Distraction Osteogenesis Versus Autogenous Onlay Grafting. Part I: Outcome of Implant Integration

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Purpose: *The primary goal of this study was to compare bone-to-implant contact (BIC) in alveolar bone augmented by distraction osteogenesis with BIC in alveolar bone augmented by onlay iliac crest grafting.* ***Materials and Methods:*** *Alveolar bone defects were created bilaterally in 5 American foxhounds, and after healing, bone augmentation was accomplished using distraction osteogenesis on 1 side of the jaw and onlay grafting on the other. Twelve weeks after consolidation, implants were placed in augmented and control sites. The animals were sacrificed and the jaws harvested for histologic analysis after an additional 8 weeks.* ***Results:*** *The mean BIC was 54.7% ± 14.6% for implants placed in distracted sites, 53.8% ± 11.8% for sites where an onlay graft was used, and 51.2% ± 14.4% for control sites. Significant differences in BIC were noted between experimental and control sites only at the apical third of the implant (19.8 ± 1.8 for distracted sites; 15.5 ± 1.5 for grafted sites; 8.0 ± 0.5 for control sites;* $P < .05$*).* ***Discussion:*** *The data showed that both distraction osteogenesis and onlay grafting produce sufficient bone for implant placement. There were no differences between procedures in regard to BIC after 8 weeks.* ***Conclusion:*** *These data suggest that both onlay grafting and vertical distraction are appropriate methods for bone augmentation prior to implant placement.* Int J Oral Maxillofac Implants 2005;20:695–702

Key words: *bone augmentation, distraction osteogenesis, implants, onlay grafts*

A major contraindication to the placement of dental implants is inadequate volume and integrity of bone at the chosen site. Patients with inadequate bone height and width or poor quality of bone in the mandible will require augmentative bone grafts prior to placement of dental implants.[1,2] These secondary procedures often involve the use of alloplastic bone substitutes or the harvesting of autogenous bone from a secondary site within the oral cavity. In cases where larger amounts of bone are required, autogenous bone may need to be taken from sites such as the iliac crest, tibia, or rib.[3,4] Repositioning of the inferior alveolar nerve may also be necessary in some patients.

These procedures are associated with morbidity, such as pain and altered function at the donor site, and altered nerve function secondary to nerve manipulation, including anesthesia, paresthesia, and dysesthesia. To avoid pain and other possible sequelae associated with autogenous grafting, vertical ridge augmentation has been attempted using autogenous bone chips[5] and demineralized freeze-dried bone allograft particles.[6] Both grafting materials have been used under resorbable[7] and nonre-

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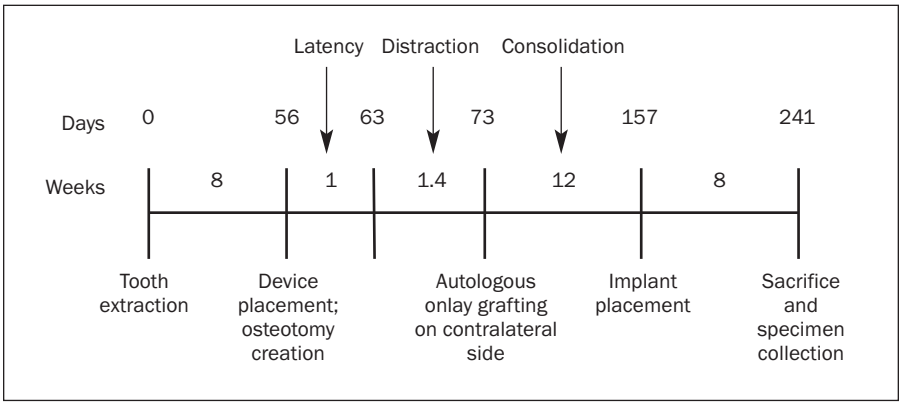

Fig 1 Schematic representation of the experimental protocol.

sorbable membranes.[8] These procedures, while less invasive than previous autogenous grafting techniques, have had variable results and limitations such as inadequate flap adaptation, inability of the bone material to withstand the overlying soft tissue pressure,[9] and poor quality of the regenerated bone, with limited vertical augmentation. Finally, augmentation of the alveolus has been attempted using "tenting procedures." For this technique, implants were placed so that they protruded occlusally from the bone crest.[6,8,10–12] These implants were grafted using autogenous and alloplastic bone chips under membranes and were allowed to heal for 12 months. Once again, problems such as exposure of the membrane and grafted bone chips led to resorption of the regenerated bone and ultimate failure to achieve desired vertical ridge augmentation.

