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Biomechanical Comparison of Titanium and Stainless Steel Miniplates / Screws for Sagittal Split Osteotomy- An in Vitro Study

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Abstract

Background: Studies on titanium and stainless-steel miniplates in Oral and Maxillofacial Surgery have been published, but none have compared their biomechanical properties for sagittal split osteotomy fixation. The objectives of the present study were to investigate the biochemical efficacy of titanium mini-plates and to examine the effectiveness of titanium mini-plates in comparison with stainless steel plates in the management of sagittal split osteotomy fixation.

Methods: The study involved 10 dry cadaveric hemimandibles, grouped into two groups: Group-SS (stainless) and Group-TT (titanium). Each mandible underwent sagittal split osteotomy and was treated with stainless steel and titanium miniplates. Biochemical testing was performed using the Instron Corporation Series IX automated system. Data were analyzed using SPSS version 16.

Results: The two-tailed probability-test showed a significant difference in parameters like "load at break", "displacement at maximum load", and "compressive strength" between 10 hemi-mandible specimens compared to stainless steel. The study revealed that stainless steel miniplates had higher maximum load values and displacement compared to titanium miniplates, with varying compressive strength and displacement. The mean maximum load was 501.20N ± 106.01 and displacement was 13.98 mm ± 3.83 mm.

Conclusions: Stainless-steel miniplates were found to be ideal for the management of sagittal split osteotomy. Stainless steel miniplates provided satisfactory osteosynthesis and were cost effective compared to

titanium plates. Titanium plates are more malleable and can be easily adapted to the varying contours of the facial skeleton which clinically translates into the reduced time required for plating.

Keywords: Titanium, Stainless Steel, Miniplates, Compression strength

Introduction

Advancements in maxillofacial surgical techniques have enabled the immobilisation and orientation of almost any part of the facial skeleton 15,22 Sagittal split osteotomy of the mandible is the preferred surgical technique for reorienting the mandible in three dimensions in cases of non-syndromic skeletal discrepancies affecting the lower facial third. However, the sustainability of this procedure in the long-term remains a matter of concern. The current research has revealed that the stability following a sagittal split osteotomy is directly influenced by several factors, including the preoperative position of the mandible, the extent of advancement, the level of tension in the paramandibular muscles, the position of the proximal segment, and the methods employed for fixation[1].

The specified miniplates should possess the following attributes: strength, ductility, biocompatibility, and stiffness. Stainless-steel and titanium miniplates have varying characteristics that make them more suitable for distinct functions or anatomic locations. Ductile materials undergo extreme plastic deformation and absorb energy prior to fracturing. Once implanted, materials are exposed to cyclic forces that act in the flexural, axial, or torsional planes, which can lead to material fatigue. This can result in the failure of miniplates at loads that are significantly lower than the tensile or yield strength of the material when subjected to a static load.

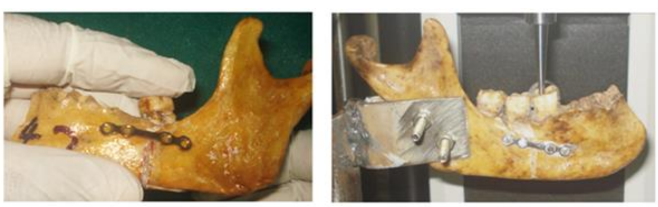
Stainless steel alloys typically exhibit greater rigidity compared to bones and have historically demonstrated durability sufficient for healing[2]. Furthermore, stainless steel is relatively affordable and well-tolerated by biological systems, largely due to its smooth surface achieved through electropolishing[3]. The benefit of this material is that it is ductile enough to contour the plate without causing fracture. Electropolished stainless steel has a superb clinical record in most anatomical locations and fracture types; however, queries have arisen concerning the corrosive nature that produces significant radiologic scatter and, thus, has largely been replaced by mainstream maxillofacial fixation with the exception of intermaxillary fixation screws, which continue to be made from stainless steel in most fixation systems.

However, titanium is more closely matched to the modulus of elasticity of bone. This flexibility might be the most biocompatible alloplastic material and is less rigid and more easily adaptable than stainless steel while maintaining sufficient strength. Furthermore, titanium alloys exhibit greater resilience to notch sensitivity and cyclical stress [4]. Titanium has also been proven to be a reliable material for internal maxillofacial fixation devices, with a proven clinical history of successful outcomes. Previous problems of "cold-welding" using commercially pure titanium screws with plates are effectively eliminated with the introduction of titanium alloys[4]. The utilisation of titanium has been restricted owing to the preferences of regional surgeons and increased expenses compared to electropolished stainless steel; however, these barriers are diminishing.

