Original

Image Analysis of Lateral Alveolar Ridge Augmentation using Periosteal Distraction Osteogenesis

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(accepted for publication, December 9, 2013)

Abstract: The aim of this study was to evaluate a novel technique for inducing osteogenesis through original periosteal distraction in a canine mandible model. A periosteal distraction device was rigidly fixed to the mandible in three adult canines (i.e., six sides total). Two sides of 1 dog served as the control. In the experimental group, periosteal distraction was started 4 weeks after placement of the periosteal distraction device. The periosteum was distracted 0.5 mm per day until a height of 3 mm was reached. Distraction continued for 8 weeks. The animals were killed 14 weeks postoperatively. Radiographs were obtained after the devices were fitted and again after distracting the periosteum. Computed tomography (CT) was performed at weeks 1 and 8. Transverse images using OsiriX software were constructed based on the periosteal device to observe the amount of augmentation. Images over time were superimposed on the reference image using Photoshop software. It revealed the changes with time, which were measured. All 6 periosteal distraction devices remained rigidly fixed to the lateral surface of the mandibles. At completion of distraction, all operative sites had healed without evidence of infection or wound dehiscence. The amount of bone augmentation was calculated by comparing CT images. The experimental group showed increased width in the area of bone growth and in the bone itself on all six sides. Average increases were 0.7 mm in bone width and 3.31 mm in the area. Bone area and bone width were decreased slightly in the control group. There were significant differences between controls and the experimental group regarding bone width and bone area. We achieved bone augmentation using a custom-made periosteal distraction device. The amount of bone augmentation was calculated by comparing CT images.

Key words: Periosteal distraction, Lateral expansion, Animal models, Bone augmentation, Image analysis

Introduction

Various reconstructive techniques have been introduced for treating congenital, post-traumatic, or surgical mandibular and maxillary defects, including autogenous bone grafting and artificial bone alternatives combined with endosseous implants. Grafting can be done relatively easily to obtain stability. However, resorption of soft tissue at the autologous bone graft donor site is required. Alveolar distraction osteogenesis can be used for augmentation of the atrophic alveolar ridge. Alveolar distraction osteogenesis requires corticotomy or osteotomy, which is difficult to carry out in the thin, short alveolar ridge. Even though distraction osteogenesis can vertically augment the atrophic alveolar ridge, bone width is not improved because it is limited to extension in the vertical direction. Kostopoulos et al.¹ stated that when attempting bone augmentation by utilizing the mechanism by which mesenchymal stem cells present in the periosteum because of the tension load of the periosteum and differentiate into osteoblasts, there is only enough bone for periosteal distraction. Various experimental periosteal devices have been developed, but they are associated with a variety of problems, such as infection of the wound and the need to remove the periosteal device.

The purpose of this study was to develop a protocol that can lead to stable results based on considering radiologically the amount of newly formed bone.

Materials and Methods

Experimental model

In this experiment, 4 adult female canines (1-2 years old) weighing 10-15 kg were used as the animal model. Three of the animals (6 sides) comprised the experimental group, and 1 animal (2 sides) was used as the control. All experimental protocols were
Distraction device

The Cranio-maxillofacial Surgery Division at the University of Bern (Switzerland) developed the periosteal distraction device. A small plate and a large plate (12×10 mm in the vertical and horizontal planes) were connected by a titanium hinge (Fig. 1B). The small plate (Fig. 1A) was rigidly fixed to the lateral mandible with two titanium screws. The large plate (Fig. 1C) was fixed to the mandible by a center screw (Fig. 1D) mounted in the center of the large plate. By rotating the center screw, the large plate was gradually centered on a hinge (Fig. 1B) and raised from the surface of the bone. Rotation of the center screw resulted in distraction of the titanium mesh and periosteum away from the bone surface by 0.5 mm per rotation.

Anesthesia, bone atrophy, alveolar ridge formation and anesthesia: periosteal distraction device placement

The animals were first sedated with intraperitoneally administered sodium pentobarbital (30 mg/kg). Local anesthesia comprised 2% lidocaine hydrochloride 1:80,000 containing epinephrine. A single dose of antibiotic (penicillin potassium) was administered to prevent postoperative infection. Preoperative treatment consisted of extracting the first postmolar and fourth premolar of both sides of the lower jaw in four of the animals (eight sides). Alveolar bone atrophy was encouraged by removing a portion of the alveolar bone (about 5 mm of its height). Also, some of the buccal alveolar bone (about 3 mm thickness) was removed also to encourage atrophy (Fig. 2). For the experimental group (three animals, six sides), a 0.9-mm diameter titanium screw was used as the center screw in the periosteal device, which was fixed under the periosteum of the bone portion and was left there for 16 weeks (Fig. 3). The surgical areas were closed primarily. We performed these operations on both the left and right sides.

