Original Article

Three-dimensional finite element analysis for best angles of dog canine teeth implantation

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Abstract

Dental implantation is a tendency treatment for teeth lesions in small animal medicine. Canine teeth damage is the most common clinical injury for small animals. The aim of this study is to investigate appropriate angles for clinical canine teeth implantation. In this study, we built a simple mandibular model according to the measured oral indexes of five beagle dogs. Three-dimensional finite element analysis for the comparisons of different canine dental implant angles (30 °-80 °) in a local bone block model were performed. The maximum equivalent elastic strain and the maximum equivalent stress for different planting angles were next compared. As for the results, the peak equivalent stress of the implant ranges was from 132.11 to 277.81 MPa between 30 °- 80 °, with the peak equivalent strain from 774.96 to 1676.50 bone strain, under the average bite force (256 N). 66 ° is the best angle for dog canine dental implantation, with a 132.11 MPa of peak equivalent stress and 744.96 peak bone strain under 256 N bite force. The acceptable angle range of oblique implantation of dog canines can be 47 °- 80 ° (200-1000 bone strains). However, for a maximum bite force (1394 N), any implantation may contribute pathological changes for alveolar bone (greater than 3000 bone strain). Our study provides a reference for appropriate clinical canine teeth implantation.

Keywords: alveolar bone, canine teeth, dental implantation, dog, mandibular model

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Introduction

Dental implantation is a tendency choice in the treatment of tooth loss. The implanted teeth may restore aesthetic as well as chew function most similar to the original teeth (Yuan and Sukotjo, 2013). Currently, dogs are usually used to observe the changes in the microcirculation of the molars after implant anchorage and tooth movement as an experimental animal model for human medicine. Thus, there have been many studies on the implantation of premolars and molars. However, there have been few studies on dental implants for canine teeth, which were used for capture and defense, that are important for daily grasping, and chewing activities. In fact, canine tooth damage is the most common clinical injury in small animal medicine (Soukup *et al*., 2015).

Compared with premolars and molars, the roots of dog canine teeth are not perpendicular to the maxilla and mandible (Tsugawa *et al*., 2003)(Figure 1). In theory, poor load orientation around the neck of a non-vertically placed implant results in greater bone resorption than that of the vertically placed implant; Tilted implants may also be curved, which may increase marginal bone stress (Chrcanovic *et al*., 2015). Therefore, there is indeed a difference in the effect of stress dispersion between vertical and inclined planting.

Figure 1 Canine and molar teeth in the dog mandible bone

The finite element method (FEM) is a kind of digital calculation method, which can be used to simulate the mechanical process by computer-aided design (Sapna *et al*., 2017). The application of FEM in the quantitative study of life science has achieved great success, especially in human biomechanical studies (Lu *et al*., 2019). The premise of FEM is to establish the finite element model; the accuracy of the model directly affects the accuracy of the analysis results, with high geometric similarity to the original object. At present, mainstream researchers usually use a local bone block model with Computer Aided Design (CAD) technology instead of a complete screening jaw model to reduce the problems of data loss or error caused by edge extraction, as well as to reduce the computational complexity and workload (Merema *et al*., 2021; Villefort *et al*., 2021). In this study, we used FEM analyzing different dental implant angles in a local bone block model as a reference for appropriate clinical canine tooth implantation.

Materials and Methods

Analysis hardware and software: A personal computer (Intel ®i5-5200U CPU @ 2.20GHz with 4.00 GB memory for Windows 10 operating system) was used for mandibular and implant modeling and three-dimensional finite element analysis as hardware. The mandible and implants were modeled by a 3D mechanical design drawing function using universally recognized CAD software, SolidWorks 19.0 (Dassault Systemes S.A, France). Three-dimensional finite element analysis of the model was performed by a computer aided engineering (CAE) software, Ansys Workbench 2020 R2 (SASIP, Inc., USA), that usually analyzes object structure in the engineering area.

