Cardiovascular Innovations and Applications
Vol. 5 No. 3 (2021) 173–181
ISSN 2009-8618
DOI 10.15212/CVIA.2019.1263

RESEARCH PAPER

# Risk Factors for Intraoperative Pressure Injury in Aortic Surgery: A Nested Case-Control Study

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*Received: 30 October 2020; Accepted: 7 November 2020*

## Abstract

**Aims and Objectives:** The aim of this study was to identify risk factors associated with an increased risk of intraoperative pressure injury in patients undergoing aortic surgery.
**Background:** Intraoperative pressure injuries are some of the most significant health problems in clinical practice. According to previous studies, patients undergoing aortic surgery are at high risk of developing an intraoperative pressure injury, with an incidence much higher than that associated with other types of cardiac surgery.
**Design:** This was a nested case-control study.
**Methods:** Following the STROBE checklist, a nested case-control approach was adopted in this study. A patient cohort was selected on the basis of inclusion and exclusion criteria from patients undergoing aortic surgery. Data were collected from these patients by means of a tailored questionnaire designed in-house. Patients with intraoperative pressure injury at the end of surgery were identified as the case group, while the control group consisted of patients without intraoperative pressure injury. Patients in the groups underwent 1:1 matching based on age and sex. Initially, a single-factor analysis was conducted between the two groups. Subsequently, risk factors for intraoperative pressure injury were identified through conditional logistic regression analysis with use of the variables that exhibited statistically significant differences in the single-factor analysis.
**Results:** A total of 400 patients were selected. Among these, 167 patients experienced intraoperative pressure injury at an incidence rate of 41.8%. Strict preoperative bed confinement, deep hypothermic circulatory arrest during surgery, application of norepinephrine or dopamine during surgery, and intraoperative skin wetting were associated with the occurrence of intraoperative pressure injury in patients undergoing aortic surgery.
**Conclusions:** Nurses should thoroughly assess the risk of intraoperative pressure injury and implement appropriate preventative interventions, particularly in high-risk patients undergoing aortic surgery.

**Keywords:** Aortic surgery; pressure injury; risk assessment; theater nursing

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## Introduction

A pressure injury is considered as skin and underlying soft tissue localized damage, which is usually related to a bony prominence or a medical device. The injury can manifest itself as complete skin or open ulcers and can be painful. Damage is caused by intense and/or prolonged pressure or a combination of pressure and shear.

Operation is an important factor attributed to pressure injury. A systematic review by Chen et al. [1] identified 17 articles that investigated the incidence of surgery-related pressure injuries in ten countries published in the preceding 5 years. They found that the incidence of surgery-related pressure injury ranges from 0.3% to 57.4%, averaging 15.0%, and the pooled surgery-related pressure injury incidence for cardiac surgery was 18.0%. Risk factors for surgery-related pressure injury include preoperative fasting, the use of medical devices, intraoperative anesthesia, resting in the same position for a long time, and changes in the volume and composition of body fluids [2, 3].

A systematic review of 12 high-quality studies that aimed to identify the risk factors associated with pressure injury in critically ill cardiac surgery patients found that the incidence of intraoperative pressure injury in these patients was 29.5% [4]. Furthermore, factors likely to increase risk in patients undergoing cardiac surgery include prolonged exposure to pressure during surgical procedures, vascular disease, and vasopressor use postoperatively; however, the impact of intraoperative factors, such as cardiopulmonary bypass time or body temperature, appears to be underexplored [4].

Evidence suggests that patients undergoing aortic surgery are at higher risk of developing an intraoperative pressure injury than patients undergoing other types of cardiac surgery [5]. The incidence rate of intraoperative pressure injury in patients undergoing aortic surgery is reported as 50% [5].

