Pergamon

Bio-Medical Materials and Engineering, Vol. 4, No. 3, pp. 000–000, 1994

0959-2989/94 $6.00 + .00

0959-2989(94)E0012-7

BIOMECHANICAL STUDIES ON NEWLY TAILORED ARTIFICIAL DENTAL ROOT

KATSUNARI NISHIHARA

Department of Oral Surgery, Faculty of Medicine, University of Tokyo, 7-3-1, Hongo, Bunkyo-ku Tokyo 113, Japan

SHIGERU NAKAGIRI

Department of Applied Physics and Applied Mechanics, Institute of Industrial Science, University of Tokyo, 7-22-1, Roppongi, Minato-ku, Tokyo 106, Japan

Abstract—Artificial roots must carry multiple forces during mastication. Stress distribution around a root depends upon the shape, material, and function of the root. Therefore, for biomechanical studies on artificial roots, triad research on the material, shape, and functional effect upon surrounding tissue is essential. For dental implants, there are two different functional systems against the masticatory force, i.e., gomphosis and ankylosis on osseointegration.

Stress analyses of functioning new type (gomphosis) artificial roots were carried out in mandibular and maxilla models to study the triad effect using finite element analysis.

The authors have already reported histological and biomechanical studies on the shape and functional effect. To observe the material effect biomechanically, artificial roots made of sintered hydroxyapatite and zirconium oxide were analyzed in the models. Thereafter, animal experiments using dogs were carried out to observe bone formation around artificial roots made of hydroxyapatite and zirconium oxide in the mandible and maxilla. The following results were obtained: The patterns of stress distribution around artificial roots of two different materials were not too different, and were exclusively dependent upon the root shape and structure of the jawbone. Around the artificial roots, bone formation coincided with a moderate stress distributing zone and principal stress trajectories.

Through these experiments, the following conclusions were obtained: (a) Osteogenesis around artificial roots coincides with the stress distribution patterns. (b) Stress distribution patterns are dependent very little upon material properties but upon both the artificial root shape and the structure of the jawbone. (c) Optimization of the artificial root shape can be obtained by FEA in the models.

Key Words—artificial root, finite element analysis, shape effect, optimization, periimplantium

INTRODUCTION

SUBSTITUTION OF dental roots, i.e., artificial roots, must carry multiple forces during mastication. Stress distribution around an artificial root depends upon the shape, material, and function of the root (1,2). Therefore, for not only biomechanical but histological studies on artificial roots, triad research on the material, shape, and functional effect upon surrounding tissue is essential. For dental implants, there are two different functional systems against the masticatory multiple forces. One is a micromoving system by gomphosis and the other is a fixed system of ankylosis (3,4).

From this point of view, the authors investigated the triad effects of new type artificial roots upon surrounding tissues. The authors tailored artificial roots of the fibrous tissue attachment type (6,7). These artificial roots had characteristic corrugated configuration with a conic shape. Minor physiological movement was applied to the artificial roots through moderate masticatory function to prevent ankylosis with alveolar bone (8,9).

Stress analyses of functioning artificial roots in a mandibular model were carried out by means of the finite element method to observe biomechanically the triad effect upon the surrounding tissues (5).

Concerning the shape and functional effect, artificial roots of different shapes were analyzed in the models and have already been reported (3,5). To observe the material effect at this time, the artificial roots made of sintered hydroxyapatite and zirconium oxide were analyzed in the models, after which they were compared. These artificial roots of different materials were implanted in the mandible and maxilla of dogs. Bone formation around the artificial roots was observed. The shape effect of the artificial root and mechanical effect of the jawbone upon stress distribution patterns were also investigated by finite element analysis (FEA). Therefore, the stress distribution patterns around two different types of hydroxyapatite artificial roots were analyzed after being implanted in the premolar region of the lower and upper jawbone in the models, and compared with each other. These results were also compared to the osteogenesis patterns in specimens obtained from animal experiments using dogs.

