Effect of design parameters of custom abutment on its mechanical property based on orthogonal experiment method

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Abstract—In this paper, the custom abutment with various gingival morphology was designed by CAD software. The finite element analysis (FEA) and orthogonal experiments design L\textsubscript{25}(5\textsuperscript{6}) were performed to investigate the influence of main design parameters of custom abutment on biomechanical property of implant system, including gingival height (GH), abutment angle (A), lingual height (LH), buccal height (BH), mesial height (MH) and distal height (DH). Results indicated that GH and A are the most important factors affecting the biomechanical performance of implant system, and LH, BH, MH and DH have less effect than others. The influence of custom abutment design parameters on biomechanical performance of implant system can be analyzed explicitly by the orthogonal experiment method, which offers a new method for estimating the mechanical characteristics of custom abutment.

1. INTRODUCTION

In recent years, dental implants have become the preferred restoration option for more and more patients with missing teeth [1,2]. The abutment, as an important repair part connecting the implant and the superstructure, is crucial to the function and aesthetic effect of the implant denture.

However, due to the difference in gingival height and gingival marginal morphology, common abutment restoration cannot achieve the ideal function and aesthetic morphological form. Custom-made abutments facilitate contouring of the perimplant soft tissue in order to develop optimal emergence profile [3,4]. With this technique, composite resin or autopolymerizing acrylic resin is applied externally on an interim prefabricated metal abutment in an attempt to support soft tissue and simulate the contours of the definitive restoration. The placement of conventional abutment teeth results in results in the inconsistency between the soft tissue contour and the final prosthesis contour [5,6].

Custom abutment is becoming the best choice for most patients for maximizing the balance of functional and aesthetic needs. Because the custom abutment is designed according to the patient's oral condition, its design parameter combinations are various, such as abutment angle, gingival height and so on. The design parameters will significantly affect the stress distribution of the implant system.
Excessive stress concentration will affect the fatigue life of the implant system under cyclic loading brought by oral activity.

To date, only a few studies have been focused on the custom abutment design and the effect of abutment design parameters on its biomechanical property. Therefore, the purpose of this study is to design a custom abutment with esthetic emergence profile. By using the 3D FEA method and orthogonal experiments design, the effect of customized abutments design parameters in terms of static mechanical performance was evaluated.

2. Material and Method

2.1 The custom abutment design

The design of the custom abutment is based on the natural gingival morphology. The anatomical morphology of the missing tooth area usually is usually saddle-shaped. In this study, the gingival surface of the custom abutment is determined by controlling four spatial points of hyperbolic paraboloid, namely lingual, buccal, mesial and distal point. The CAD model of custom abutment with irregular gingival profile was obtained using solidworks software, and its main parameters included gingival height (GH), abutment angle (A), lingual height (LH), buccal height (BH), mesial height (MH) and distal height (DH). The main dimensions of the custom abutment are presented in Figure 1.

![Fig. 1 CAD models of custom abutment and their main parameters and size.](image)

2.2 Orthogonal experiment design

In order to further study the influence of different parameters on the biomechanical property of implant system, the finite element analysis (FEA) was performed to calculate its 3D stress distribution in the implant system. However, considering the large number of custom abutment models formed under different parameter combinations, Orthogonal experiments design L25 (5^6) was adopted in this research, which contains six major factors (GH, α, LH, BH, MH and DH). Five levels were set under each experimental factor and a total of 25 experiments are required. Orthogonal experiment design L25 (5^6) is shown in Table 1.

| Levels | A (°) | GH (mm) | LH (mm) | MH (mm) | DH (mm) | BH (mm) |
|--------|------|---------|---------|---------|---------|---------|
| 1      | 5    | 2       | 1.7     | 2.1     | 2.1     | 1.7     |
| 2      | 15   | 3       | 2.4     | 3.2     | 3.2     | 2.4     |
| 3      | 25   | 4       | 3.1     | 4.3     | 4.3     | 3.1     |
| 4      | 35   | 5       | 3.8     | 5.4     | 5.4     | 3.8     |
| 5      | 40   | 6       | 4.5     | 6.0     | 6.0     | 4.5     |