A procedure that allows for augmentation of the implant site without the need for bone graft material from a secondary donor site or augmentative grafting is needed. The application of the technique of distraction osteogenesis[13] to the augmentation of the dental implant site would be a beneficial alternative in this regard. Distraction osteogenesis has been used for ridge augmentation,[14,15] but the techniques of onlay grafting and distraction osteogenesis for implant placement have not been compared in the same study. The primary goal of this study was to compare the integrity and rate of implant integration in alveolar bone augmented by distraction osteogenesis with that of bone augmented by onlay iliac crest grafts. This study could lead to a better understanding of the ability to treat patients by additional surgical options with less morbidity. A dog model was utilized to study the differences in osseointegration and in osseous density between cases where implants were placed into onlay grafted bone and those where implants were placed in distracted bone. The authors hoped to gain insight into the biologic processes that influence new bone formation at implant placement sites.

MATERIALS AND METHODS

Animal Model

Five adult male American foxhound dogs weighing between 25 and 30 kg were used in the study according to a protocol approved by the Institutional Animal Care and Use Committee at Baylor College of Dentistry. Animals were quarantined for an acclimation period of 10 days. At the beginning of the first phase, each dog was weighed and tagged with a numbered collar for identification purposes.

The study was performed in 3 phases (Fig 1). In the first phase, simulation of atrophic ridge, bilateral extraction of the mandibular premolars and second and third molars was performed in all 5 dogs. The first molars were left to maintain occlusal stability. Eight weeks were allowed for healing of the mandibular ridge. In the second phase, the augmentation phase, distraction osteogenesis was performed on the left side of each mandible and autogenous onlay grafting was performed on the right side. Twelve weeks of consolidation were allowed for the augmentation phase. In the third phase, 8 endosseous implants were placed in each dog. Eight weeks were allowed for osseointegration prior to sacrifice and collection of the specimens.

Surgical Procedure: Preparation of Atrophic Ridge

At each phase, anesthesia was induced with ketamine HCl (20 mg/kg; Wyeth/Fort Dodge Animal Health, Overland Park, KS) and xylazine (2 mg/kg; Ben Venue Laboratories, Bedford, OH) injected intramuscularly. After intubation, general anesthesia was maintained with a mixture of 2% halothane and oxygen at a rate of 1 L/min. The general anesthetic was delivered and monitored under the supervision of an experienced animal technician.

For all phases, after the induction of general anesthesia, a local anesthetic (2 to 4 mL of 2% lidocaine HCl with 1:100,000 epinephrine) was administered at

