

# Optimization of Osteosynthesis Positioning in Mandibular Body Fracture Management using Numerical Finite Element Method Simulation and Polymeric Model Testing

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## Research Article

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# Abstract

The study aims to optimise surgical management for mandibular body fractures by application of finite element method (FEM) with verification from polymeric model tests. The study investigates two issues regarding the application of osteosynthesis plates for mandibular body fractures: the effect of miniplate positioning and mandibular body height decrease.

Computed tomography (CT) images of cadaveric mandibles with heights of resp. 21, 15, and 10 mm were used to create a FEM-model with a unilateral straight-line fracture, fixated with a standard commercially available 6-hole 2 mm titanium miniplate. Outcomes were compared with a series of mechanical tests with polymeric models fixed in a customized device and loaded with a mechanical test bench.

Firstly, the study illustrates that the optimal plate position appears to be the upper border. Secondly, lower mandibular height increases instability and requires a stronger fixation. Thirdly, optimal fracture reduction is essential for gaining stability. In conclusion, FEM and polymeric testing outcomes of unilateral non-comminuted fractures were highly comparable to the current opinions in mandibular fracture treatment. In future, the FEM may be used to predict the treatment of more complex fractures. However, more analysis needs to be conducted to say whether FEM alone is sufficient for fracture analysis.

## Introduction

Osteosynthesis plates are used for the fixation of mandibular fractures and reconstructive surgery.<sup>1-3</sup> Champy et al. (1976) previously discussed mandibular fracture management with osteosynthesis miniplate fixation by describing the ideal line for miniplate positioning.<sup>9</sup> The applied (mastication-) forces on the mandible will cause different zones of tension and compression based on the plate's location.<sup>8,10</sup> The mandibular body upper border is the tension zone, and the lower border is the compression zone.<sup>8,9</sup> According to Tams et al. (1997), the plate's position affects the bending forces, torsional moments, and bending moments across mandibular body fracture.<sup>8</sup>

A decrease of mandibular body height in an edentulous state results in a narrow range for positioning the plate to fix mandibular body fractures.<sup>4,5</sup> According to Ellis et al. (2008), the atrophic mandible requires a more aggressive approach for fracture management.<sup>11</sup> The studies by Kroon et al. (1991) and Suguira et al. (2009) showed that the miniplate fixation system does not sufficiently manage the bending or torsional moments.<sup>10,12</sup>

Failure of fracture treatment caused by instability can be a significant problem and requires further investigation. Finite Element Method (FEM) analysis is a proper tool to mechanically analyse mandibular body fracture fixation and propose solutions regarding plate positioning and understanding problems due to height decrease.<sup>6,7</sup>

The purpose of this paper is to optimize the surgical treatment of mandibular body fracture by studying the effect of different plate positioning, especially in cases with a reduced mandible height. Using FEM gives a better understanding of the use of the osteosynthesis plate system and enables studying different cases. In the study, results from FEM analysis are compared and validated using polymeric model testing and compared with earlier publications. We hypothesize that plate positioning and mandible height have a significant effect on fracture stability. We also hypothesize that FEM is a proper tool to analyse and optimize fracture management.

## Methods

### Assembly modelling

Three cadaveric mandibles with heights of resp. 21, 15, and 10 mm were selected (Fig. 1a). The cadaver mandibles were obtained from the section anatomy of the Department of the Neurosciences of the University Medical Center Groningen (UMCG, Groningen, the Netherlands). Legal and ethical approval for the use of the human cadavers in this study was provided by this department. The cadavers have been donated for medical research and educational purposes according to the legal and ethical guidelines of the Dutch uniform anatomical gift act. A computed tomography (CT) scan was conducted from each cadaveric mandible, and digital imaging and communication in medicine (DICOM) files were generated. The cadavers were returned after gaining the CT scans. The iCAT-Vision computer program (Cone Beam 3D Dental Imaging, Hatfield, England) enabled the dimension measurements for three dimensional (3D) modelling (Fig. 1b). The 3D mandible models were created in the Solidworks (version 2014, 3D Modelling and Simulation, Waltham, Massachusetts, USA) (Fig. 1c). In this study, the same type of straight-line unilateral mandibular body fracture was applied for each analysis (Fig. 2).

A standard commercially available 6-hole 2 mm osteosynthesis titanium miniplate with a length of 36.3 mm and 6 x 2 mm miniscrews with a length of 18.4 mm was modelled in Solidworks. Three different assemblies were created in Solidworks for mandibles with heights of resp. 21, 15, and 10 mm.

### FEM

FEM analysis was performed in Comsol Multiphysics computer simulation program (version 4.4, 3D Modelling and Simulation, Stockholm, Sweden). The analysis started with positioning the osteosynthesis miniplate at the mandibles' upper border and lowered from the upper border toward the lower border along the fracture line. Therefore, the osteosynthesis miniplate is placed in different positions at the mandibular body to determine the effect of plate positioning (Fig. 2).

A force of 300N, the average maximum mastication force was applied downward on the anterior of the mandible at the symphysis line at the Y-axis (Fig. 3a).<sup>13,14</sup> The mandible was fixed at the condylar edges of the temporomandibular joint (TMJ) using fixed geometry (Fig. 3b).

