STUDIES ON PERIODONTAL TISSUES AROUND A NEW TYPE HYDROXYAPATITE ARTIFICIAL ROOT

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ABSTRACT

In order to develop a fibrous tissue attachment type hydroxyapatite artificial root which has two functional components of the natural tooth system, i.e., the periodontal ligament and the alveolar bone proper (the lamina dura), human root shapes of all types of teeth were surveyed and analyzed their common characteristics. The interface between these artificial roots and the surrounding alveolar tissue is thought to be quite different from that of the common dental implant. To substantiate this, animal experiments were performed using dogs. Same-shaped artificial roots made of several different materials were implanted. Light and scanning electron microscopy (SEM) were used to investigate histopathologically the nature of the binding between the artificial root and adjoining tissues. Calcified tissue attached to the artificial root surface was surveyed with a microanalyzer (Kevex 8000) and by analyses of FT-IR. The animals were sacrificed, after which nondecalcified and decalcified specimens were prepared, stained, and observed. The implanted artificial roots were excised and observed by SEM. Favorable epithelial attachments were observed on these artificial roots, with the formation of bone tissue resembling the alveolar bone proper. Fibrous tissues having nearly the same thickness were observed around the artificial roots. They ran at right and acute angles to the artificial roots throughout, and some ran parallel. Observation by SEM revealed lamination in the form of a calcified layer, various attached materials and fibrous tissue. Fibrous and osseous tissues were observed by microanalyzer Kevex 8000 to be attached to the artificial root surface with a porous calcified layer. Analyses with FT-IR revealed that the calcified materials on the artificial root surface resembled the cementum in pattern.

INTRODUCTION

The tooth is classified as a unique entity in the mechanical supportive organ systems and is known by comparative morphology to show an inseparable relationship between its form, function, and constitutional components. Clearly, the binding system is the most important element underlying the success or failure of any artificial root implantation. Today, it is not considered important to have periodontal structures around the dental implant. However, for the human mastication system with its delicate movements of the temporomandibular joint, the peri-implant structures as substitutes for the periodontal ligament and alveolar bone proper seem to be indispensable for long-term function of the artificial roots. From this point of view, an artificial root of the fibrous tissue attachment type was devised. The aim of this investigation is to describe the reaction of soft tissue and bone to hydroxyapatite, zirconium oxide, and titanium artificial roots with uniform functional shapes.

MATERIALS AND METHODS

1. Fabrication of the Artificial Roots

Artificial roots were devised emphasizing conical, corrugated configurations common to human natural roots in order to stimulate the formation of bone and fibrous tissue resembling the lamina dura (the alveolar bone proper) and periodontal ligament which support natural teeth were developed. Physiologic movement of the artificial root was attained by encouraging mastication soon after implantation so as to stimulate the production of peri-artificial root-supporting tissue. This prevented the osseous adhesion of these artificial roots. In this study, standard-type artificial roots of sintered hydroxyapatite, zirconium oxide, and titanium (ϕ4mm) were prepared and implanted in the premolar sites of adult dogs. The artificial roots were fabricated by the Asahi Optical Company, Tokyo, Japan.

2. Implantation Procedures

Eight adult mongrel male dogs (age one to two years and weight 9-12 kg) were used in this experiment. The artificial roots were implanted at the time of extraction of the upper or lower premolars. The post extraction sockets were enlarged using a 4-mm diameter trephine, and the bone and other tissues including the periodontal ligament were entirely removed. The site was excavated using a bur (ϕ4mm) and was adjusted to the size of the artificial root. That part of the artificial root corresponding to the dental crown was shaped using a carborundum point to obtain the form of a cusp approximating the clinical crown of the dog premolar. The artificial root was implanted in isolation because the dog premolar possesses mainly the function of sphen alone. For implantation into the upper premolar sites, the maxillary alveolar bone was perforated so that the implanted roots would project into the base of the nasal cavity. This procedure was performed to simulate similar occurrences of perforation into the maxillary sinus in humans. The animals were placed on a soft diet for two weeks following implantation, and were thereafter maintained on a solid diet.

3. Processing of the Specimens

After a fixed period (1 to 17 months), the dogs were sacrificed at different intervals, and nondecalcified and decalcified specimens were prepared. The alveolar bone sections together with the artificial roots were removed seven months after implantation, and the root surfaces were observed by SEM. Some clinically applied cases with small diameter artificial roots were extracted 11 months after operation and reimplanted with larger diameter artificial roots. The extracted artificial roots were then observed by SEM and analyzed by F-T infrared absorption. Nondecalcifed specimens of the mirror polished surfaces were prepared for the microanalyzer. The specimens were observed and analyzed with a Kevex 8000.

RESULTS

Of the 30 implanted artificial roots, 3 were fractured and 3 were exfoliated. Macroscopically, the state of implantation of the remaining 24 artificial roots was satisfactory with no evidence of infection.