The 25 representative 3D models of custom abutment were created using computer-aided design software following dimensions observed in Table 1. Each 3D model represented an experimental combination as listed in table 1. A CAD model of a simplified maxillary bone block with a 1-mm layer of cortical bone was created. A conical implant was adjusted to all custom abutments, and they were simplified to a single unit. The implant is spatially embedded into the alveolus bone by using Boolean
operations. The custom abutments was assembled on the implant and secured with a central screw. The assembled solid models were then imported into ANSYS Workbench to generate the FEA models (Fig. 2).

Fig. 2 Computer-aided design model of custom abutment (direction of occlusal force indicated by red arrow).

The surface of the bone segment opposite the alveolus was treated as a fixed boundary. To simulate the delayed loading of osseointegrated implants, a bonded condition was set at all the implant-bone interfaces. All materials used in the simulation were considered isotropic, homogeneous, and linearly elastic. Uniform finite element meshes were generated by using tetrahedral elements with a mesh size of 0.5 mm. The models presented a number of elements that ranged from 69869 to 207133 and a number of nodes that ranged from 118352 to 318986. The mechanical properties used for the simulation are shown in Table 2.

| Component       | Material          | Young’s modulus (GPa) | Poisson’s ratio (ν) |
|-----------------|-------------------|-----------------------|---------------------|
| Implant         | TA4 [8]           | 105                   | 0.33                |
| Abutment, screw | Ti-6A1-4V ELI [8] | 110                   | 0.32                |
| Maxillary bone  | Cortical bone [9,10] | 14.0                  | 0.3                 |
|                 | Cancellous bone [9,10] | 3                     | 0.3                 |

The static analysis of implant system was conducted to ensure the safety of the gingival profile designs of the custom abutments. The stress distribution, maximum von Mises stress were visualized and quantified under an occlusal force of 250N, which was normally applied to the custom abutment at an angle of 45 ° to the occlusal plane [11]. In particular, the calculated maximum von Mises stress of the implant system is used as the evaluation index of this orthogonal experiment.

3. RESULTS
Using the orthogonal experimental design method and the testing parameters listed in Table 3, 25 sets of experiment were performed, with calculated maximum von Mises stress value of the implant system for each experiment. Experiment results are shown in Table 3.

| NO  | Experimental factor | Max stress (MPa) |
|-----|---------------------|------------------|
|     | A GH LH MH DH BH    |                  |
| 1   | 1(5°) 1(2mm) 1(1.7mm) 1(2.1mm) 1(2.1mm) 1(1.7mm) | 258.21           |
| 2   | 1 2(3mm) 2(2.4mm) 2(3.2mm) 2(3.2mm) 2(2.4mm) | 254.03           |
| 3   | 1 3(4mm) 3(3.1mm) 3(4.3mm) 3(4.3mm) 3(3.1mm) | 269.24           |
| 4   | 1 4(5mm) 4(3.8mm) 4(5.4mm) 4(5.4mm) 4(3.8mm) | 277.91           |
| 5   | 1 5(6mm) 5(4.5mm) 5(6.0mm) 5(6.0mm) 5(4.5mm) | 273.12           |
| 6   | 2(15°) 1 2 3 4 5 | 370.78           |
Further, a range analysis was performed on the experiment results, and the results are presented in Table 4.

