The Use of Bioabsorbable Implants as Orthodontic Anchorage in Dogs

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The purpose of this study was to investigate the possibility of using a bioabsorbable implant as orthodontic anchorage. The implant under investigation in this study was a miniscrew, 2.0 mm × 8.0 mm, made from poly-L-lactic acid (PLLA; molecular weight: 200,000), a bioabsorbable bone-bonding material. The implants were placed in the mandibles of eight male beagle dogs. After implantation, traction was immediately applied to the third premolar (P3) using the implant as anchorage. After the completion of each study period (three and six months) following installation, tensile test, histological examination, and molecular weight measurement were performed. The results suggested that the bioabsorbable implant evaluated had favorable biocompatibility and strength, and that it showed promising potential for use in orthodontic treatment.

Key words: Bioabsorbable implant, Anchorage, Orthodontics

INTRODUCTION

In orthodontic treatment, the securing of an anchor is one of the most important aspects that must be carefully considered when developing and executing a treatment plan. In cases where high orthodontic force is required, such as moving a molar tooth or depressing posterior teeth, extra- or intra-oral anchorage is usually needed. However, the successful use of both extra- and intra-oral anchorage is highly dependent on patient cooperation since patients frequently complain of the inconvenience associated with their use, particularly in terms of appearance and comfort. Loss of anchorage due to lack of patient cooperation is considered to be one of the major causes of prolonged treatment period and undesirably low level of treatment effectiveness.

Since the 1980s, use of implants has been seen as a reliable means of obtaining an anchorage when moving teeth during orthodontic treatment, and numerous reports on this subject have been published.1–36 Nearly all of the implants that were initially used as anchors in orthodontic treatment were conventional implants functioning as prosthetic appliances for missing teeth. However, starting in the 1990s, implants particularly designed for orthodontic treatment began to be developed. At present, various types of implant – ranging from miniscrews to miniplates anchored with bone screws – have been developed and widely applied in clinical orthodontics.27–30

Orthodontic implants are required to have unique properties that differ from those of prosthetic implants in that they are only to be used temporarily and to be removed promptly after their use as anchors during orthodontic treatment. The clinical usefulness of orthodontic implants has now been widely accepted because they are not dependent on the degree of patient cooperation. In addition, they ensure high level of treatment effectiveness, shorten treatment period, and prevent the need for extraction. However, while it is inevitable that soft tissue and bone will invade the implant, the problem is made worse in that it is necessary to remove the orthodontic implant after treatment. Further, since implants have become smaller, more complications have arisen – such as the breakage of implants inside bone. Against this backdrop of problems and complications surrounding orthodontic implants, there arises the need for a bioabsorbable material.35–41

In this study, therefore, we examined in vivo whether it was possible or not to use implants made of polylactic acid as anchorage in orthodontic treatment.

MATERIALS AND METHODS

Bioabsorbable implant
The implant to be evaluated in this study was a miniscrew, 2.0 mm × 8.0 mm, composed of poly-L-lactic acid (PLLA; molecular weight 200,000) – which is a bioabsorbable bone-bonding material (Fixsorb-MX, Takiron, Tokyo, Japan) (Fig.1).

Implant installation
Eight male beagle dogs (age: 8–10 months; body weight: 10–11 kg) were used in this study. Pretreatment entailed extracting the left and right fourth premolars (P4s) in the lower jaw so as to acquire space for the distal movement of the third premolars.
Bioabsorbable implant (poly-L-lactic acid, molecular weight: 200,000, 2.0 mm × 8.0 mm).

For painless surgery, general anesthesia was induced using pentobarbital at 0.5 ml/kg body weight, followed by direct infiltration of a local anesthetic to the surgical site. The left and right lower premolars (P4s) were then extracted. All procedures for animal care were approved by the Animal Management Committee of Aichi-Gakuin University.

After confirming the healing of extraction wounds three months after the P4s were extracted, the implants were installed. The following procedure was likewise performed under anesthesia. The buccal gingiva and periosteum of the molars (M1s) were ablated, followed by drilling at a location 3 mm away from the region to the root apices of the M1s. Subsequently, all implants were installed and confirmed to be free from breakage and deflection.

A temporary crown – made of resin – with a button was fabricated on a working model. After etching the P3 – which was not subject to any prior preparation – with 60% aqueous phosphoric acid, the temporary crown was attached to the P3 with dental adhesive (Super-Bond, Sun Medical, Shiga, Japan).

Once implant was installed, traction was immediately applied to the P3 using the implant as anchorage.

Ni-Ti coil spring was established between the P3 and the implant with ligature wire. Traction was applied using the Ni-Ti coil spring and adjusted to apply a continuous traction force of 100 gf (Fig. 2). A control group was also established in which the implants were simply connected with ligature wire without applying any orthodontic force.