Pressure injuries pose a significant economic burden to patients, prolong their hospitalization time, reduce their quality of life, and increase the incidence of other complications [6, 7]. The treatment cost of pressure injuries is 3.6 times higher than the prevention cost [8]. Risk assessment is the first step for prevention. At present, the identification of patients at risk of pressure injuries is often achieved with pressure injury risk assessment tools. However, a systematic review of 17 high-quality diagnostic studies that assessed the predictive validity of three stress injury risk scales (Braden, Norton, and Waterlow scales) showed that none of the three methods was suitable for patients, with only moderate predictive validity [9]. Moreover, as these scales are not tailored for use in surgery, their predictive value in this setting is considered quite limited [10, 11]. A key element of risk assessment is to effectively identify risk factors and implement targeted, protective measures to mitigate such risks. A systematic review concluded that the use of a structured risk assessment tool, rather than clinical judgment alone, does not reduce the incidence of pressure injury [12].

The objective of the present study was to investigate the incidence of and to identify risk factors for intraoperative pressure injury in patients undergoing aortic surgery. The results should help increase awareness among nurses regarding potential risk factors, assist them in identifying and implementing appropriate protective measures, and inform the design of future studies investigating interventions to prevent intraoperative pressure injury in patients undergoing aortic surgery.

## Methods

### Protocol

The STROBE guidelines for reporting observational studies in epidemiology were used as a methodological checklist for this study (see Supplementary File 1).

### Design

A nested case-control approach was adopted in this study [13]. A patient cohort was selected on the basis of inclusion and exclusion criteria from patients undergoing aortic surgery. Data were collected from these patients with use of a tailored questionnaire designed in-house. On the basis of a review of domestic and foreign literature, a 36-factor questionnaire was designed. In addition to the questionnaire data, the incidence rate of intraoperative pressure injury was assessed. The areas vulnerable to the development of pressure injury and the stages of intraoperative pressure injury are described. Patients with intraoperative pressure injury were categorized as the case group, while the control group consisted of patients without intraoperative pressure injury. Patients in the groups underwent 1:1 matching based on age and sex. The factors were analyzed between the two groups, and risk factors for intraoperative pressure injury were identified. The determination and stage standards of pressure injury were based on the announcement regarding the change in terminology (i.e., from pressure ulcer to pressure injury) and updates related to the stages of pressure injury [14].

## Participants

A convenience sampling method was adopted to select 400 patients undergoing aortic surgery between July 2016 and March 2017. The inclusion criteria were (1) age of 18 years or greater, (2) patients undergoing aortic surgery, (3) successful surgery and return to the intensive care unit with stable vital signs, and (4) provision of informed consent and voluntary participation. The exclusion criteria were (1) the presence of serious skin diseases or skin injuries prohibiting easy observation of the integrity of the skin, (2) the presence of pressure injury before the surgery, and (3) a recommendation of complete bed rest.

There were 268 men and 132 women in this study (Table 1). The average age was 48.28 years ± 12.67 years (range 18–78 years). This population included 171 cases of type A aortic dissection, 47 cases of type B aortic dissection, 155 cases of aneurysm, and 27 cases of other aortic diseases.

**Table 1** Patient Demographics.

| Item | Number |
|---|---|
| Age | |
| 18–59 years | 309 (77.3%) |
| ≥60 years | 91 (22.7)% |
| Sex | |
| Male | 268 (67.0%) |
| Female | 132 (33.0%) |
| Ethnic group | |
| Han | 378 (94.5%) |
| Other ethnic groups | 22 (5.5%) |
| Education | |
| Bachelor's degree and above | 106 (26.5%) |
| College level and below | 294 (73.5%) |
| Medical payment | |
| Health insurance | 243 (60.8%) |
| Public medical care | 4 (1.0%) |
| New rural cooperative medical care | 141 (35.3%) |
| Other | 12 (3.0%) |

## Ethical Considerations

This study was approved by the institutional review board of Beijing Anzhen hospital.

## Statistical Analysis

Data analysis was performed with IBM SPSS Statistics version 22.0. Analysis of each factor was conducted between the case group and the control group by a *t* test with interval variables following a normal distribution. Nonnormally distributed data were analyzed by the nonparametric Wilcoxon test. Categorical variables were analyzed by the chi-squared test. Subsequently, risk factors for intraoperative pressure injury were identified through conditional logistic regression analysis with use of the variables that exhibited statistically significant differences in the single-factor analysis. A receiver operating characteristic curve validated the regression equation.

