



Timing and Surgical Phases of Glove Perforation in Orthopedic Trauma Surgery: A Prospective Study

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University of Health Sciences Türkiye, Balıkesir Atatürk City Hospital, Clinic of Orthopedics and Traumatology, Balıkesir, Türkiye

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ABSTRACT

Objective: To evaluate the frequency, timing, surgical-stage distribution, anatomical location, and factors associated with glove perforation during orthopaedic trauma surgery.

Methods: This prospective study included 354 orthopaedic trauma procedures, categorized into small-bone, intermediate-bone, and large-bone fracture groups. A standardized double-gloving protocol was used, and outer gloves were assessed for perforation at 10-minute intervals using a saline inflation test. Timing, surgical stage, anatomical location, and hand dominance of the perforations were recorded.

Results: Glove perforation occurred in 74 of 354 procedures (20.9%). Perforation rates increased significantly across procedure types: small-bone (10.2%), intermediate-bone (20.3%), and large-bone (32.2%) ($p<0.001$). Mean time to perforation was 32.4 ± 11.9 minutes and differed significantly among fracture-size groups ($p<0.001$). Fracture reduction accounted for 48.6% of perforations, and the index finger was the most frequently affected site (54.1%). The dominant hand was involved in 67.6% of perforations. Inner-glove perforation occurred in six procedures (1.7%). Mean operative duration was longer in procedures with perforation than in those without (54.1 vs. 42.6 minutes; $p<0.001$). In multivariable analysis, each one-category increase in fracture bone size was associated with a 2.14-fold increase in the odds of perforation [95% confidence interval (CI), 1.52-3.01; $p<0.001$], while each additional minute of operative duration increased the odds by 6% (odds ratio 1.06; 95% CI, 1.03-1.09; $p<0.001$).

Conclusion: Glove perforation is common during orthopaedic trauma surgery and is associated with larger fracture size and longer operative duration. Fracture reduction is the surgical stage most frequently implicated. These findings may help identify procedures and surgical phases requiring increased attention to glove integrity.

Keywords: Surgery, gloves, orthopedic procedures, traumatology

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Corresponding Author:

Murat GÖK

University of Health Sciences Türkiye,
Balıkesir Atatürk City Hospital, Clinic
of Orthopedics and Traumatology,
Balıkesir, Türkiye

✉ dr.muratgok@yahoo.com

ORCID ID: 0000-0002-9435-0225

INTRODUCTION

Maintaining the integrity of surgical gloves in orthopaedic surgery is critical to the safety of both the surgical team and the patient. Surgical gloves serve as a barrier to reduce exposure to blood and body fluids and to maintain the sterility of the surgical field. However, glove perforation is a commonly encountered problem, particularly in surgical fields involving high mechanical stress such as orthopaedic trauma surgery. Glove tears may lead to contamination of the surgical field, an increased risk of contact with potential pathogens, and a higher likelihood of infection in both patients and healthcare workers. Therefore, determining the timing, distribution, and surgical stages during which perforation most frequently occurs is of great importance for improving surgical safety.¹⁻⁴

Orthopaedic trauma surgery is among the surgical procedures with the highest risk of glove perforation. This is due to the

nature of trauma, which involves the application of high forces during surgery, frequent manipulation of sharp and irregular bone fragments, extensive soft-tissue injury, and a surgical process that is often less controlled and less predictable. Surgical stages such as fracture reduction, temporary fixation, implant placement, and tissue dissection involve mechanical loading that increases the risk of surgical glove perforation. Compared with elective procedures, trauma surgeries are more heterogeneous, urgent, and technically demanding, making the prediction of perforation risk and timing more difficult.⁵⁻⁷

Although numerous studies on glove perforation are available, most focus on elective orthopaedic procedures or on general surgical practice. Data specific to trauma surgery regarding perforation timing, identification of the highest-risk surgical stages, and the relationship between perforation rates and



fracture size remain limited. Dynamic monitoring of glove integrity throughout the surgical procedure is essential to determine when perforation occurs. However, many previous studies rely solely on postoperative glove testing, which does not provide sufficient information about the timing of perforation or its association with intraoperative surgical stages.^{8,9}

Considering the unique mechanical stresses, variability in fracture patterns, and degree of surgical difficulty inherent in trauma surgery, obtaining trauma-specific data on glove perforation is of great importance.^{2,5}

Given the lack of data on glove perforation in trauma surgery, this study addresses an important gap in the literature. Understanding the intraoperative dynamics of glove perforation may contribute to the development of practical strategies to enhance surgical team safety and reduce surgical field contamination. Furthermore, the development of targeted glove-changing strategies based on perforation timing may provide a valuable approach for clinical practice, particularly given the high-risk nature of trauma surgery.^{3,4,8,10}

The aim of this study was to comprehensively evaluate the frequency, timing, high-risk surgical stages, anatomical distribution, and factors affecting surgical glove perforation in orthopaedic trauma surgery.

