Abstract: This study aimed to show the effects of metal artifacts on the in vivo micro-CT of mini-implants by measuring bone volume. We drilled a hole in the cortical bone of a rat tibia and embedded a titanium orthodontic mini-implant (diameter, 1.5 mm) in the hole. Twelve individually weighed hydroxyapatite grains (HA grains) were placed around the implant either by one dentist (method 1) or separately by 12 dentists (method 2). In vivo micro-CT was used to scan the model after placement of each grain to measure increases and decreases in bone volume voxel number. The subtracted bone voxel volume increased with HA weight in both methods. Simple linear regression analysis showed a significant correlation between weight and volume in both methods (method 1: regression coefficient: 516.502, \( P < 0.05 \); method 2: regression coefficient: 4837.432, \( P < 0.05 \)). Metal artifacts did not appear to influence measurements of bone volume, although further studies are required to determine the effect of thicker implants. (J Oral Sci 54, 55-59, 2012)

Keywords: metal artifact; in vivo micro-CT; orthodontic mini-implant.

Introduction

Cone-beam computed tomography has been used to study orthodontic mini-implants and anchoring screws (1-6) and to provide measurements such as bone thickness, bone density, and bone volume. Micro-CT has been used for fundamental studies in several dental fields; however, the recent development of in vivo micro-CT (7) enables living subjects to be investigated. Although such in vivo studies have been conducted on experimental animals such as rats (8), the effects of metal artifacts have not been investigated.

If metal artifacts influence the bone around the mini-implant anchor, then the implant material has an important effect on errors in measuring bone thickness and volume. This study therefore examined the effect of metal artifacts on a mini-implant. Specifically, we assessed whether there was a detectable effect on measurements of bone volume by in vivo micro-CT.

Materials and Methods

In vivo micro-CT

We used in vivo micro-CT (R_mCT, Rigaku Co., Tokyo, Japan) for archiving image data (Fig. 1). The
microfocus X-ray tube had a minimum spot size of 7 μm. The voxel size was set at 30 × 30 × 30 μm, and scanning time was 2 min. The *in vivo* micro-CT operated at 90 kV and 150 μA. Projection data for a total of 512 frames were collected and reconstructed on I-View-R (J. Morita Mfg. Corp., Kyoto, Japan).

**Sample model procedure**

First, we prepared a sample consisting of a rat tibia containing a titanium mini-implant (Keisei Medical Industrial Co. Ltd., Tokyo, Japan). A hole 2.7 mm in diameter was drilled in the tibia, into which a 1.5-mm-diameter implant was embedded. Sufficient space was left around the implant for the addition of hydroxyapatite (HA) grains. The tibia was fixed in the plastic sample holder with acrylic resin, and water was added to the plastic sample holder to maintain tibia wetness (Fig. 2a–c).

**Study protocol**

The plastic holder containing the sample was placed on the object stage of the *in vivo* micro-CT device (Fig. 3), and 12 HA grains (Apaceram-AX; HOYA Co., Tokyo, Japan) were added to the space around the mini-implant.

To inspect the effect of HA distribution, the HA grains were added in two ways. In the first method, an experimenter weighed each HA grain, and the HA grains were then placed around the mini-implant, one at a time, by a single dentist (method 1). In the second method, an
experimenter weighed each HA grain, and 12 dentists placed one grain each around the mini-implant (method 2). In both methods, we scanned the model with in vivo micro-CT every time a grain was added (Fig. 4a–c). All volume image data were saved to a hard disk drive.

To determine the correlation coefficient between the weight of the HA grain and HA grain bone volume (bone volume numbers), we used BV-measuring software (Kitasenju Radist Dental Clinic, i-View Image Center, Tokyo, Japan) to calculate bone volume from the voxel measuring volume area ($3 \times 3 \times 2$ mm) (Fig. 5). We calculated number of voxels by subtracting voxel decrease from voxel increase, which yielded the bone volume voxel number (Fig. 6). We used automatic-alignment software to match the position of each data point.

Simple linear regression analysis was used to determine the correlation coefficient between HA weight and bone volume voxel number. The analysis was performed using SPSS for Windows (SPSS, Chicago, IL, USA).

Results

Table 1 lists HA weights and decreased, increased, and subtracted bone voxel volumes. The increased bone volume voxel numbers ranged from 17,905 to 81,759 for method 1, and from 27,866 to 78,277 for method 2.

The subtracted bone volume voxel numbers ranged from 6,529 to 72,121 for method 1, and from 10,723 to 61,446 for method 2. The HA weight difference ranged from 0.08 to 0.18 in method 1 and from 0.06 to 0.22 in method 2.

The value for subtracted bone voxel volume also increased with HA weight in both methods (Figs. 7a and b). In simple linear regression analysis, a significant correlation was observed between weight and volume for both methods (method 1: regression coefficient: 516.502, $P < 0.05$; method 2: regression coefficient: 4837.432, $P < 0.05$).

Discussion

We used in vivo micro-CT to evaluate the effect of metal artifacts on measurement of bone volume. In both
methods 1 and 2, bone volume voxel number was positively associated with weight of HA grains.

Bone volume voxel number did not perfectly fit the regression line because grains sometimes overlapped in the space around the implant, rather than being placed side-by-side. This overlap resulted in misalignment and the weight was different even though the size was identical.

Our findings indicate that errors are due to human factors and HA grain characteristics, not to the metal artifacts. Indeed, most orthodontic mini-implants are made from titanium, which is reported to have little effect on CT imaging (9,10). Therefore, we believe that the mini-implant material will not affect measurement of bone volume if in vivo micro-CT is conducted in the manner described in this study.

Our mini-implants were 1.5 mm in diameter; however, if the diameter were larger, it is possible that the metal artifact would surround the implant and affect the findings. Moreover, the slope of the regression line differed in graphs of methods 1 and 2. The difference represented an approximately 10% absolute error, and bone volume numbers measured on an implant of different size and under different scan conditions would reflect this difference. It is therefore important to conduct additional studies with implants of larger diameters to evaluate

Table 1  HA weight and bone volume voxel numbers

<table>
<thead>
<tr>
<th>N</th>
<th>HA grain cumulative weight (μg)</th>
<th>Method 1</th>
<th>Method 2</th>
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<tbody>
<tr>
<td></td>
<td></td>
<td>Bone Volume Voxel numbers</td>
<td>Bone volume voxel numbers</td>
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<tr>
<td></td>
<td>Decrease</td>
<td>Increase</td>
<td>Subtraction</td>
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<tr>
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<tr>
<td>12</td>
<td>1.63</td>
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Regression coefficient = 516.502, slope = 42694.87, \( r^2 = 0.995, P < 0.05 \)  
Regression coefficient = 4837.432, slope = 30560.11, \( r^2 = 0.962, P < 0.0 \)

Fig. 7  Relationship between bone volume (y-axis, number of voxels) and HA grain weight (x-axis, μg). (a) method 1, (b) method 2.
the effect of thicker metal artifacts on bone volume. The bone burr and bone dust must also be sufficiently removed from the mini-implant to ensure the accuracy of bone volume measurements.

Acknowledgments

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References