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Research Article

Evaluation of Polymethylmethacrylate (PMMA) Cement for Stabilizing Loosened Screws in Mandibular Angle Fracture Fixation: A Biomechanical Study

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Abstract

Aim: Mandibular angle fractures account for 23-42% of all mandibular fractures, with treatment options often debated due to the region's anatomical complexity. While single miniplate fixation has shown low complication rates, issues like screw loosening remain a challenge. Polymethylmethacrylate (PMMA) has been widely used in orthopedic surgery to improve screw stability. This study aimed to evaluate the effect of PMMA on the stability of loosened screws in mandibular angle fractures.
Material and Method: Twenty hemimandibles from sheep cadavers were divided into control and experimental groups. In the control group, standard 2.0 mm screws were inserted without PMMA augmentation. In the experimental group, a 1.6 mm pilot hole was used to simulate screw loosening, and PMMA was injected into the screw tracts before screw insertion. Both groups underwent vertical force testing using a hydraulic device, with displacement values measured at 50 N of force. Statistical analysis was performed using the Student t-test, with significance set at $p<0.05$.
Results: The mean maximum displacement in the control group was 5.60±2.22 mm, while in the experimental group it was 6.49±3.21 mm. There was no statistically significant difference between the two groups ($p=0.479$). The biomechanical behavior of both groups was similar, indicating that PMMA did not significantly affect displacement values under the tested conditions.
Conclusion: PMMA cement did not significantly improve the stability of loosened screws in mandibular angle fractures. Further research with different force applications and screw conditions may provide more insights into the potential benefits of PMMA augmentation.

Keywords: Mandibular angle fractures, polymethylmethacrylate, screw loosening, miniplate fixation, biomechanical stability

INTRODUCTION

Mandibular angle fractures account for approximately 23-42% of all mandibular fractures, making them a significant subset of facial trauma cases (1,2). Despite their frequency, the optimal treatment of mandibular angle fractures remains a topic of debate due to the unique anatomical and mechanical challenges presented by the region. The complex anatomical structures surrounding the mandibular angle, coupled with the technical difficulties in surgical manipulation, necessitate a range of treatment approaches. Internal fixation techniques, while commonly used, are associated with a relatively high risk of infection, particularly in the mandibular angle region. Additionally, these fractures are often complicated by high postoperative complication rates, which can make their management particularly challenging for surgeons (3-5).

A variety of miniplate configurations and screw positions have been evaluated in the literature to optimize fracture stabilization. Single miniplate fixation on the lateral aspect of the mandibular angle, acting as a tension band, has been shown to yield low complication rates, with reported figures between 12% and 16% (6,7). Proper adaptation of non-compression miniplates to the bone surface is critical for effective fracture treatment. The anatomical difficulty of the mandibular angle, exacerbated by limited access via the trans-oral route, further complicates the surgical

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approach. Non-compression miniplates must be correctly adapted to the bone to provide adequate stability; any maladaptation can generate torque forces that result in complications such as bone resorption, screw loosening, or impaired fracture healing (8-11).

During fixation, the thin cortical bone in the mandibular angle may suffer from additional microfractures as a result of drilling and screw insertion, further increasing the risk of damage to adjacent structures, including vessels, nerves, and tooth roots (11,12). Polymethylmethacrylate (PMMA), a material widely used in dentistry and orthopedic surgery, offers significant benefits due to its biocompatibility and ease of preparation both intraoperatively and preoperatively (13). In orthopedic surgery, the attachment of PMMA to bone is achieved through the retention forces generated by acrylic cement infiltration into the trabecular bone structure (14). Multiple orthopedic studies have demonstrated that augmenting pedicle screws with PMMA or similar cements can improve the fixation of screws to bone, increasing both stability and resistance to mechanical forces (15-17).

The objective of this study was to evaluate the efficacy of PMMA in improving the stability of loosened screws in mandibular angle fractures. While PMMA has been previously studied for use in miniplate fixation with non-loosened screws, (18). this study specifically explores its application in cases where screws have become loosened. We hypothesized that mandibular angle fractures treated with PMMA-augmented loosened screws would exhibit displacement values comparable to those observed in a control group with non-loosened screws, under hydraulic pressure forces.