# Results

## Incidence of Intraoperative Pressure Injury in 400 Patients Undergoing Aortic Surgery

Among the 400 patients examined in this study, 167 patients developed intraoperative pressure injury (41.8%). Among these, 162 patients experienced stage 1 injury and five patients experienced stage 2 injury. Moreover, 146 patients experienced pressure injury during surgery in the recumbent position and 21 patients experienced pressure injury during surgery in the lateral position. Notably, the occurrence of sacrococcygeal region pressure injury was greater in the patients who underwent surgery in the recumbent position (137 patients). During surgery, the patients' heels were suspended and the pressure was transferred to the gastrocnemius muscle. The implementation of such measures may greatly reduce the occurrence of heel pressure injury according to the recommendations in the National Pressure Ulcer Advisory Panel/European Pressure Ulcer Advisory Panel/Pan Pacific Pressure Injury Alliance quick reference guide [15]. There was a higher incidence of pressure injury at the hip (17 patients) and armpit (14 patients) in patients who underwent surgery in the lateral position. Moreover, pressure injury occasionally occurs in other parts, such as the knee joint and shoulder joint. Furthermore, 80 cases of intraoperative pressure injury were reported in patients with type A aortic dissection, 23 cases were reported in patients with type B aortic dissection, 56 cases were reported in patients with aortic aneurysm, and eight cases were reported in patients with other types of aortic diseases (Table 2).

### Single-Factor Analysis of Intraoperative Pressure Injury in Patients Undergoing Aortic Surgery

The single-factor analysis showed that 17 variables demonstrated statistically significant differences: low preoperative level of serum albumin; strict preoperative bed confinement; preoperative Waterlow score; preoperative activities of daily living score; application of deep hypothermic circulatory arrest (DHCA) during surgery; intraoperative use of epinephrine, norepinephrine, or dopamine; surgical position; intraoperative one-lung ventilation; type of intraoperative skin protection measures; intraoperative skin wetting; increased level of lactic acid during surgery; surgery time; warming time; blood loss during surgery; and duration of cardiopulmonary bypass (Tables 3 and 4).

**Table 2** Intraoperative Pressure Injury in the Case Group ($n = 167$).

| Item | Number |
|---|---|
| Stage | |
| 1 | 162 (97.0%) |
| 2 | 5 (3.0%) |
| Surgical position | |
| Recumbent | 146 (87.4%) |
| Lateral | 21 (12.6)% |
| Location | |
| Sacrococcygeal region | 137 (82.0%) |
| Heel | 4 (2.4%) |
| Sacrococcygeal region and heel | 1 (0.6%) |
| Hip | 8 (4.8%) |
| Armpit | 5 (3.0%) |
| Hip and armpit | 8 (4.8%) |
| Armpit, hip, and knee | 1 (0.6%) |
| Shoulder | 1 (0.6%) |
| Back | 2 (1.2%) |
| Type of aortic disease | |
| Stanford type A aortic dissection | 80 (47.9%) |
| Stanford type B aortic dissection | 23 (13.8%) |
| Aortic aneurysm | 56 (33.5%) |
| Other type | 8 (4.8%) |

### Multifactor Analysis of Intraoperative Pressure Injury in Patients Undergoing Aortic Surgery

Pressure injury was considered as the dependent variable. Factors showing statistically significant differences in the single-factor analysis as independent variables were included in the regression equation. The risk factors for intraoperative pressure injury in adult patients undergoing aortic surgery, according to the conditional logistic regression analysis, were as follows (in descending order of impact): (1) use of norepinephrine during surgery (odds ratio [OR] 11.108); (2) intraoperative skin wetting (OR 9.641); (3) use of dopamine during surgery (OR 6.184); (4) intraoperative deep hypothermic circulatory arrest (OR 2.053); and (5) strict preoperative bed confinement (OR 1.844). The results are shown in Table 5.

