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Finite Element Analysis of Appropriate Implant Site to Antagonize Bone Resorption in Edentulous Mandible

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Abstract

Objective: To explore the influence of uneven stress distribution due to inaccurate implant sites in clinical that show to drive the jaw resorption. We discussed the effects of static occlusal force loading on the von Mises stress distribution of mandible and obtained the best repairing method for different site design of implant denture in edentulous mandible at combating bone absorption.

Methods: CBCT data of a normal healthy male volunteer was collected. Thirteen sets of finite element models were established using Mimics, Geomagic Studio and Solidworks software. One of the models were used “all on four” design (6-24), and the remaining twelve groups implant placement positions of models were 6-245, 6-246, 6-345, 6-346, 6-356, 7-237, 7-247, 7-257, 7-267, 7-347, 7-357, 7-367. Based on Abaqus FEA simulations, the distribution and size of von Mises stress around the implants in all models and the weak zones of the mandible were analyzed.

Results: In 6-24, 6-245 and 6-246 models, the stress of mentum, mandibular angle and mandibular condyle were (10.78, 8.29, 15.77), (0.30, 0.60, 1.56) and (0.06, 0.07, 0.35) MPa, respectively. In 6-345, 6-346 and 6-347 models, the stress of mentum, mandibular angle and mandibular condyle were (8.75, 6.85, 9.52), (0.51, 0.66, 1.31) and (0.07, 0.23, 0.26) MPa, respectively. For the 7-237, 7-247, 7-257 and 7-267 models, the stress of mentum, mandibular angle and mandibular condyle were (14.25, 10.21, 6.80, 6.23), (4.41, 4.01, 2.46, 17.34) and (0.86, 0.49, 0.49, 1.39) MPa, respectively. For the 7-347, 7-357 and 7-367 models, the stress of mentum, mandibular angle and mandibular condyle were (8.71, 8.91, 9.13), (3.67, 3.34, 3.46) and (0.30, 0.28, 0.53) MPa, respectively.

Conclusions: Different implant sites and repair methods have a remarkable impact on the von Mises stress distribution in the weak areas of the mandible (mentum > mandibular angle > mandibular condyle). In the present study, model 6-346 (46, 44, 43, 33, 34, 36) and 7-357 (47, 45, 43, 33, 35, 37) was considered as the best scheme for implant denture in edentulous mandible.

Keywords: edentulous mandible, implant overdenture, stress distribution, finite element analysis, bone resorption.

Introduction

Implant denture is the preferred prosthetic strategy for patients with tooth loss due to its excellent retention, superior masticatory efficiency, well comfort and aesthetic function. Since the key factors maintaining the stability of implant is osseointegration, compared with the natural tooth lack of periodontal ligament mechanics feedback on regulation of mechanism, but the implant cannot sense the size of occlusal force in the teeth under poor prosthesis design, which are prone to lead to the force overload of implants, the phenomena of tooth occlusal trauma, resulting in a series of clinical complications, such as implant broken, peri-implantitis, bone absorption, etc. Clearly, more aspects on implantation study such as mandibular absorption, peri-implantitis, implants dimensions and accurate three-dimensional position in the jaw should be further investigated.

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The design of implant overdenture for edentulous patients have always been considered as one of the difficulties in fixed prosthesis. The problems of the standard care for edentulous mandible toward the previous complete dentures are frequently reported due to poor stability, strong foreign body sensation, and low chewing efficiency. However, implant-fixed prostheses provide not only a significantly better retention and stability, but also the related improvement in chewing and comfort[1-3]. Currently, biomechanics studies on implant restoration mainly focus on the stress distribution of the implants and peri-implant bone[4] whereas there are few studies on the effect of implant itself resulting in the stress distribution in edentulous mandible. In addition, the bone-implant interface was considered perfect, with 100 % osseointegration and force conduction can reach the whole mandible especially mandibular symphysis, angle, and condyle. The question arises as to whether these abnormal stress distribution result in jaw resorption, peri-implant inflammation, even fracture or temporomandibular joint disease, which may have an important significance on the long-term success of restoration.[5-7]

Commonly, the numbers and sites of implant are considered as the major cause of implant failure [8-9]. The risk of excessive load and fracture of prostheses can be decreased by adequate implants and appropriate position[10,11]. Actually, the ideal implant design is based on the comprehensive evaluation of multiple factors, such as the three-dimensional anatomical architecture of jaw [12], the coordination of muscle function [13], occlusal balance [14], the improvement of facial aesthetic and the mechanical conduction balance of implant-bone tissue interface[15,16]. Therefore, the optimal prosthetic design cannot be obtained only by considering the local stress distribution of implant. Previous studies investigating load response and the stress distribution patterns of edentulous mandible implant denture are still limited. Different methods had been used to investigate the forces on prosthesis and on tissue interfaces. The finite element analysis (FEA) has been largely accepted as a commonly used non-invasive tool to detect the stress distribution and displacement in mechanical system [17-20]. Such as predicting the effects of stress on implants and the surrounding bone or evaluating the long-term success of implants from the result of different aspects (loading modality, prosthetic platform, surface and geometrics of implants, and the characteristics of the surrounding bone). FEA allows an analytical evaluation of the distribution of stress through a mathematical virtual model that includes the aforementioned variables in order to offer directions to the dental practitioners on the most favorable choice [21-23].

