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# Two-screw osteosynthesis of the mandibular condylar head with different screw materials: a finite element analysis

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**ABSTRACT**

This study compared the biomechanical behavior of titanium, magnesium, and polylactic acid screws for two-screw osteosynthesis of mandibular condylar head fractures using finite element analysis. Von Mises stress distribution, fracture displacement, and fragment deformation were evaluated. Titanium screws performed the best in terms of carrying the highest load, resulting in the least fracture displacement and fragment deformation. Magnesium screws showed intermediate results, while PLA screws were found to be unsuitable with stress values exceeding their tensile strength. These findings suggest that magnesium alloys could be considered a suitable alternative to titanium screws in mandibular condylar head osteosynthesis.

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Finite element analysis; mandibular condylar head screw osteosynthesis; titanium; magnesium; polylactic acid

## Introduction

Optimal treatment of mandibular condylar head fractures is a subject of ongoing research and discussion. Open reduction and internal fixation (ORIF) is the preferred approach in many cases, but two types of complications must be considered. Firstly, multiple drilling and pressure through screw heads can result in condylar bone resorption, which can be addressed by reducing the number of screws inserted (Johner et al. 2021). Secondly, surgery in the pre- or retro-auricular region carries the risk of injury to adjacent structures, potentially causing facial nerve paresis, auriculotemporal nerve damage, ear canal stenosis, fistula formation, maxillary artery injury with severe bleeding, or disruptive scarring (Müller-Richter et al. 2011; Xiang et al. 2014). As leaving titanium screws *in situ* over a prolonged period can lead to screw migration and possible damage to the articular disc or fossa, non-resorbable screws should be removed after fracture healing, necessitating second surgery (Smolka et al. 2018). Screws fabricated from resorbable materials such as magnesium or poly-lactic acid (PLA) could help reduce morbidity by eliminating the need for a second surgery for hardware removal. Promising results have been reported for maxillofacial osteosynthesis with both magnesium (Cho et al. 2012; Lee et al. 2014; Kozakiewicz 2020; Kozakiewicz and Gabryelczak 2022) and PLA (Oki et al. 2006; Abdel-Galil and Loukota 2008; McLeod and Saeed 2016; McLeod and Van Gijn 2018) screws.

Our previous FEA study demonstrated that two titanium screws appear to provide sufficient stability in the osteosynthesis of mandibular condylar head fractures. The aim of this study was to compare the biomechanical behavior of titanium screws with that of resorbable screws made from magnesium and PLA using a validated finite element model.

## Materials and methods

The finite element model used for this study was based on a previously validated FEA model of a mandible with an AO CMF type p condylar head fracture (Neff et al. 2014) on the right side, described in detail in Schönegg et al. (2022). To facilitate analysis, the model was improved by increasing the number of nodes and elements in the main area of interest around the fracture gap, so that the top screw was now modeled with 1,076,558 nodes and 740,550 elements, and the bottom screw with 1,082,002 nodes and 728,267 elements (Figure 1). Load boundaries were again applied based on a validated model by de Zee et al. (2007).

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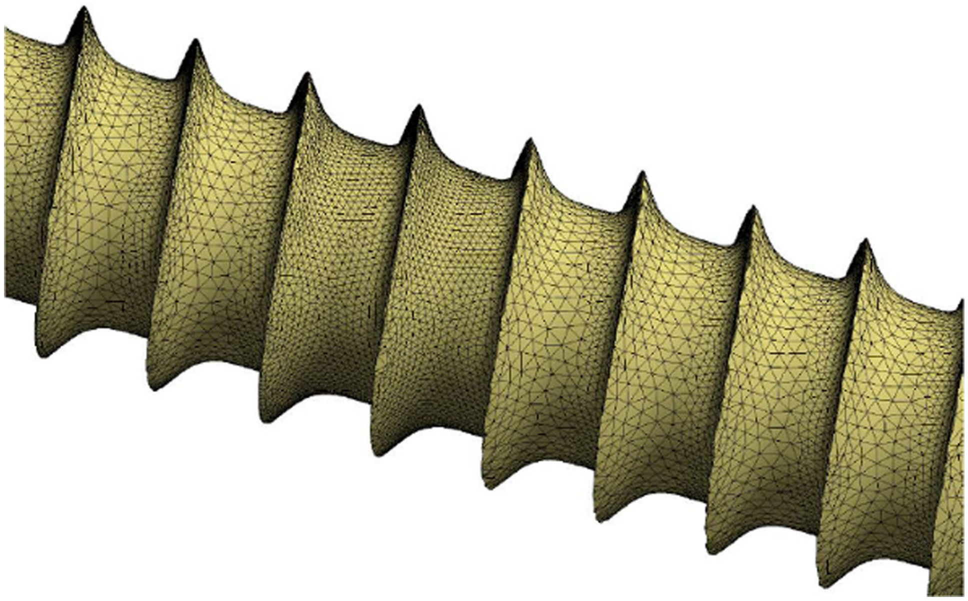

Figure 1. Finite element model of the bottom screw, showing the increased number of nodes and elements in the main area of interest.

