Experimental Alveolar Ridge Augmentation by Distraction Osteogenesis Using a Simple Device that Permits Secondary Implant Placement

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The purpose of this study was to develop an improved technique of alveolar ridge augmentation by distraction osteogenesis using distraction screws, and to investigate tissue reactions to titanium implants at the distraction site. The left mandibular premolars were extracted from 6 adult dogs. After 12 weeks, a box-shaped osteotomy of the alveolar bone was carried out, and distraction devices were placed on the transport and base segments. After a 7-day latency period, the alveolar bone was augmented by 7 mm vertically at a rate of 1.0 mm/day. Just after distraction, these devices were replaced with dental implants for fixation of the transport segment and bone formation of the distraction site. Histologic and radiographic evaluations were made at 8 and 12 weeks after distraction. Vertical augmentation averaged 6.1 mm after 12 weeks of consolidation. It was possible to lengthen the alveolar bone without great difficulty, and good bone formation was recognized in the distraction site. Greater integration between the implant and the distracted bone was observed at 12 weeks after distraction than at 8 weeks. Distraction osteogenesis was successfully applied to alveolar ridge augmentation by this improved technique, and the implants osseointegrated in the augmented ridge. (INT J ORAL MAXILLOFAC IMPLANTS 2000;15:95–102)

Key words: *alveolar ridge augmentation, dental implants, distraction osteogenesis*

Alveolar ridge augmentation (ARA) is a requisite pretreatment procedure for the correction of severely resorbed alveolar bone when prosthetic treatment is planned using a conventional or implant-supported prosthesis. Bone grafting,[1–3] guided bone regeneration (GBR),[4,5] and alloplastic materials[4–6] are currently used for ARA. However, the distraction osteogenesis procedure has also been established as a treatment modality for ARA.[7–11]

The concept of distraction osteogenesis was established by Ilizarov[12,13] in the field of orthopedic surgery. His research suggested that new bone formed parallel to the tension vector perpendicular to the bone's long axis during tibia widening using a modified apparatus for lateral distraction.[12] This result demonstrated the possibility of applying distraction osteogenesis to ARA. Distraction osteogenesis has the following advantages: no need for a donor site, no limit to lengthening, and simultaneous lengthening of the surrounding soft tissues, such as skin, muscle, blood vessels, and nerves. The disadvantages, however, include a long treatment period, need for a suitable distractor, and danger of infection.

Recently, distraction osteogenesis has also been applied to the lengthening and reconstruction of the maxillofacial region, and satisfactory experimental and clinical results have been reported.[7–11,14–25] However, studies on distraction osteogenesis for ARA are still rare.[7–11] Whereas a suitable distraction device generally requires space for manipulation and sufficient bone volume for connection to both the transport and base segments, the anatomic conditions surrounding the atrophic ridge preclude circumferential devices. A previous study[11] indicated the possibility of ARA by distraction osteogenesis using titanium implants. However, some problems

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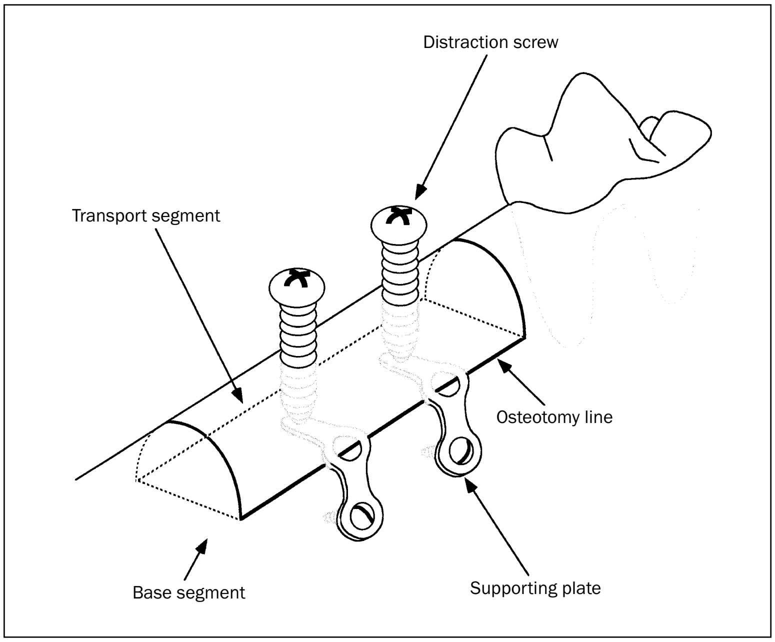


Fig 1 Schematic drawing of the distraction device and the operation. A box-shaped osteotomy of the atrophic alveolar bone was performed. The distraction devices consisted of a distraction screw and a supporting plate.

were revealed in that study. The most unpredictable problem was the risk that the titanium implants, which had contaminated surfaces, had to be placed into the bone segment. Therefore, the purpose of this study was to develop an improved technique of alveolar distraction using new devices, and to investigate the bone responses to titanium implants placed into the alveolar bone augmented by distraction.