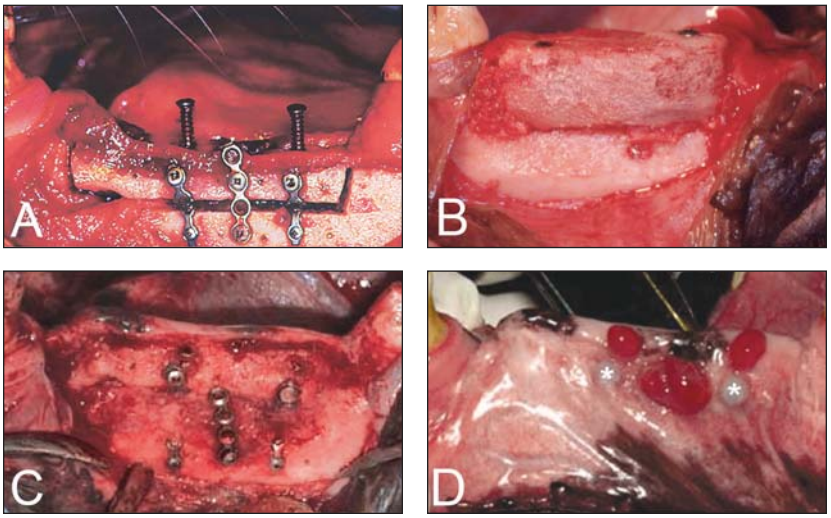

Fig 2 *Photographs of the alveolar ridges of the dogs during ridge augmentation.*

Fig 2a An alveolar ridge is shown with the distraction device holding the transport segment in place prior to the latency period.

Fig 2b An alveolar ridge with onlay graft placed and held in position with 2 screws.

Fig 2c An alveolar ridge shown after completion of distraction, just prior to implant placement, with new bone visible below the transport segment.

Fig 2d Buccal surface of the alveolar ridge. Erythematous and edematous tissue can be seen. Screw heads are designated by asterisks.

the surgical site, and a full-thickness mucoperiosteal flap was reflected to allow for surgical sectioning of the teeth. All mandibular premolars, as well as the second and third molars, were sectioned to the root furcation level using high-speed carbide burs under constant saline irrigation. Each tooth was then individually removed with minimal trauma.

The bone segment from the distal edge of the canine to the mesial edge of the first molar was then prepared using an oscillating saw (Walter Lorentz, Jacksonville, FL). Vertical cuts, 1 distal to the canine and the other mesial to the first molar, were made through the alveolus to a depth of 10 mm. A horizontal osteotomy cut was then made connecting these vertical cuts, and an alveolar segment was removed. The flaps were repositioned and closed with a 4-0 silk suture to ensure complete coverage of the alveolar bone.

Postoperatively, for all phases, the animals received a mixture of penicillin G procaine and penicillin G benzathine (300,000 units/mL) in a dose of 1 mL/5 kg of body weight intramuscularly. This dose was repeated after 48 hours. Ibuprofen (10 mg/kg) was administered by mouth twice daily for 2 to 3 days, and the animals were placed on a soft-food diet until completion of the study. After a healing period of 8 weeks, the augmentation phase was initiated.

Surgical Procedure: Augmentation Phase

In the augmentation phase, the left side of the mandible was augmented using distraction osteogenesis, while the right side was augmented with an onlay graft placed at the beginning of the consolidation phase of the distracted left side.

Left Side—Distraction Osteogenesis. All 5 dogs were premedicated and anesthetized using the protocol described previously. Following flap resection as before, and preserving the mandibular nerve, vertical osteotomies were performed from approximately 5 mm posterior to the canine to approximately 5 mm anterior to the first molar. Care was taken not to extend the cuts through to the lingual tissue.

Taking similar care, the vertical osteotomies were connected using a horizontal osteotomy 5 mm from the crest to maintain a 5-mm-thick transport segment. Although the mandibles of the dogs were of different heights, it was not necessary to laterally reposition any nerves. The distraction device was designed to promote vertical distraction of 10 mm (Fig 2). Two 2.0-mm-diameter 3-hole bone plates were attached to the transport segment and secured using 4-mm-long screws. Two 1.5-mm 3-hole bone plates were aligned below the 2-mm bone plates and attached to the mandible using 4-mm-long screws. Next, two 15 × 2.0-mm screws were placed to approximate the inferior plates. Because the 1.5-mm plates were used inferiorly, the 2.0-mm screws could not engage or penetrate the inferior plate and thus elevate the transport segment upon turning. Finally, a 2.0-mm-diameter 4-hole stabilization plate was attached to the mandible and transport segment. This plate would also serve to guide the distraction process in a vertical direction.