The mandible material properties were set at an elastic modulus of 14500 MPa, shear modulus of 4500 MPa, mass density of 1180 kg/m<sup>3</sup>, tensile strength of 135 MPa, yield strength of 140 MPa and Poisson's ratio of 0.2.<sup>15</sup>

The properties for the osteosynthesis miniplate and screws were: elastic modulus of 123000 MPa, shear modulus of 46000 MPa, mass density of 4650 kg/m<sup>3</sup>, tensile strength of 1160 MPa, yield strength of 1070 MPa, Poisson's ratio of 0.33, compressive strength of 1170 MPa, thermal expansion coefficient of 9e-006 /K and thermal conductivity of 7.8 W/(m\*K).<sup>4</sup>

Using the Contact-Set option enabled defining the boundary conditions between the mandible, plate, and screws (Fig. 3c). The connection between the two fracture surfaces was modelled by using Contact-Set with a fixed distance of 0.001 mm between the fracture surfaces (Fig. 3d), representing optimal fracture reduction. A mesh was designed with a maximum mesh ratio of 1.5 (Fig. 3e). The mesh curvature resolution was set to 0.6, and the mesh resolution of the narrow region was set to 0.5. The maximum mesh element size was 0.00938 mm, and the minimum element size was 0.00169 mm. These boundary conditions and parameters were identical for all FEM studies.

## FEM mesh verification

The mesh dimensions were checked in the simulation models to determine if they were chosen correctly. The mesh size was reduced until the results were independent of the mesh size.

## Polymeric model testing

The polymeric mandible is made of synthetic polyurethane foam and is an adequate substitution of cadaveric human bone for testing.<sup>16</sup> It has shown to be a successful simulator for the human bone made in similar size and shape.<sup>17,18</sup> Bredbenner et al. (2000) show the substitution of human cadaveric bone for Synbone where the resistance of Synbone is half compared to cadaveric bone, therefore assuming that the material properties such as Young's modulus are twice as less as the human bone. Based on the previous studies, we can make two assumptions: firstly, the material properties of Synbone are half of the human bone properties, therefore half the strength and Young's modulus. Secondly, based on the factor two differences between the material properties, deformation outcomes between FEM simulations at 300 N are comparable with the polymeric model testing at 150 N.<sup>16-19</sup>

In this study, polymeric model testing was conducted in a mechanical test bench (DYNA-MESS Prüfsysteme, Stolberg, Germany) for validating the FEM analysis. Polymeric mandible replicas with heights of resp. 20.5, 16, and 10.5 mm were obtained from Synbone (Malans, Switzerland). All mandibles were made from cortical and cancellous polymeric "bone" with general dimensions of 108 mm length, 129 mm width, and 57 mm total height. A straight-line unilateral fracture was applied on each mandibular body and fixated with the osteosynthesis plate system. For polymeric model testing of 21 and 15 mm mandibular height, a 4-hole plate with four screws was used. For 10 mm mandibular height, a 6-hole plate with six screws was used. The polymeric model testing only included the osteosynthesis plate positioned at the upper border of the mandible. The testing was conducted three times for each of the three

polymeric mandible replicas (resp. 20.5, 16, and 10.5 mm height) with a total of nine polymeric model tests.

A custom device was built for positioning the mandibles in the mechanical test bench (Fig. 4). A force was applied on the mandible, representing the mastication force, gradually increasing with the rate of 10 N/s (Fig. 4a). The values were set in the computer system of the mechanical test bench. The force on the mandible was continuously increased until the failure point where the mandible breaks down were reached (Fig. 4d). Computerised sensors on the mechanical test bench recorded data. All three mandible heights were tested using the same technique.

## Results

### FEM

The results of the FEM simulations are presented in Table 1. The maximum stress and deformation values in the table are present at the edge of the miniplate, touching the mandibular body at the unilateral fracture site (Fig. 5a-f). The table shows that stress and deformation increase when the mandibular height decreases. The same applies to when the plate is lowered from the mandibular upper border toward the lower border along the fracture line.

Table 1  
FEM simulation results illustrating Von-Mises stress and deformation values in the Y-axis.

Height [mm]	Plate Position	FEM Simulation Analysis	
		Von-Mises Stress [GPa]	Deformation Y-axis [mm]
21	1	2.0	15.9
	2	2.7	16.0
	3	4.0	16.6
	4	6.3	18.1
	5	16.0	19.0
15	1	3.5	37.7
	3	6.2	38.6
	5	8.4	40.1
10	1	4.0	61.4
	3	5.9	61.7
	5	7.2	76.2

# Polymeric model testing

The deformation outcomes for polymeric model testing are displayed in Table 2. The table shows that a decrease in mandibular body height results in an increase in deformation and a decreased failure rate time. This indicates a faster failure rate and lesser force carried by the assembly when the mandibular height decreases.

Table 2

Polymeric model testing failure time and deformation at 150 N compared with FEM deformation at 300 N.

Height [mm]	Test Nr. <sup>a</sup>	Polymeric Model Testing		FEM
		Failure Time [sec]	Deformation [mm] at 150 [N] force <sup>b</sup>	Deformation [mm] at 300 [N] force <sup>c</sup>
21	I	305	3.14	
	II	265	2.58	
	III	298	1.88	
	Mean	289	2.53	15.9
15	I	180	1.77	
	II	183	3.11	
	III	122	5.09	
	Mean	162	3.32	37.7
10	I	97	2.76	
	II	92	4.90	
	III	96	5.22	
	Mean	95	4.29	61.4
<sup>a</sup> All the test numbers (Test Nr. I-III) are done under the same condition when the plate is located at the mandibular upper border.				
<sup>b</sup> The deformation in polymeric model testing at 150 N force.				
<sup>c</sup> The deformation in FEM analysis at 300 N force.				

The polymeric testing showed a similar pattern compared to FEM, namely: decrease in mandibular body height results in an increase of fixation instability leading to implant failure.

## Verification

The FEM plots show that the Von-Mises stresses (Fig. 6a) and deformation (Supplementary Fig. 1a) increase when the height of the mandible decreases. The same applies when the plate is lowered from the mandibular upper border towards the lower border along the fracture line. The plot from polymeric model testing (Supplementary Fig. 1b) shows deformation at 150N for polymeric model testing, where deformation increase when the height of the mandible decrease. Figure 6b shows the deformation relation between polymeric model testing and FEM simulation analysis. Both FEM analysis and polymeric model testing illustrate a similar pattern: a decrease in height results in an increase of deformation and a faster failure rate. The results shows, mandible with decreased height (atrophic mandible; from 10mm) requires a different approach than a normal height mandible (non-atrophic; from 21 of 15 mm) in order to gain fracture stability and optimal management.