MATERIALS AND METHODS

Animal Management

Six adult mongrel dogs served as the experimental subjects. Their weights ranged from 17 to 20 kg. The protocol and guidelines for this study were approved by the Institutional Animal Care and Use Review Committee of the Nagoya University School of Medicine, Nagoya, Japan. The animals were procured from the Nagoya University Experimental Animal Center. The preoperative and postoperative care of these animals was overseen by university veterinarians to ensure proper and humane treatment.

Approximately 1.5 mL of local anesthesia (1% lidocaine with epinephrine 0.01 mg/mL) was injected into the surgical sites. Surgery was carried out using intravenous general anesthesia with pentobarbital sodium (25 mg/kg), and the animals received approximately 300 mL of lactated Ringer's solution intravenously. Surgery was performed under aseptic conditions, and the animals received a prophylactic antibiotic, cefazolin sodium (20 mg/kg), intravenously, which was continued intramuscularly for 3 days postoperatively. The animals were fed a soft diet to reduce mechanical interference with wound healing after surgery.

Distraction Device

The distraction device consisted of a distraction screw and a supporting plate (Fig 1). The distraction screw was a specially designed, blunt-end, 18-8 stainless steel screw 15 mm in length and 3.0 mm in diameter. The supporting plate was a long-type miniplate with 4 holes and was cut off in the middle. Then, the cut ends were bent into an L shape and adjusted to fit the bone when actually applied.

Surgical Procedure

The procedure utilized in this study consisted of 5 steps: tooth extraction, osteotomy and device setting, bone lengthening at 1.0 mm/day for 7 days, device removal and implant placement, and fixation for 8 or 12 weeks. The animals were divided into 2 groups of 3 dogs each, which were allowed consolidation periods of 8 and 12 weeks, respectively, after distraction. In the first operation, the left mandibular premolars were extracted, and an alveoloplasty was performed to create an atrophic alveolar ridge (Fig 2a). After 12 weeks, following the alveolar crest incisions, a box-shaped osteotomy of the alveolar bone was performed, and the transport segment (5 × 30 mm) was constructed (Fig 2b). The procedure for preparing a box-shaped transport segment with distraction screws, instead of with a titanium

Fig 2 Serial photographs of operation and distraction.

Fig 2a Before operation.

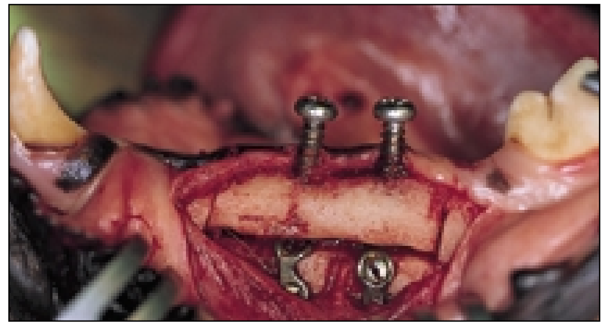


Fig 2b Osteotomy of alveolar bone and distraction device setting.

Fig 2c Before distraction. The upper portion of the distraction screws was exposed in the oral cavity.

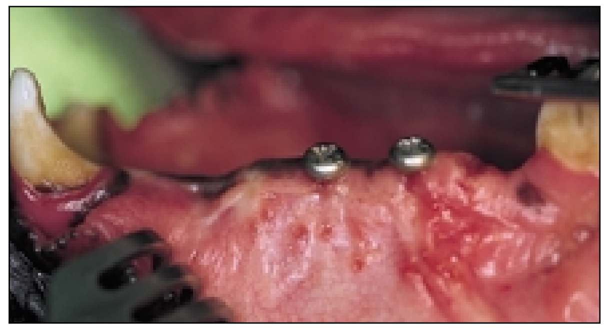


Fig 2d After distraction. Note the augmented alveolar ridge.

implant, is the same method described in detail in a previous study.[11] Two distraction screws were placed 5 mm into the transport alveolar segment, leaving 10 mm exposed. Furthermore, an osteotomy was completed as far as the lingual cortical bone after confirming initial fixation of the distraction screws. The mobility of the transport segment was confirmed. The supporting plates were secured with a self-tapping miniscrew in the base segment. They supported the distraction screws to prevent them from passing through the base segment (Figs 1 and 2b). The surgical wound was sutured with 3-0 silk. The crowns of the maxillary premolars were ground to reduce mechanical interference with the surgical sites from the opposing dentition.