Table 1. Elastic moduli and Poisson's ratios assigned to the different screw materials.

| material | elastic modulus [MPa] | Poisson's ratio |
|---|---|---|
| titanum ASTM F136 | 113,800 | 0.342 |
| magnesium alloy | 44,100 | 0.27 |
| PLA | 4,000 | 0.325 |

All screws had the same geometric design (Medartis MODUS® Mandible Hexadrive 1.8 mm cortical screws, 13 mm length; Medartis AG, Basel, Switzerland). The screw materials were an ASTM F136 titanium alloy, a magnesium alloy, and PLA, with the respective elastic moduli assigned as shown in Table 1.

Von Mises stress distribution within the top and bottom screw, fragment deformation, and fracture displacement were analyzed for a loading scenario simulating biting on the left (contralateral) molars with 350 Newton, which had been proven to lead to the highest forces within fragments and screws in a previous study. The same scenario was calculated for the three different screw materials, and a qualitative analysis of the results was performed.

## Results

### Fragment deformation and fracture displacement

Fragment deformation and fracture displacement were similar when comparing osteosynthesis with titanium and magnesium screws. With PLA osteosynthesis, there was an obvious increase in both fragment deformation and fracture displacement, with the fracture gap opening anteriorly. Figure 2 graphically compares fragment deformation for the three screw materials.

### von Mises stress distribution

It was found that von Mises stress within the screws is highest in the region of the fracture gap and is concentrated on the root of the bottom screw. An example of the distribution of von Mises stress within the screws is shown in Figure 3.

For both magnesium and PLA, the maximum von Mises stress was found to exceed the respective material tensile strength in the lateral fracture fragment at the level of the fracture gap. Compared to titanium, maximum von Mises stress in the critical area was reduced in magnesium and PLA screws. For magnesium, the tensile strength was still exceeded by 479%. For PLA, the tensile strength was exceeded by 569%, despite a 71% reduction in the maximum von Mises stress. Figure 4 shows the graphical comparison of von Mises stress between the three screw materials.

## Discussion

The advantages of this finite element model have been discussed in detail in the previous work (Schönegg et al. 2022). Among the most notable are the validated boundary conditions and truthful geometry, the placement of screws according to clinical standards, and a high number of elements and nodes. The increased number of nodes in the main region of interest allowed the minimization of singularities, thus facilitating the analysis. Again, in a scenario that intentionally simulates the most extreme loading conditions within the physiological range of bite forces,

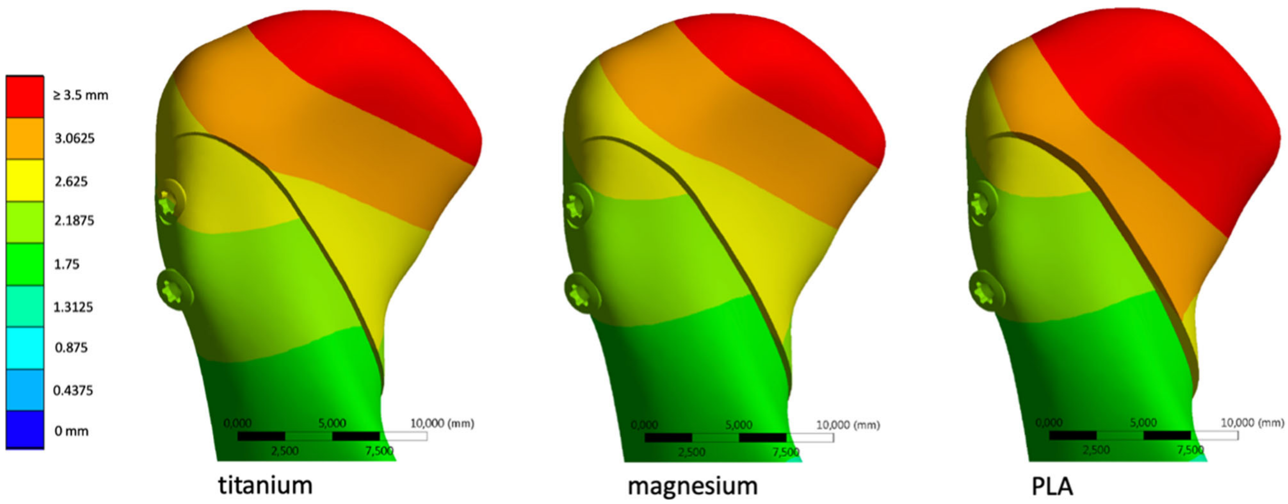


**Figure 2.** Fragment deformation in osteosynthesis with a) titanium, b) magnesium, and c) PLA screws when simulating biting on the contralateral molars with 350 N.