METHODS

Between February 2025 and June 2026, 354 patients who underwent orthopaedic trauma surgery at our clinic were included in this prospective study, based on a power analysis. All procedures were performed by a comparable surgical team under standardized double-gloving conditions. The surgical team consisted of three specialist surgeons and three surgical nurses, each with at least five years of orthopaedic trauma experience.

Inclusion and Exclusion Criteria

The inclusion criteria were the presence of a fracture requiring surgical treatment due to trauma, complete implementation of the double-gloving protocol during surgery, and complete data records.

Cases with open fractures, severe contamination, primary intervention at another center, non-compliance with the glove protocol during surgery, multitrauma, and revision surgeries were excluded from the study.

Fracture Classification

Fractures were classified into three groups according to bone size. The small-bone group included phalangeal, metacarpal, metatarsal, carpal, and tarsal fractures; the intermediate-bone group included distal radius/ulna, ankle malleolar, olecranon, and patellar fractures; and the large-bone group included femur, pelvis, acetabulum, tibia, humerus, and large-surface complex fractures. This pragmatic grouping, intended to explore whether

differing mechanical demands were associated with glove perforation, was based on the anatomical size of the involved bones and the anticipated extent of surgical manipulation. It is not a standardized fracture classification and may not fully reflect the complexity of individual procedures.^{2,11}

Surgical Protocol and Assessment of Glove Perforation

All procedures were initiated using a double-gloving protocol. Standard latex or nitrile surgical gloves were used as the outer layer, and thinner barrier gloves were used as the inner layer. Powder-free gloves manufactured by Beybi® (Türkiye) were used, and the same brand and thickness were maintained throughout the study.

To determine the timing of perforation, a stopwatch was started at the beginning of each operation. At 10-minute intervals, the outer glove was removed under sterile conditions and tested using a saline inflation method. Air-bubble formation or fluid leakage during saline inflation was considered evidence of perforation. When a perforation was detected, the glove was immediately replaced and the detection time was recorded. If no perforation was detected, the same glove was reapplied. The inner glove was tested at the end of the procedure, using the same method (Figure 1).



Figure 1. Example of a surgical glove perforation detected using the saline inflation test

Surgical Stages and Intraoperative Assessment

To investigate the surgical phase associated with glove perforation, the intraoperative procedure was divided into five predefined stages: fracture reduction, temporary fixation, cutting and drilling, implant placement, and wound closure. Fracture reduction was defined as restoration of the fracture to an anatomical or functional position using open or closed techniques. Temporary fixation involved stabilization with Kirschner wires, clamps, or other fixation devices. The cutting/drilling stage included drills, saws, or reamers, whereas implant placement included plate-screw systems, intramedullary nails, or external fixation devices. Wound closure included suturing and skin closure. For each detected perforation, the active surgical stage at the time of detection was prospectively documented by the same observer to ensure consistency of data collection.

Anatomical Assessment and Data Collection

For gloves with a detected perforation, the affected anatomical location was classified as the thumb, index finger, middle finger, ring or little finger, or palmar or dorsal surface. Whether the perforation involved the dominant or non-dominant hand and whether it occurred in a surgeon or a surgical nurse were also recorded. Data were documented in real time throughout the procedure. For each perforation, the detection time, active surgical stage, affected anatomical site and the affected hand, the team member involved, and the presence of simultaneous inner-glove perforation were recorded. All data forms were reviewed after surgery for completeness.

Ethical Approval

This study was approved by the University of Health Sciences Türkiye, Balıkesir Atatürk City Hospital Scientific Research Ethics Committee (decision number: 2025/02/21, date: 20.02.2025). The study was conducted in accordance with the Declaration of Helsinki. Written informed consent was obtained from all participants included in the study.

Statistical Analysis

All statistical analyses were performed using SPSS 20.0 (IBM Corp., Armonk, NY, USA). Descriptive statistics were presented as means, standard deviations, counts, and percentages. The chi-square test was used to compare glove perforation rates among fracture-size groups. One-way analysis of variance was

used to compare perforation times among fracture-size groups. No data were missing for the variables included in the analysis. Multivariable logistic regression analysis was performed to identify independent factors associated with glove perforation. Statistical significance was set at $p < 0.05$.