## Discussion

### Analysis of Risk Factors for Intraoperative Pressure Injury in Patients Undergoing Aortic Surgery

#### *Strict Preoperative Bed Confinement*

Patients under strict preoperative bed confinement were subjected to a fixed position for a long period before surgery. Such preoperative confinement may lead to consistent failure of pressure relief interventions, increasing the risk of pressure injury in the anatomical areas under interface pressure [16].

#### *Application of Deep Hypothermic Circulatory Arrest during Surgery*

DHCA is an extracorporeal circulation technique that arrests blood circulation under the condition of deep hypothermia, creating clear and bloodless

**Table 3** Single-Factor Analysis of Categorical Variables.

| Factor | Control group (*n*=165) | Case group (*n*=165) | β² | P |
|---|---|---|---|---|
| Low preoperative serum albumin level | | | 8.194 | 0.004 |
| No | 95 (57.6%) | 69 (41.8%) | | |
| Yes | 70 (42.4%) | 96 (58.2%) | | |
| Strict preoperative bed confinement | | | 26.839 | 0.000 |
| No | 110 (66.7%) | 63 (38.2%) | | |
| Yes | 55 (33.3%) | 102 (61.8%) | | |
| Waterlow score | | | 11.155 | 0.004 |
| Medium risk | 3 (1.8%) | 1 (0.6%) | | |
| High risk | 109 (66.1%) | 82 (49.7%) | | |
| Very high risk | 53 (32.1%) | 82 (49.7%) | | |
| ADL score | | | 10.342 | 0.006 |
| Basic self-care | 45 (27.3%) | 24 (14.5%) | | |
| Partially dependent on others | 64 (38.8%) | 62 (37.6%) | | |
| Fully dependent on others | 56 (33.9%) | 79 (47.9%) | | |
| Intraoperative use of DHCA | | | 17.016 | 0.000 |
| No | 88 (53.3%) | 51 (30.9%) | | |
| Yes | 77 (46.7%) | 114 (69.1%) | | |
| Intraoperative use of norepinephrine | | | 22.734 | 0.000 |
| No | 157 (95.2%) | 127 (77.0%) | | |
| Yes | 8 (4.8%) | 38 (23.0%) | | |
| Intraoperative use of epinephrine | | | 13.946 | 0.000 |
| No | 136 (82.4%) | 106 (64.2%) | | |
| Yes | 29 (17.6%) | 59 (35.8%) | | |
| Intraoperative use of dopamine | | | 20.303 | 0.000 |
| No | 34 (20.6%) | 7 (4.2%) | | |
| Yes | 131 (79.4%) | 158 (95.8%) | | |
| Surgical position | | | 7.649 | 0.006 |
| Recumbent | 158 (95.8%) | 144 (87.3%) | | |
| Lateral | 7 (4.2%) | 21 (12.7%) | | |
| Intraoperative one-lung ventilation | | | 9.076 | 0.003 |
| No | 159 (96.4%) | 144 (87.3%) | | |
| Yes | 6 (3.6%) | 21 (12.7%) | | |
| Intraoperative skin wetting | | | 16.872 | 0.000 |
| No | 163 (98.8%) | 144 (87.3%) | | |
| Yes | 2 (1.2%) | 21 (12.7%) | | |
| Increase in blood lactate level | | | 8.943 | 0.003 |
| No | 87 (52.7%) | 60 (36.4$) | | |
| Yes | 78 (47.3%) | 105 (63.6%) | | |
| Preventive measures | | | – | 0.006 |
| No protection | 0 (0%) | 4 (2.4%) | | |
| Cotton cushion | 100 (60.6%) | 80 (48.5%) | | |
| Hydrocolloid dressing | 2 (1.2%) | 3 (1.8%) | | |
| Foam dressing | 1 (0.6%) | 0 (0%) | | |
| Cotton cushion and hydrocolloid dressing | 31 (18.8%) | 24 (14.5%) | | |
| Cotton cushion and foam dressing | 31 (18.8%) | 54 (32.7%) | | |

ADL, activities of daily living; DHCA, deep hypothermic circulatory arrest.