The present study aims to evaluate the mandible stress distribution as a consequence of loading on implant-supported fixed dentures that was planned with different implant numbers and locations, then the best repairing method for the fixed restoration of edentulous mandible against bone absorption was obtained using three-dimensional FEA.

Material and methods

3D model generation and their components

3D model creation

Based on the cone beam computed tomography (CBCT) data (including 440 images) of a male patients' skull whose mean horizontal width of alveolar crest at mandibular anterior area is more than 7 mm and the distance between mandibular canal and alveolar crest at mandibular molar area is more than 10 mm. The mandibular bone was then separated as a sole mask through region growing, which the default bony gray value range of 226 ~ 2311 was set to the threshold using the Mimics software program (19.0, Materialise, Leuven, Belgium). A 3D model represented as a triangular mesh (also known as the STL file) was created based on the mandibular bone mask (Fig. 1). Then to reconstruct the denture (respectively, restore to the first molar and second molar) models as the same way and being exported as STL (surface stereolithography) format.

Figure 1: Process of Mimics software program.

3D Retro deformation in Geomagic

The 3D models including mandible and denture were imported to Reverse Engineering software Geomagic Studio (2013, Raindrop, America) and then faired up by the function of "Grid doctor". After that, the curve contour graph, called non-uniform rational basis spline (Nurbs) cartography, should be fitted, which was performed through a series of procedures called "Curvature detected" → "Outline downgraded" → "Patch constructed" → "Grating constructed" → "Kyrtograph fitting". The above acquired cartography models of the femoral shaft were exported to Solidworks 2013 (SolidWorks, America), for further assembly.

In order to obtain models of cancellous bone, the previous mandible should be performed through procedures called "excursion", which removed 2 mm from the surface (Fig. 2) [24,25]. Then to deal with the denture (restore to the first molar and second molar) models as the same way and being exported as STL (surface stereolithography) format. (Fig. 3)

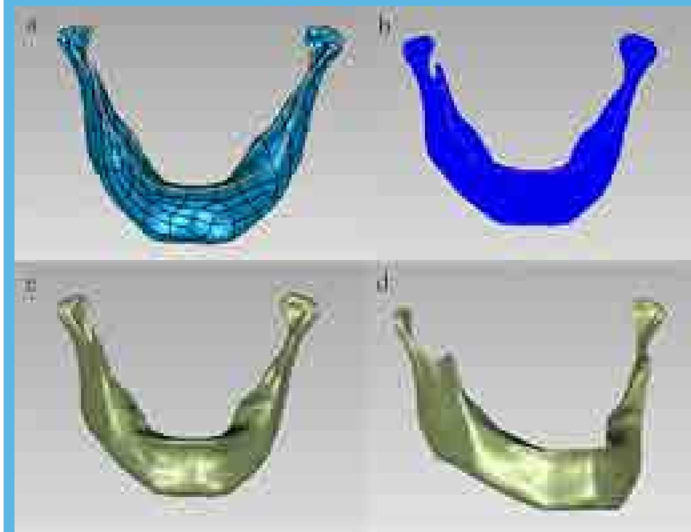

Figure 2: Process of Geomagic Studio. (a) Curvature detected. (b) Grating constructed. (c) Non-uniform rational Basis spline (NURBS) cyrtography. (d) Models of cancellous bone.

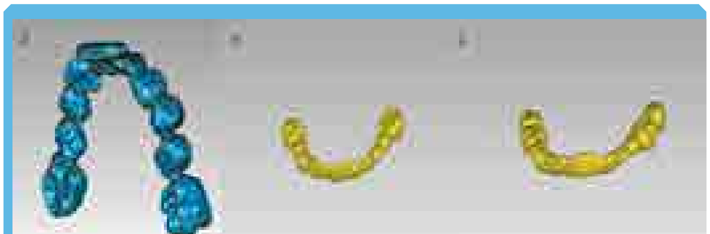

Figure 3: Process of Geomagic Studio.

3D assembly in Solidworks

a) Establishment of implant model

The implants were columnar and the diameter of the implant in the anterior tooth area was 3.75 mm and the length was 10 mm and in the posterior tooth area was 4.25 mm and the length was 10 mm. Thread height 0.3 mm, width 0.3 mm, spacing 0.8 mm. The Solidworks was applied to establish the implant model according to the implant contour data. In this experiment, implant threads and the connection between abutment and implant were neglected.

b) Assembly and grouping of each part model

Implants were assembled to the opposite tooth positions according to different tooth positions (except for the "all on four" design, the distal implant is tilted 30° to the far side). In addition, the remaining groups of implants are parallel to each other. Secondly, the .x_t format of the mandibular bone and cortical bone derived from Geomagic will be assembled in Solidworks, and finally the implant and upper dentition and mandible were assembled. The cancellous bone and cortical bone were assembled, and six sets of models were created (Fig. 4, 5), which was exported in .x_t format to prepare for the next step. The number and location of implants are shown in Table 1.

Table 1: Number and location of implants.