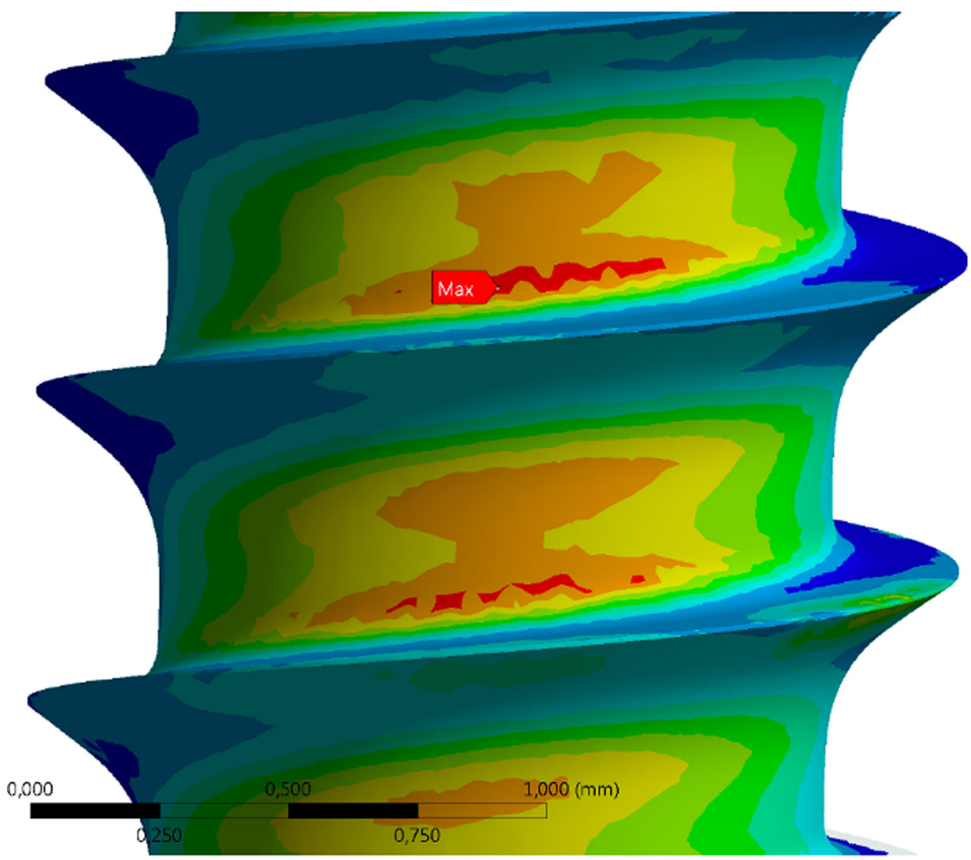


**Figure 3.** Maximum von Mises stress can be found at the root of the screw.

where a failure of osteosynthesis is likely, only qualitative conclusions can be drawn from this FEA. In general, results of finite element analyses should always be supported by further studies and experiments, else they can only be used as a reference for clinical applications and not solely relied upon without further validation.

The three screw materials generally showed similar biomechanical behavior in the FEA. Von Mises stress was highest for all materials approximately 1.5 screw turns lateral to the fracture gap at the root of the bottom screw. This is consistent with other FEA studies (Hijazi et al. 2016; Schönegg et al. 2022).

The maximum forces at the critical point were found to be lower in magnesium screws than in titanium screws (16% at the top screw and 27% at the bottom screw). Since the tensile strength of magnesium is 77% lower than that of titanium, this reduction is