Distraction Procedure and Implant Placement

The latency period used for periosteal healing and callus formation was 7 days, after which distraction was begun. Bone lengthening was achieved at a rate of 1.0 mm/day by turning the distraction screws 1 revolution. These screws were brushed with a solution of 0.5% chlorhexidine gluconate before tightening to prevent infection. It took 7 days to complete distraction, and a lengthening of 7 mm was achieved and confirmed by radiographs.

Fig 2e Twelve weeks after distraction. The augmented ridge was maintained by the implants. The cover screws were exposed in this case.

After distraction was completed, the distraction screws and supporting plates were removed, and the screw holes were enlarged with twist drills. The holes were then made with a countersink drill and a screw-tap. The depth used was equal to the sum of the height of the transport segment and the length of the distraction. To adequately secure the transport segment, a shallow countersink was made. Finally, the dental implants were placed in the screw hole sites for maintenance of the distraction gap and its integration with both the transport segment and the distracted bone under unloaded conditions. The implants were cylindric, threaded (0.6 mm in pitch), and 13 mm in length and 3.75 mm in diameter (standard threaded implant, 3i System, Implant Innovations, West Palm Beach, FL).

The animals underwent radiographic examinations at 0, 2, 4, 8, and 12 weeks after distraction. For evaluation of the vertical augmentation, the thickness of the transport segment was subtracted from the distance between the top of the transport segment and the inferior edge of the implants as observed radiographically. Clinical changes in the gingiva over the distraction area were examined.

Specimen Preparation and Analysis

Animals were sacrificed by an intravenous overdose of pentobarbital sodium 8 or 12 weeks after distraction. The implants, together with the surrounding bone and soft tissues, were removed en bloc. The specimens were fixed in 10% phosphate-buffered formalin, dehydrated in alcohol, and embedded in acrylic resin. The implants were cut midaxially in a buccolingual plane into 150-µm thick sections and subsequently ground to approximately 30-µm thick sections using an EXAKT Cutting Grinding System (EXAKT Apparatebau, Norderstedt, Germany). The specimens were stained with toluidine blue. The sections were studied and photographed using a light microscope, and their images were digitized by a Macintosh computer equipped with NIH Image version 1.61 image analysis program (National Institutes of Health, Bethesda, MD). For each thread of each implant, the area occupied by mineralized bone and the amount of bone-implant contact were calculated and expressed as a percentage of the total area and length of the thread. The following parameters were recorded for the buccal and lingual aspects of each implant:

1. Bone-implant contact with transport segment: Proportion of bone-to-implant contact from the top to the bottom of the transport segment
2. Bone-implant contact with distracted bone: Proportion of bone-to-implant contact in the distraction gap from the bottom of the transport segment to the top of the base segment
3. Bone area within transport segment: Proportion of bone area from the top to the bottom of the transport segment
4. Bone area within distracted bone: Proportion of bone area in the distraction gap from the bottom of the transport segment to the top of the base segment

RESULTS

Clinical Findings

All animals tolerated the procedures well. During the distraction period, 1 screw in 2 animals slipped off the supporting plate, resulting in a minor dislocation of the transport segment, but there were no problems with the host. During the experimental period, all animals were able to eat without any problems. Elevation of the transport segment was observed with the tightening of the distraction screws (Fig 2). No evidence of infection or breakdown of the soft tissues was observed. After distraction, no implants failed because of infection. With lengthening of the alveolar bone, the attached gingiva on the lingual side over the distraction site was also lengthened and appeared normal. The attached gingiva on the buccal side of the transport segment had moved upward, together with the transport segment, while the buccal alveolar mucosa over the distraction gap showed little change. The alveolar ridge appeared bone-like at 4 weeks after distraction. Six of 12 cover screws became exposed to the oral cavity during the consolidation period.

Radiographic Findings

Vertical augmentation averaged 6.83 ± 0.21 mm after the completion of distraction and 6.10 ± 0.53 mm after a 12-week consolidation period.