## Discussion

This study focuses on numerical simulation of optimal surgical treatment for mandibular body fracture using the osteosynthesis miniplate system. The study makes use of FEM simulation analysis together with polymeric model testing compared to previous literature. The study confirms that two factors play an essential role in mandibular fracture fixation stability, namely: the mandibular body height and the miniplate positioning.

Firstly, according to Tams et al. (1997), plate positioning is a crucial factor for mandibular fracture fixation stability.<sup>8</sup> Lowering the plate along the fracture line from the mandibular upper border towards the lower border decreases the fracture fixation stability. Therefore, locating the plate on the upper border results in increased fixation stability. Based on Champy et al. (1976), upper border plate placement is based on the fact that mastication creates a tensile force on the upper border and compression force at the lower border.<sup>9</sup> Upper border plate placement causes the closing of the two fracture surfaces. This study's FEM simulation analysis illustrates similar results where von-misses stress and deformation increase when the plate is lowered along the fracture line (Table 1, Fig. 6a, Supplementary Fig. 1a).

Secondly, according to Ellis et al. (2008), the mandibular height significantly affects fracture fixation stability.<sup>11</sup> Based on Suguira et al. (2009), decreased mandibular height increases fracture fixation instability.<sup>12</sup> In cases with decreased mandibular height (atrophic), it is more difficult to achieve stability with the same miniplate implant used in an average mandibular height. It means that the miniplate implant used in a regular height mandible (non-atrophic, 21 or 15 mm height) cannot be used in a mandible with decreased height (atrophic, from 10 mm or less). FEM analysis and polymeric model testing confirm the presence of this clinical problem. The literature suggests several possibilities regarding solving instability in the management of mandibular fractures with decreased height: e.g., thicker miniplate or more screws at each fracture side.<sup>3,11,12</sup>

In this study, FEM analysis confirmed that the mandibular height and the location of the plate are significant factors in fracture fixation stability. The plate placement at the mandibular upper border provides the most stability resulting in a tensile force on the plate and a compression force at the lower border closing the fracture. This effect becomes much more significant for the mandibles with decreased height (atrophic) (Table 1, Fig. 6a). The normal chosen 2 mm thick miniplate does not provide sufficient stability for the lower mandibular heights (atrophic, 10 mm height). Therefore, a different approach is necessary when the mandible height decreases (e.g. thicker miniplate).

Furthermore, FEM analysis shows that proper fracture reduction has an integral part in fracture stability. FEM makes use of Contact-Set fixed distance of 0.001 mm between the fracture surfaces for optimal reduction and fracture surfaces alignment (Fig. 3d). An increase in the distance between fracture surfaces and non-symmetric reduction may result in increased instability. However, this needs to be further examined in future studies.

The polymeric model testing was conducted for verification of the FEM simulation outcomes. Therefore, the polymeric testing was done only for the upper border plate positioning (Table 2, Supplementary Fig. 1b). A 4-hole plate with four screws was used for the management of the unilateral straight-line fracture in polymeric models of 20.5 and 16 mm height. For 10.5 mm mandibular height, a 6-hole plate with six screws was used to achieve fixation stability. However, FEM analysis included only a 6-hole plate with six screws in order to specifically simulate the effect of plate positioning and mandibular body height on fixation stability.

The polymeric model testing outcomes indicate that only using a longer miniplate (6-hole in 10.5 mm compared to 4-hole in 20.5 and 16 mm mandibles) is not sufficient for lower mandibular height fracture management. Therefore, the 10 mm or lower mandibular height fracture fixation requires a different approach. However, the question remains of what type of plate and which number of screws provides optimal stability for the healing of fractures in the extremely resorbed mandible.

In the study, the outcomes of FEM analysis are verified by polymeric model testing, illustrating similar stress patterns regarding the plate positioning at the upper border and decrease in mandibular body height (Fig. 6b). However, the deformation values between FEM analysis and polymeric model testing are not similar in Table 2 due to: firstly, the difference between the shape and form of the mandibles. Polymeric models are made in a similar shape as human mandible, where the FEM mandibles were simplified for optimal mesh and solving mesh problems during simulation analysis. Secondly, the polymeric mandibles have a similar structure as the human mandible, namely cortical and cancellous bone, where the FEM mandibles are modelled only as one type of bone structure. Thirdly, setups (including boundary conditions) between the tests are not precisely similar. The polymeric mandibles are fixed at the ramus region near the mandibular condyle replicating similar fixation as temporomandibular joint (TMJ) (Fig. 4), where the FEM simulation is fixed at the condylar edges of TMJ (Fig. 3b). Finally, the material properties of polymeric mandibles is twice as less as the human mandible used in FEM analysis; therefore, twice as less strong. However, both studies illustrate that the height decrease results in higher

deformation and lower stability. Therefore, polymeric model testing partly confirms that FEM studies were conducted correctly since the deformation pattern for the decrease in height remains similar between the two studies.

Finally, FEM analysis and polymeric model testing outcomes are similar and comparable with the earlier publications.<sup>4,8-11</sup> The similar deformation pattern between the results from FEM analysis and polymeric model testing, together with the verification with earlier studies, shows that the study was conducted correctly. However, it is difficult to say whether FEM analysis can be used to test all kinds of fracture management without using the more expensive and time-consuming model testing as validation. Therefore, more studies need to be conducted in order to determine whether FEM alone is sufficient enough to optimise surgical fracture management. Furthermore, future investigations are necessary to determine fracture management for lower atrophic mandibular fractures (from 10 mm or less). Especially analysing the effect of fracture reduction (e.g., contact-sets of more than 0.001 mm between fracture surfaces or anatomical symmetrical reposition) and the effect of various osteosynthesis implants (e.g., use of a thicker miniplate or different plate and screw configurations).