Measurement of P3 movement

Individual trays were prepared, impressions were acquired with an alginate impression material, and molds were fabricated with ultrahard plaster at the start of traction, as well as after three months and six months. The cusp of the canine, the apex of the mesial cusp of M1, and the button of the temporary crown of P3 were used as measurement points. Distances between the points were measured in order to calculate the three-dimensional movement distance of P3 with a digital caliper (Digi-Kanon, Nakamura, Tokyo, Japan) (n=10).

Observation of implant surface properties by SEM

Each implant was carefully excised from the mandible three and six months after installation. Surface properties were then observed with SEM (JSM-6400FX, JEOL, Tokyo, Japan) after removal of the surrounding tissue.

Measurement of implant breaking strength

After the completion of each study period following installation, the dogs were sacrificed with deep anesthesia, and the implants were excised along with the mandible bone and surrounding tissue (3-month and 6-month groups). After fixing the excised bone for both the study group (whereby an orthodontic force was applied) and the control group (whereby an orthodontic force was not applied), a tensile test was performed with a universal material tester (EZ-Test, Shimadzu, Tokyo, Japan) at a cross-head speed of 5mm/min to measure the implant breaking strength.

In addition, a 0-month group was also established in which the implant was installed in the excised bone and immediately subjected to the tensile test.

Histological examination

Non-decalcified polished sections were prepared by removing sites that exhibited implant and bone union. The sections were then subjected to toluidine blue staining and histologically examined under a light microscope. Bone histomorphometry was performed using modified stereological point-hit and linear intercept methods. Bone occupancy rate surrounding the implant was measured as the proportion of bone that occupied the surface area of troughs directly beneath a straight line connecting the apices of the screw threads of the implant, as seen on images of the tissue. In addition, bone surface contact rate was measured to determine the proportion of the
distance over which the bone surface and implant were in contact within the troughs between the apices of the screw threads of the implant.

*Measurement of PLLA molecular weight*
Molecular weight of PLLA was calculated from the intrinsic viscosity in chloroform solution at 25°C. Results obtained in this study were tested for statistical significance with Student's t-test.

**RESULTS**

**Macroscopy and X-ray findings of implant and surrounding tissue**
Macroscopy of the implants installed in the mandibles revealed that none of them were damaged or dislodged in the 3-month and 6-month groups. In addition, the P3s demonstrated marked tipping in the distal direction due to the traction force of the spring. Although there were some sites where the spring cut through the soft tissue resulting in its reddened appearance, no prominent infiltration of inflammatory cells was observed, including the tissue surrounding the implants (Fig. 3).

**P3 movement**
The group in which orthodontic force was applied for three months demonstrated an average movement distance of 2.64 mm, while the group in which orthodontic force was applied for six months demonstrated an average movement distance of 5.41 mm. In addition, no implants were damaged or dislodged during the study period.

**SEM images of implant surface**
Although the implant surfaces were smooth prior to installation, they showed cracks—the number of which increased over time in the 3-month and 6-month groups (Fig. 4).

![Fig. 3 X-ray findings. P3s demonstrated marked tipping in the distal direction due to the traction force of the spring.](image)

![Fig. 4 SEM images of implant surface. Surface of implant prior to installation was smooth (0 month). Then it showed cracks, the number of which increased over time in the 3-month and 6-month groups.](image)
Histological examination

Histological examination performed immediately after implant installation showed large gaps between bone tissue and implant. However, these gaps decreased over time in the 3-month group (Fig. 5). Bone occupancy rate in the 3-month group was significantly higher than that in the group immediately after installation (p<0.01) (Fig. 6). Bone surface contact rate in the 3-month group was also significantly higher than in the group immediately after installation (p<0.001) (Fig. 7). There were no significant differences observed in bone occupancy rate and bone surface contact rate between the 3-month and 6-month groups. In addition, no infiltration of macrophages or other inflammatory cells was observed in the tissue surrounding the implants in either group.

Fig. 5 Tissue surrounding the bioabsorbable implant. Histological examination performed immediately after implant installation showed large gaps between the bone tissue and implant. But these gaps decreased over time in the 3-month group.

Fig. 6 Bone occupancy rate. The bone occupancy rate was significantly higher in the 3-month group than that immediately after installation (p<0.01).

Fig. 7 Bone surface contact rate. The bone surface contact rate was significantly higher in the 3-month group than that immediately after installation (p<0.001).
Implant breaking strength
Compared to the implantation immediately after installation, the mean breaking strength decreased significantly over time, as seen in the 3-month and 6-month groups, and in both groups where orthodontic force was applied continuously and where it was not applied (p<0.001, p<0.01). In addition, there were no significant differences observed between the group in which orthodontic force was applied continuously and that in which it was not, for both the 3-month and 6-month groups (Fig. 8).

PLLA molecular weight
Compared to the implant prior to its installation, the molecular weight of PLLA became significantly lower over time at three months following installation, and further reduced at the six-month period (p<0.001) (Fig. 9).