RESULTS

A total of 354 orthopaedic trauma surgery cases were included in the analysis. Glove perforation was detected in 74 cases, corresponding to an overall perforation rate of 20.9%.

Perforation Rates According to Fracture Bone Size

Glove perforation rates differed significantly by the size of the fractured bone (Table 1). Perforation occurred in 12 (10.2%) of 118 cases in the small-bone group, 24 (20.3%) of 118 cases in the intermediate-bone group, and 38 (32.2%) of 118 cases in the large-bone group. The perforation rate increased progressively with fracture size, and the difference among the three groups was statistically significant ($p < 0.001$).

Timing of Glove Perforation

The mean time to detection of glove perforation was 32.4 ± 11.9 minutes overall (Table 2). The mean time to perforation detection was 21.7 ± 8.4 minutes in small-bone procedures, 26.7 ± 9.1 minutes in intermediate-bone procedures, and 41.3 ± 12.6 minutes in large-bone procedures. The mean time to detection of perforation differed significantly among the fracture-size groups ($p < 0.001$). As glove integrity was assessed every 10 minutes, these values indicate approximate detection times rather than the exact moments of perforation.

Distribution According to Surgical Stage

The distribution of glove perforations according to surgical stage is presented in Table 3. Fracture reduction was the most frequently implicated stage, accounting for 36 of the 74 perforations (48.6%). This was followed by implant placement in 14 cases (18.9%), temporary fixation in 9 cases (12.2%), wound closure in 8 cases (10.8%), and cutting/drilling in 7 cases (9.5%).

Anatomical Distribution and Hand Dominance

The index finger was the most frequently affected anatomical site, accounting for 40 of 74 perforations (54.1%), followed by the thumb (20 cases, 27.0%) and the middle, ring, and little fingers (14 cases, 18.9%) (Table 4). No perforations

Table 1. Perforation rates according to fracture bone size

Fracture bone group	Total cases (n)	Cases with perforation (n)	Perforation rate (%)
Small bone	118	12	10.2
Intermediate bone	118	24	20.3
Large bone	118	38	32.2
Total	354	74	20.9

The chi-square test was used to compare glove perforation rates according to fracture bone size ($p < 0.001$)

were detected on the palmar or dorsal surfaces of the glove. Regarding hand dominance, 67.6% of perforations occurred in the dominant hand and 32.4% in the non-dominant hand. The majority of perforations occurred among surgeons rather than among surgical nurses. Inner-glove perforations were detected in six of the 354 procedures (1.7%).

Operative Duration and Risk Factors for Glove Perforation

Mean operative duration was significantly longer in procedures with glove perforation than in those without perforation (54.1 vs. 42.6 minutes, $p<0.001$). In multivariable logistic regression analysis, increasing fracture size and longer operative duration were independently associated with glove perforation. Each one-category increase in fracture size was associated with a 2.14-fold increase in the odds of glove perforation [odds ratio (OR) 2.14, 95% confidence interval (CI) 1.52-3.01; $p<0.001$], while each additional minute of operative duration was associated with a 6% increase in the odds of perforation (OR 1.06, 95% CI 1.03-1.09; $p<0.001$).

DISCUSSION

This prospective study evaluated the frequency, timing, surgical-stage distribution, anatomical characteristics, and factors associated with glove perforation during orthopaedic trauma surgery. Glove perforations were detected in 20.9% of procedures, and the perforation rate increased significantly as fracture size increased. The mean time to perforation was 32.4 ± 11.9 minutes, with fracture reduction representing the most frequently involved surgical stage (48.6%). The index finger was the most commonly affected anatomical site, and perforations occurred more frequently in the dominant hand. Inner glove perforation was detected in 1.7% of procedures. Multivariable logistic regression identified fracture size and operative duration as independent factors associated with glove perforation.

