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貴財団より助成金を受領して行った研究テーマについて報告いたします。

添付資料： 研究報告書

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1．助成金額： 780,000 円

2．研究テーマ

機能性生体用チタン合金の開発と歯科臨床への実用化

3．成果の概要（100字程度）

チタン合金リンガルバーによる床下粘膜へのストレスを有限要素力学解析により明らかにした．粘膜中のストレスを制御するためには，チタン合金リンガルバーの断面形態に十分な配慮をするべきである．

4．研究組織

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Ti-6Al-7Nb および Co-Cr によるリンガルバーの形態が粘膜の応力集中に及ぼす影響

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Abstract

Three-dimensional finite element models of nine lingual bars with different dimensions (thickness: 1.5, 2.0, or 2.5 mm; height: 4, 5, or 6 mm) with underlying mucosa were produced for a Kennedy Class II case. These models were used to study the effects of cross-section dimension in lingual bars on deflections of Ti-6Al-7Nb and Co-Cr removable partial denture frameworks. The stress distributions in the structures and underlying mucosa were also investigated. Each framework included occlusal rests on the first premolars of both arch sides. The bottom surface of the mucosa and rest on the edentulous side were fixed in a vertical direction. The rest on the tooth-supported side was fixed in all directions. The elastic moduli of 200 and 123 GPa were input into the program to simulate the Co-Cr and Ti-6Al-7Nb alloys, respectively. A 30 ° buccally oblique biting force of 20 Newtons was directed towards each of the three missing teeth locations. Ti-6Al-7Nb frameworks exhibited approximately 1.2 times the maximum stress in the mucosa than in Co-Cr frameworks with the same cross-section dimensions. The framework displacement and stress in the mucosa reduced as the thicknesses or heights of the bars increased. The maximum principal compressive stress of 1.84 MPa within the mucosa was estimated at the posterior ridge crest when the smallest cross-section Ti-6Al-7Nb bar was used. In conclusion, the Ti-6Al-7Nb lingual bar had a rigidity comparable to the Co-Cr lingual bar if the former had a cross-section dimension 0.5 mm thicker or 2.0 mm higher than the latter.

Key words

Finite analysis, stress, denture, lingual bar, mucosa, titanium, dental alloy

Introduction

Ti-6Al-7Nb alloy has recently been developed to pose excellent biocompatibility, resistance to abrasion and other advantages that put it as an alternative to the existing removable partial denture (RPD) alloys[1]. Like other titanium alloys, Ti-6Al-7Nb has a modulus of elasticity that is approximately half that of Co-Cr, which increases its resiliency and makes it suitable for flexible clasps[2]. However, the flexibility may become disadvantageous when used in the other components such as lingual bars, occlusal rests and minor connectors. Flexible major connectors can cause stress concentration in the framework structures, injury to the periodontal tissues and residual ridges, and discomfort to the patients. Previous studies explored the effect of cross section shape on rigidity of lingual bars by means of in-vitro cantilever bending tests[5]. However, optimal dimensions in lingual bar to ensure favorable stress transmission to the abutments and supporting oral mucosa, has not been well assessed in relation to the rigidity of the alloys.

This study examined the effect of cross-sectional dimension in lingual bars on deflection of Ti-6Al-7Nb and Co-Cr RPD frameworks and stress distribution both in the framework structure and oral mucosa under simulated occlusal loadings. It was hypothesized that lingual bar made of the Ti-6Al-7Nb alloy with an increased thickness and width has comparable rigidity to that made of the Co-Cr alloy, which was claimed to be the most rigid partial denture alloy.

Materials and Methods

We created three-dimensional finite element models of mandibular RPD frameworks designed for the edentulous area distal to the right first premolar (ANSYS 7.0, ANSYS Inc., Canonsburg, PA). Each framework included an extension denture saddle, two occlusal rests on the first premolars on both sides of the arch, minor connectors, and one of the nine lingual bars with different cross-sectional dimensions (Fig. 1). Vertical distance from the lower edge of the lingual bar to the edentulous ridge was 12 mm, and that to the occlusal plane was 17 mm. The distance between both sides of the mandibular ridge crests at the distal ends was 55 mm. Sagittal length from the anterior to right posterior end of the bar along the midline was 36 mm. The thickness and height of the nine lingual bars (Fig. 2) were; 1.5 mm / 4 mm, 2.0 mm / 4 mm, 2.5 mm / 4 mm, 1.5 mm / 5 mm, 2.0 mm / 5 mm, 2.5 mm / 5 mm, 1.5 mm / 6 mm, 2.0 mm / 6 mm, and 2.5 mm / 6 mm. Clasps, artificial teeth, and the resin denture base were excluded from the model.