**Table 4** Single-Factor Analysis of Interval Variables.

| Factor | Case group (median/quartile spacing) | Control group (median/quartile spacing) | *Z* | P |
|---|---|---|---|---|
| Intraoperative blood loss (mL) | 1300/1000 | 1000/700 | −3.898 | 0.000 |
| Duration of surgery (min) | 473/184 | 432/145 | −4.545 | 0.000 |
| Duration of warming (min) | 71/44 | 61/31 | −2.466 | 0.014 |
| Duration of CPB (min) | 166/85 | 144/75 | −2.329 | 0.020 |

CPB, cardiopulmonary bypass.

**Table 5** Results of Multifactor Analysis.

| Factor | *B* | SE | Wald | df | P | OR | 95% CI |
|---|---|---|---|---|---|---|---|
| Application of DHCA | 0.719 | 0.351 | 4.197 | 1 | 0.041 | 2.053 | 1.032–4.086 |
| Intraoperative use of norepinephrine | 2.408 | 0.687 | 12.291 | 1 | 0.000 | 11.108 | 2.891–42.677 |
| Intraoperative use of dopamine | 1.822 | 0.578 | 9.937 | 1 | 0.002 | 6.184 | 1.992–19.196 |
| Intraoperative skin wetting | 2.266 | 0.885 | 6.555 | 1 | 0.010 | 9.641 | 1.701–54.636 |
| Strict preoperative bed confinement | 0.612 | 0.310 | 3.889 | 1 | 0.049 | 1.844 | 1.004–3.386 |

CI; confidence interval; df, degrees of freedom; DHCA, deep hypothermic circulatory arrest; OR, odds ratio.

fields, to ensure safe surgery on large blood vessels [17, 18]. Deep hypothermia reduces the metabolism of tissues and organs; however, cessation of circulation leads to tissue hypoxia. Moreover, reperfusion injury can further aggravate reversible injury during the ischemic period and induce pressure injury. In addition, vasoconstriction caused by hypothermia leads to a reduction in blood supply to the anatomical areas under interface pressure, resulting in an anoxic state of the skin. During the warming process, the use of equipment (i.e., a circulating-water mattress) to raise the temperature of the body surface also increases the risk of intraoperative pressure injury. Studies have shown that, during the warming process, an increase in temperature by 1°C results in a 10% increase in tissue metabolism and oxygen consumption. When continuous pressure results in tissue ischemia, an increase in temperature may increase the risk of pressure injury [19].

### Intraoperative Use of Vasoactive Drugs

The use of vasoactive drugs, such as norepinephrine and dopamine, increases blood circulation resistance. Norepinephrine leads to a marked contraction of almost all arterioles and venules, except for the coronary arteries [20]. Studies have shown that the total number of hours of norepinephrine use is an independent risk factor for the occurrence of pressure injury [21]. The effect of dopamine depends on the dose; a high dose (10 μg/kg · min) and above activates both α receptors and β receptors [22]. Peripheral vasoconstriction increases in parallel with myocardial contractility, and consequently the increased peripheral vascular resistance aggravates tissue ischemia and hypoxia.

### Intraoperative Skin Wetting

A large volume of flushing fluid is often used to rinse the anastomosis during aortic surgery. In the hemostatic process, saline is also required to observe possible bleeding. The thoracoabdominal incision is performed with the patient in the lateral position, and during surgery the flushing fluid, mixed with blood, occasionally spills out of the body cavity through the incision, wetting the sheets. This results in exposure of the anatomical areas under interface pressure to a humid environment for a prolonged period. Wetting may cause maceration, which predisposes the skin to injury by weakening the immunity of the skin. The flushing fluids also alter the pH of the skin, causing changes to the local skin microenvironment, rendering the skin more vulnerable to injury. Simultaneously, the wetness increases the friction and shear forces between the skin and the sheets, further increasing the risk of pressure injury in the anatomical areas under interface pressure.