## Declarations

## Acknowledgment

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## Author contributions

Omid Daqiq conducted the study design, 3D modelling, finite element method simulation analysis, polymeric model testing, and writing the article. Fred W. Wubs assisted with Comsol simulation analysis and verification. Ruud R.M. Bos and Baucke van Minnen were responsible for the supervision and providing continuous guidance. All authors read and approved the manuscript.

## References

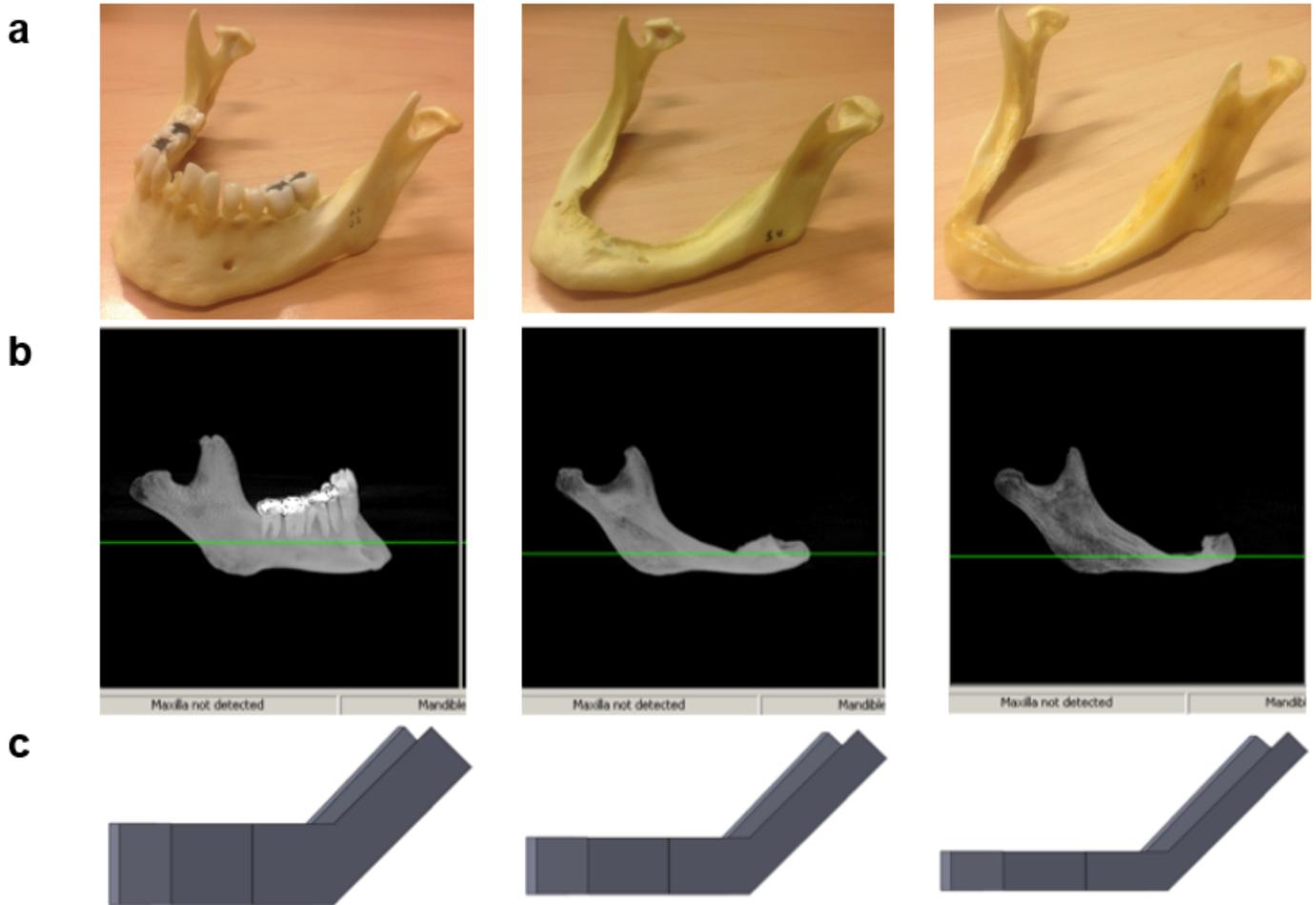
1. Payan, Y. *et al.* Biomechanical models to simulate consequences of maxillofacial surgery. *Comptes Rendus - Biol.* **325**, 407–417 (2002).
2. Wong, R. C. W. *et al.* Review of biomechanical models used in studying the biomechanics of reconstructed mandibles. *Int. J. Oral Maxillofac. Surg.* **40**, 393–400 (2011).
3. Buijs, G. J. *et al.* A randomized clinical trial of biodegradable and titanium fixation systems in maxillofacial surgery. *J. Dent. Res.* **91**, 299–304 (2012).