The overall perforation rate of 20.9% observed in this study is consistent with the increased mechanical demands expected during orthopaedic trauma procedures. Trauma surgery frequently requires manipulation of irregular fracture fragments, substantial force during reduction and fixation, and repeated interaction with instruments and implants. These factors may expose surgical

Table 2. Timing of perforation		
Fracture bone size	Mean time to perforation detection (min)	Standard deviation
Small bone	21.7	± 8.4
Intermediate bone	26.7	± 9.1
Large bone	41.3	± 12.6
Total	32.4	± 11.9
One-way analysis of variance was used to compare perforation times according to fracture bone size ($p<0.001$)		

Table 3. Distribution of perforation according to surgical stages		
Surgical stage	Number of perforations (n)	Rate (%)
Fracture reduction	36	48.6
Temporary fixation	9	12.2
Cutting/drilling stage	7	9.5
Implant placement	14	18.9
Wound closure	8	10.8
Total	74	100
Data are presented as number and percentage		

Table 4. Anatomical distribution of perforation		
Anatomical region	Number of perforations (n)	Rate (%)
Index finger	40	54.1
Thumb	20	27.0
Middle/ring/little finger	14	18.9
Palmar/dorsal surface	0	0
Total	74	100
Data are presented as number and percentage		

gloves to greater mechanical stress than procedures involving less demanding tissue or bone manipulation.^{12,112} In the present study, perforation rates increased from 10.2% in small-bone procedures to 20.3% in intermediate-bone procedures and 32.2% in large-bone procedures. This progressive increase suggests that the mechanical demands associated with larger and more complex fractures may play an important role in glove integrity.

Previous studies have demonstrated that glove perforation is influenced by the type and duration of surgery, with orthopaedic procedures representing a setting in which mechanical stress is particularly relevant.^{78,13} The higher perforation rates observed in the large-bone group in the present study may be related to the greater extent of manipulation required during these procedures. However, fracture size is also likely to reflect several other characteristics of surgical complexity; therefore, the observed association should not be interpreted as a direct causal relationship between bone size alone and glove failure.

The timing of perforation provides an additional clinically relevant finding. The overall mean time to perforation was 32.4±11.9 minutes, while mean perforation times increased progressively across the small-, intermediate-, and large-bone groups. The mean time to perforation was 21.7 minutes in small-bone procedures, 26.7 minutes in intermediate-bone procedures, and 41.3 minutes in large-bone procedures. These findings indicate that the timing of glove failure is not uniform across orthopaedic trauma procedures and may vary according to the characteristics of the fracture and the duration of surgical manipulation. Previous studies using intraoperative or postoperative glove assessment have also demonstrated variation in the timing of perforation across different surgical procedures.^{5,10,14}

Fracture reduction was the most frequently identified surgical stage at the time of perforation, accounting for 48.6% of all detected perforations. This finding is clinically plausible because reduction frequently requires direct manipulation of fracture fragments, application of substantial force, and repeated adjustment of fragment positions. Previous studies have similarly suggested that stages involving intensive mechanical manipulation may represent periods of increased risk for glove damage.^{5,11} Nevertheless, the present study was designed to describe the distribution of perforations across surgical stages rather than to establish a causal relationship between a specific surgical maneuver and glove failure. The concentration of nearly half the detected perforations during fracture reduction may nevertheless be useful when considering intraoperative glove monitoring or replacement strategies.

The anatomical distribution of perforations showed a marked predominance of the index finger, which accounted for 54.1% of all perforations, with the thumb accounting for 27.0%. Similar distributions have been reported in orthopaedic surgical settings.⁷⁸ The index finger and thumb are frequently involved in instrument handling, tissue retraction, fracture manipulation, and

stabilization of surgical components. Their frequent use during these activities may explain their greater representation among the detected perforations. No perforations were detected on the palmar or dorsal surfaces of the glove, which further suggests that the fingers were the primary sites of glove damage.

Perforations were detected more frequently in the dominant hand, which accounted for 67.6% of cases. This observation is consistent with the functional role of the dominant hand during surgical manipulation. However, because hand dominance was evaluated descriptively in cases in which perforation had already occurred, this finding should not be interpreted as evidence that use of the dominant hand independently increases the overall risk of perforation. Further studies specifically designed to compare exposure and perforation rates between dominant and non-dominant hands would be required to establish such an association.

The majority of detected perforations occurred among surgeons rather than among surgical nurses. This finding may reflect differences in the type and intensity of intraoperative tasks performed by members of the surgical team. Surgeons generally have more direct contact with fracture fragments, reduction instruments, drills, fixation devices, and implants. However, without denominator data describing the number and duration of procedures performed by each team member, the present findings cannot be used to quantify the relative risk of perforation between surgeons and nurses.¹⁵

The low frequency of inner-glove perforation is an important finding in the context of double gloving. Inner-glove perforations were detected in 6 of 354 procedures (1.7%). These six cases represented 8.1% of the 74 procedures in which outer-glove perforation was detected. The substantially lower frequency of inner-glove damage compared with outer-glove perforation is consistent with the protective role of the additional glove layer reported in previous studies and systematic reviews.^{6,16-23} Although the present study did not directly compare single- and double-gloving protocols, the findings support the continued use of double-gloving in orthopaedic trauma surgery, particularly in procedures involving substantial mechanical manipulation.