Lifting of the transport segment was radiographically observed with the turning of the distraction screws (Figs 3a and 3b). Radiolucency was still observable in the distraction gap at 4 weeks after distraction, but the radiopacity of the distraction site had increased gradually (Fig 3c). The radiograph showed considerable density in the distracted area after 8 weeks. There was little difference in bone density in the distraction gap between 8 and 12 weeks (Figs 3d and 3e). The anterior and posterior edges of the transport segment appeared to be smooth by the fourth week. A small amount of bone resorption was recognized in the transport segment.

Histologic Findings

The mean and standard deviations for the histomorphometric parameters for each group are as follows. Bone-implant contact with the transport segment averaged 46.0 ± 20.7% and 40.4 ±19.2%, and bone area within the transport segment averaged 76.8 ± 10.9% and 68.0 ± 11.3% at 8 weeks and 12 weeks, respectively. Bone-implant contact with the distracted bone averaged 15.7 ± 17.8% and 30.2 ± 19.1%, and bone area within the distracted bone averaged 39.3 ± 24.8% and 56.9 ± 30.5% at 8 weeks and 12 weeks, respectively. At 8 and 12 weeks after

Fig 3 Serial radiographs of the alveolar bone.

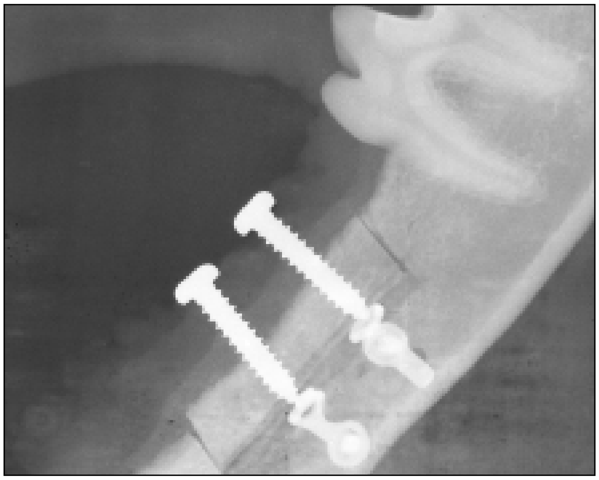


Fig 3a Lateral radiograph taken immediately after the osteotomy and the placement of distraction devices.

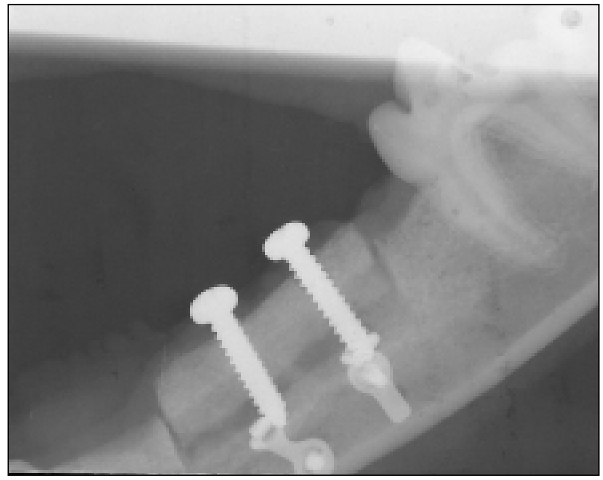


Fig 3b During distraction, the lengthened bone shows radiolucency, and lifting of the transport segment is observed. The anterior screw slipped off the plate in this case.

Fig 3c After distraction, the device was removed and dental implants were placed.

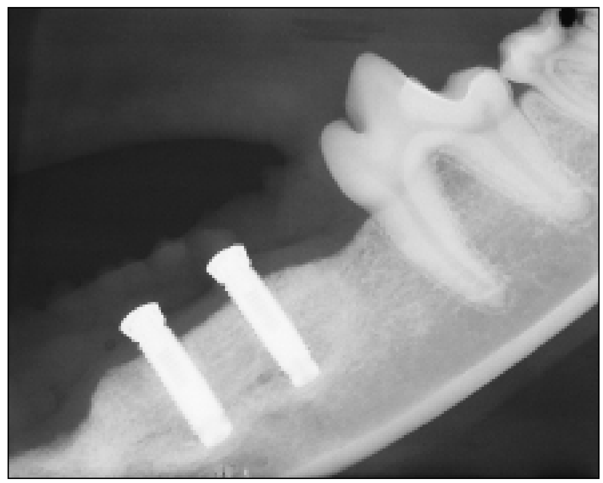


Fig 3d At 8 weeks after distraction, radiopacity of the distraction site increased, and the edge of the transport segment appeared to be smooth.