From these experiments, the following results and conclusions were obtained: From the biomechanical viewpoint, the material effect of the new type artificial roots was negligible. Stress distribution patterns were dependent upon artificial root shape and jawbone structure. Bone formation around the artificial roots coincided with the stress distribution pattern. Therefore, optimization of artificial roots could be introduced by FEA.

METHOD

Models of mandibulars of two different conditions and a maxilla, premolar, buccal-lingual section were made for the assumption of the plane strain state implanted with standard type artificial roots (hydroxyapatite and zirconium oxide) for the FEA (5) (Figs. 1, 2 a,b). The experimental conditions and material constants are described in Table 1.

Figures 1 and 2 show the element division used. In these models, around the artificial root, connective tissue 0.15 mm in width and bone tissue 0.5 mm in width (alveolar bone proper) were supposed to exist. A static 6 kgf/mm load was applied to the top of the artificial roots with inclinations of 90° and 45° to the horizontal plane. The fixed points are indicated as

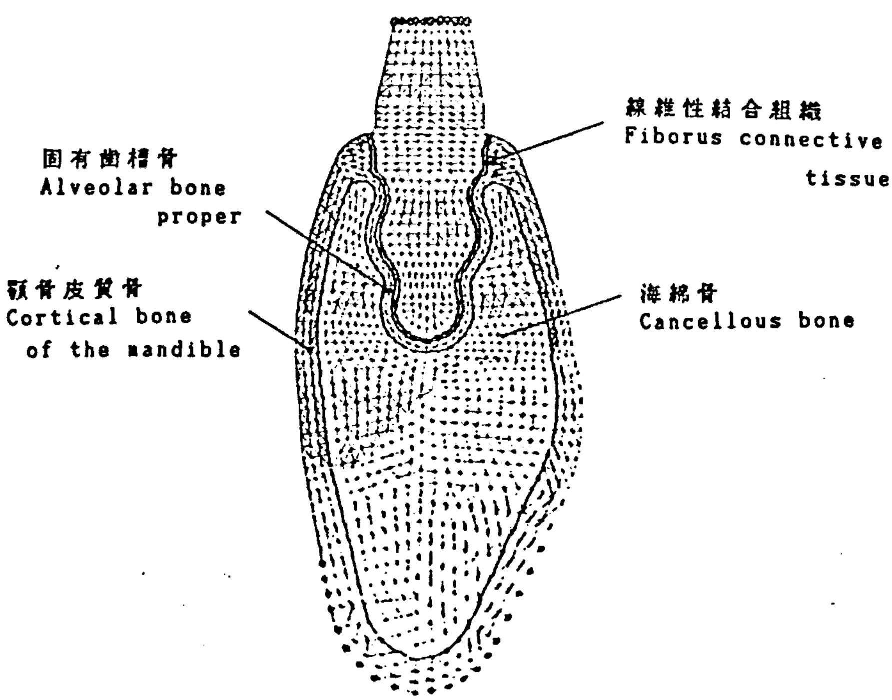


FIG. 1. Element division of artificial root (standard type) in mandible.