Measurement of basic mandibular data of beagle dogs: Five adult (three years old) male beagle dogs were anesthetized by intravenous injection of 10 mg/kg Zoletil® 50 (VIRBAC, France). X-ray of canine teeth and mandible bone were taken with a dental digital radiography (DR, Model 30-A2195, Midmark Corporation, USA). The alveolar fossa diameter, alveolar depth, thickness of cancellous bone of mandible and the angle between the canine root and alveolar fossa plane were measured by PROGENY® IMAGING software (Midmark Corporation, USA). The animal use protocol had been reviewed and approved by the Sichuan Agricultural University Animal Ethical and Welfare Committee (Approval No. 20210215).

Establishment of mandibular bone model: The mandible model was divided into two parts (cortical bone and cancellous bone) for model building respectively (Himmlova *et al*., 2004). First, the cross-section sketch of the bone block was created on SolidWorks. Then "stretch" command was used for cross section. The mechanical Elastic Modulus parameters of cortical bone and cancellous bone were set to 13,700 MPa and 1,370 MPa respectively, with Poisson's ratio 0.30, according to dog anatomy (Zhou *et al*., 2018). In this model, mandible was simplified as a bone block with length 19.8 mm, width 5.0 mm, height 11.1 mm. The height of the dense bone was set as 0.5 mm, according to the previous measurement of beagle dog mandibular data.

Establishment model of implant: Using SolidWorks software, we designed an outer diameter of 3.5 mm, inner diameter of 2.7 mm, length of 7.3 mm cylindrical implant, which concerning as a clinic implant (NingBo Juxing Peteeth Medical Smart Technology Co., Ltd, China). The implant modeling method was modified from a previous study (Himmlova *et al*., 2004). First, the two-dimensional profile of the implant was drawn by using the two-dimensional "Draw" function of SolidWorks. The cylindrical implant matrix model was generated after rotation. Second, the thread with 0.4 mm pitch was drawn on the implant matrix model by using the "Helix/Spiral" function. Material mechanical Elastic Modulus parameters were set to 15,200 MPa with Poisson's ratio 0.31 for the implants according to a Ti-6Al-4V force experiment (Suresh *et al*., 2021). Finally, the "Render" function was applied to build a three-dimensional solid model with a similar visual effect as the physical implant model.

Implant and mandibular bone block assembly: The implant fossa was made using the "the Boolean subtraction operation" function in SolidWorks. The mandible with implant fossa and the implant were assembled using "Assemble" function. "Automatic meshing" function was then used to divide the cell mesh from the model. In the model, the implants and mandibles were assumed to be continuous, homogeneous, and isotropic linear elastic materials and the interface contact of the implants was set as fixed contact (without relative displacement). The succussed model in SolidWorks was then imported into AnsysWorkbench 2020 R2. The occlusal force under vertical loading was set as the average canine bite force 256 N and max force 1394 N (Brassard *et al*., 2021) with direction from perpendicular to the mandible.

Results

Measurement of basic mandibular data of beagle dogs: According to the DR measurement, the depth of alveolar fossa in beagle dogs was 19.8±0.46 mm. The diameter of alveolar fossa of canine tooth was 7.75±0.42 mm. The angle between canine root and alveolar fossa plane was 50.23±3.84 °. The thickness of the dense bone of the mandible was 0.50±0.04 mm. The measured values were next applied to build model.

Equivalent strain and stress of implants at different angles for bite force: Since the average angle between root and alveolar fossa plane was 50.23 °, the implant angle was set between 30 °- 80 °. When a canine average bite force (256 N) applied to the implant in the vertical direction, the peak equivalent stress of the implant ranges from 132.11 to 1164.6 MPa between 30 °- 80 °. The implant angle of the maximum and minimum equivalent stress was 30 ° and 66 °, respectively. The peak equivalent strain of the implant ranges between 30 °- 80 ° was from 744.96 to 7697.30 bone strain. The implant angle of maximum and minimum equivalent stress strain was 30 ° and 66 °, respectively (Figure 2).