**TABLE IV. INTUITIVE ANALYSIS OF EXPERIMENTAL RESULTS**

| Index | A  | GH | LH | MH | DH | BH |
|-------|----|----|----|----|----|----|
| K1    | 1332.52 | 1972.36 | 2251.39 | 2272.01 | 2279.41 | 2321.64 |
| K2    | 1857.90 | 2068.47 | 2364.64 | 2174.61 | 2245.58 | 2222.96 |
| K3    | 2254.01 | 2295.77 | 2242.90 | 2272.64 | 2218.65 | 2121.95 |
| K4    | 2755.67 | 2320.96 | 2144.57 | 2162.70 | 2285.17 | 2231.86 |
| K5    | 2938.13 | 2430.67 | 2135.13 | 2256.27 | 2109.42 | 2239.82 |

**R** = for the intended factor (A, GH, LH, MH, DH or BH), sum of the maximum stress values for level i = 1, 2, 3, 4, 5; 

| A  | GH | LH | MH | DH | BH |
|----|----|----|----|----|----|
| 321.13 | 91.66 | 45.9 | 22.0 | 35.11 | 39.34 |

From the intuitive analysis, it is seen that, without considering the interaction between various factors, the degree of effects of the factors on the static performance of custom abutment is as follows: abutment angle (A) > gingival height (GH) > lingual height (LH) > buccal height (BH) > distal height (DH) > mesial height (MH).

Figure 3 shows the von Mises stress (MPa) of implant system for No. 1 and No. 25 Experimental Group. A larger maximum stress values was observed in No. 25 group, which was much greater than No. 1 group. The peak stress concentration of custom abutment was located in the abutment collar in contact with implant.
4. DISCUSSION

The custom-made CAD/CAM custom abutment has been widely used because of their good accuracy fit and esthetic emergence profile [12]. Few studies on CAD/CAM custom abutments have been done in the literature especially on the design parameters and static mechanical property of this designed method. The present study explored a novel method to design a custom abutment with an esthetic anatomical emergence profile. Through 3D FEA and orthogonal experimental design, the effects of design parameters on its mechanical performance were evaluated.

The gingiva is continuous scallops in a natural and healthy state. In order to be close to the natural shape of the gingiva, the gingival profile of custom abutment is not a regular shape, but it needs to match the anatomical morphology of the gingiva to achieve soft tissue closure around the implant, which is the most important feature different from the common abutment. Some literatures have shown that the b-spline curve formed by four coordinate points on the missing gingival contour can be used to determine the gingival curved surface, so that the abutment has an anatomical contour [13].

In present study, by controlling the four boundary coordinate points of the hyperbolic paraboloid, the gingival curved surface with an anatomical morphology was obtained and can be parameterized. The main design parameters of the gingival curved surface are GH, A, LH, BH, MH and DH (see Fig.1). However, considering the large number of custom abutment models formed under different parameter combinations, orthogonal experiments design was employed to reduce the required experiment times.

Orthogonal experimental design is extensively used in experimental research of various subjects, which involve multivariate and multilevel factors. Based on orthogonality, representative samples of test points were selected from comprehensive test variables. These representative test points were generally uniformly dispersed and neatly comparable. This statistical analysis technique has been demonstrated to be a highly efficient, fast, and economical experimental design method in evaluating effects of various factors on structure performance [14], and other scientific researches [15,16]. In this method, representative levels of factors having stronger influences to a property to be studied were selected based on Normalized Orthogonal Table. By understanding the importance of the various factors, the major advantage of the method was to reduce the number of tests required but still provide the best level of combination of factors. Thus, the orthogonal experimental design L25 (5^6) was used in this research to study the influences of various geometric parameters on static mechanical performance of custom abutment.

The orthogonal experiment result demonstrate that the calculated maximum von Mises stress of the implant system under different gingival profile is different, because the design parameters of the custom abutment have a certain influence on biomechanical performance of the implant system. Further intuitive analysis of experimental results showed that A and GH were the most important factors affecting the biomechanical performance of the implant system. The influence of the LH, BH, DH and MH were not as prominent as the other factors evaluated. The stress cloud diagram of custom abutment showed that stress concentration occurs at the abutment collar in contact with implant, which corresponds with the clinical finding of maxillary crestal bone loss.
It might provide the clues to design a custom abutment and interpret the mechanical effect of its clinical use. However, the whole system is still in experimental set-up phase at present, so the evaluation of its reliability and accuracy was preliminary. In the future, laboratory quantitative tests and clinic experiments will be carried out in order to improve and practice the system.