MATERIAL AND METHOD

The study was conducted using 20 hemimandibles obtained from sheep cadavers, each of which had been fed under similar conditions and had an average weight of 40 kg. The hemimandibles were kept moist and refrigerated at 4°C until the experimental procedures commenced. To facilitate the experiment, all skin and muscle tissues were removed, and the coronoid processes and condyles were excised to ensure that the specimens conformed to the physical constraints of the experimental setup. Surgical pens were used to mark the angular fracture lines on each hemimandible before the samples were randomly assigned to one of two groups (n=10 per group).

In the control group, pilot holes were created using a 1.2 mm diameter drill bit, while the experimental group used a 1.6 mm diameter drill bit, both under 1500 rpm, with physiological saline irrigation for cooling and debris removal (Figure 1). Four-holed, non-compression, straight titanium miniplates (1 mm thickness, Medplates/Türkiye) were positioned at the angle region of the mandible, with the osteotomy line centered on the miniplate. Bicortical osteotomies were performed using a diamond-tipped saw, and to simulate mandibular angle fractures, chisels and hammers were used to complete the fracture line due to the relative weakness of sheep mandibles compared to human mandibles (Figure 2) (19).

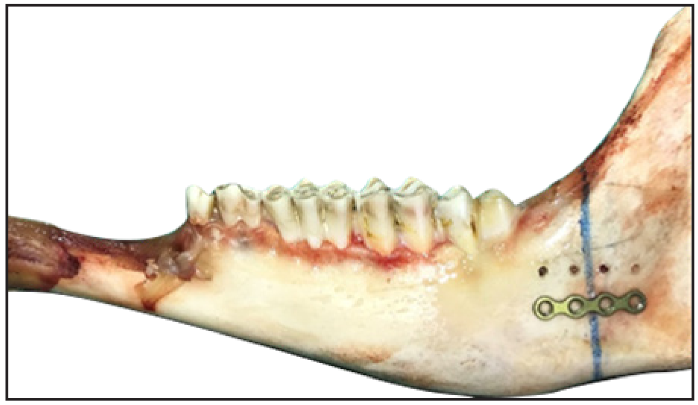

Figure 1. Preparetion of pilot holes and osteotomy line

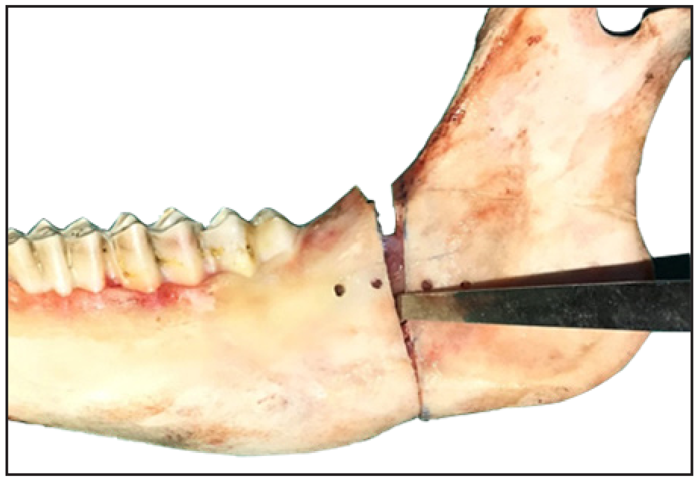

Figure 2. A chisel osteotome used for creating fracture site

In the experimental group, PMMA (Cemex, Tecrecs, Italy) was prepared and allowed to reach a toothpaste-like viscosity (approximately three minutes post-preparation). The PMMA was retrogradely injected into the 1.6 mm diameter screw tracts using a 10 ml syringe before screw placement (Figure 3). The screws (2.0 mm diameter, 11 mm length) were inserted into the PMMA-augmented tracts using a torque-controlled physiodispenser set to 40 Nm, simulating the clinical insertion of dental implants (Figure 4).

