the cut-off point where a higher risk of developing HAPUs starts. As we know, the development of HAPUs depends on both intrinsic and extrinsic factors.[1,29] Patients have to be risk assessed for pressure ulcer development and prevention measures planned by healthcare professionals and operating room teams should be based on this.

No patient developed pressure ulcers in this study. The patients included in the study were relatively healthy with an ASA score of 1 or 2. Almost all patients were mobile and the types of surgery they underwent were not considered to be especially high risk in regard to HAPU development.

Consequently, positioning a patient for surgery is a complicated task to perform. The operating team needs special skills to know how to reach lower pressure point readings using micro repositioning. The use of pressure mapping has the potential to increase the operating teams' awareness of pressure points.

4.1 | Method discussion

This is, to our knowledge, the first study to evaluate the use of pressure mapping equipment in an operating room context. Data collection was only carried out in one operating room department, but this was considered appropriate for this pioneering study. The strength of the ABA design is that it allows researchers to control the intervention and to evaluate the outcome after the removal of the intervention.[34] One question is if phase A1 does actually reflect a baseline.[35] Information given to personnel could have been limited before and during phase A1 to avoid bias. In this study, the interface pressure was measured as a mean pressure in a sacrum square measuring 12.7 × 12.7 cm^2. How pressure within that square changed during surgery was not examined. The question as to what is the most effective way of measuring interface pressure needs to be investigated in further research. The method used here to evaluate if patients developed pressure ulcers was skin assessment. Skin assessment is difficult and requires in-depth knowledge and a high level of skill.[1] We do not know if the nurses would have benefitted from more training and a higher level of support in this task. However, the research nurse was trained in skin assessment and was the only one carrying out skin assessments on Day 1 postoperatively.

5 | CONCLUSION

This quasi-experimental study showed that pressure mapping during surgery significantly lowered patients' interface pressure and initiated micro repositioning. Using pressure mapping made it possible for the operating room team to reach consensus regarding the risk of pressure point development and to switch focus from the surgery to the nurses' responsibility to prevent pressure ulcers. The complex task of positioning the patient for surgery and performing micro repositioning during surgery requires specific skills, but these alone are not enough to ensure that pressure ulcers do not develop. To ensure that low interface pressure has been obtained, an objective way to measure interface pressure is needed. Pressure mapping can facilitate the nurses in their crucial responsibility to ensure patient safety during surgery. Also, pressure mapping could increase learning about important factors to decrease the risks of pressure ulcer development during surgery. More research is needed in this area.

AUTHOR CONTRIBUTIONS

Eva B. M. Sving: Conceptualization; data curation; formal analysis; funding acquisition; methodology; project administration; resources; visualization; writing—original draft. **Lena A. C. Gunningberg**: Conceptualization; formal analysis; methodology; writing—review and editing. **Carina B. Bååth**: Conceptualization; formal analysis; methodology; writing—review and editing. **Catrine U. S. Björn**: Conceptualization; data curation; formal analysis; funding acquisition; investigation; methodology; visualization; writing—original draft.

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CONFLICT OF INTERESTS STATEMENT

The authors declare no conflict of interest.

DATA AVAILABILITY STATEMENT

Data available on request from the authors.

TRANSPARENCY STATEMENT

The lead author Eva Birgitta Margareta Sving affirms that this manuscript is an honest, accurate, and transparent account of the study being reported; that no important aspects of the study have been omitted; and that any discrepancies from the study as planned (and, if relevant, registered) have been explained.

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