DISCUSSION
Since the 1970s, numerous attempts have been made to use implants as anchors in orthodontic treatment. Roberts et al.3), Miotti et al.24), and Parr et al.26) carried out experiments using the long tubular bone of rabbits, whereas Turley et al.7), Block et al.23), and Wehrbein et al.26) performed experiments using the median region of the palate and premolar region of the upper jaw in dogs and monkeys. In several other studies7),10,21,22), the premolar region of the mandible in dogs and monkeys was used as the implant site. However, in most of these reports, the implants used were of a conventional type having a diameter of 3-4 mm and a length of 5-10 mm, and they were used as prostheses for missing teeth. These conventional implants had the limitation of being implantable only at certain sites because of their size. Subsequently, the direction switched from the development of permanent implants used in the area of missing teeth to that of temporary implants used exclusively for orthodontic applications and which must be removed after functioning as an anchorage3,20).

At present, nearly all of the temporary implants used clinically on a routine basis are either of the
plate type or the small screw type, and numerous reports have been published describing their usefulness.17,20 Both the small screw type and plate type provide stability by being anchored to the bone with bone screws. After their use as orthodontic anchors, a second surgical procedure is required to remove them from the bone. Implants developed for use on a temporary basis have become increasingly smaller as compared with conventional implants for reasons such as reducing invasiveness into the bone, improving the degree of freedom in installation site selection, and reducing patient discomfort. However, the use of smaller implants has resulted in accidents stemming from breakage. Park22,34 suggested that, if a miniscrew implant that is close to a root broke within the bone, it is better to leave the bone because of the highly invasive surgery required for its removal. However, considering the likelihood of future medical problems, leaving a foreign object in the body is undesirable. Therefore, we decided to focus on the development of a bioabsorbable implant that does not require surgical removal. However, if accidents do occur, it requires only a minimally invasive surgery to remove the residual portions of the implant.

Orthodontic implants should satisfy the following criteria: 1) an initial strength capable of withstanding orthodontic force; 2) the ability to maintain that strength for a stipulated period; and 3) harmlessness to the body. Based on these criteria, high-strength PLLA screws were selected for use as orthodontic anchorage. Since an initial strength higher than the strength of the cortical bone can be obtained by secondary processing to semi-crystalline PLLA, we sought to investigate the possibility of using bioabsorbable, high-strength PLLA screws as anchorage for orthodontic treatment. The PLLA implant assessed had a mean molecular weight of about 200,000 and a low crystallinity of about 40-50%. According to the tensile test results, the mean initial strength was 14.75 kgf, which was believed to be sufficient for the immediate loading of orthodontic force. However, as the duration of implant installation increased, the breaking strength subsequently decreased. This was supposedly due to the bioabsorbable implant undergoing hydrolysis at random locations in its molecular chain at areas in contact with water (body fluids). This in turn caused a decrease in molecular weight, ultimately leading to a decrease in mechanical strength. However, the mean breaking strength of the 6-month group in which continuous orthodontic force was applied was 3.47 kgf, while that of the 6-month group in which no continuous orthodontic force was applied was 1.98 kgf, indicating that this implant could adequately withstand the orthodontic force generally used during orthodontic treatment. Matsusue et al.25-37 stated that the rate of decomposition of a bioabsorbable material is influenced by the environment inside the body, with the rate of decomposition being higher at sites having a good blood flow than at sites having a poor blood flow, and at sites subjected to a load as opposed to sites not subjected to a load; and that the difference is considerable depending on the shape and size of the material. In this study, there were no significant differences observed between the group in which continuous orthodontic force was not applied and the group in which it was applied. It is thought to be due to the load of only 100 gf for continuous orthodontic force, which was only 1/100 of the initial strength of the implant of about 15 kgf – thus making no impact in terms of physical properties.

In histological examination, large gaps were observed between the bone tissue and implant immediately after implant installation. However, these gaps decreased with time. Both bone occupancy rate and bone surface contact rate around the implant were significantly higher three months after installation than immediately after implantation. This was supposedly due to new bone formation. In addition, although a thin layer of fibrous soft tissue was present at the interface around the implant between cancellous bone and the implant in both the 3-month and 6-month groups, infiltration of inflammatory cells was not observed. Therefore, the high-strength PLLA screws used in this study were considered to have favorable biocompatibility. High-strength PLLA is inferior in terms of hydrophilicity at the crystalline phase. Thus, the early onset of side effects resulting from a local formation of excessive decomposition products did not occur. However, a sudden decrease in mass caused by phagocytosis is said to begin usually after 18 to 24 months.25-37 Therefore, there is a potential for rapid infiltration of inflammatory cells at that time, indicating a need for future research to investigate on long-term biocompatibility.

On one hand, it is desirable for implants to maintain adequate strength relative to the load of orthodontic force applied to the implants for as long as necessary during the orthodontic treatment. On the other hand, it is also desirable for the implants to decompose, be absorbed, and disappear after being used as anchors. On this note, further research is required to investigate an effective method for regulating the absorption of these bioabsorbable implants.

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