### Risk Assessment of Intraoperative Pressure Injury in Adults Undergoing Aortic Surgery

The incidence of intraoperative pressure injury in patients undergoing aortic surgery is much higher than that reported in patients undergoing other cardiovascular surgical procedures. The key to the prevention of pressure injury is accurate, dynamic, and comprehensive risk assessment of patients. Reliable assessment tools can be used to effectively evaluate the risk of pressure injury. However, commonly used tools for risk assessment of pressure injury in clinical settings, such as the Norton, Waterlow, and Braden scales, are not applicable to the operating room environment without the consideration of relevant intraoperative factors. At present, the most appropriate frequency and time of risk assessment for pressure injury in perioperative patients has not been standardized [21]. Therefore, a continuous, dynamic, and specially designed risk assessment scale for pressure injury during surgery is warranted [23].

The 2014 version of *Prevention and Treatment of Pressure Ulcers: Quick Reference Guide*, developed by the National Pressure Ulcer Advisory Panel, European Pressure Ulcer Advisory Panel, and Pan Pacific Pressure Injury Alliance, recommends the use of a structured approach to risk assessment [15]. It is suggested that the score of a total risk assessment tool alone may not be sufficient for risk-based prevention. Subscale scores of risk assessment tools and other risk factors should also be examined to guide risk-based intervention measures. Apart from risk assessment tools, additional factors should be considered as part of a comprehensive risk assessment. Nevertheless, clinical judgment is essential, regardless of the use of a structured risk assessment [15].

Since our study is unique for this setting and the population in which it was performed, the results cannot be generalized to other operating room settings nationally or internationally. Further research is needed to explore the causal relationship between the identified risk factors and pressure injury in patients undergoing aortic surgery. Also, the need for a risk assessment scale specifically for patients undergoing aortic surgery will become necessary and indispensable.

## Conclusion

Patients undergoing aortic surgery are at high risk of experiencing intraoperative pressure injury. Nurses in the operating room should therefore accurately identify risk factors for pressure injury in patients undergoing macrovascular surgical procedures. This includes identifying patients under strict preoperative bed confinement and those for whom the use of DHCA during surgery is planned. Nurses should then determine the areas more vulnerable to pressure injury in different aortic surgery positions, select the appropriate pressure injury prevention tools, and use them in an appropriate manner. Nurses must also evaluate the presence and consequences of intraoperative skin wetting and vasoactive drugs with regard to the potential for pressure injury. It is reasonable to conclude that operating room nurses in appropriate positions may reduce the risk of intraoperative pressure injury in patients undergoing aortic surgery with appropriate measures taken according to the results of risk assessments.

## Relevance to Clinical Practice

The incidence of intraoperative pressure injury in patients undergoing aortic surgery is high.

There are many risk factors that can contribute to an increased risk of intraoperative pressure injury in patients undergoing aortic surgery.

Operating room nurses should know how to predict and reduce the risk of intraoperative pressure injury in these patients and take appropriate measures to mitigate these risks.

This research has provided further clinical evidence regarding factors that can increase the risk of intraoperative pressure injury in patients undergoing aortic surgery.

Implementation of risk reduction interventions can significantly impact the incidence of intraoperative pressure injury in these patients. Operating room nurses should therefore have an understanding of risk factors for intraoperative pressure injury in order to implement preventative strategies for high-risk patients.

## Impact Statement

**What Does This Article Contribute to the Wider Global Clinical Community?**

The aim of this research is (1) to identify the risk factors associated with the development of intra-operative pressure injury in patients undergoing aortic surgery and (2) to increase awareness of this issue among nurses and assist them in identifying and implementing appropriate protective measures.

The results of this research will inform the design of future studies investigating interventions to prevent intraoperative pressure injury in patient undergoing aortic surgery.

## Acknowledgments

The authors thank the operating room nurses for their contribution to data collection during this study.

## Conflicts of Interest

The authors declare that they have no conflicts of interest with respect to the research, authorship, or publication of this article.

## Contributions

Yao Dong: research design, data collection, analysis, and drafting of the paper. Jun-E Liu: research design and critical revision. Ling Song: critical revision. All authors: approval of the final version.

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**Supplemental Material:** The online version of this article (DOI: 10.15212/CVIA.2019.1263) offers supplementary material, available to authorized users at the following link: https://cvia-journal.org/wp-content/uploads/2020/11/Supplementary_File_1_STROBE_Checklist.pdf.