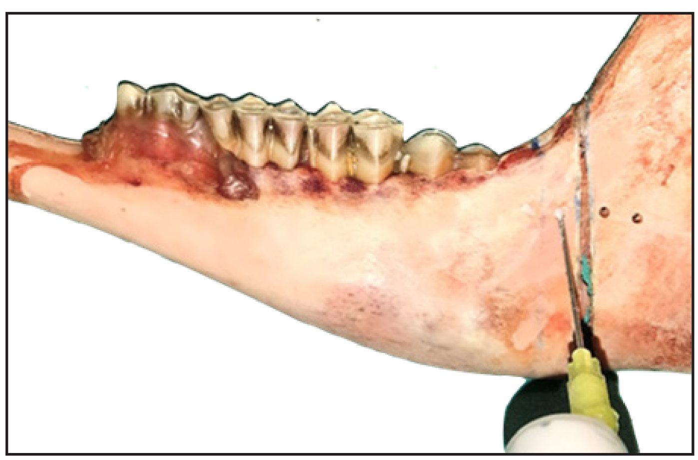

Figure 3. PMMA application using a 10 ml syringe

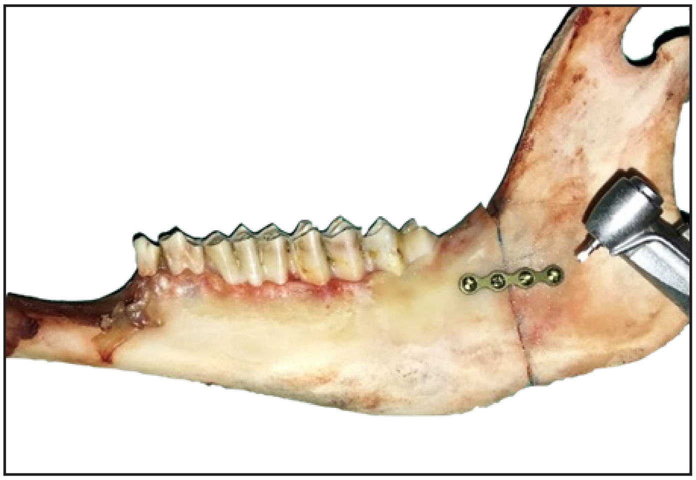

Figure 4. Insertion of screws using an electronic screw driver

Each hemimandible was secured in a custom L-shaped metal device, which provided stable fixation during biomechanical testing using a hydraulic test device (Universal Autograph AGS®, Shimadzu Scientific Instruments, Kyoto, Japan). A vertical progressive force was applied to the molar region, with force being measured via a sensor in the testing machine's headstock. The machine applied a maximum force of 50 N at a displacement speed of 5 mm/min, with the force being transmitted to the occlusal plane after calibration.

Statistical analyses were performed using IBM SPSS Statistics 22 (SPSS IBM, Türkiye). The normal distribution of the data was verified using the Shapiro-Wilk test, and a Student's t-test was employed to compare the two groups, with statistical significance set at $p<0.05$.

RESULTS

The displacement values and maximum displacement means (SD) for both groups under a force of 50 N are presented in Table 1 and Figure 5. There was no statistically significant difference between the maximum displacement values in the study and control groups (p: 0.479, $p>0.05$). However, slight differences in biomechanical behavior were observed in a few individual specimens across the two groups.

Table 1. Displacement values (mm) of control and experimental group at 50 N force.

Control group	Maximum displacement values in milimeters	Experimental group	Maximum displacement values in milimeters
C1	2.63120	E1	3.00970
C2	3.58770	E2	7.36940
C3	4.83117	E3	3.98627
C4	6.60770	E4	6.88127
C5	9.20647	E5	9.25287
C6	6.78773	E6	2.35607
C7	3.16280	E7	4.56293
C8	4.24957	E8	5.74287
C9	6.92790	E9	9.21117
C10	8.01130	E10	12.5765
Mean (SD)	5.60±2.22	Mean (SD)	6.49±3.21

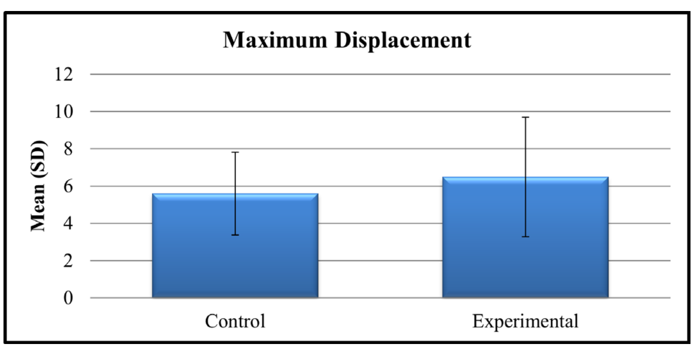

Figure 5. Graphical representation of mean (SD) displacement values of hemimandibles

DISCUSSION

This study sought to investigate whether PMMA cement could enhance the stability of loosened screws in mandibular angle fractures stabilized with miniplates. Most of the literature highlights the high incidence of mandibular angle fractures and the associated challenges of their management (20). Treatment approaches for these fractures remain controversial, with various fixation techniques being explored. Champy's introduction of miniplates revolutionized mandibular fracture management, as clinical studies demonstrated their efficacy in minimizing complications (21). A single miniplate secured with monocortical screws has been shown to offer reliable fixation with fewer complications than two-plate systems (6,7,8,20).