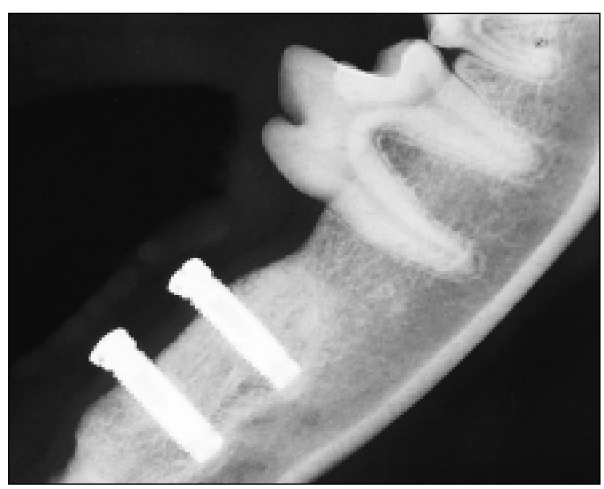
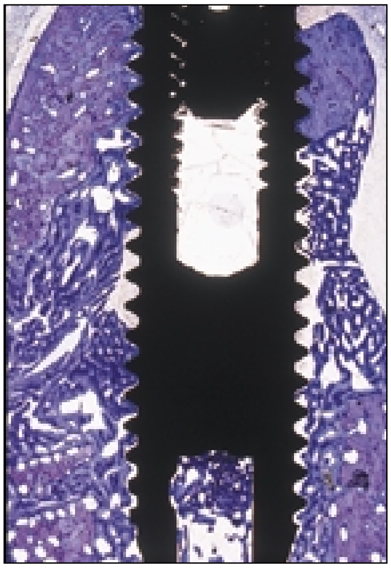


Fig 3e *(Right)* At 12 weeks after distraction. No remarkable change was seen compared with 8 weeks.



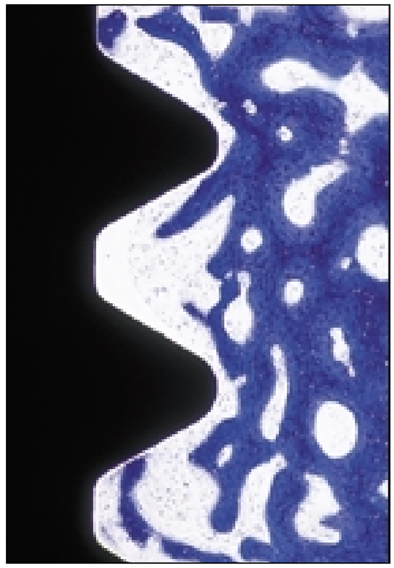
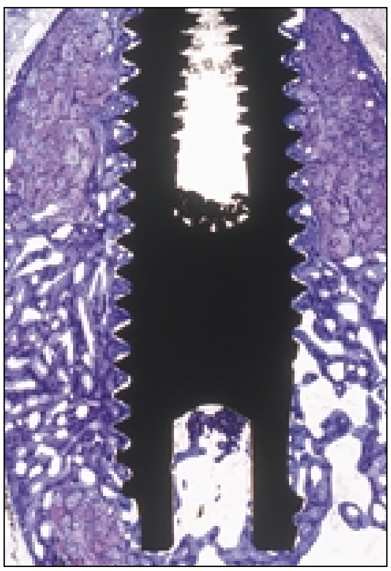


Fig 4a *(Left)* Photomicrograph of cross section of the mandible after 8 weeks. Integration between the implant and transport segment is observed (toluidine blue stain; original magnification ×1.6).

Fig 4b *(Right)* High-magnification view of the distracted area. Newly formed bone had not fully entered between the implant threads (toluidine blue stain; distance between thread peaks: 600 μm).