Experimental grouping	**Number of implants**	**Implant position**
	Repair to the first molar	
6-24	4	"All on four"(44 42 32 34)
6-245	6	45 44 42 32 34 35
6-246	6	46 44 42 32 34 36
6-345	6	45 44 43 33 34 35
6-346	6	46 44 43 33 34 36
6-356	6	46 45 43 33 35 36
	Repair to the second molar	
7-237	6	47 43 42 32 33 37
7-247	6	47 44 42 32 34 37
7-257	6	47 45 42 32 35 37
7-267	6	47 46 42 32 36 37
7-347	6	47 44 43 33 34 37
7-357	6	47 45 43 33 35 37
7-367	6	47 46 43 33 36 37

Figure 4: Assembled model.

Figure 5: Assembled model.

Construction of three-dimensional FE model

The cancellous bone, cortical bone, denture, and implants were imported to Abaqus 16.4 (Simulia, America). Mechanical properties of the materials were simulated from the literature [26-28], and were listed in Table 2.

Table 2: Mechanical properties of the materials used in modeling.

Material	Young's Modulus (MPa)*	Poisson's Ration
Titanium alloy (implant and abutment)	117,000	0.33
Fixed bridge	89,500	0.33
Cortical bone	13,700	0.3
Cancellous bone	4,900	0.3

The mandibular condyles were fixed in all degrees of freedom and there are several muscles areas which are masseter muscle medial pterygoid muscle, lateral pterygoid muscle, anterior temporal muscle and posterior temporal muscle on the mandible were fixed (Fig. 6) [29]. Loading was applied vertically and applied on the teeth symmetrically to simulate bite force and was listed in Table 3. The implant- bone interface was considered to be static. As shown in Fig. 7 and Table 4, while putting six implants into the mandible, the nodes range from 700000 to 1000000, while putting seven implants into the mandible, the nodes range from 300000 to 500000.

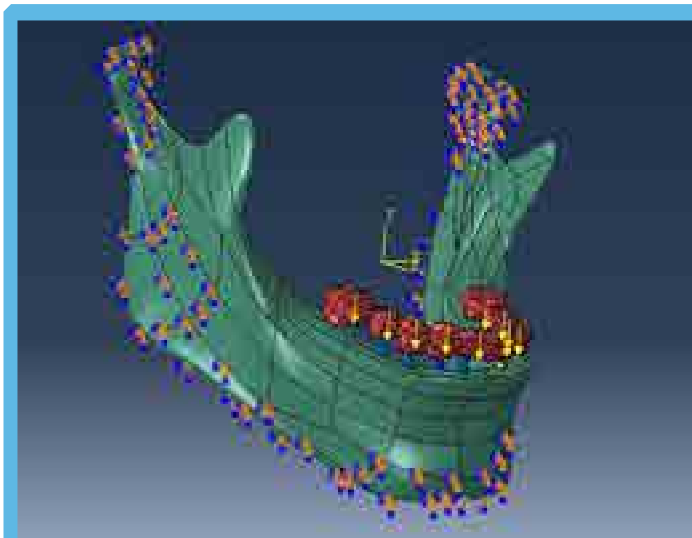

Figure 6: Boundary constraints

Table 3: Loading conditions for the numerical analysis.

	Incisor region	canine region	Premolar region	first molar region	second molar region
force{N)	60	100	150	200	200

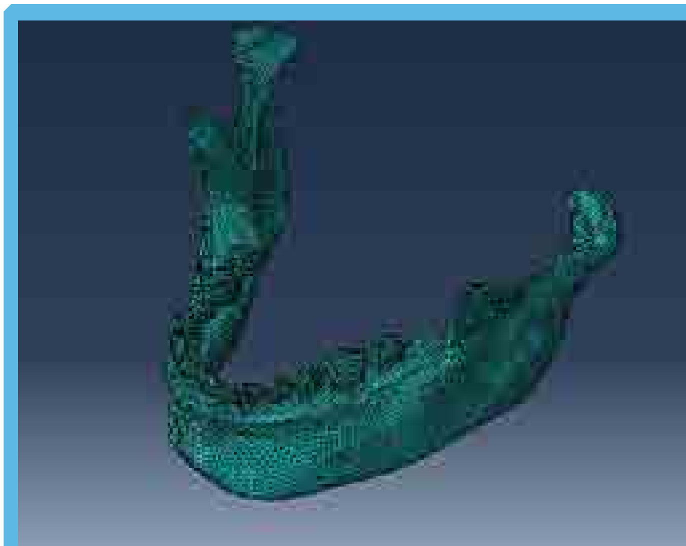

Figure 7 Boundary constraints

Result

As presented in Table 5, the von Mises stress values and distribution among mentum, mandibular angle and mandibular condyle in edentulous mandible.

Repairing to the first molar

In 6-24, 6-245 and 6-246 models, the stress of mentum was 10.78, 8.29 and 15.77 MPa; the stress of mandibular angle was 0.30, 0.60 and 1.56 MPa; the stress of mandibular condyle was 0.06, 0.07 and 0.35 MPa. In 6-345, 6-346 and 6-347 models, the stress of mentum was 8.75, 6.85 and 9.52 MPa; the stress of mandibular angle was 0.51, 0.66 and 1.31 MPa; the stress of mandibular condyle was 0.072, 0.23 and 0.26 MPa (Fig. 8, 9, 10).