When a max 1394 N bite force applied to the implant in the vertical direction, the peak equivalent stress of the implant ranges from 719.37 to 6341.5 MPa between 30 °- 80 °. The implant angles of the maximum and minimum equivalent stress were as same as general bite force experiment (30 ° and 66 ° respectively). The peak equivalent strain of the implant ranges was from 4056.5 to 41914 bone strain (Figure 2).

Discussion

Shapes and solid of mandible bone is related to factors including craniofacial morphology, dental status, malocclusion, TMJ dysfunction, age, and sex (Kim *et al*., 2018). For hundreds of dog breeds, mandible bone and dental implantation may become various. Although the mandible is a complex and irregular geometry, according to a comparative study of Meijier (Meijer *et al*., 2010), there is little difference between the analysis results of the three-dimensional model of the partial mandible or whole mandible. Therefore, part of the mandible model in our study was performed instead of whole bone for stress analysis of implant and mandible, which is widely used (Balshi *et al*., 1996; Carvalho *et al*., 2004). In this experiment, a simple three-dimensional model of healthy adult (three-year-old) male beagle mandible bone and the implant were established as a primary reference.

At present, most of the FEM of implants mainly focuses on the stress at the interface between implants and jaws (Bektas and Yalcin, 2021; Choi *et al*., 2021; Demirbas *et al*., 2021; Huang *et al*., 2022). Stress may lead to jaw bone resorption, resulting in implant failure

(Kim *et al*., 2011). From the force distribution along the vertical direction, the main force on the mandible is around the implant fossa, which is similar as the conclusion that “the maximum principal stress area is distributed in the bone tissue in contact with the implant neck” by Robau-Porrua (Robau-Porrua *et al*., 2020). In our study, the mandible around the implant fossa, the stress and strain are mainly concentrated in the cortical bone of the upper part of the implant, which is the same as the conclusion drawn from the review of Kim (Kim *et al*., 2011).