Periosteal distraction schedule

After a latency period of 4 weeks, the center screw of the periosteal device was exposed in the oral cavity. Distraction was increased by 0.5 mm once a day for 6 days. According to this schedule, by postoperative day 6 the periosteum would be distracted a total of 3 mm. Periosteal distraction was maintained for 8 weeks.

Image analysis study

Multi-slice computed tomography (CT) was undertaken (Asteion; Toshiba, Tokyo, Japan) with the animals under sedation 1 week after periosteal distraction and again at 8 weeks. The occlusal plane of each dog was set parallel to the CT table. The exposure conditions were 120 kV intratube voltage, 150 mA intratube current, and 0.5 mm thick slices. Coronal images with 0.5 mm slice thickness and 0.3 mm slice intervals were obtained directly. The diameter of the field of view was set at 100 mm. The pixel size was 0.195 mm. The two-dimensional reconstructed images required for image measurements were constructed using
three-dimensional image construction software (version 5; OsiriX, Geneva, Switzerland). In the experimental group, we obtained jawbone coronal images in four locations to accommodate the 2 mm distal, 2 mm mesial, and the mesial end of the center screw of the device (Fig. 4). In the control group, we obtained jawbone coronal images in four locations at 2-mm intervals in the centrifugal direction from the distal end of the third premolars. The amount of bone augmentation was measured based on periosteal distraction between the first week after placement of the device and that at 8 weeks. The CT images were binarized by 350 HU of the CT value using the Misch classification. The jawbone coronal images obtained were stored as a digital imaging and communication in medicine (DICOM) file. The images obtained 1 week after the start of periosteal distraction underwent reversal of the black and white layers using image editing software (Photoshop version 12.0; Adobe Systems, San Jose, CA, USA) in accordance with the method of Naito et al.2) Next, the images obtained 8 weeks after the start of periosteal distraction were opened as a separate layer and were superimposed in the same position on the basis of the control jawbone and third premolars (Fig. 5). The permeability of the two images was set at 50%. When the images were superimposed, areas that showed no changes in bone morphology were gray, areas with increased bone were white, and areas that indicated bone resorption were black.

In the experimental group, a region of interest (ROI) was chosen in the periosteal distraction portion, where the number of pixels in the white areas (bone growth) was counted. The bone growth area was then calculated by multiplying the area of one pixel (0.1952 mm²) by that number. In addition, the increase in bone width was measured as the maximum width of the bone surface of the white area. The same measurements were made in the control group.

### Results

All animals survived placement of the periosteal distraction device, which remained rigidly fixed to the lateral ramus for the entire experimental period. There was no dehiscence of soft tissue or exposure of the distraction at any of the sites. At the completion of distraction, all operative sites healed without evidence of infection.

In the control group, there were slight decreases in bone area and bone width between the measurements at 1 and 8 weeks after three-dimensional image construction software (version 5; OsiriX, Geneva, Switzerland). In the experimental group, we obtained jawbone coronal images in four locations to accommodate the 2 mm distal, 2 mm mesial, and the mesial end of the center screw of the device (Fig. 4). In the control group, we obtained jawbone coronal images in four locations at 2-mm intervals in the centrifugal direction from the distal end of the third premolars. The amount of bone augmentation was measured based on periosteal distraction between the first week after placement of the device and that at 8 weeks. The CT images were binarized by 350 HU of the CT value using the Misch classification. The jawbone coronal images obtained were stored as a digital imaging and communication in medicine (DICOM) file. The images obtained 1 week after the start of periosteal distraction underwent reversal of the black and white layers using image editing software (Photoshop version 12.0; Adobe Systems, San Jose, CA, USA) in accordance with the method of Naito et al.2) Next, the images obtained 8 weeks after the start of periosteal distraction were opened as a separate layer and were superimposed in the same position on the basis of the control jawbone and third premolars (Fig. 5). The permeability of the two images was set at 50%. When the images were superimposed, areas that showed no changes in bone morphology were gray, areas with increased bone were white, and areas that indicated bone resorption were black.