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5. INCLUSION
In this paper, the Finite element analysis (FEA) and orthogonal design method were performed on the custom abutment with different geometric parameters to evaluate the effects of six parameters on the static biomechanical performance of the implant system. The maximum von Mises stress was used as an indication of the biomechanical performance. The experiment results suggest that the ranking of the effect of the six factors were: abutment angle > gingival height > lingual height > buccal height > distal height > mesial height. Custom abutment with smaller abutment angle exhibited better biomechanical performance than that with larger abutment angle. Gingival height was the second most important in affecting biomechanical performance of implant system. As the gingival height increased the maximum von Mises stress value of the implant system decreased. The influence of the lingual height, buccal height, distal height and mesial height were not as prominent as the other factors evaluated.

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REFERENCES
[1] Abou-Obaid AI, Al-Otaibi HN, Akeel RF. Effect of singl off-axis implant placement on abutment screw stability under lateral loading. Int J Oral Maxillofac Implants, 2016, 31:520-6.
[2] Fuster-Torres MA, Albalat-Estela S, Alcañiz-Rayas M, Peñarrocha-Diago M. CAD/CAM dental systems in implant dentistry: update. Med Oral Patol Oral Cir Bucal, 2009, 3:e141-5.
[3] Kerstein RB, Castellucci F, Osorio J. Ideal gingival form with computergenerated permanent healing abutments. Compend Contin Educ Dent, 2000, 21:793-7
[4] Cobb GW, Reeves GW, Duncan JD. Guided tissue healing for single-tooth implants. Compend Contin Educ Dent, 1999, 20:571-8.
[5] Neale D, Chee WW. Development of implant soft tissue emergence profile: a technique. J Prosthet Dent, 1994, 71:364-8.
[6] Lewis S. Anterior single-tooth implant restorations. Int J Periodontics Restorative Dent, 1995, 15:31-41.
[7] Tepper G. Three-dimensional finite element analysis of implant stability in the atrophic posterior maxilla A mathematical study of the sinus floor. Clinical oral implants research, 1999, 13(6):657-665.
[8] Brosh T, Pilo R, Sudai D. The influence of abutment angulation on strains and stresses along the implant/bone interface: comparison between two experimental techniques. J Prosthet Dent, 1998, 79:328–34.
[9] Da, S.N.J.P., Jardim, P.M., Neves Flávio Domingues das, Xediek, C.R.L., Dos, S.M.B.F. Stress analysis of different configurations of 3 implants to support a fixed prosthesis in an edentulous jaw. Braz Oral Res, 2014, 28:67-73.
[10] Dong, W., Kebin, T., Jiang, C., Hua, J., Wenxiu, H., Yuyu, L. A further finite element stress analysis of angled abutments for an implant placed in the anterior maxilla. Computational and Mathematical Methods in Medicine, 2015, 1-9.

[11] Chen J, Zhang Z, Chen X, et al. Design and manufacture of customized dental implants by using reverse engineering and selective laser melting technology. J Prostheth Dent, 2014,112: 1088–1095.

[12] Marchack, C.B. A custom titanium abutment for the anterior single-tooth implant. The Journal of Prosthetic Dentistry, 1996, 76:288–291.

[13] Ting Wu, Wenhe Liao, Ning Dai, et al. Design of a custom angled abutment for dental implants using computer-aided design and nonlinear finite element analysis. Journal of Biomechanics, 2010, 43:1941-1946.

[14] Gao X, Zhang Y, Zhang H, et al. Effects of Machine Tool Configuration on Its Dynamics Based on Orthogonal Experiment Method. Chinese Journal of Aeronautics, 2012, 02:147-153.

[15] Su L, Zhang J, Wang C, et al. Identifying main factors of capacity fading in lithium ion cells using orthogonal design of experiments. Applied Energy, 2016,163:201-210.

[16] Zhou Y, Feng P, Hu H, et al. Pre-design and Analysis of Flow Field of Spacer-Free Nozzle of Aluminum Roll-Casting. Lecture Notes in Electrical Engineering, 2011, 87.