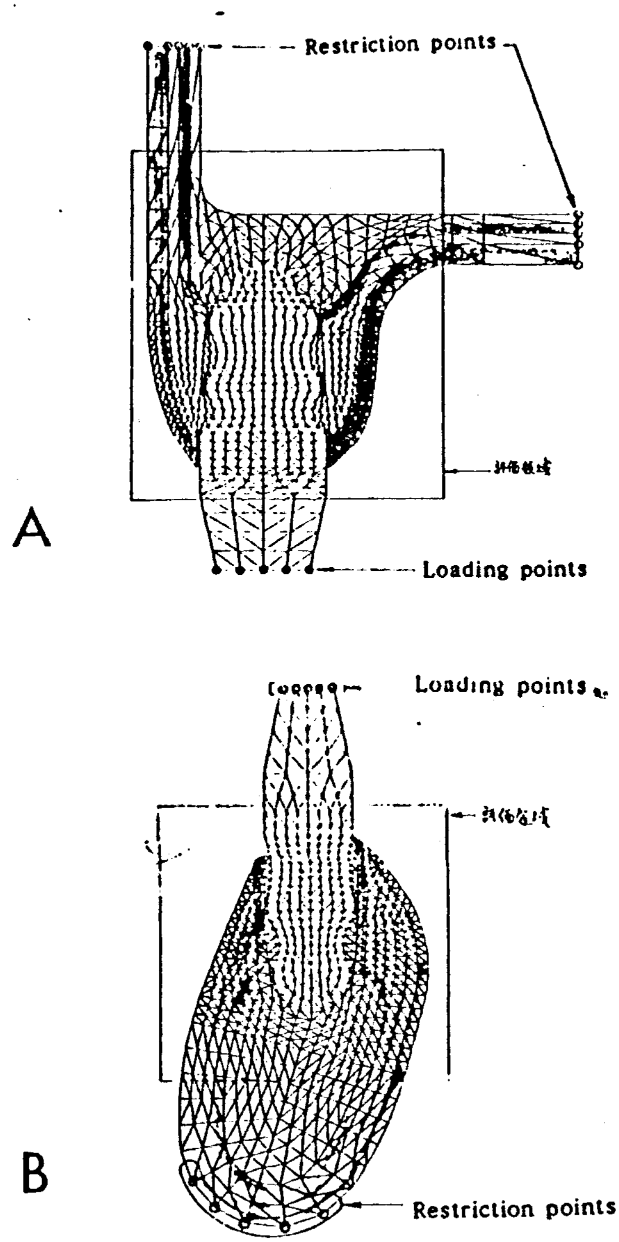


FIG. 2. Element division of two different artificial root types in mandible and maxilla.

black points at the bottom of the mandible. The evaluation was performed by Mises equivalent stress and principal stress trajectories. The computer used was Fujitsu VP30E with software FEM4. Artificial roots used in the experiments had a corrugated cone columnar shape. Therefore, for an exact numerical experiment, analyses of the three-dimensional state

Table 1. Experimental Conditions and Material Constants

Sintered Compact	Young's Modulus (GPa)	Poisson's Ratio
Hydroxyapatite	35.2	0.28
Zirconium Oxide	220	0.3
Cortical Bone	11.6	0.45
Cancellous Bone	0.51	0.3
Fibrous Tissue	0.0714	0.3

were required. However, the aim of the analyses was not to obtain the exact stress value but the stress distribution pattern under loading conditions. Therefore, FEAs under a plane strain state were carried out. It is supposed that every part of the model was constructed of isotropic materials and within elastic limits, and neither sliding nor separating occurred at the interface of each different material with different material constants.

Bone formation was compared around newly tailored artificial roots of standard type in experimental specimens of dogs with the Mises equivalent stress and principal stress distribution patterns of FEA.

RESULTS

From animal experiment specimens, no marked differences between aspects of zirconium oxide and hydroxyapatite concerning bone tissue formation around roots were observed. However, at the surface of the hydroxyapatite artificial root, a calcified layer resembling cementum was observed (1,2,7,10,11). On the contrary, at the surface of the zirconium oxide artificial root, a dense layer resembling cartilage was observed (2,11). Around both of them, bone formation similar to alveolar bone proper with fibrous tissue was observed. Epithelial attachment without inflammation could be observed in both materials. Mises equivalent stress distribution patterns of sintered hydroxyapatite and zirconium oxide artificial roots are shown in Fig. 3. The stress distribution patterns around artificial roots of different materials resembled each other even though the material constants were different. Young's modulus of ceramics and elastic fibrous tissue differ 500 to 300 times. Therefore, differences of material properties between hydroxyapatite and zirconium oxide become negligible. For this reason, stress distribution patterns of different materials could not show different distributions. The stress distribution patterns obtained by the FEA (abbreviated as