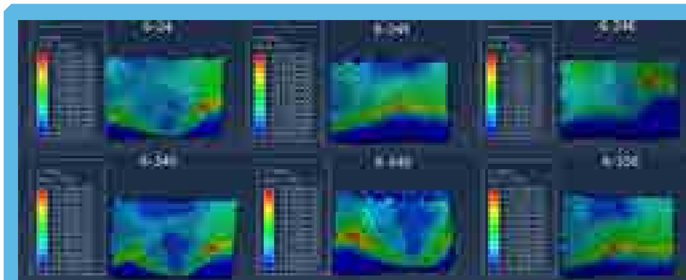

Figure 8: Distribution of von Mises stress in the mentum, while repairing to the first molar.

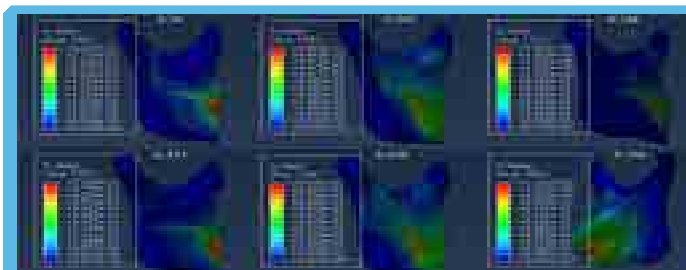

Figure 9: Distribution of von Mises stress in the mandibular angle while repairing to the first molar.

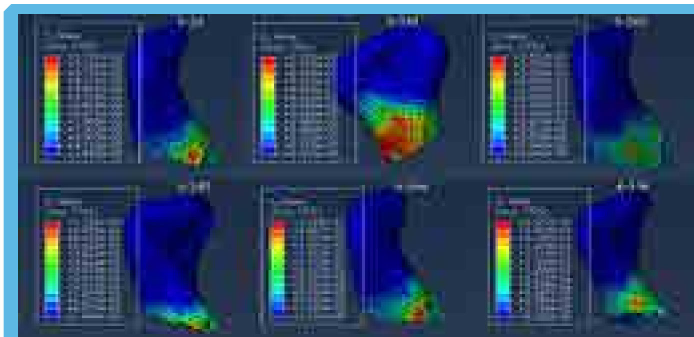

Figure 10: Distribution of von Mises stress in the mandibular condyle, while repairing to the first molar.

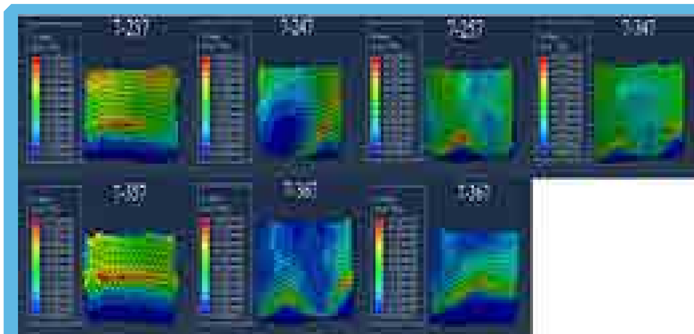

Figure 11: Distribution of von Mises stress in the mentum, while repairing to the second molar.

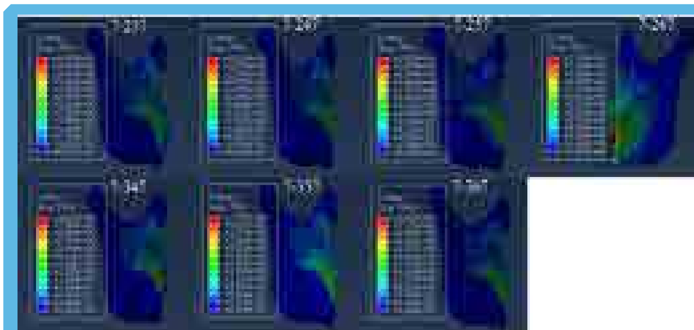

Figure 12: Distribution of von Mises stress in the mandibular angle, while repairing to the second molar.

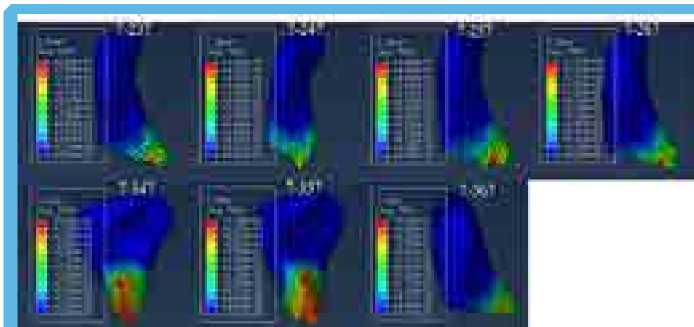

Figure 13: Distribution of von Mises stress in the mandibular condyle, while repairing to the second molar.

Table 4: Each models' elements and nodes.

Model	elements	nodes
6-24	4408767	717609
6-245	5221549	852087
6-246	5699369	1024089
6-345	4680265	772634
6-346	4482462	743269
6-356	4400068	736663
7-237	2240838	427289
7-247	2159521	410381
7-257	2086508	374853
7-267	1955642	358466
7-347	3101235	577255
7-357	2301845	457418
7-367	2950217	522084

Table 5: The Von Mises stress value and distribution of the mandible.