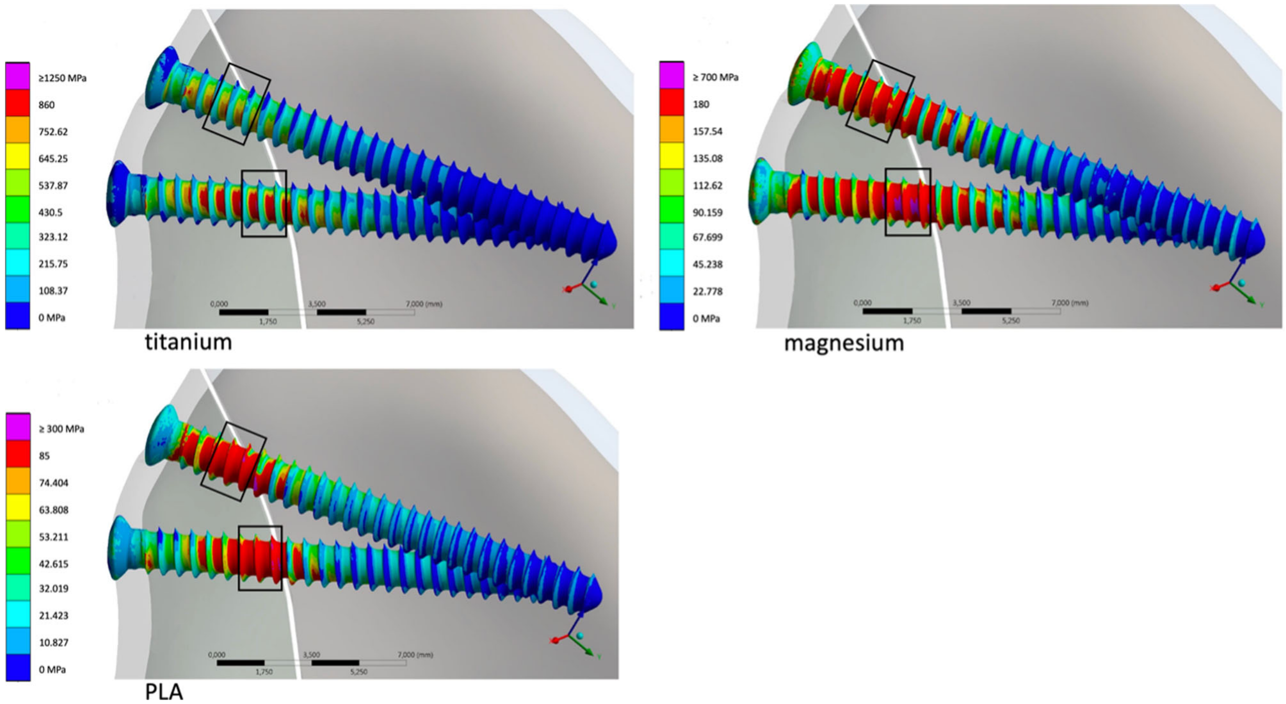


**Figure 4.** Comparison of the von Mises stress within the screws. Areas above the respective tensile strength are shown in purple for a) titanium, b) magnesium, and c) PLA screws.

not sufficient - the tension force surmounts the tensile strength by 479%. The same trend is seen for PLA screws: the maximum stress is reduced by 38% for the top screw and 71% for the bottom screw, but the tensile strength is still exceeded by 569%. For values above the plasticization limit, this suggests that plastic deformation of the material would occur. As the material characteristics of PLA do not allow insertion (drilling) of a standard screw, in a clinical setting, PLA would need to be used in the form of an ultrasound-activated pin. Further FEA studies must show whether and how it is possible to design a PLA screw in a shape or form that meets both mechanical and clinical needs.

From a clinical perspective, the use of resorbable screws may have several advantages over titanium screws for ORIF of mandibular condylar head fractures. The incidence of temporomandibular joint (TMJ) dysfunction secondary to remodeling processes seems to be significantly lower (Leonhardt et al. 2017, 2020; McLeod and Van Gijn 2018; Skroch et al. 2020). In clinical case series, undesirable effects of material resorption such as gas formation or changes in ambient pH were not found to be relevant (Cho et al. 2013; Skroch et al. 2020), which is also reflected by low clinical complication rates (Lee et al. 2010; Jeon et al. 2016; Sukegawa et al. 2018).

As suggested by experts in the field (Leonhardt et al. 2021; Kozakiewicz et al. 2022), screws fabricated from magnesium alloys might be a clinically suitable alternative to titanium screws for mandibular condylar head osteosynthesis. Further studies are needed to determine whether two or three magnesium screws provide the best clinical results and whether changes in screw shape, microarchitecture, or diameter could further improve the stability of osteosynthesis after a mandibular condylar head fracture.

## Conclusion

Considering the requirements for osteosynthesis of the mandibular condylar head such as fragment stability, minimization of surgical complications, and rapid restoration of temporomandibular joint function, resorbable screw materials offer an interesting alternative to the currently most used titanium screws.

In this FEA, polylactide screws appeared to be too soft for stable osteosynthesis of the mandibular condylar head. Magnesium screws, on the other hand, showed favorable biomechanical behavior. With optimized resorption characteristics and improved intraoperative handling, magnesium screws might replace titanium screws in selected cases in the future.

Before a comprehensive clinical trial, further FEA studies simulating different screw positions or screw geometries could provide certainty on the ideal placement of magnesium osteosynthesis screws in the mandibular condylar head.

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