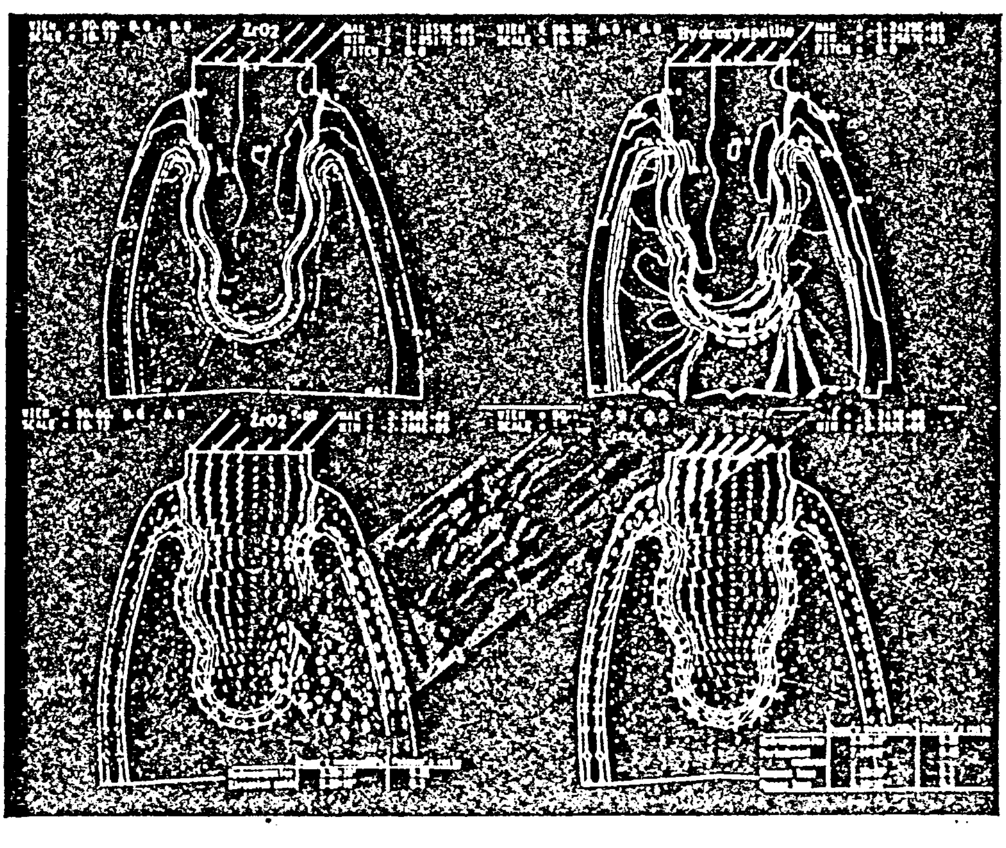
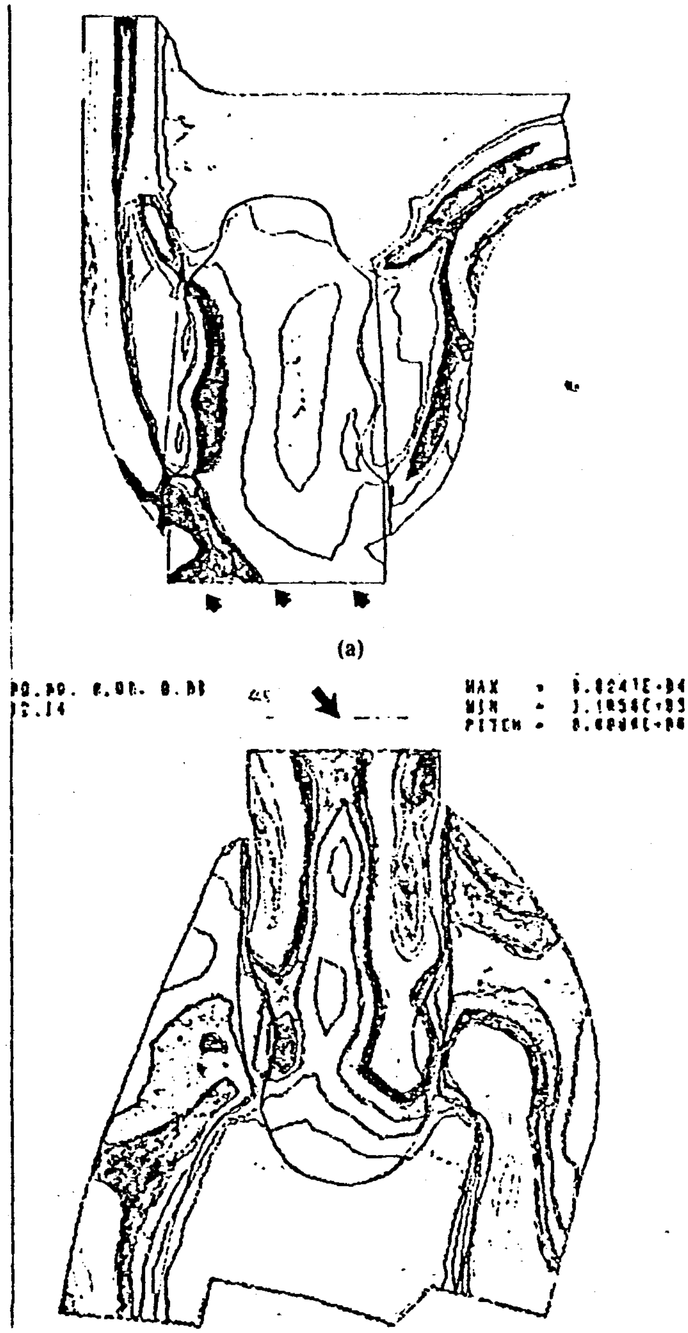