Models	Mentum	Mandibular angle	Mandibular condyle
6-24	10.78	0.3009	0.057
6-245	8.29	0.5966	0.07391
6-246	15.77	1.558	0.3532
6-345	8.748	0.5134	0.07238
6-346	6.849	0.6647	0.2255
6-356	9.516	1.311	0.2579
7-237	14.25	4.406	0.8628
7-247	10.21	4.012	0.4884
7-257	6.803	2.455	0.4865
7-267	6.233	17.34	1.39
7-347	8.714	3.672	0.3042
7-357	8.913	3.335	0.2788
7-367	9.127	3.461	0.5265

While repairing to the first molar, no matter the anterior implant was placed in the lateral incisor or canine, as the posterior implant gets closer to the far center, the stress in the mandibular angle becomes higher, the stress in the mentum is various from each group but in the mandibular condyle is not. The anterior implant was placed in the lateral incisor and the first premolar areas, the stress value in the mentum: 6-245<6-24<6-246; the stress value in the mandibular angle: 6-24<6-245<6-246. while distal implant was placed in the second premolar area, the stress in the mentum decreased; whereas distal implant was placed in the first molar area, the stress in the mentum increased. Besides, for the mandibular angle, the stress in 6-246 was much higher than 6-245. Therefore, when the anterior implants are placed in the lateral incisor and the first premolar areas, it is suggested that the posterior implant should be implanted in the second premolar (Fig. 14). The anterior implant was placed in the canine zone, the stress in the mentum: 6-346<6-345<6-356, which shown that the more uniform the implant site was in the mandible, the lower stress value of the mentum can obtain the better stress conduction. The stress value of mandibular angle increased with the distance of implant, but the difference was smaller than that of mentum. Consequently, when the current implant is implanted in the canine area, the posterior implant is recommended to be selected in the first premolar and the first molar (Fig. 14).

The stress values of the mandibular angle and the mandibular condyle were not significantly different when the anterior implant was placed in the lateral incisor or canine area, but the stress values of the mentum were generally lower when the anterior implant was placed in the canine area than in the lateral incisor area. Maybe because the dental arch of the three-dimensional model established was oval and the canine area located at the turning point of the dental arch, so the stress value transferred to the mentum becomes smaller, which is more conducive to the conduction and dispersion of the force. Therefore, when repairing to the first molar, it is recommended to select the anterior implant in the canine area.

Repairing to the second molar

In 7-237, 7-247, 7-257 and 7-267 models, the stress of mentum was 14.25, 10.21, 6.80 and 6.23 MPa. The stress of mandibular angle was 4.41, 4.01, 2.46 and 17.34 MPa. The stress of mandibular condyle was 0.86, 0.49, 0.49 and 1.39 MPa. In 7-347, 7-357 and 7-367 models, the stress of mentum was 8.71, 8.91 and 9.13 MPa, the stress of mandibular angle was 3.67, 3.34 and 3.46 MPa, the stress of mandibular condyle was 0.30, 0.28 and 0.53 MPa (Fig. 11,12, 13).

Figure 15 shown that in 7-237, 7-247, 7-257 and 7-267 models, the von Mises stress on the mentum decreased successively, but the reduction trend of the mandible angle was not obvious. Since the second molar are close to the mandibular ascending ramus and the attachment of masticatory muscles, so the lever action with the second molar as the fulcrum will be formed here. Under the same loading condition, as the position of the intermediate implant gets closer to the far center, the lever arm decreases, and the von Mises stress on the mentum decreases accordingly. While in model 7-267, the von Mises stress of the mandibular angle was significantly greater than that of the remaining three groups, indicating that the lever effect was markedly affected by different implant sites, and the maximum von Mises stress was exerted on the mandibular angle when the implant was located at the lateral incisor. In the models 7-347, 7-357 and 7-367, the von Mises stress values of the mentum and the mandibular angle were not significantly different, indicating that the leverage effect formed by bilateral implants at the canine area was much less significant than that at the lateral incisor area. Consequently, different implantation sites and repair methods under the same loading condition had an impact on the stress size and distribution of the weak areas of mandible.

Currently, the von Mises stress on the mandible angle at the second molar was greater than that at the first molar (Fig. 14, 15), showing that different restoration methods have a greater influence on the von Mises stress at the mandible angle. When the second molar is repaired, the stress at the mandible angle increases. Fig. 10 and 13 show that the von Mises stress on the mandibular condyle of the first molars and the second molars is small, with an average value of 0.41 MPa, regardless of the repair method. However, the stress values of mandibular condyle in models 7-267, 6-246 and 6-356 were increased compared with other groups, suggesting that the stress values transmitted to the

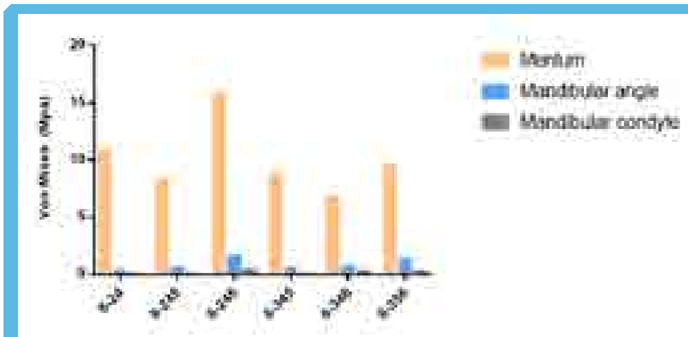

Figure 14: The von Mises stress value and distribution of the mandible, while repairing to the first molar.