The intramuscular administration of procaine and penicillin G benzathine (300,000 units/mL) in a dose of 1 mL/5 kg of body weight was repeated after 48 hours. Ibuprofen (10 mg/kg; Advil; Whitehall-Robins Healthcare, Madison, NJ) was also administered orally twice a day for 2 to 3 days. Chlorhexidine digluconate (0.12% diluted in water) was used twice a day until sutures were removed at 7 to 10 days.

After a latency period of 7 days, the superior screw of the stabilization plate was removed from the transport segment. Activation of the devices began

at a rate of 0.5 mm twice a day for 10 days by turning the bone screws 1.5 times in a clockwise direction. At the time of consolidation, the second part of the augmentation phase, onlay grafting was performed.

Right Side—Autogenous Onlay Graft. The dogs were premedicated and anesthetized using the protocol described. Block grafts measuring 45 mm long, 10 mm high, and 8 mm wide were harvested from the right iliac crest. The recipient site, the right hemimandible between the canine and first molar, was prepared by making a longitudinal incision in the buccal vestibule approximately 2 cm from the alveolar crest. The block graft was then placed into the defect to ensure a snug fit and secured using 15-mm-long bone screws (Stryker, Kalamazoo, MI). A mucoperiosteal flap was then elevated over the crest of the graft and residual ridge.

Onlay grafting effectively augmented the ridge 10 mm in height. Tissues were closed using 4-0 silk sutures. The postoperative regimen was the same as described for the previous surgical procedures. Following the consolidation period, the last phase, implant placement, was initiated.

Bilateral Implant Placement

The final phase was begun after 12 weeks of consolidation of the distracted and grafted sides. For this phase, all 5 dogs were premedicated and anesthetized using the same protocol described previously. An alveolar crestal incision was made, and full-thickness mucoperiosteal flaps were elevated to expose the sites for implant placement. The osteotomy sites were prepared using a 2.2-mm twist drill to a depth of 12 mm. Then, 2.8-mm and 3.5-mm twist drills were used to a depth of 12 mm. Sandblasted, large-grit, acid-etched solid screw-type implants (SLA; Straumann, Waldenburg, Switzerland) 4.1 mm in diameter and 12 mm long were placed using the ITI ratchet and insertion device apparatus (Straumann). The implants were covered with a 2-mm closure screw. Each dog received 8 implants (3 implants in the augmented sites and 1 implant in the control site bilaterally). The flaps were closed with silk sutures in a stage-1 approach.

Specimen Collection

At the time of specimen collection, animals were anesthetized with 20 mg/kg ketamine HCl and 2 mg/kg xylazine administered intramuscularly. Anesthesia induction was followed by the administration of a mixture of 390 mg/mL phenobarbital sodium and 50 mg/mL phenytoin sodium (Beuthenasia-D; Schering-Plough, Kenilworth, NJ) at a dose of 1 mL/5 kg. The dogs were perfused with 4% paraformaldehyde at less than systolic pressure through the carotid arteries. The mandible was removed en bloc using a bone saw (Stryker), and blocks containing individual implants surrounded by alveolar bone were prepared and stored in numbered vials containing perfusion solution.

Preparation of Undecalcified Specimens

Mandibular sections containing implants were left in 10% buffered formalin for 7 to 10 days. Specimens were dehydrated using a series of graded ethanols and were placed into embedding molds containing methylmethacrylate resin to cure at room temperature for 2 to 3 weeks. The blocks were serially sectioned parallel to the long axis of the implant in a buccolingual direction. Sectioning was performed using a low-speed diamond blade saw (Isomet; Buehler, Lake Bluff, IL) under constant irrigation to produce tissue-implant sections 0.5 mm thick. These were reduced to 30 to 50 μm in thickness using petrographic grinding techniques on a roll grinder containing sandpaper of decreasing grit size (Isomet; Buehler). The cut surface was mounted on a microscopic slide with epoxy-resin, polished, and stained with Stevenel's blue. The sections were evaluated using the MetaMorph imaging system (Universal Imaging, West Chester, PA).