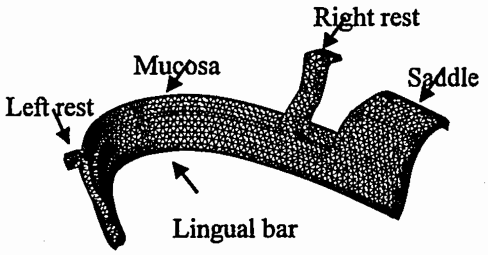


Fig. 1. A meshed finite element model of a framework includes an extension denture saddle, two occlusal rests, lingual bar, and the underlying oral mucosa.

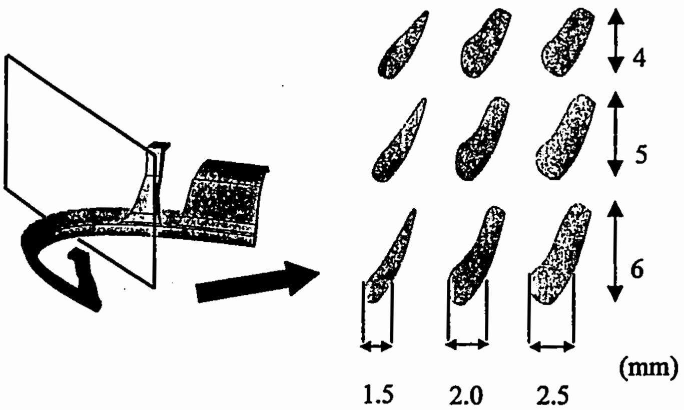


Fig. 2. Cross-sections of the lingual bars designed in this study. Each bar had one of the thicknesses of 1.5 mm, 2.0 mm, or 2.5 mm; and one from the heights of

Each model was meshed by elements defined by eight nodes with three degrees of freedom in tetrahedral bodies. Poisson's ratio of 0.3 and a modulus of elasticity of 200 GPa were input into the program to simulate Co-Cr alloy[3], while those of 0.3 and 135 GPa were for Ti-6Al-7Nb alloy. Poisson's ratio of 0.45 and a modulus of elasticity of 3.4 x 10^{-3} GPa were used for the mucosa[4]. The loading and boundary condition (Fig. 3) was based on a previous studies[5]. The rest on the left (tooth-supported) side was fixed in all directions. This complete fixation was based on an assumption that the clasps placed on healthy abutments were rigid enough to retain this part of the framework unmovable. The rest on the right (edentulous) side was fixed only in a vertical direction to allow for horizontal movements of this component. The bottom surface of the oral mucosa was also vertically fixed based on an assumption that the bone was a rigid structure but it allowed horizontal distortion of the overlying mucosa. A 30 ° buccally oblique biting force of 20 N was directed simultaneously towards the center of each of the three missing posterior teeth locations (total 60 N). Under the simulated occlusal loading, the framework displacements and the principal stress distribution both in the framework and the mucosa were calculated.

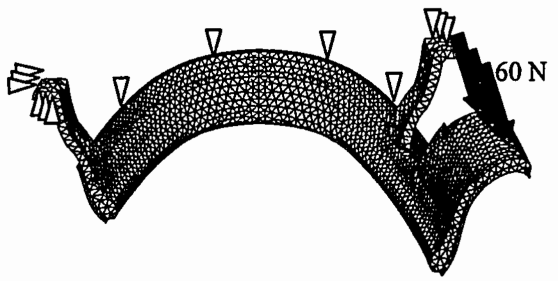


Fig. 3. A 30 ° buccally oblique biting force was directed simultaneously towards each of the three missing posterior teeth locations on the saddle (total 60 N).

Results

The maximum stresses in the supporting oral mucosa were shown in Fig. 4. The maximum vertical displacement was observed at the posterior edge of the saddle for all the frameworks.