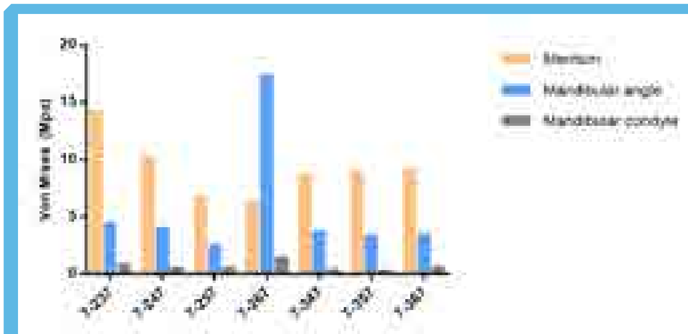

Figure 15: The von Mises stress value and distribution of the mandible, while repairing to the second molar.

mandibular condyle were increased when the implant location was closer to the distal middle and mandibular angle.

Discussion

The present study was designed to explore the influence of uneven stress distribution due to inaccurate implant sites in clinical that show to drive the bone resorption. Based on FE modeling, we obtained the best repairing method for different designs of implant denture in edentulous mandible at combating bone absorption.

The long-term success of implant denture is related to the stress distribution of the surrounding bone tissues. Bone resorption appears to be a biomechanical adaptation or overload related.[30] It was generally acknowledged that the stress concentrates in the mentum, mandibular angle and mandibular condyle, because they have relatively brittle cortical bones with narrow cross-sectional areas and hence are considered "weak" regions of the mandible [30-32]. Restoration using an implant supported overdenture is the easiest and currently accepted treatment modality to increase prosthetic stabilization and patient satisfaction in edentulous patients. The insertion of implants to the weaken mandibular bone decreases the strength of the bone and may lead to fractures either during or after implant placement [7,33]. For example, implantation when the bone loss of the mandible is severe, it is very easy to cause the occurrence of mandibular fractures [34-36]. It is worth noting that the degree of bone loss of the mandible caused by different etiologies is not the same: bone loss after tooth extraction mainly occurs within the first 6 months after tooth extraction, and the width and height of the alveolar ridge can be lost up to 50% and the buccal bone plate absorbs more, resulting in lateral displacement of the alveolar ridge tongue/palate, and more horizontal bone loss than vertical. In the end, the changes in the contour of the missing tooth sites increase the difficulty of implant restoration [37-39]. Additionally, tooth loss is mainly caused by periodontal disease, because the long-term inflammatory response eventually leads to the detachment of the periodontal ligament from cementum, the formation of periodontal pockets, alveolar bone resorption, gum recession, and tooth movement [40]. The loss of teeth makes the alveolar bone lack of physiological stimulation, which further leads to bone resorption [41]. However, bone resorption is irreversible regardless of the reason, and it has a great impact on the stability of the implant. One major concern with this study is whether the values of stress generated by loading will damage the weak area of the mandibular (jaw fracture). Actually, the surface layer of the mandible is cortical bone, and the inside is cancellous bone. Although the mandible is dense, the blood supply is poor, so it is difficult to heal better when severely injured. Some scholars have shown that the longitudinal ultimate shear stress of cortical bone is 67 MPa, while its ultimate tensile stress is 135 MPa, and its ultimate compressive stress is 205 MPa [42,43]. By contrast, the stress value reported in our study is much smaller than the above limit value. Under normal bite force loading, the maximum von mises stress of the weak area of the mandible was less than 20 MPa, indicating that the probability of fracture in the weak area of the mandible under normal bite force was extremely low.

Accurate implant sites and different designs of implant denture in the models considered in the present study are utmost priority in clinical practice, however, FEA has its own limitations when it comes to solving problems in biomechanics. The anatomical structure of the mandible is unique, but usually endowed with constant properties in FEA. Herein, only static loading was adopted, and we neglected the complex mechanical behaviors in the process of mandible movement. For this reason, further implant-animal models should be established in the future to verify the theoretical results in terms of histopathological conditions and mechanical properties of implant interface.

Conclusion

Considering the study design, it can be concluded that different implant sites and repair methods have a great impact on the von Mises stress distribution in the weak area of edentulous mandible (mentum > mandibular angle > mandible condyle). In the clinical setting, in order to reduce the stress value of mandible when the quality of bone tissue is poor, the prosthesis should be repaired to the first molar with the implant located in the anterior and premolar regions as far as possible. Model 6-346 (46, 44, 43, 33, 34, 36) was considered as the best scheme for implant denture. To improve chewing efficiency, the prosthesis needs to be repaired to the second molar, in order to make the von Mises stress as evenly distributed as possible, it is better to make the implant evenly distributed in the mandible. Model 7-357 (47, 45, 43, 33, 35, 37) is considered as the best plan for implant denture.