Measurement of Bone-Implant Contact

The counterstained slides were scanned using an Epson Expression 1600 (Seiko Epson, Nagano, Japan) flatbed scanner at a resolution of 600 dpi and saved as TIFF files. These images were then evaluated using MetaMorph. The entire implant surface was traced using the appropriate MetaMorph tools. This information was then converted to a spreadsheet. The image was evaluated for direct bone-to-implant contact (BIC). The tracing tools in the Metamorph system allowed for BIC of various segments to be measured and recorded in a spreadsheet. These distances were then totaled and divided by the total distance of the entire implant, which was recorded as a percentage. After the initial percentage of BIC was determined and statistically analyzed, the implants were re-evaluated by dividing them into upper (coronal), middle, and lower (apical) thirds. The same methods were used to evaluate and record percent BIC. These data were also evaluated for differences among the upper, middle, and lower thirds in regard to BIC.

RESULTS

In 1 of the dogs, the distraction segment appeared fenestrated, but in the remaining dogs, the implants became well integrated in the augmented or dis-

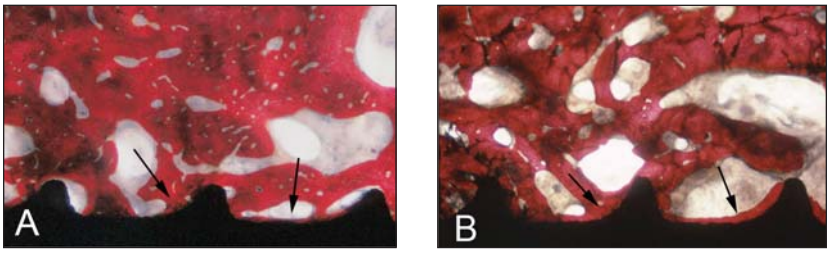

Fig 3 Micrographs of histologic sections showing undecalcified sections of bone tissue and implants. In *(a)* the bone was augmented by distraction osteogenesis; onlay grafting was used in the case shown in *(b)*. The mineralized bone appears red and the titanium implant appears black. The white areas are spaces between trabeculae of newly formed bone. Note the close contact between the mineralized bone and the implant surface *(arrows)*.

tracted bone (Fig 3). There was no apparent collapse of the bone around the implant in either the distracted or the onlay grafted bone. The BIC for each implant and each dog is given in Table 1. The mean BIC (± SD) for implants placed in the distracted sites was 54.7% ± 14.6%; for the onlay grafted sites 53.8% ± 11.8%; and for the control sites 51.2% ± 14.4%. There was no statistically significant differences between the 3 groups in overall BIC ($P > .05$).

The upper, middle, and lower thirds of the implants were also evaluated to determine whether a difference in BIC existed at different depths into the augmented bone. The BIC in each third was calculated as a percentage of total BIC contact for each implant (Table 2). Differences in percent BIC from these latter measurements compared to the measurements of whole implants (Table 2) reflect differences in scoring whole implants versus scoring regions of implants. Evaluation of upper, middle, and lower thirds using 1-way analysis of variance (ANOVA) and the post-hoc Tukey test revealed a statistically significant difference ($P < .05$) in the percent BIC for the lower third in the control group compared to the other groups (Table 2). To determine whether a difference existed between the percent BIC in distracted sites versus the onlay graft sites, a Student t test was used. No significant differences between the 2 experimental groups were found for upper, middle, or lower third.

Table 1 Percent BIC

Dog/ type	Implant 1	2	3	Control
1				
Distracted	79.2	66.6	56.1	67.7
Onlay	58.5	65.6	72.9	53.4
2				
Distracted	60.1	50.3	51.7	41.9
Onlay	50.2	41.6	36.2	34.2
3				
Distracted	42.0	45.6	60.7	52.2
Onlay	53.3	49.1	50.3	53.0
4				
Distracted	58.7	33.3	71.4	35.5
Onlay	57.4	77.4	57.5	41.6
5				
Distracted	37.4	33.2	74.2	80.8
Onlay	37.4	46.0	53.0	51.4

Table 2 Percent BIC for the Upper, Middle, and Lower Thirds of Implants (Mean ± SE)

	Distracted	Grafted	Control
Upper	20.52 ± 1.79	20.67 ± 1.79	19.09 ± 1.45
Middle	19.08 ± 1.42	15.69 ± 1.29	16.34 ± 0.99
Lower	19.78 ± 1.76	15.46 ± 1.50	8.00 ± 0.47*

*The control group differed significantly from the experimental groups in this region ($P < .05$; ANOVA with post-hoc Tukey test).