FIG. 3. Mises equivalent stress distribution and principal stress trajectory patterns of zirconium oxide

the FEA pattern hereafter) shaped of artificial roots of similar shape implanted in different mandibular models were distinctly different. The FEA patterns of artificial roots implanted in the maxilla and mandible were also markedly different (Fig. 4).

At the apex of the artificial roots implanted in both the upper and lower jaws, osteogenesis could not be observed in the specimens (Fig. 5). In FEA patterns in both the upper and lower jaws, no stress distribution could be observed around the apex. The observed osteogenesis occurred according to the principal stress trajectories in the moderate stress zone of Mises equivalent patterns. Therefore, for optimization, the artificial root shape was changed to cut



(a)

(b)

FIG. 4. Mises equivalent stress distribution patterns of upper and lower jaws. Loading condition is 45° to horizontal plane.

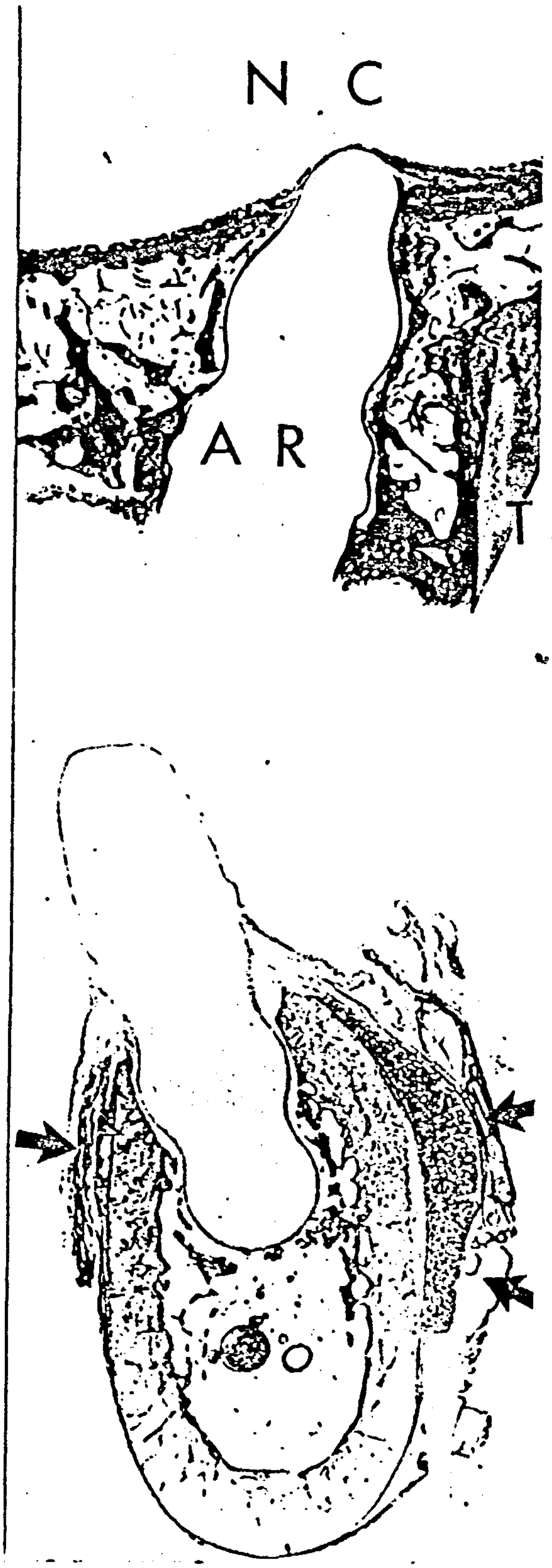


FIG. 5. Bone formation around artificial root (zirconium oxide) in upper (4 months) and lower jaws (2 months) of dog mandible.

off the part of the root where stress was not distributed. After that, a bifurcated root could be obtained in both the lower and upper jaws in a plane strain state (Fig. 6). From this research, the following results were obtained: The patterns of stress distribution around artificial roots of two different materials were not too different, and were exclusively dependent upon the root shape and structure of the jawbone. Around the artificial roots, bone formation coincided with a moderate stress zone and principal stress trajectories (5).