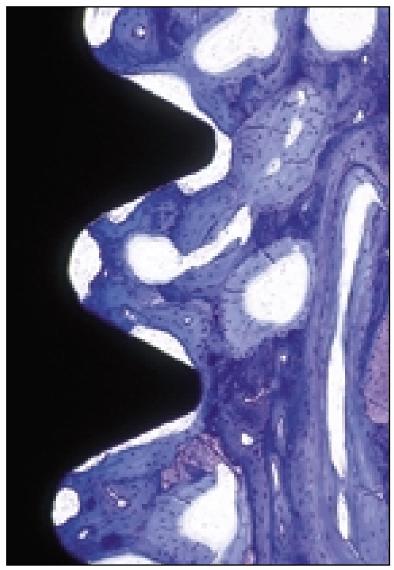


Fig 5a *(Left)* Photomicrograph of cross section of mandible after 12 weeks. Integration between the implant and transport segment is also observed (toluidine blue stain; original magnification ×1.6).

Fig 5b *(Right)* High-magnification view of the distracted area. Greater integration between the implant and the distracted bone is observed (toluidine blue stain; distance between thread peaks: 600 μm).

distraction, integration of the implants within the transport segment was observed. However, the bone-implant contact rate and bone area in the distracted bone were lower at 8 weeks than at 12 weeks after distraction. At 8 weeks after distraction, newly formed bone had not entered between the implant threads, but by 12 weeks, bone formation between the threads had increased (Figs 4 and 5). The amount of newly formed bone in the distracted area was larger on the lingual side than on the buccal side at 8 and 12 weeks. The regenerated bone did not show the maturity associated with cortical, spongy bone structure, but lamellar structure and bone remodeling were observed in the distraction site. A vertical orientation of the nutrient canals and cementing lines in the distracted area was also observed (Fig 5). The lower ends of the implants were confirmed to have sunk 0.67 ± 0.12 mm into the base segment. No difference between the lengthened and normally attached gingiva was observed histologically.

DISCUSSION

The application of distraction osteogenesis for lengthening and reconstruction has been accomplished in tubular bones as well as in jawbones. However, in most studies of distraction osteogenesis, the subject underwent osteodistraction parallel to the long axis of the bone, and there was not much bone widening. Nishimura et al[7] and Block et al[8,9] reported the potential of distraction osteogenesis for ARA in animal experiments. Chin and Toth[10] demonstrated clinical cases of alveolar distraction. A previous study[11] showed that distraction osteogenesis could be successfully performed by the simultaneous placement of implants. Nevertheless, the failure of implants due to infection was a disadvantage of that method. However, in this study, no implant failure was observed, because the polluted distraction screws were removed after completion of the procedure, and the infected bone was removed by enlarging the screw holes.

Ilizarov[12] demonstrated that stability of the distractor was necessary for sufficient bone formation. In the present study and in a previous study,[11] there was concern that the fixation of the transport and base segments would not be sufficient to achieve the desired distraction. However, this was not the case. The mucosa and periosteum around the transport and base segments appeared to provide enough stability. Two distraction screws slipped off the supporting plate and thus did not result in distraction. The distraction device in this experiment was only a prototype composed of different metal. Although metal corrosion was a concern because of the contact of 2 different metals, no trouble was observed, possibly because of the short period in which the device was in place. However, these potential problems will be resolved on improvement of the device.

Some relapse of distraction was observed with this experiment. It was thought to be caused mainly by bone resorption of the transport segment and distraction loss by sinking the implants into the cancellous bone of the base segment under masticatory pressure or tension from surrounding soft tissue. Some resorption of the transport segment could not be avoided because of the need to elevate the mucoperiosteal flap and to perform an osteotomy of the alveolar bone. To prevent the implant from sinking into the base segment, the supporting plate should be left after distraction and the implant placed on top of it.

In this experiment, half of the cover screws became exposed. It was thought that this was caused by the top of the implants projecting into the oral cavity, since the countersinks had to be sufficiently shallow to secure the transport segment.

Histomorphometric findings revealed that integration between the bone and the implant in the distracted area was greater at 12 weeks than at 8 weeks. This result suggests that implants placed just after distraction should preferably not be exposed to a masticatory load until the 12th week. Most studies[7–9,11,20,21] of distraction osteogenesis have shown that greater bone formation was seen in the lingual distracted site than in the buccal site. In this study, the same phenomenon was also observed. It was thought that new bone formation on the buccal side was less than on the lingual side as a result of the damage to the surrounding tissue from the operation (ie, incision, flap detachment, and osteotomy), particularly the periosteum.

CONCLUSION

Alveolar ridge augmentation was carried out by distraction osteogenesis without major difficulty using an improved technique. The implants osseointegrated in the augmented ridge, and the integration between implants and regenerated bone was better at 12 weeks after distraction than at 8 weeks after distraction.

ACKNOWLEDGMENTS

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