4. Hart, R. T., Hennebel, V. V., Thongpreda, N., Van Buskirk, W. C. & Anderson, R. C. Modeling the biomechanics of the mandible: A three-dimensional finite element study. *J. Biomech.* **25**, 261–286 (1992).
5. Goh, B. T., Lee, S., Tideman, H. & Stoelinga, P. J. W. Mandibular reconstruction in adults: a review. *Int. J. Oral Maxillofac. Surg.* **37**, 597–605 (2008).
6. Daas, M., Dubois, G., Bonnet, A. S., Lipinski, P. & Rignon-Bret, C. A complete finite element model of a mandibular implant-retained overdenture with two implants: Comparison between rigid and resilient attachment configurations. *Med. Eng. Phys.* **30**, 218–225 (2008).
7. Ammar, H. H., Ngan, P., Crout, R. J., Mucino, V. H. & Mukdadi, O. M. Three-dimensional modeling and finite element analysis in treatment planning for orthodontic tooth movement. *Am. J. Orthod. Dentofac. Orthop.* **139**, e59–e71 (2011).
8. Tams, J., van Loon, J. P., Otten, E., Rozema, F. R. & Bos, R. R. A three-dimensional study of bending and torsion moments for different fracture sites in the mandible: an in vitro study. *Int. J. Oral Maxillofac. Surg.* **26**, 383–388 (1997).
9. Champy, M. & Lodde, J. P. Synthèses mandibulaires. Localization des synthèses en fonction des contraintes mandibulaires [Mandibular synthesis. Placement of the synthesis as a function of mandibular stress]. *Rev. Stomatol. Chir. Maxillofac.* **77**, 971–976 (1976).
10. Kroon, F. H. M., Mathisson, M., Cordey, J. R. & Rahn, B. A. The use of miniplates in mandibular fractures. An in vitro study. *J. Cranio-Maxillofacial Surg.* **19**, 199–204 (1991).
11. Ellis, E. & Price, C. Treatment Protocol for Fractures of the Atrophic Mandible. *J. Oral Maxillofac. Surg.* **66**, 421–435 (2008).
12. Sugiura, T. *et al.* Biomechanical Analysis of Miniplate Osteosynthesis for Fractures of the Atrophic Mandible. *J. Oral Maxillofac. Surg.* **67**, 2397–2403 (2009).
13. Schupp, W., Arzdorf, M., Linke, B. & Gutwald, R. Biomechanical Testing of Different Osteosynthesis Systems for Segmental Resection of the Mandible. *J. Oral Maxillofac. Surg.* **65**, 924–930 (2007).
14. Kumar, S. *et al.* Comparative evaluation of bite forces in patients after treatment of mandibular fractures with miniplate osteosynthesis and internal locking miniplate osteosynthesis. *J. Int. Soc. Prev. Community Dent.* **4**, 26 (2014).
15. Xiao, J. R. *et al.* The biomechanical analysis of simulating implants in function under osteoporotic jawbone by comparing cylindrical, apical tapered, neck tapered, and expandable type implants: A 3-dimensional finite element analysis. *J. Oral Maxillofac. Surg.* **69**, 273–281 (2011).
16. Haug, R. H., Peterson, G. P. & Goltz, M. A biomechanical evaluation of mandibular condyle fracture plating techniques. *J. Oral Maxillofac. Surg.* **60**, 73–80 (2002).
17. Murphy, M. T., Haug, R. H. & Barber, J. E. An in vitro comparison of the mechanical characteristics of three sagittal ramus osteotomy fixation techniques. *J. Oral Maxillofac. Surg.* **55**, 489–494 (1997).
18. Aymach, Z., Nei, H., Kawamura, H. & Bell, W. Biomechanical evaluation of a T-shaped miniplate fixation of a modified sagittal split ramus osteotomy with buccal step, a new technique for

mandibular orthognathic surgery. *Oral Surgery, Oral Med. Oral Pathol. Oral Radiol. Endodontology* **111**, 58–63 (2011).

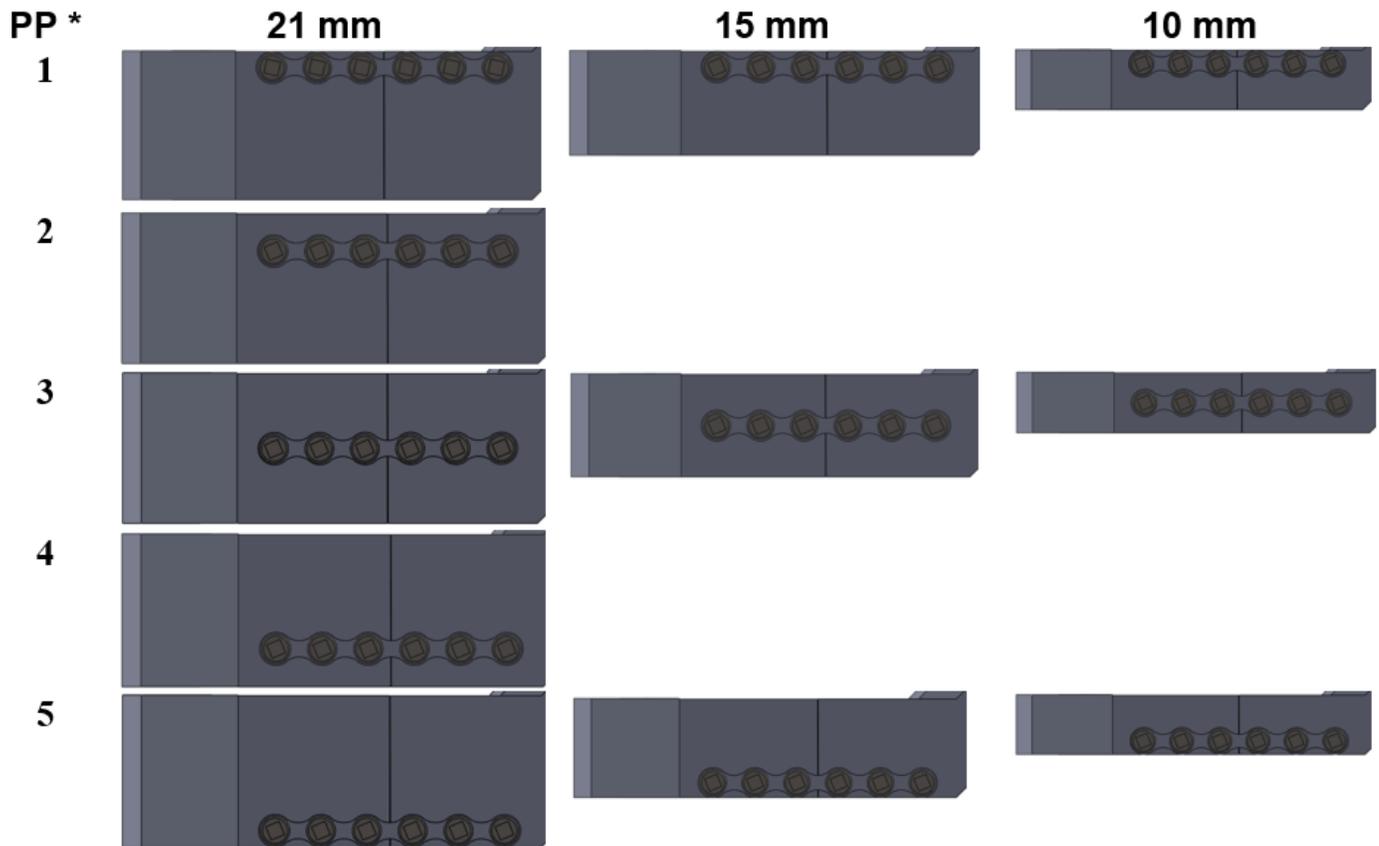
19. Bredbenner, T. L. & Haug, R. H. Substitutes for human cadaveric bone in maxillofacial rigid fixation research. *Oral Surg. Oral Med. Oral Pathol. Oral Radiol. Endod.* **90**, 574–580 (2000).