DISCUSSION

The patterns of stress distribution around newly tailored artificial roots made of two different materials with quite different, Young's moduli and Poisson's ratios were not too different.

The FEA patterns were dependent upon the artificial root shape. However, the stress distribution pattern was dependent also upon the jawbone structure.

From animal experiments, osteogenesis patterns coincided with the moderate stress zone and the principal stress trajectory patterns (5). This phenomenon is relevant to Wolff's law (12–19). Therefore, bone formation around the artificial root was dependent upon the artificial root shape as well as the jawbone shape and structure.

The structure of the jawbone is different in the maxilla and mandible. The maxilla consists of two cortices: The lower side is the alveolar process and the upper is the bottom of the maxillary sinus. Between them there is bone marrow. The mandible consists of a horseshoe-shaped tubular bone with cortex outside and bone marrow inside.

The stress distribution pattern in jawbone is dependent upon implant shape, loading condition, bone-ceramic joint system, and the structure and shape of the constructed bone.

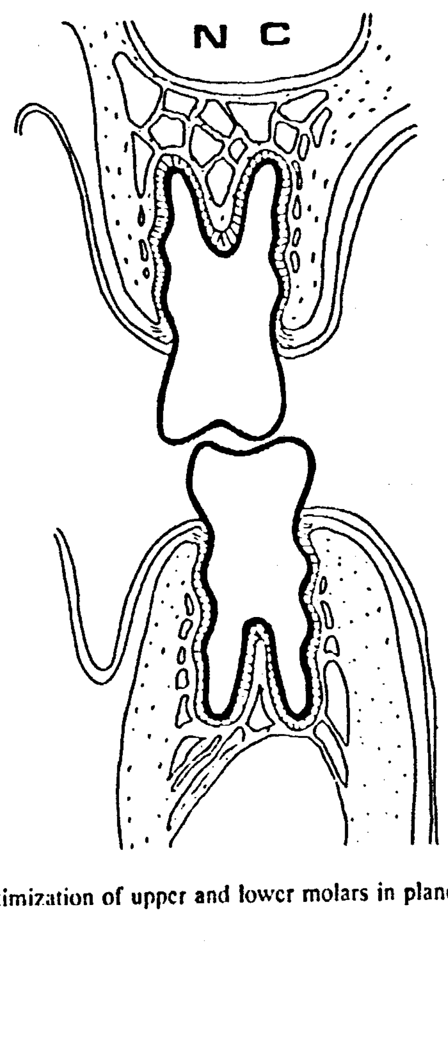


FIG. 6. Optimization of upper and lower molars in plane strain state.