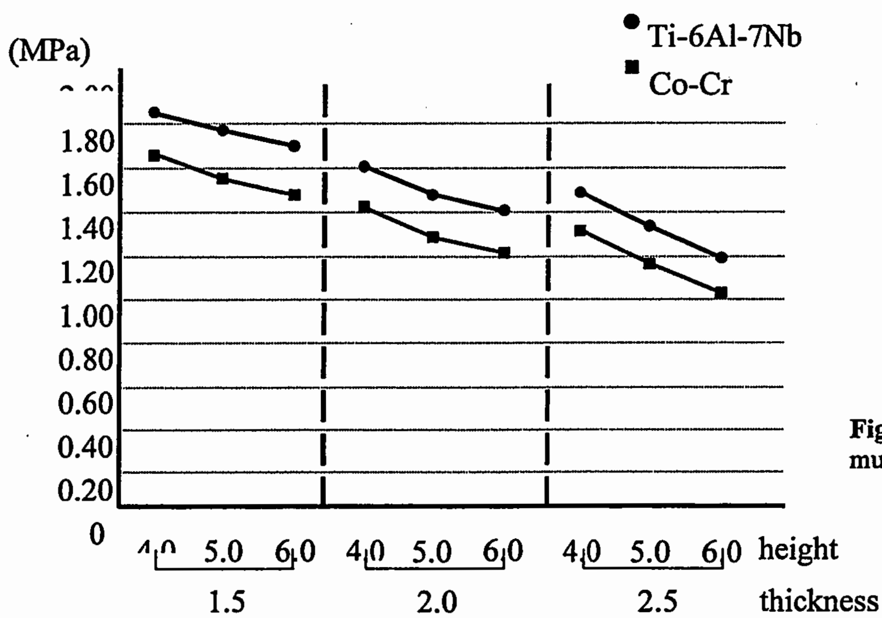


Fig. 4. The maximum stress in mucosa shown in each model.

The maximum displacements reduced as the thickness or the height of lingual bar increased. They ranged from 86.6 μm to 148.4 μm for the Ti-6Al-7Nb bars and from 73.4 μm to 127.2 μm for the Co-Cr bars. The maximum stress in the framework was recorded at the midline on the polishing surface of each lingual bar. The maximum stress reduced as the thickness or the height of the bar increased. The stresses ranged from 233.2 MPa to 628.5 MPa for the Ti-6Al-7Nb bars and from 230.3 MPa to 632.8 MPa for the Co-Cr bars. The maximum stress in the oral mucosa was shown on its bottom surface right above the posterior edentulous ridge crest (Fig. 5). The maximum stress reduced as the thickness or the height of lingual bar increased, ranging from 1.14 MPa to 1.80 MPa for the Ti-6Al-7Nb bars and from 0.97 MPa to 1.61 MPa for the Co-Cr bars. The lowest maximum displacement and the stresses were recorded in the model with the largest cross-section (2.5 mm-thickness and 6.0-mm height) for each alloy.

Discussion

The Ti-6Al-7Nb framework caused the largest vertical deflection of approximately 150 μm and the peak stress of 1.80 MPa. They were both close to the physiological limitations of the mucosa and the supporting alveolar bone, therefore likely to cause a detrimental effect on the alveolar bone. The result of this study suggests that the increase of the thickness be recommended in designing the lingual bars because it was clearly effective in reducing the peak stress in mucosa under the oblique occlusal loadings. From studying all data, it was indicated that the Ti-6Al-7Nb lingual bar had rigidity comparable to the Co-Cr lingual bar if the former had a cross-section dimension 0.5 mm thicker than the latter with a same height, or 2.0 mm greater height with a same thickness. The result supported our hypothesis that the lingual bar made of the Ti-6Al-7Nb alloy with an increased thickness and width has comparable rigidity to that made of the Co-Cr alloy.

The maximum principal stress within the lingual bar considerably decreased as the thickness or the height of the bar increased; however, it was insensitive to the elastic moduli of the alloys. The result was reasonable in the linear elastic models in this study. The location of the peak stress in all the models indicated that the bars are likely to fail at the midline. Failure probability of the prostheses is often estimated by comparison of the peak stress in the materials with their strength values. The highest maximum principal stress within the Ti-6Al-7Nb and Co-Cr bars (628.5 MPa and 632.8 MPa, respectively) were slightly below the reported yield strengths of corresponding alloys (890 MPa and 710 MPa, respectively). If principal tensile stresses that are close to the yield or tensile strengths are considered in the finite element models, the deformation or the fracture of the lingual bar of smaller cross-section dimension might occur in the loading condition in this study.

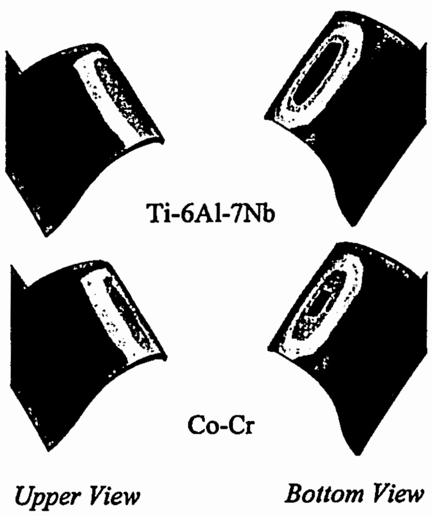
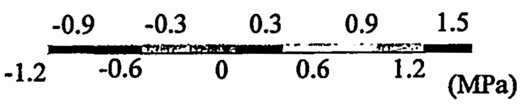


Fig. 5. Stress contours in the mucosa for the Ti-6Al-7Nb (left) and Co-Cr (right) frameworks with the lingual bar of 2.0 mm-thickness / 5 mm-height, viewed from above and bottom. For each model, the maximum compressive stress was shown in the bottom surface of the mucosa right above the top of the posterior edentulous ridge crest.



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