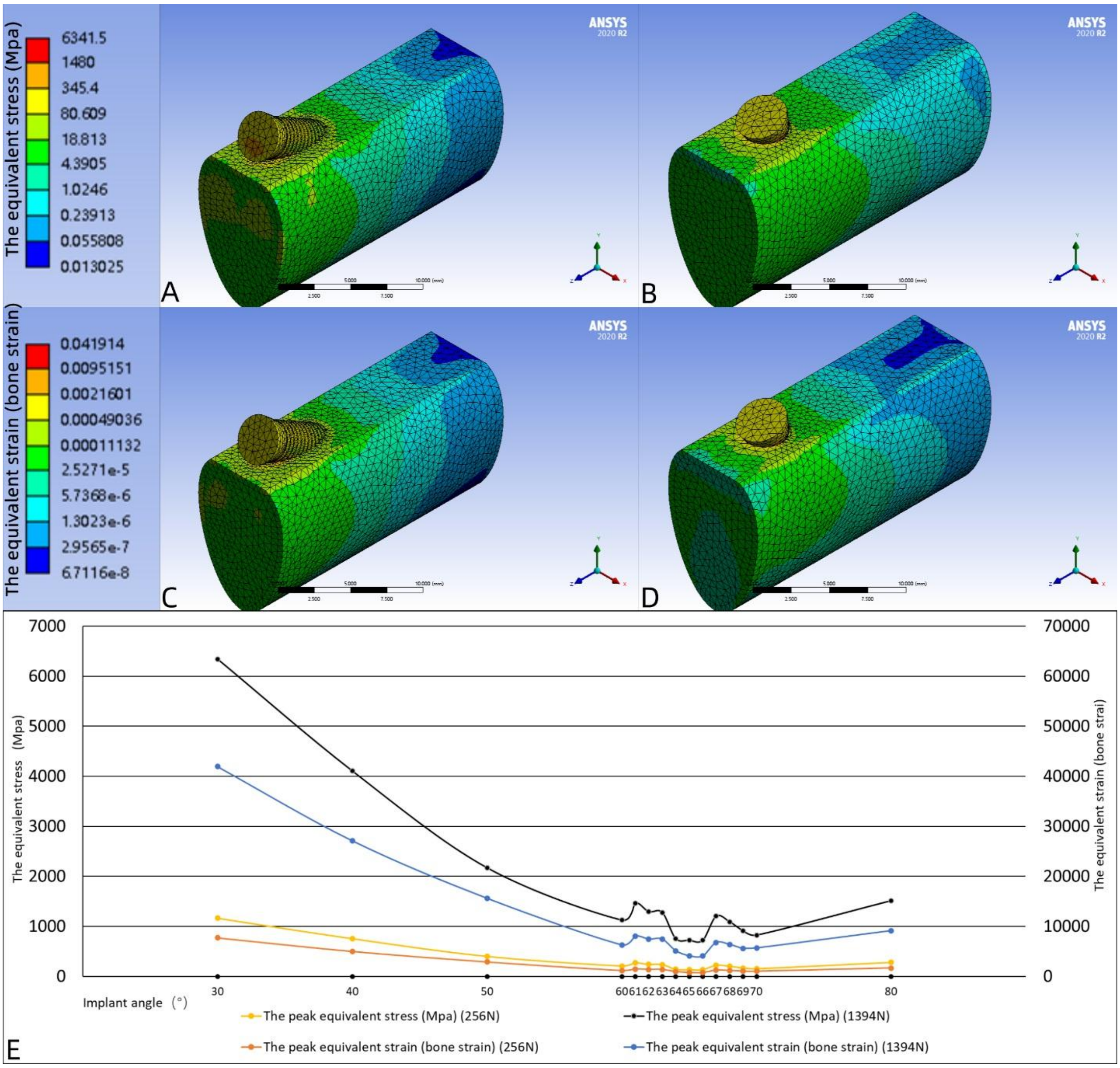

Figure 2 Cloud maps of three-dimensional finite element analysis for different angles of dog canine teeth implantation. Cloud maps of equivalent stress and equivalent strain of 30 ° implantation model (A, C) illustrated more pressure and deformation than 66 ° (B, D), respectively, under the canine maximum bite force (1396 N) vertically. (E) Line chart of the peak value of equivalent stress and equivalent strain when the implant angle is between 30 ° and 80 ° under the canine maximum bite force (1396 N) and the average bite force (256 N), respectively.

According to “mechanical steady-state theory” (Frost and biology, 2003; Frost, 2004), the morphology and material properties of bones are in a state of dynamic equilibrium. When a bone tissue produced less 200 strains, the bone tissue will be in a state of disuse; 200-1000 bone strains are the adaptive range for a bone tissue, which is the best for implantation; Lamellar bone will be formed in the moderate overload range at 1000-3000 bone strains; When bone strains reached 3000, the bone tissue will have pathological changes (such as resorption and dissolution). Therefore, in the analysis of different implant angles, bite equivalent stress is not only considering factors but also equivalent strain causing by the force for cancellous and cortical bone of the mandible.

In our study, when a general force (256 N) was applied to the implant in the vertical direction, the equivalent strain of 64 °- 66 ° implant angle was between 200-1000 bone strains, which is best for canine teeth implantation. However, it is well known from clinical experience, that not always possible to make implants into an ideal position. The equivalent strain of the implant at 47 °- 80 ° implant angle was less than 3000 bone strains, which is acceptable. However, for a maximum bite force (1394 N), any angle of implantation may contribute greater than 3000 bone strain. Although the largest bite may lead to bone resorption, it only occurs in some large dogs in extreme cases, such as violent hunting and bite. In this case, the native canine teeth may also suffer fracture or other damages. For another reason, the maximum bite force usually lasts for a short time, which may have little effect on the implant-mandibular osseointegration.

To sum up, the angle range of canine teeth oblique implantation of dog implant can be 47 °- 80 °, while the best angle range is 64 ° -66 ° theoretically.

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