Operative duration was also significantly associated with glove perforation. The mean operative duration was 54.1 minutes in procedures with perforation, compared with 42.6 minutes in procedures without perforation ($p<0.001$). In multivariable analysis, longer operative duration remained independently associated with perforation, with an OR of 1.06 per additional minute of surgery (95% CI 1.03-1.09; $p<0.001$). This association is biologically plausible because longer procedures increase cumulative exposure to mechanical loading, friction, instrument handling, and repeated contact with surgical materials.^{24,10,11} The independent association observed after adjustment for fracture size further emphasizes operative duration as a potentially

relevant factor in assessing glove integrity during trauma surgery.

Bone fracture size also remained independently associated with glove perforation in the multivariable model (OR 2.14, 95% CI 1.52-3.01; $p < 0.001$). This finding is consistent with the significant gradient in perforation rates observed across the three fracture-size groups. Larger fractures generally require more extensive exposure and manipulation, although the present observational design does not allow determination of which individual surgical characteristics account for this association.

From a practical perspective, these findings underscore the importance of maintaining glove integrity during procedures involving large bones and prolonged operations. The observation that 48.6% of perforations were detected during fracture reduction suggests that this stage warrants particular vigilance, including prompt glove replacement when damage is suspected or identified.^{24,25} However, the 10-minute testing intervals cannot establish the exact stage at which a perforation occurred, and stage-specific exposure durations were not measured; therefore, the distribution of detected perforations does not establish that the reduction has the highest stage-specific risk. The present study also did not evaluate the clinical effectiveness or cost-effectiveness of scheduled glove changes. Specific monitoring intervals and stage-specific replacement strategies require prospective evaluation before they can be recommended as evidence-based interventions.

The prospective design and standardized intraoperative assessment represent important strengths of this study. Unlike studies relying exclusively on postoperative glove inspection, the 10-minute assessment protocol allowed the approximate timing of perforation to be documented and enabled perforations to be linked to predefined surgical stages.^{5,10} The inclusion of different fracture-size groups also allowed exploration of the relationship between fracture characteristics and glove perforation within a trauma-specific population.

Study Limitations

Several limitations should be acknowledged. First, this single-center study may limit the generalizability of the findings to other institutions and surgical teams. Second, although the participating surgeons and nurses had substantial trauma-surgery experience, individual differences in surgical technique and glove handling could not be completely eliminated. Third, the classification of fractures into three bone-size groups is a pragmatic categorization and may not fully capture the complexity of individual fracture patterns or surgical procedures. Fourth, perforation was assessed at 10-minute intervals; therefore, the recorded time represents only an approximate detection time, not the exact moment when the glove was torn. The surgical stage recorded at detection may likewise differ from the stage at which the perforation occurred, and stage-specific exposure times were not available. The study

was observational and did not compare different glove materials, glove-changing protocols, or single- versus double-gloving strategies. Accordingly, the findings should be interpreted primarily as describing patterns and associations rather than demonstrating causal effects.

CONCLUSION

In this prospective study of orthopaedic trauma surgery, glove perforation occurred in approximately one in five procedures and was significantly more frequent during surgery for fractures of larger bones and in longer operations. Nearly half of all detected perforations occurred during fracture reduction, while the index finger was the most frequently affected anatomical site. Inner-glove perforation was uncommon despite the relatively frequent occurrence of outer-glove perforation. These findings highlight the importance of maintaining awareness of the integrity of gloves during mechanically demanding and prolonged trauma procedures and provide a basis for future studies evaluating targeted glove monitoring and replacement strategies.

Ethics

Ethics Committee Approval: This study was approved by the University of Health Sciences Türkiye, Balıkesir Atatürk City Hospital Scientific Research Ethics Committee (decision number: 2025/02/21, date: 20.02.2025). The study was conducted in accordance with the Declaration of Helsinki.

Informed Consent: Written informed consent was obtained from all participants included in the study.

Footnotes

Authorship Contributions

Surgical and Medical Practices: M.G., A.A.E.K., Ö.K., Concept: M.G., Ö.K., Design: M.G., Data Collection or Processing: M.G., A.A.E.K., Analysis or Interpretation: A.A.E.K., Ö.K., Literature Search: A.A.E.K., Ö.K., Writing: M.G., A.A.E.K.

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