The artificial roots of hydroxyapatite, zirconium oxide, and titanium showed satisfactory epithelial and submucosal fibrous tissue attachments at the periodontal region similar to those of natural teeth (Figures 1, 3, 5). A layer of connective tissue rich in blood vessels was present in constant width around the artificial roots of hydroxyapatite, zirconium oxide, and titanium, and bone tissue similar to the alveolar bone proper formed around the layer (Figures 2, 4, 6). At the concave site of the artificial root, the bone was connected to the artificial root surface by means of fibrous connective tissues that ran at right or acute angles (Figures 2, 4, 6). Occasionally, the bone was indirectly attached to the artificial root through the layer of fibrous tissue running parallel with the root surface (Figures 2, 5, 7, 8). At the convex site, fibrous connective tissues ran parallel with the artificial root surface.

The SEM findings of the surface of the extracted apatite artificial roots which were applied clinically, showed attached tissues that varied morphologically according to the site, as follows: Numerous attached cells similar to cementoblasts were present on the concave surface of the artificial roots (Figure 10). The attached substance was similar to calcified material observed on the surface of the natural root (Figures 9, 11).

The analyses of F.T.-infrared absorption of the 11-month clinically applied specimens revealed that the calcified material on the artificial root surface was similar to cementum or bone (Figure 12).

Observation by a SEM with a Kevex 8000 of the mirror polished surfaces of dog specimens 17 months after implantation revealed calcified material similar to cementum or bone attached to the apatite artificial root surface (Figures 13-17). This observation is substance specific for hydroxyapatite. The surface of the sintered hydroxyapatite appeared porous and seemed to remineralize after having dissolved once (Figures 13-17). Calcium and phosphate contents similar to cementum or bone was detected by the Kevex 8000 microanalyzer system (Figure 18).

Figure 1: A nondecalcified section of hydroxyapatite artificial root in the mandible 8 weeks postop. Epithelial attachment can be observed (arrow).

Figure 2: A nondecalcified section of hydroxyapatite artificial root 6 weeks postop. Functionally-oriented fibrous tissue can be observed between the artificial root and alveolar bone.

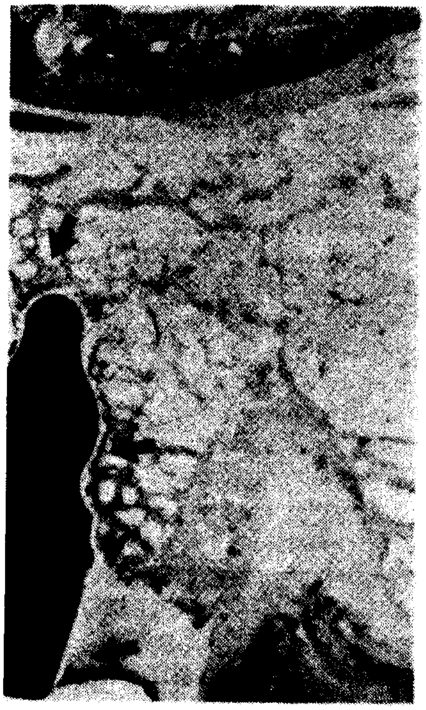


Figure 3: A nondecalcifed section of titanium artificial root in the maxilla 16 weeks postop. Epithelial attachment and formation of alveolar bone proper can be observed (arrows).

Figure 4: A decalcified section of titanium root 16 weeks postop. Fibrous tissue can be observed between the artificial root and alveolar bone.

Figure 5: A nondecalcified section of zirconium oxide artificial root in the maxilla 16 weeks postop. Epithelial attachment and formation of alveolar bone proper can be observed (arrows). The perforation to the nasal cavity was intentional.

Figure 6: A decalcified section of zirconium oxide artificial root 16 weeks postop. Marked functionally-oriented fibrous tissue and blood vessels can be observed.

Figure 7: A decalcified section of hydroxyapatite artificial root with apatite granules (Gr) 36 weeks postop. Dense lamellae attached to the artificial root can be observed.

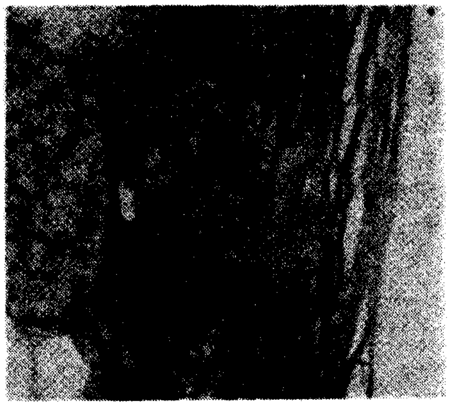


Figure 8: A decalcified section of hydroxyapatite artificial root 68 weeks postop. Lamellae attached to the artificial root surface have become calcified with functionally-oriented fibrous tissue.