While resin mandible models are commonly used in fracture studies to standardize variables, such models may not accurately replicate the biomechanical properties of human bone. Fresh sheep mandibles, as used in our study, are widely accepted as a reliable alternative due to their similarity in size and cortical thickness to human mandibles (22).

Chewing forces in post-surgical mandibular fracture patients have been reported to reach 90 N within the first week after surgery, increasing to approximately 148 N by the sixth week (22). In our study, we applied a vertical force of 50 N, simulating the immediate post-fixation scenario and assessing the stability of the screws under moderate load. This force is reflective of early postoperative conditions rather than maximum force endurance.

Previous studies have indicated no significant differences in stability between locking miniplates and standard titanium miniplates with diameters of 2 mm when subjected to forces up to 60 N (23). Based on these findings, we selected non-compression, four-holed miniplates with monocortical screws (2 mm diameter) to reflect routine clinical practice.

A larger pilot hole diameter has been associated with reduced screw holding power. Heidemann et al. recommend that pilot holes should not exceed 80% of the screw's external diameter to avoid weakening the screw's retention in the bone (24). In this study, we used a 1.6 mm pilot drill, which represents 80% of the external diameter of our 2.0 mm screws, to simulate screw loosening.

Several strategies have been proposed in the literature for increasing the retention strength of loosened screws, such as increasing screw diameter. However, this approach is often limited by anatomical constraints, and larger screws can increase the risk of cortical fracture (25-27). PMMA cement has been demonstrated in multiple orthopedic studies to be an effective means of augmenting screw fixation (16,17,28,29). The cement's biocompatibility, ease of use, and ability to form immediate bonds with cancellous bone make it a widely favored material (10,30-33). In this study, PMMA was used to augment loosened screws, reducing the displacement values in mandibular angle fractures.

One concern with the use of PMMA is its potential to leak into surrounding tissues, causing damage to nerves and blood vessels. The optimal quantity of PMMA to inject in mandibular fractures has not been well established. To minimize leakage, we employed a retrograde injection technique as described by Chang et al., (10). and ensured that the viscosity of the PMMA was appropriate for application.

In conclusion, this study demonstrates the potential of PMMA cement to stabilize loosened screws in mandibular angle fractures. Our findings suggest that PMMA augmentation offers a viable solution for increasing the retention strength of screws during fixation procedures. It also can stabilize a loosened screw during fixation of mandibular angle fractures, maintaining comparable biomechanical behavior to non-loosened screws without augmentation. Although there was no statistically significant difference between the experimental and control groups regarding displacement values, the application of PMMA provided enhanced fixation strength in cases of screw loosening, suggesting its potential utility in clinical settings where screw stability is compromised.

One of the key limitations of our study is the in vitro nature of the experiment. Sheep mandibles, while structurally similar to human mandibles, may not perfectly replicate the biomechanical properties of human bone, especially under clinical conditions. Moreover, the short-term nature of the mechanical testing did not allow us to evaluate long-term outcomes, such as screw loosening due to cyclic loading or potential bone resorption around the screws over time. Future studies should focus on long-term evaluation of PMMA augmentation in vivo, possibly incorporating finite element analysis to model stress distribution around augmented screws under dynamic loads.

Additionally, further research is required to optimize the quantity and viscosity of PMMA injected into the bone. While our study aimed for a toothpaste-like consistency of the PMMA cement, real-time monitoring of cement flow during screw placement—perhaps aided by imaging techniques like intraoperative computed tomography or 3D navigation—could significantly reduce the risk of cement leakage into soft tissues, nerves, or vascular structures. Furthermore, the exploration of novel screw designs, such as fenestrated screws, may provide even greater control over cement distribution and enhance fixation strength.

CONCLUSION

In conclusion, PMMA augmentation of loosened screws offers a promising solution for improving screw stability in the fixation of mandibular angle fractures. Although the technique requires careful attention to the quantity and handling of the cement to avoid complications such as leakage, it remains a valuable option in cases where screw retention strength is compromised. Future developments in cement application methods and screw design are likely to further enhance the efficacy and safety of this approach, providing oral and maxillofacial surgeons with an additional tool in the management of complex mandibular fractures.

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