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Table 1. Measurement of amount of bone change in the control group

<table>
<thead>
<tr>
<th>Animal</th>
<th>side</th>
<th>Min to Max(mm²,mm)</th>
<th>Min to Max(mm²,mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Increase bone area, Increase bone width</td>
<td>Increase bone area, Increase bone width</td>
</tr>
<tr>
<td>control</td>
<td>Rigrt</td>
<td>-0.38 to -0.19, -0.20 to 0.00</td>
<td>-0.27, -0.1</td>
</tr>
<tr>
<td>control</td>
<td>Left</td>
<td>-0.38 to -0.27, -0.40 to 0.00</td>
<td>-0.34, -0.15</td>
</tr>
</tbody>
</table>

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Figure 5. Superimposed images
Site overlapping the computed tomography scans of 8 weeks after the start of periosteal distraction over those obtained at 1 week. Agreement is indicated by gray, increase in bone as white, decrease in bone by black.

Figure 6. Amounts of bone change in the control and experimental groups (p < 0.001)
the start of periostal distraction. The average decreases were 0.13 mm in bone width and 0.31 mm in bone area (Table 1). There was slight vertical resorption in the alveolar crest. In contrast, the experimental group showed an increase in the width of the area of bone growth and the bone itself on all six sides. The average increases were 0.7 mm in bone width and 3.31 mm in bone area (Table 2). Bone width and bone area were significantly different between the control and experimental groups according to the Mann–Whitney test and the t-test for each parameter (p < 0.001, Fig. 6).

### Discussion

Various proposals have been suggested for ridge reconstruction using atrophy and tooth removal in the maxillary and mandibular jaw. Endosseous implants in the atrophic alveolar ridge are often limited by the lack of alveolar bone height and width. Reconstruction of the atrophic jaw has been done with autogenous bone grafting and alveolar distraction osteogenesis. Autogenous bone grafting requires a donor site, and resorption is often a problem. Alveolar distraction osteogenesis requires corticotomy, which is difficult to perform in the thin alveolus and reduces the available alveolar bone. The native atrophic alveolar ridge is often knife-edged, so bone grafting may be required. It has been reported that overcorrection is needed because of postoperative bone resorption\(^{15}\). Fracture and dislocation of bone fragments and wound dehiscence have been reported\(^{16}\). In contrast, bone augmentation by periostal distraction has been successful in the mandible and skull of rabbits\(^{6,7}\) and in the forehead of pigs\(^{10}\).

Periosteum is generally described as a tissue consisting of two layers: (1) an outer, nonosteogenic, fibrous layer and (2) an inner, cellular, osteogenic (cambrium) layer\(^{9}\). Osteogenesis can be achieved by periostal distraction. This method obtains new bone tissue by using periostal mesenchymal stem cells that are capable of differentiating into osteoblasts\(^{1,10,11}\). Distraction osteogenesis is successful because under appropriate levels of stimulation periostal mesenchymal stem cells differentiate into osteoblasts and produce early subperiosteal callus within the osteotomized gap\(^{12,13}\). Kostopoulos et al.\(^{1}\) stated that tenting the periosteum on the lateral ramus after placement of a subperiosteal capsule is sufficient to produce significant amounts of subperiosteal bone and tension on the periosteum, which can lead to the production of subperiosteal bone. Schmidt et al.\(^{10}\) performed bone augmentation by periostal distraction with a custom-made periostal distraction device. They stated that controlled distraction of the periosteum is technically feasible, and generation of bone in situ through periostal distraction without corticotomy is theoretically ideal for producing small amounts of bone in the oral and maxillofacial region.

Bone augmentation by periostal distraction, however, presents various problems, which must be addressed if we are to obtain stable results. Our study was performed in canines, which are said to exhibit bone remodeling similar to that in humans\(^{15}\). Displacement of the periostal distraction device, wound dehiscence, and infection prevention.

In previous studies there have been problems with the protocol. Also, the shape and function to the periostal distraction device itself created problems. In the experiment of Schmidt et al.\(^{11}\) 1 of 10 devices was lost 24 hours after insertion. Device displacement was observed in 8 of 12 animals in studies using rabbit calvaria. Also, the rod of the periostal device was exposed in 10 of 16 (62.5%) devices in the canine mandibular branch in the experiment of Estrada et al.\(^{7}\) This exposure rate is comparable to the results of Hasse et al.\(^{16}\) in a study of canine animals that underwent mandibular distraction osteogenesis. Henkel et al.\(^{17}\) reported wound infection and dehiscence associated with horizontal alveolar distractions in 9 of 15 pigs.

Experiments have been conducted with periostal distraction devices using various protocols and animals. In many cases, it was not possible to obtain stability because of dehiscence, infection, wound problems, and the periostal device itself. Because the structure and organization size or device has been considered the cause of failure in some cases, we developed a small device that provides excellent stability and operability. In our study, the use of periostal devices in 6 sides (3 animals) was not associated with wound infection, displacement, or dehiscence of the mucosa, leading to consistently stable results.