A conclusion regarding the most suitable metal for sagittal split osteotomy cannot be drawn by comparing the disadvantages and advantages of the biomechanical properties of each metal, as the outcome is not clear. It could be that neither metal hold universal superiority over the other, but that each possesses unique properties which may render it superior to the other in specific anatomical locations. The durability and strength of the construct were heavily influenced by the number and position/composition of the miniplates employed. The study’s purpose was to compare the biochemical efficacy of stainless steel and titanium miniplates for better stabilisation of the bone segments in bilateral sagittal split osteotomy.

Materials and Methods

Dry mandibles were obtained from the dental institute and divided into hemimandibles through midline sectioning. Sagittal split osteotomy was performed following the technique of Hunsuck and Epker [5,6]. The distal segment was repositioned with a 5 mm setback and split into two groups. Half of the specimens were fixed passively using stainless steel miniplates with gaps and monocortical screws, while the other half were fixed with titanium miniplates and monocortical screws (Figure 1).



A B

Figure 1: A-Titanium miniplates, B-Stainless steel miniplates

Each specimen was tested using an Instron Corporation Series IX Automated Testing System with a custom cantilever fixation device, applying forces ranging from 0 to 900N (molar loading) until mechanical failure. The load at break, displacement at the maximum load, and compressive strength of both groups were recorded and compared. Data analysis was conducted using the Statistical Package for the Social Sciences (SPSS) version 16.

Results

Data on the maximum load and corresponding osteotomy displacement are presented in Table 1. When force was applied, Group–SS exhibited higher mean maximum load values of 501.20N ± 106.01 compared to Group-TT, which recorded a mean maximum load value of 268.00N ± 100.90. The displacement data indicated that upon application of load, Group-SS showed greater displacement than Group-TT. The mean displacement recorded in Group-SS was 13.98 mm ± 3.83, while that recorded in Group-TT was 7.12 mm ± 3.31. The differences in maximum load ($p < 0.01$) and displacement ($p < 0.05$) between the groups were found to be statistically significant. The mean compressive strength (N/mm2) in Group-SS was 124.06 +26.24 while that of Group-TT was 66.34 + 24.97 which was statistically significant ($p <0.01$).

Table 1: Comparison of mean maximum load (N), displacement (mm) and compressive strength (N/mm2) between two Groups

Parameter	Group	Mean ± SD	t value	P value
Maximum Load (N)	SS	501.20 ± 106.01	3.563	< 0.01
	TT	268.00 ± 100.90		
Displacement (mm)	SS	13.98 ± 3.83	3.034	< 0.05
	TT	7.12 ± 3.31		
Compressive strength	SS	124.06 ± 26.24	3.563	< 0.01
	TT	66.34 ± 24.97		

The data on the maximum load displacement and compressive strengths of the two groups are listed in Table 3, and their force-path diagrams are shown in Figure 2 and 3.

Table 2: Data on load, displacement and compressive strength between two groups

Sl. No.	Load (N)	Displacement (mm)	Compressive Strength (N/mm2)
SS			
1	431.00	14.86	106.68
2	438.00	12.17	108.42
3	406.00	20.28	100.50
4	636.00	10.79	157.43
5	595.00	11.82	147.28
TT			
1	267.00	10.7	66.09
2	235.00	6.32	58.17
3	203.00	9.07	50.25
4	441.00	7.52	109.16
5	194.00	1.98	48.02

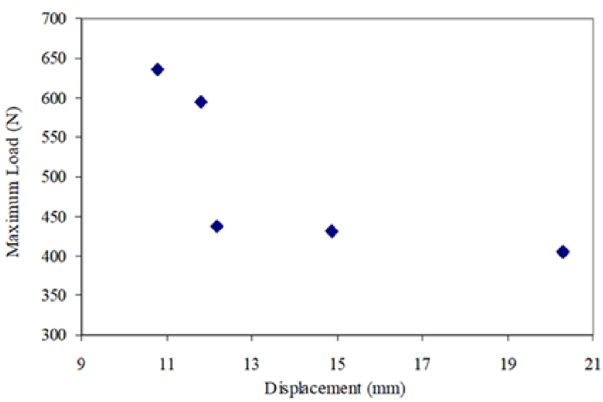


Figure 2: Force-path diagram for Stainless Steel group

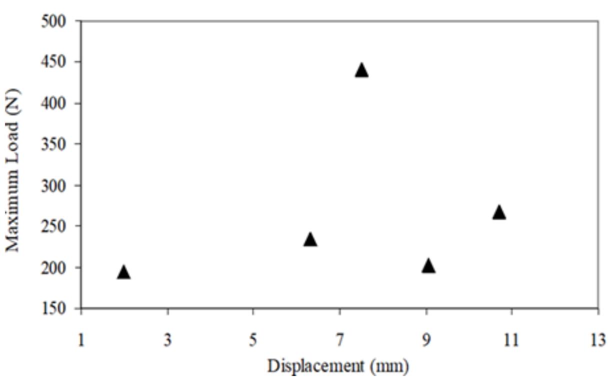


Figure 3: Force-path diagram for Titanium group

Discussion

The speciality of maxillofacial surgery arose and has significantly expanded and developed over the last 50 years [7]. Developments in biomaterials over the last decade have contributed to dramatic advances in the overall therapeutic armamentarium of the oral and maxillofacial regions [8-10].