Therefore, the FEA patterns around the same shape artificial root are different in the lower and upper jaws.

Interactions between artificial root shape and jawbone structure could be observed in stress distribution patterns. As a result, optimization of artificial roots could be understood as depending upon the jawbone structure, masticatory movement of the mandible, and the joint system of the tooth to the jawbone. From the finding of the FEA on shape and functional effect of the artificial root and of the structure of the jawbone, optimization of the artificial root could be carried out. By interaction of jawbone morphology and artificial root shape, there was observed a noninteracting zone, where no stress was distributed in either the artificial root or the jawbone. The part of no stress zone was removed, after which a bifurcated root could be obtained in a plane strain state (Fig. 6).

CONCLUSION

From biomechanical studies of the material, shape, and functional as well as histopathological component effects of a newly tailored artificial tooth root, the following conclusions were obtained: (a) Biomechanically, the material effect of the artificial root upon surrounding tissue with the fibrous tissue attachment system was negligible. (b) Stress distribution patterns depended upon both the artificial root shape and the jawbone structure. (c) The patterns of osteogenesis around the new type artificial root with micromoving function and stress distribution patterns of FEA showed a close correlation. and (d) Optimization of the artificial root shape can be obtained by FEA in the models.

REFERENCES

1. Nishihara, K.; Kobayashi, T.; Akagawa, T. Light microscopic and SEM observation of tissue around new type artificial roots. In: Kanazawa, T.; Abe, Y.; Umegaki, T., eds. Phosphorous research bulletin 1. Tokyo: Nihon Printing Co., Ltd; 1991:185–190.
2. Nishihara, K.; Akagawa, T. Comparative studies on periodontal tissues around new type artificial roots made of zirconium oxide, titanium, and hydroxyapatite. In: Kanazawa, T.; Abe, Y.; Umegaki, T., eds. Phosphorous research bulletin 1. Tokyo: Nihon Printing Co., Ltd; 1991:179–184.
3. Nishihara, K.; Jiang, L.; Kobayashi, T.; Yanai, A.; Nakagiri, S. Studies on functional effect of hydroxyapatite artificial root upon surrounding tissue. Bioceramics 5:333–342; 1992.
4. Brånemark, P.-I. Osseointegration and its experimental background. J. Prosthet. Dent. 50:399–410; 1983.
5. Nishihara, K. Biomechanical studies on shape effect of hydroxyapatite artificial root upon surrounding jawbone. Clin. Mater. In press.
6. Nishihara, K.; Akagawa, T. Development and clinical application of natural-type hydroxyapatite artificial roots. In: Kawahara, H. ed. Oral implantology and biomaterials. Amsterdam: Elsevier Science Publishers B.V.; 1989:41–46.
7. Nishihara, K.; Kobayashi, K.; Akagawa, T. Studies on periodontal tissue around a new type hydroxyapatite artificial root. Bioceramics 3:171–181; 1991.
8. Nishihara, K.; Akagawa, T. Case report on artificial root therapeutics. Bioceramics 3:183–192; 1991.
9. Nishihara, K.; Akagawa, T. Clinical applications of hydroxyapatite artificial root of fibrous tissue attachment type. Bioceramics 4:223–230; 1991.
10. Nishihara, K. Studies on peri-root tissue formation around new type artificial root made of dense hydroxyapatite. Clin. Mater. 12:159–167; 1993.
11. Nishihara, K.; Kobayashi, T.; Akagawa, T. Successful periodontal tissue formation around new type hydroxyapatite artificial root. In: Transaction of Fourth World Biomaterials Congress, Berlin ISBN; 1992:381.
12. Wolff, J. Ueber die innere Architectur der Knochen und ihre Bedeutung für die Frage vom Knochenwachsthum. Archiv für pathologische Anatomie und Physiologie und für Klinische Medizin, Virchovs Archiv. 50:389–453; 1870.
13. Wolff, J. Die Lehre von functionellen Pathogenese der Deformitaten. Archiv fur Klinische Chirurgie 53 Bd Heft 4:831–905; 1884.