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Original article

Morphological factors of mandibular edentulous alveolar ridges influencing the movement of dentures calculated using finite element analysis☆

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Abstract

Purpose: The aim of this study was to determine the importance of each morphological factor of edentulous alveolar ridges according to its influence on the movement of complete dentures.
Methods: The shapes of casts and waxed complete dentures were digitized. The determined shapes of the ridges were uniformly divided circumferentially and radially. Principal component (PC) analysis was performed using the coordinates of the points on the grid as the variables (morphological PC). The denture movement under bilateral and unilateral loads was analyzed using a finite element (FE) model constructed from the digitized shape, following PC analysis of the displacement of representative points on the denture (displacement PC). The effects of the morphological PCs were evaluated by means of stepwise multiple regression analysis with displacement PC as a dependent variable.
Results: The ridge height, clearance between the ridge and the occlusal plane, and various inclinations, were significantly selected as independent variables where the dependent variable was the displacement PC under a bilateral load. Under a unilateral load, the displacement PC was mainly influenced by the ridge height. The influence of morphological PCs of the non-loaded side tended to be larger than that of loaded side.
Conclusion: Under a bilateral load, ridge height, clearance to the occlusal plane, and inclination of the ridge are considered to account for denture movement. To evaluate the effect of the ridge morphology on denture movement under a unilateral load, it is effective to determine the partitioned shape together with the height in general.

Keywords: Edentulous alveolar ridge; Finite element analysis; Denture movement; Principal component analysis; Multiple regression analysis

1. Introduction

Edentulous alveolar ridge morphology is regarded as important in the evaluation of edentulous patients [1,2]. To evaluate it, objective criteria such as the vertical height of the mandible on panoramic radiography [3], basal area and volume of alveolar ridges [4] have been employed.

In practice, the morphological characteristics of residual ridges are usually evaluated as some of the items in classification systems for edentulous patients [5–7]. These evaluation items, like ridge height, are always simpler than the objective methods described above for practical convenience. However, these items depend on the classification system, and are not always selected based on scientific evidence. In addition, it is not clear how many items are necessary to evaluate the morphology of edentulous ridges.

Needless to say, the importance of the morphology of the ridge is due to its great effect on the support and stability of the complete denture. In our previous study [8], we showed that several principal components (PCs) were sufficient to express the morphology of mandibular edentulous alveolar ridges. Thus, clarifying the effects of these PCs on denture movement would enable us to assign their order of priority. The aim of this study was therefore to investigate the effects of these PCs on denture movement calculated using finite element analysis, in order to select those with probable clinical importance. The research hypothesis was that, using finite element analysis, each of the main PCs for calculated denture movement under loads

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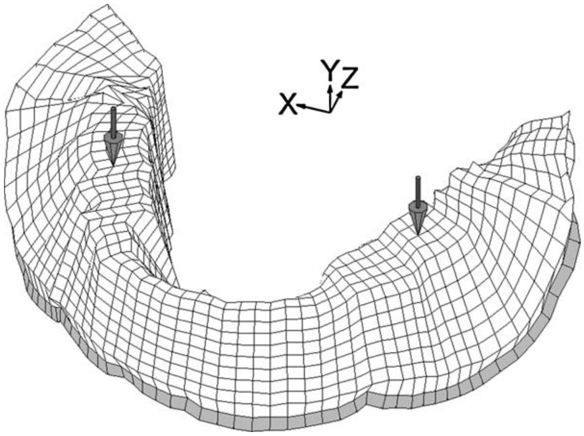

Fig. 1. Finite element model and loading points.

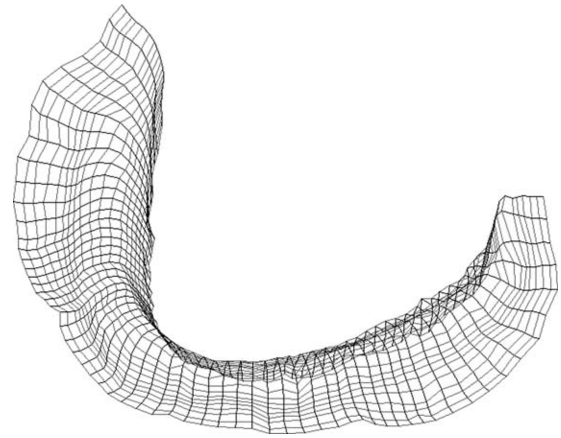

Fig. 3. An example of the grid on a ridge to determine measuring points for the morphology and nodes for the finite element model.