## Figures



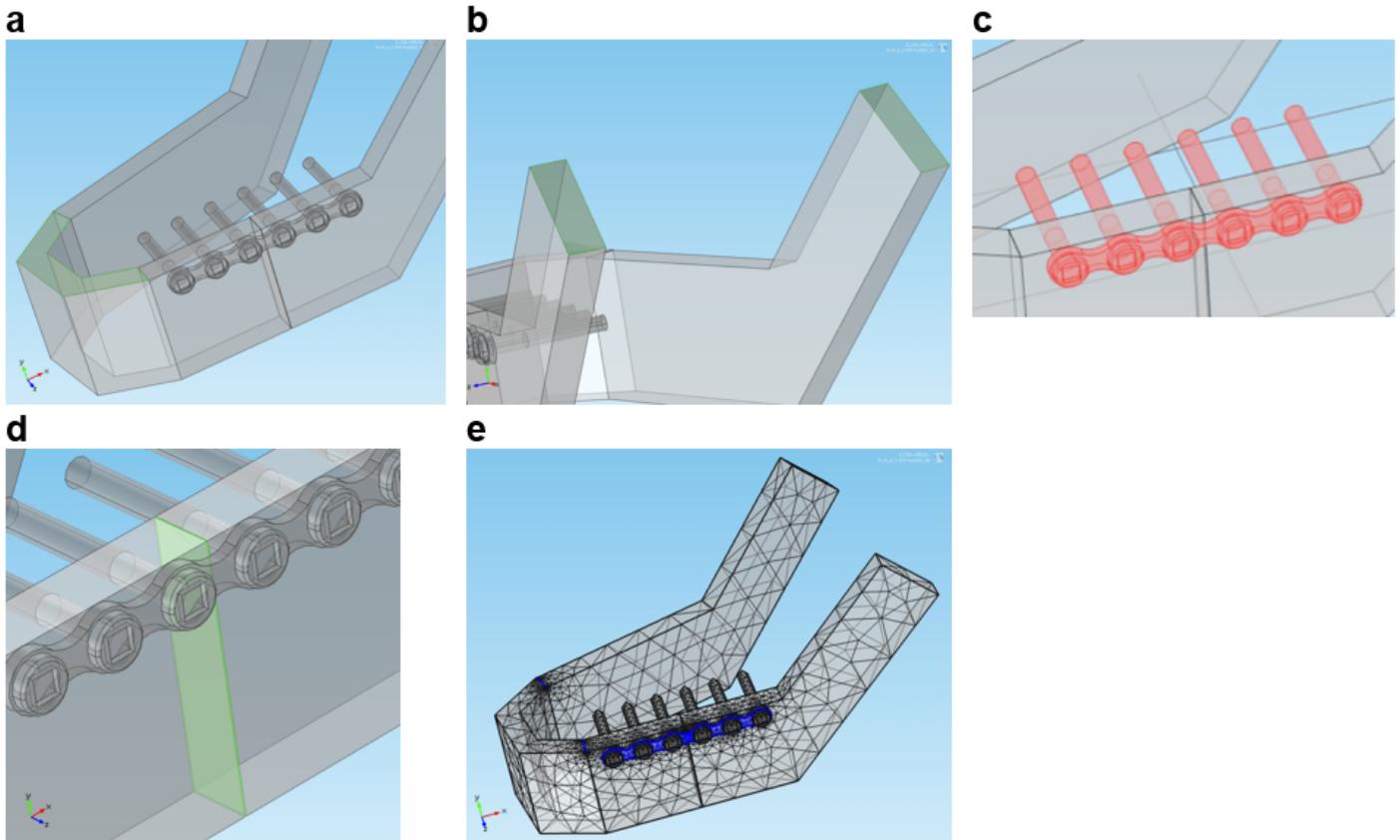
**Figure 1**

Assembly modelling: (a) Three selected mandibles with heights of resp. 21, 15, and 10 mm (left to right). (b) iCAT-Vision program viewing the CT transferred DICOM files. (c) Mandibles designed in Solidworks software with heights of resp. 21, 15, and 10 mm (left to right).