Figure 9: A SEM of a clinically applied hydroxyapatite artificial root surface implanted in a dog, 28 weeks postop. Calcified lamellae 20 μm thick can be observed (arrow).

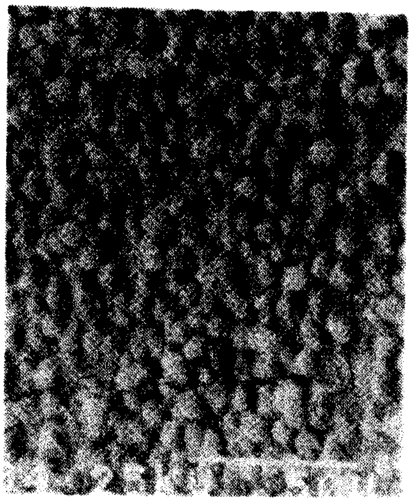


Figure 10: A SEM of a clinically applied hydroxyapatite artificial root surface 44 weeks postop. Numerous cells similar to cementoblasts are observed in the concave artificial root surface.

Figure 11: Calcified substance attached to the root surface can be observed in the same specimen as Figure 10.

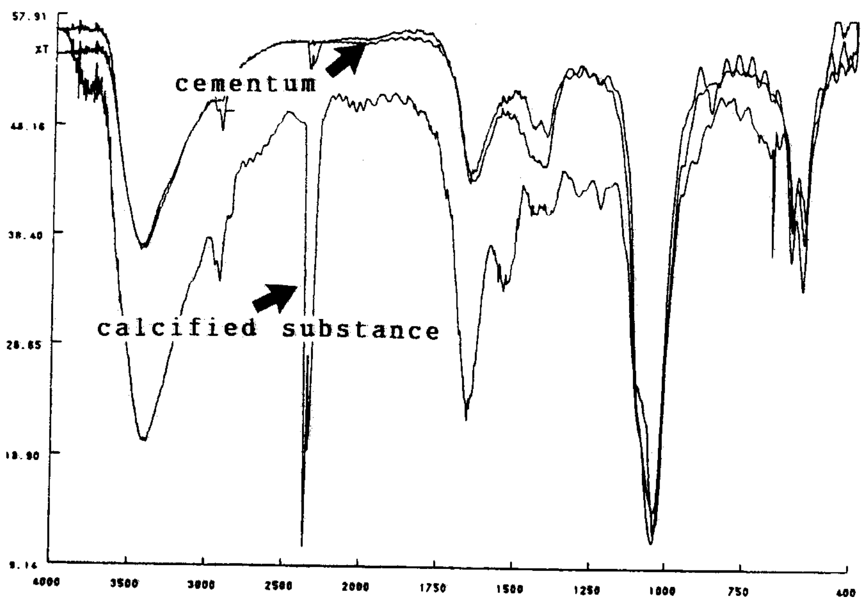
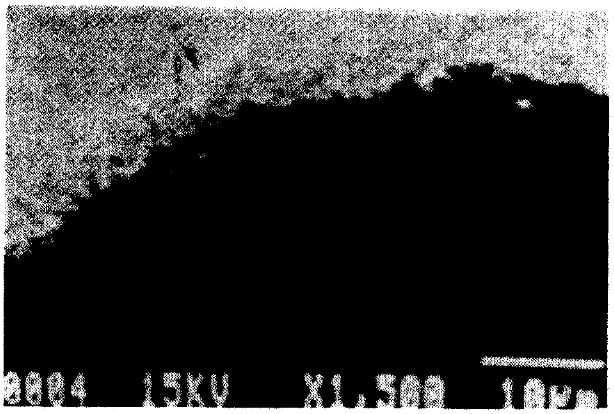


Figure 12: FT-IR absorption patterns of healthy cementum and calcified material attached to artificial root surface.



Figures 13, 14: An SEM of mirror-polished hydroxyapatite artificial root specimens, 36 weeks pos-top. The artificial root surface has become porous, and calcified substance has formed into lamellae, fusing with the root surface.

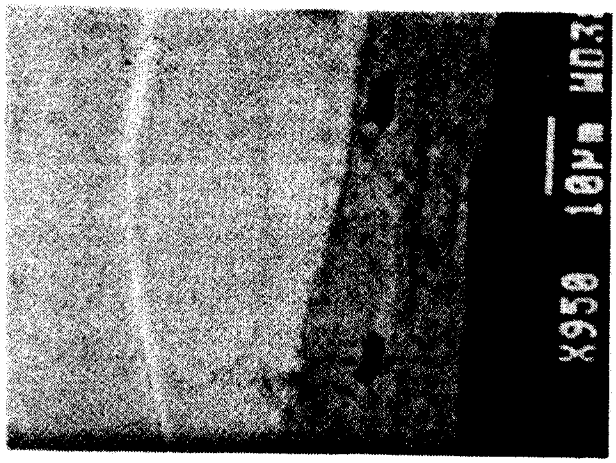


Figure 15: A SEM of a mirror-polished hydroxy-apatite artificial root of the same specimen as Figure 13. Osteoankylosis can be observed at the interface of the bone and artificial root. A porous hydroxyapatite layer appeared.