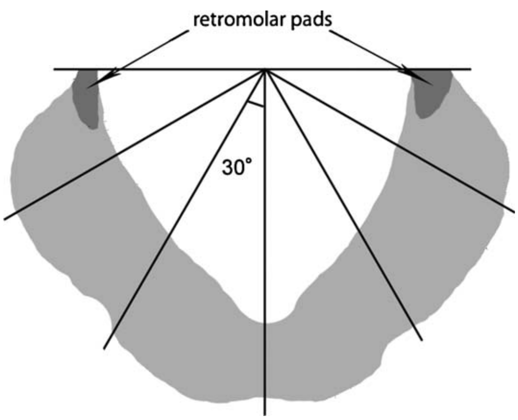

Fig. 2. Division of the ridge shape and the origins of the distances to the points on the ridge surface used for the principal component analysis.
The shape of the ridge was divided into six parts with the planes perpendicular to the occlusal plane.

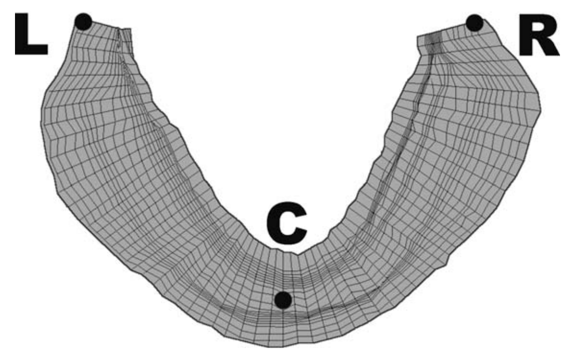

Fig. 4. Representative points on the mucosal surface for measuring displacement of dentures.
L and R: the most buccal and posterior points on each side, C: buccolingual center on the midline.

could be explained by a multiple regression equation with the morphological PCs as independent variables.

2. Materials and methods

2.1. Subjects and measurements

Seventy-six pairs of mandibular edentulous casts and trial waxed-up complete dentures were examined in the Department of Oral Rehabilitation, Hokkaido University Hospital, by means of a previously reported procedure [9] that measures the cast and defines the shape of the ridge. The measurement of the shape of a cast mounted on an articulator with/without a denture, together with three spheres attached to the articulator for use as reference fields, was carried out with a three-dimensional laser scanner (LPX-250; Roland DG Corp., Shizuoka, Japan) at intervals of 0.06 mm. The pair of surfaces was superposed with reference to the calculated center of the spheres. From the surface of the cast consisting of small quadrilaterals, 61 cross sections of the ridge perpendicular to the occlusal plane as assumed from the occlusal surface of the denture, were defined. Each cross section was divided linearly into 20 equal-length portions using c-spline interpolation. To unify the variance of the shape between sides, a mirror image reflecting the midsagittal plane was generated from each case and they were used together in the following analysis.

2.2. Finite element analysis of denture movement

A finite element (FE) model consisting of a denture and underlying mucosa from the digitized shape [9] (Fig. 1) was constructed for each subject. Each model consisted of 5124 nodes and 2400 eight-node-hexahedron isoparametric elements. According to our previous studies [9,10], Young's modulus and Poisson's ratio for the elements corresponding to the denture were 3000 and 0.3, respectively. For those corresponding to mucosa, 10.0 and 0.45 were used, respectively. The nodes corresponding to the bone surface were restrained for all direction. Sliding and detachment at the interface between a denture and mucosa were allowed [10]. We located a loading point on each side at the buccolingual center of occlusal surface in the anteroposterior middle of the denture defined with reference to its mucosal surface, and analyzed denture movement under bilateral and unilateral loads, using the MSC.Marc2005 finite element analysis software package (MSC Software Corp., Santa Ana, CA).