Horizontal bone increase was observed for all 6 sides in our experiment. In contrast, slight bone resorption was observed in the control group. Schmidt et al.\(^{11}\) who studied the rabbit mandibular branch, reported that their bone augmentation averaged

<table>
<thead>
<tr>
<th>Animal</th>
<th>side</th>
<th>Min to Max(mm(^2),mm)</th>
<th>Mean(mm(^2),mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>Right</td>
<td>4.79 to 6.69, 0.59 to 1.17</td>
<td>5.49, 0.88</td>
</tr>
<tr>
<td>A</td>
<td>Left</td>
<td>2.47 to 3.23, 0.59 to 0.78</td>
<td>2.90, 0.64</td>
</tr>
<tr>
<td>B</td>
<td>Right</td>
<td>2.22 to 3.61, 0.20 to 0.59</td>
<td>3.04, 0.35</td>
</tr>
<tr>
<td>B</td>
<td>Left</td>
<td>0.59 to 1.86, 0.59 to 1.17</td>
<td>1.26, 0.83</td>
</tr>
<tr>
<td>C</td>
<td>Right</td>
<td>3.80 to 5.63, 0.40 to 0.98</td>
<td>4.55, 0.69</td>
</tr>
<tr>
<td>C</td>
<td>Left</td>
<td>2.40 to 2.78, 0.59 to 1.17</td>
<td>2.64, 0.78</td>
</tr>
</tbody>
</table>
2.9 mm, with 7.0 mm extension of the periosteum. Sencimen et al. also studying the rabbit mandibular branch, found an average increase of 14.4 mm² after bone distraction of 5 mm. Schmidt et al. and Sencimen et al. calculated the amount of bone augmentation in histological specimens. We calculated the amount of raw bone augmentation and compared it radiologically at the start of periosteal bone distraction and after treatment in the same individuals. The amount of increase is small because the experiment was carried out under conditions that would not normally occur in most cases with periosteal distraction. We consider the results realistic and more accurate than those in previous experiments.

Periosteal distraction operations have been conducted under various conditions, depending on the study. Estrada et al. tried two patterns: distraction of 0.5 mm/day and 0.25 mm/day. Kessler et al. compared the bone increase histologically over 10 days in the case of performing extension all at once or gradually at increments of 5 mm of extension by periosteal distraction, which allowed early bone formation. We also reported dense trabecular bone formation.

The presence of inflammation or bacterial infection is a negative factor that hinders the measurement of bone augmentation, as does dehiscence of the wound, which might be due to tension on the gingival flap. Also, after closing the wound, the amount of extension of the primary closed device was set at a total of 3.0 mm (0.5 mm/day) to avoid incurring dehiscence. As a result, we obtained good results without having any cases of dehiscence. The reduced periosteal distraction amount is also considered one of the reasons the bone increase was small.

Kessler et al. reported that there is no limit to the amount of bone augmentation that can be accomplished by dynamic periosteal distraction. It depends on the distraction width of the periosteal device. It also requires that the surgeon pay attention to the possibility of dehiscence if the distraction width is increased. There is no resorption of bone as is found with techniques that use autogenous bone. Thus, the risk of infection is less. We consider it necessary to continue to evaluate the periosteal distraction conditions with the goal of maintaining an advantage over distraction osteogenesis and autogenous bone graft. By taking such care, we plan to further increase the amount of bone periosteal distraction.

We have succeeded in performing bone augmentation in higher animals—in the oral cavity of dogs in this study. We calculated bone increase by radiological analysis and found an average increase of 0.7 mm. Generation of a few millimeters of alveolar bone height and width would allow endosseous implants in the case of an atrophic, edentulous jaw. The generation of bone in situ through a mechanism of periosteal distraction is theoretically ideal for producing small amounts of bone in the oral and maxillofacial regions. However, this theory cannot yet be stated as fact because there were significant differences in the amount of bone proliferation among individuals in our experiment, although the differences between the left and right sides in individuals themselves were the same. We believe that it is necessary to expand the amounts of periosteal distraction in the future to increase bone augmentation. It would make the procedure clinically useful.

Acknowledgements

The authors thank all the members of Department of Oral and Maxillofacial Surgery and Department of Oral Pathology, School of Dentistry, Aichi Gakuin University and radiology technicians of Aichi Gakuin University Dental Hospital for their help with the examinations.

References