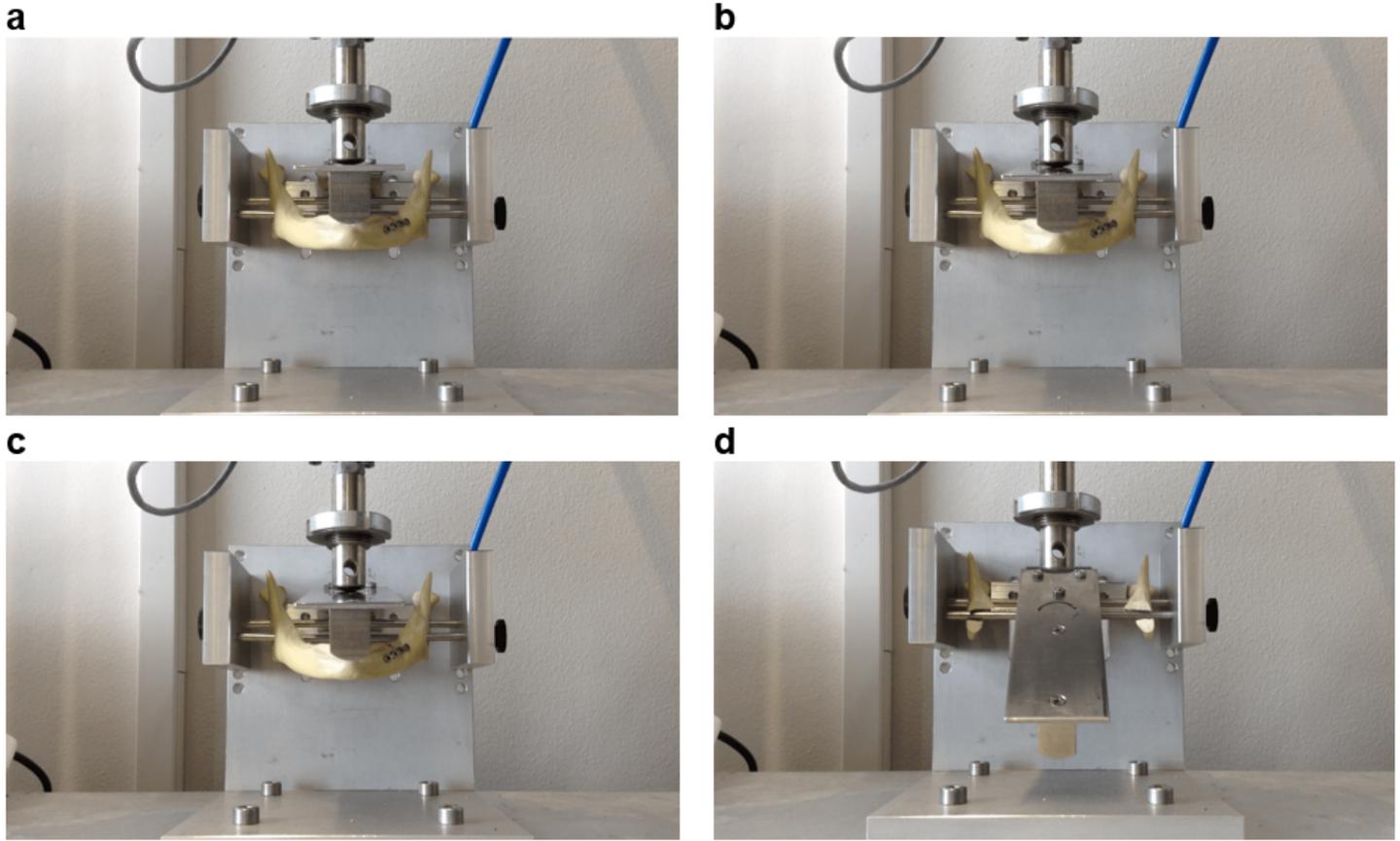
**Figure 2**

\* Osteosynthesis plate positioning (PP) at the unilateral mandibular body fracture for the 21, 15, and 10 mm mandibular body height (left to right). Position: (1) is at the upper border of the mandibular body for 21, 15, and 10 [mm] height mandible, (2) is 2/5 from the upper border downward along the fracture line for 21 [mm] height mandible, (3) is at the middle of the mandibular body for 21, 15 and 10 [mm] height mandible, (4) is 4/5 from the upper border downward along the fracture line for 21 mm height mandible, and (5) is at the lower border of the mandibular body for 21, 15 and 10 [mm] height mandible.