Conflicts of interest

The authors declare that no conflict of interest exists.

Acknowledgement

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Authors' contributions

BPZ conceived the design. KLZ and BPZ supervised the study. JWX, JS and QXL performed all the simulation experiments. JWX, JS, QXL and ZBZ analyzed the data. JWX, QXL and YCL wrote the manuscript. BPZ and KLZ reviewed the manuscript. All authors reviewed and approved the manuscript.

Availability of data and materials

The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

Ethics approval and consent to participate

None.

References:

1. Sánchez-Siles M, Ballester-Ferrandis JF, Salazar-Sánchez N, Gómez-García FJ, Moraleja-Ruiz R, Camacho-Alonso F. Long-term evaluation of quality of life and satisfaction between implant bar overdentures and conventional complete dentures: A 23 years retrospective study. *Clin Implant Dent Relat Res* 2018;20:208-14.
2. Kanazawa M, Tanoue M, Miyayasu A, Takeshita S, Sato D, Asami M, Lam TV, Thu KM, Oda K, Komagamine Y, Minakuchi S, Feine J. The patient general satisfaction of mandibular single-implant overdentures and conventional complete dentures: Study protocol for a randomized crossover trial. *Medicine (Baltimore)* 2018;97:10721.
3. Torsiglieri T, Raith S, Rau A, Deppe H, Hölzle F, Steiner T. Stability of edentulous, atrophic mandibles after insertion of different dental implants. A biomechanical study. *J Craniomaxillofac Surg* 2015;43:616-23.
4. Marcián P, Wolff J, Horáčková L, Kaiser J, Zikmund T, Borák L. Micro finite element analysis of dental implants under different loading conditions. *Comput Biol Med* 2018;96:157-65.
5. Antic S, Vukicevic AM, Milasinovic M, Saveljic I, Jovicic G, Filipovic N, Rakocevic Z, Djuric M. Impact of the lower third molar presence and position on the fragility of mandibular angle and condyle: A Three-dimensional finite element study. *J Craniomaxillofac Surg* 2015;43:870-8.
6. Gallas Torreira M, Fernandez JR. A three-dimensional computer model of the human mandible in two simulated standard trauma situations. *J Craniomaxillofac Surg* 2004;32:303-7.
7. Ayali A, Bilginaylar K. Evaluating the biomechanical effects of implant diameter in case of facial trauma to an edentulous

atrophic mandible: a 3D finite element analysis. *Head Face Med* 2017;13:5.