Figure 16: A SEM of a mirror-polished hydroxyapatite artificial root of the same specimen, 68 weeks postop. The cementum-like layer fused with porous hydroxyapatite of the artificial root surface can be observed.

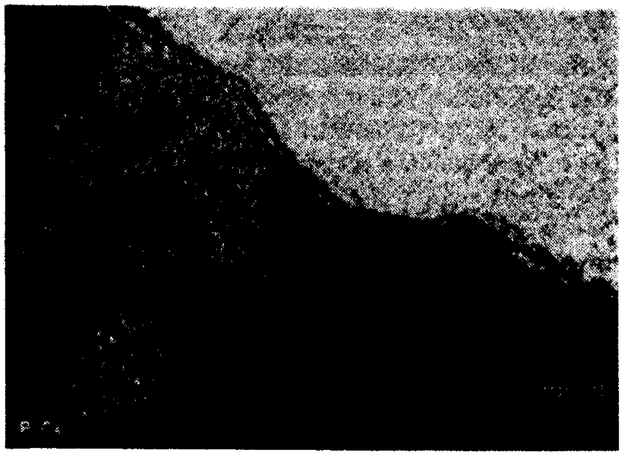


Figure 17: X-ray map of the mirror-polished hydroxyapatite artificial root specimen, 68 weeks postop. Calcium and phosphate are detected. Calcified substance can be seen between the artificial root, connective tissue, and bone.

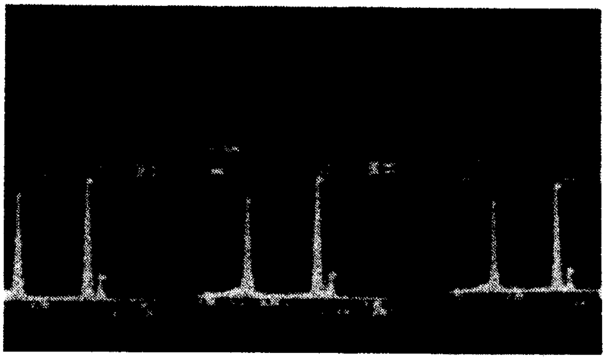


Figure 18: A microanalyzer pattern of the hydroxyapatite artificial root. The calcified substance has a more compact density than the bone, but less than that of the sintered apatite.

DISCUSSION

Recently, artificial roots of titanium/ceramics are being developed and applied clinically. At the same time, infection, alveolar bone resorption, and fracture of artificial roots have become serious issues. Recently, osseous adhesion or osseointegration has been commonly accepted as an ideal bonding system of artificial root to the jawbone. However, teeth with osseous adhesion are found in animals of a lower order without systematic mastication as in mammals. These teeth are isodontic and polyphydontic with only prehensile functions. On the other hand, mammalian teeth bond to the jawbone by means of gomphosis and have ligamentous articulation, by which oral digestion, i.e. mastication, can be performed effectively.

From this point of view, artificial roots need some form of "peri-artificial root-tissue" to substitute for the periodontal tooth-supportive organ. However, conventional dental implants have been developed without such concepts. They are just planted into the jawbone as if they are anchors for a removable prosthesis. On the contrary, mechanical supportive organs, i.e., the periodontal ligament and the alveolar bone proper, are indispensable for the mastication function of human teeth. Therefore, some mechanism must be introduced to induce the formation of these supportive organs around the artificial root after the implantation procedure.

Mechanical supportive organ systems such as teeth or bones have a close correlation between their morphology and functions. From this point of view, it is believed that proper configuration and adequate masticatory function of the tooth can induce peri-artificial root-tissues around the root resembling periodontal tissues.

The tooth is one effective vehicle of force which disperses the occlusal stress equally in the jaws and invites osteogenesis, according to Wolff's law of trajectorial architecture in cancellous bone, by means of the periodontal ligament around the root. Proper morphology of the root and periodontal ligament are essential in human mastication.

In this experiment, fibrous tissue attachment and osteogenesis similar to lamina dura were observed in all artificial roots regardless of the materials used. From these results, the shape is believed to be the most important factor for mechanical supportive organ systems such as teeth and bone. Among the materials observed, hydroxyapatite was unique in that calcified material very similar to cementum in pattern attached to the artificial root. Therefore, hydroxyapatite is considered to be the most suitable for use as an artificial root.

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