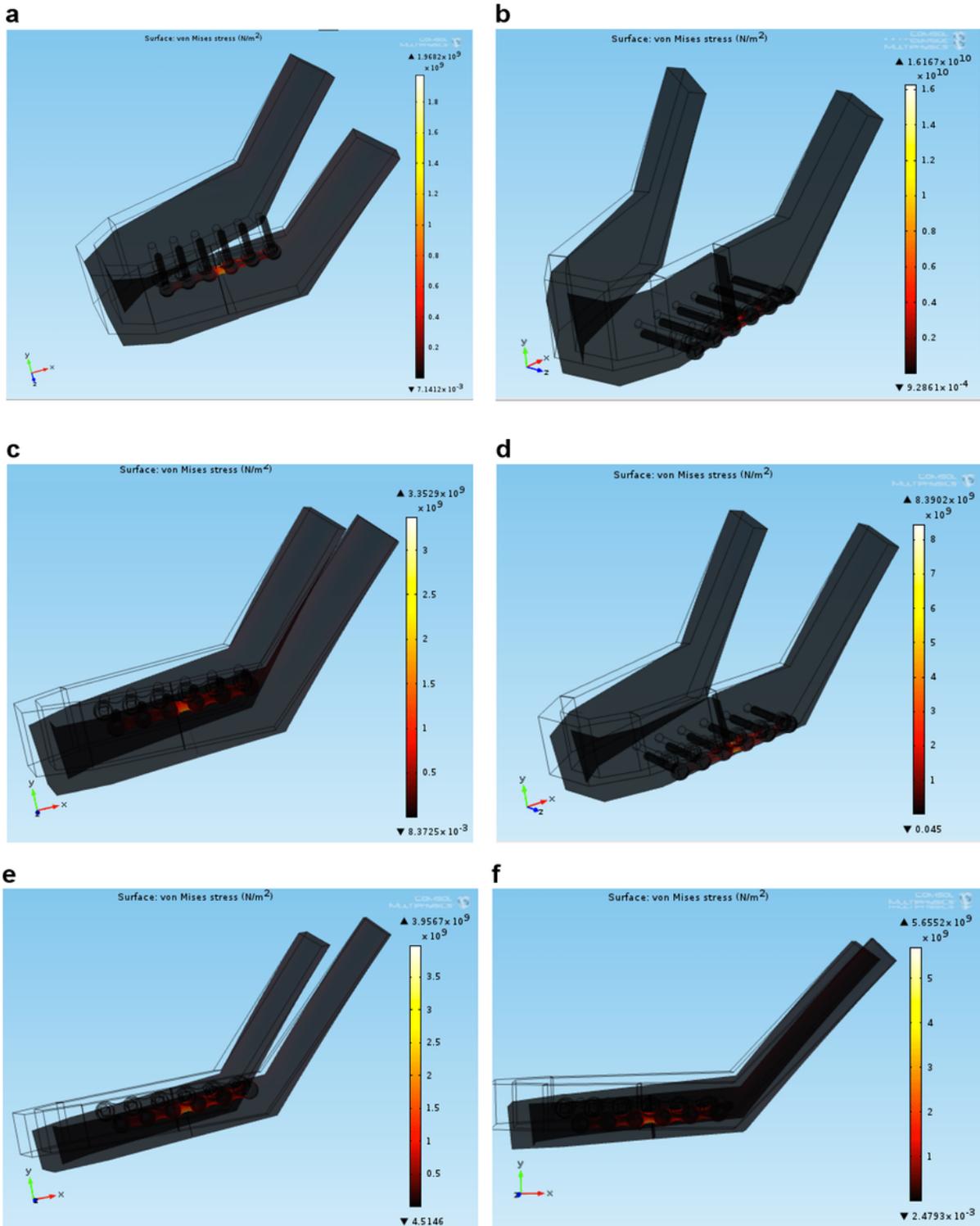
**Figure 3**

FEM Simulation set up: (a) Average maximum mastication force of 300 N applied downward on the anterior of the mandible. (b) Mandibular fixation at the condylar edge of the temporomandibular joint with fixed geometry. (c) Contact-Set between the mandible, plate, and screws. (d) Contact-Set boundaries between the fracture surfaces with a fixed fracture distance of 0.001 mm and no penetration. (e) Mesh elements.



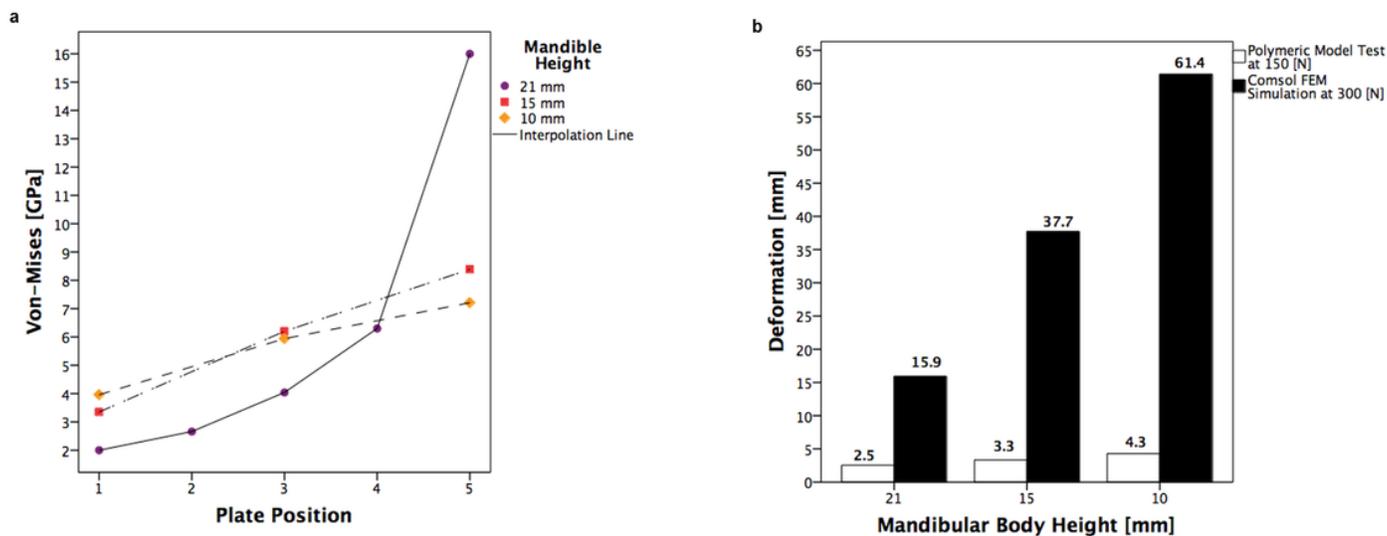
**Figure 4**

Mandible (with straight-line fracture and plate fixation) positioned on the custom made device and loaded in a mechanical test bench. The starting point is (a) until it reaches the breaking point (d).



**Figure 5**

FEM simulation for Von-Mises [GPa]: (a,b) 21 mm height mandible, (c,d) 15 mm height mandible and (e,f) 10 mm height mandible. (a,c,e) plate positioned at the upper border and (b,d,f) plate positioned at the lower border.



**Figure 6**

(a) FEM Von-Mises stress plot in GPa based on outcomes shown from table 1. (b) Deformation comparison between polymeric model testing at 150 N and FEM at 300 N.

## Supplementary Files

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