8. Dimililer G, Kücükkurt S, Cetiner S. Biomechanical effects of implant number and diameter on stress distributions in maxillary implant-supported overdentures. *J Prosthet Dent* 2018;119:244-9.
9. Kan B, Coskunses FM, Mutlu I, Ugur L, Meral DG. Effects of inter-implant distance and implant length on the response to frontal traumatic force of two anterior implants in an atrophic mandible: three-dimensional finite element analysis. I*nt J Oral Maxillofac Surg* 2015;44:908-13.
10. Song X, Li L, Gou H, Xu Y. Impact of implant location on the prevalence of peri-implantitis: A systematic review and meta-analysis. *J Dent* 2020;103:103490.
11. French D, Grandin HM, Ofec R. Retrospective cohort study of 4,591 dental implants: Analysis of risk indicators for bone loss and prevalence of peri-implant mucositis and peri-implantitis. *J Periodontol* 2019;90:691-700.
12. Li Y, Sun C, Jia H, Luo XJ. Analysis of the effect of mesial implant position on surrounding bone stress of mandibular edentulous jaw under dynamic loads. *Zhonghua Kou Qiang Yi Xue Za Zhi* 2017;52:672-7.
13. Ferrario VF, Tartaglia GM, Maglione M, Simion M, Sforza C. Neuromuscular coordination of masticatory muscles in subjects with two types of implant-supported prostheses. *Clin Oral Implants Res* 2004;15:219-25.
14. Flanagan D. Bite force and dental implant treatment: a short review. *Med Devices (Auckl)* 2017;27:141-8.
15. Buser D, Sennerby L, De Bruyn H. Modern implant dentistry based on osseointegration: 50 years of progress, current trends and open questions. *Periodontol 2000* 2017;73:7-21.
16. Kern JS, Kern T, Wolfart S, Heussen N. A systematic review and meta-analysis of removable and fixed implant-supported prostheses in edentulous jaws: post-loading implant loss. *Clin Oral Implants Res* 2016;27:174-95.
17. Berger JB, Wadley HN, McMeeking RM. Mechanical metamaterials at the theoretical limit of isotropic elastic stiffness. *Nature* 2017;543:533-7.
18. Arregui-Mena, José David, Worth, Robert Numa, Hall, Graham, Edmondson, Philip D, Giorla, Alain B, & Burchell, Timothy D. A Review of Finite Element Method Models for Nuclear Graphite Applications. *Arch Computat Methods Eng* 2018;27:331-50.
19. Kilinç Y, Erkmen E, Kurt A. Biomechanical Evaluation of Different Fixation Methods for Mandibular Anterior Segmental Osteotomy Using Finite Element Analysis, Part One: Superior Repositioning Surgery. *J Craniofac Surg* 2016;27:32-5.
20. Li Q, Ren S, Ge C, Sun H, Lu H, Duan Y, Rong Q. Effect of jaw opening on the stress pattern in a nor,mal human articular disc: finite element analysis based on MRI images. *Head Face Med* 2014;19:24.
21. Lauritano F, Runci M, Cervino G, Fiorillo L, Bramanti E, Cicciù. Three-dimensional evaluation of different prosthesis retention systems using finite element analysis and the Von Mises stress test. *Minerva Stomatol* 2016;65:353-67.
22. Cicciù M, Cervino G, Bramanti E, Lauritano F, Lo Gudice G, Scappaticci L, Rapparini A, Guglielmino E, Risitano G. FEM Analysis of Mandibular Prosthetic Overdenture Supported by Dental Implants: Evaluation of Different Retention Methods. *Comput Math Methods Med* 2015; 2015:943839.
23. Kanjanaouthai A, Mahatumarat K, Techalertpaisarn P, Versluis A. Effect of the inclination of a maxillary central incisor on periodontal stress: finite element analysis. *Angle Orthod* 2012;82:812-19.
24. Dorogoy A, Rittel D, Shemtov-Yona K, Korabi R. Modeling dental implant insertion. *J Mech Behav Biomed Mater* 2017;68:42-50.
25. Lee H, Park S, Noh G. Biomechanical analysis of 4 types of short dental implants in a resorbed mandible. *J Prosthet Dent* 2019;121:659-70.
26. Huang HL, Chang CH, Hsu JT, Fallgatter AM, Ko CC. Comparison of implant body designs and threaded designs of dental implants: a 3-dimensional finite element analysis. *Int J Oral Maxillofac Implants* 2007;22:551-62.
27. Yang HS, Lang LA, Molina A, Felton DA. The effects of dowel design and load direction on dowel-and-core restorations. *J Prosthet Dent* 2001;85:558-67.
28. Walker M P. Dental Materials and Their Selection. *J Prosthodont* 2003;12:152-3.
29. Peixoto HE, Camati PR, Faot F, Sotto-Maior BS, Martinez EF, Peruzzo DC. Rehabilitation of the atrophic mandible with short implants in different positions: A finite elements study. *Mater Sci Eng C Mater Biol Appl* 2017;1:122-8.
30. Lopez CAV, Vasco MAA, Ruales E, Bedoya KA, Benfatti CM, Bezzon OL, Deliberador TM. Three-Dimensional Finite Element Analysis of Stress Distribution in Zirconia and Titanium Dental Implants. *J Oral Implantol* 2018;44:409-15.
31. Santos LS, Rossi AC, Freire AR, Matoso RI, Caria PH, Prado FB. Finite-element analysis of 3 situations of trauma in the human edentulous mandible. *J Oral Maxillofac Surg* 2015;73:683-91.
32. Patussi C, Sassi LM, Cruz R, Klein Parise G, Costa D, Rebellato NLB. Evaluation of different stable internal fixation in unfavorable mandible fractures under finite element analysis. *Oral Maxillofac Surg* 2019;23:317-24.
33. Raghoebar GM, Stellingsma K, Batenburg RH, Vissink A. Etiology and management of mandibular fractures associated with endosteal implants in the atrophic mandible. *Oral Surg Oral Med Oral Pathol Oral Radiol Endod* 2000;89:553–9.
34. Almasri M, El-Hakim M. Fracture of the anterior segment of the atrophic mandible related to dental implants. *Int J Oral Maxillofac Surg* 2012;41:646–9.

35. Meijer HJA, Raghoebar GM, Visser A. Mandibular Fracture Caused by Peri-Implant Bone Loss: Report of a Case. *J Periodontol* 2003;74:1067–70.

36. Oh W, Roumanas ED, Beumer J. Mandibular fracture in conjunction with bicortical penetration, using wide-diameter endosseous dental implants. *J Prosthodont* 2010;19:625–9.

37. Sbordone C, Toti P, Martuscelli R, Guidetti F, Ramaglia L, Sbordone L. Retrospective volume analysis of bone remodeling after tooth extraction with and without deproteinized bovine bone mineral insertion. *Clin Oral Implants Res* 2016;27:1152-9.

38. Tan WL, Wong TL, Wong MC, Lang NP. A systematic review of post-extractional alveolar hard and soft tissue dimensional changes in humans. *Clin Oral Implants Res* 2012;23:1-21.

39. Xiang SJ, Pan J. Recent research advances on alveolar ridge preservation after tooth extraction. *Hua Xi Kou Qiang Yi Xue Za Zhi* 2019;37:97-101.

40. Guiglia R, Di Fede O, Lo Russo L, Sprini D, Rini GB, Campisi G. Osteoporosis, jawbones and periodontal disease. *Med Oral Patol Oral Cir Bucal* 2013;18:93-9.

41. François Bodic, Luc Hamel, Emmanuelle Lerouxel, Michel Félix Baslé, Daniel Chappard. Bone loss and teeth. *Joint Bone Spine* 2005;72:215-21.

42. van Eijden TM. Biomechanics of the mandible. *Crit Rev Oral Biol Med* 2000;11:123-36.

43. Reilly DT, Burstein AH. The elastic and ultimate properties of compact bone tissue. *J Biomech* 1975;8:393-405.

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