Titanium is preferred for facial osteosynthesis [11,12]. The biotechnological advances and the inherent advantages of this material in the recent past has seen it become the traditional choice for craniomaxillofacial reconstruction, implantology, traumatology, cosmetic osseous surgeries etc.[13,14]. Titanium is considered to be a highly biocompatible and corrosion-resistant material with excellent osseointegration, and its pliability is an added advantage for better adaptability. In the present study, 10 cadaveric hemimandibles were selected for in vitro comparison to investigate the efficacy of titanium and stainless-steel plates for sagittal split osteotomy. Several authors have described and appreciated the use of Ti plates. The advantages of this metal are also discussed in detail [12,15]. However, complications can also occur.

Mechanical testing is a highly effective method for assessing the strength of osteosynthesis constructs and provides outcomes that may offer potential approaches for clinical use. The majority of research efforts have concentrated on mechanical parameters, such as strength to failure and plate stiffness. Interestingly, it is not always the case that increased implant stiffness results in a stronger construction. In a study conducted by Jain et al., the mechanical properties of titanium and stainless-steel plates were evaluated for dog radii with and without bone defects. Specifically, researchers have assessed the deformation and strength of plates used in bone repair. They discovered similar torsional and bending stiffnesses in the absence of bone defects. When a gap was present, stainless steel demonstrated greater resistance to bending than titanium. However, their overall strength to failure was not dissimilar [16].

The present study used human mandibles and found that bone resistance remained stable with age, as age-related mandibular fractures were not observed in dentulous mandibles. However, obtaining this material for legal and ethical reasons is challenging, and standardisation of samples is nearly impossible, potentially affecting the results due to morphological characteristics and variations in bone quantity and quality. This study focused on the complex forces exerted by the maxillofacial muscles, which differ significantly from other biomechanical models. The main limitation of biomechanical tests is their inability to accurately simulate the action of the masticatory muscles during mandibular movements. This test was conducted using a biomechanical cantilever-bending model.

Overall, a statistically significant ($p<0.05$) difference was observed between the titanium and stainless steel miniplates in the “load at break”, “displacement at maximum load” and “compressive strength showing almost double the value obtained for stainless steel. The load at break of the titanium miniplates and stainless steel ranged from 194 to 441 N and 406 to 636 N, respectively, suggesting that the study could be conducted on fresh cadaveric mandibles for more accurate results.

The present study compared the results with older studies, as there are no recent articles available. The study results align with Lukota and Shelton's 1995 comparison of titanium and stainless-steel miniplates' mechanical strength [17]. They found similar bending stiffnesses in the flat and edgewise directions. However, they noted that the stainless steel plates were overdesigned and had mechanical strength beyond the clinical requirements. They suggested reducing fixation plate stiffness to improve the clinical results. The findings of this study support the importance of considering these factors in miniplate design.

Stainless steel, which is a mixture of iron, chromium, nickel, and molybdenum, is a strong and rigid material used in maxillofacial fixation systems. It is more corrosive and produces more radiological scatter than other metals, making it less popular. Despite being the material of choice until the mid-1980s, it was replaced by titanium owing to its strength and affordability. Intermaxillary fixation screws are still made from stainless steel in most fixation systems [18].

Titanium plating systems are made from pure titanium and oxygen or titanium alloys, making them less rigid and more adaptable than stainless steels. They form a protective oxide that resists corrosion and achieves tissue biocompatibility. Titanium also has unique properties of osseointegration and binding to bone. Unlike stainless-steel screws, titanium screws have a release torque that exceeds the insertion torque. Titanium plating systems for maxillofacial surgery are available from several major manufacturers. However, titanium plates have disadvantages such as screw migration, radiographic obstruction, growth restriction, and psychological or physiologic complications [18]. Hans et al. compared stainless steel plates to less-rigid titanium-alloy plates for internal fracture fixation. They found that titanium alloy plates resulted in a small amount of periosteal callus without fracture instability, and produced physiological remodeling of cortices, normal bone structure, and mass during the remodeling phase with less soft tissue reaction[19].

The study revealed that a laboratory method for perfectly simulating mandibular movements is yet to be described, and the complex interaction between the mandible and adjacent musculature makes biomechanical models insufficient for determining the best clinical options for fixation of mandibular sagittal split osteotomies. This investigation provides valuable information to guide surgeons in selecting the best fixation material for each case.

Conclusion

Stainless steel miniplates are cost-effective and effective for osteosynthesis, with a reduction in bite force postoperatively. Titanium miniplates, owing to their biocompatibility and malleability, are also suitable for less rigid fixation systems as they carry loads with the osteosynthesis system and healing bone, gaining worldwide acceptance.

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