DISCUSSION

The placement of dental implants requires sufficient quality and quantity of bone and soft tissue. Distraction osteogenesis provides an alternative method for the augmentation of bone and soft tissue that is similar in quality to the existing tissues. Present bone grafting techniques require harvesting bone from secondary sites, adding to potential surgical risks. Distraction osteogenesis allows for the augmentation of the alveolar ridge without a secondary donor site.

This study simulated atrophic ridges bilaterally in the mandible using the canine model by surgically resecting defined segments of the alveolar ridge. Augmentation was performed using iliac crest onlay grafts or distraction osteogenesis, and dental implants were successfully placed and integrated into both grafted and distracted bone based on clinical and histomorphometric analysis. Integration of implants placed into augmented sites was equal to that of the control sites, and there was no difference in integration between the grafted and distracted sites.

Fresh autogenous bone grafts heal in a fashion similar to fractures, and distraction osteogenesis is essentially a controlled fracture. In both augmentation procedures, bone healing follows normal fracture healing patterns. In bone transplants such as onlay grafts, osteocytes of the compact bone must rely on the functioning capillaries that are close enough to the remaining living osteocytes for func-

tion. However, the osteogenic cells of the periosteum and endosteum are more likely to be sufficiently bathed in tissue fluid to survive than the osteocytes within the transplant. The portion of the bone that does not survive is not necessarily completely lost, as new bone is deposited on dead bone, and becomes firmly cemented to it. Resorption of non-vital bone subsequently occurs on the outer surfaces of the transplant between trabeculae of new bone. Compact bone grafts may be considered preferable to cancellous bone grafts, since the surface cells can be easily bathed in tissue fluid. However, the canalicular mechanism is so inefficient that most of the bone cells of the trabeculae die, resulting in compact bone graft resorption. Cancellous portions of bone grafts serve a very useful purpose in recipient sites—they stimulate the osteogenic cells, osteoblasts, and undifferentiated marrow cells of the host bone to grow into their midst and lay down bone on their surfaces.[16] Cancellous bone revascularizes much more quickly than the cortical bone grafts; however, cortical bone is much stronger.[17] The ideal graft has cancellous and cortical bone.[18] The combination of cortical and cancellous bone in grafts promotes early vascularization and maximum graft maintenance. This study utilized a corticocancellous bone graft to maximize the benefits of the compact and cancellous portions of the onlay graft.

Sykaras and associates[19] described the ability to accurately assess the bone-to-implant interface as being of paramount importance for the clinical evaluation of implant function. They used standardized periapical radiographs and compared them to histomorphometric data acquired from undecalcified sections of bone and implant together to provide information on their diagnostic potential. Statistically significant differences were found between the 2 methods, with radiographic evaluation demonstrating a tendency for overestimation of the actual BIC.

Histomorphometric analysis can be performed in different ways.[20–22] These various methods take various parameters into consideration and result in a wide spectrum of reported values. Implant length, implant diameter, design, material, and surface topography, along with implantation time, site, loading conditions, analyzed length, and specimen thickness are factors that affect histomorphometric results.[9] It has been shown that no significant differences exist for the total BIC in specimens that are prepared for sectioning in the transverse or longitudinal direction.[23]

Because of the increased demand for earlier placement and loading of dental implants, implant companies have developed different surfaces and characteristics to enhance osseointegration. It has been suggested that the implants used for this study, SLA Straumann implants, can become integrated within 6 to 8 weeks in ideal situations. Buser and colleagues[24] tested the removal torque values of titanium implants in the maxillae of miniature pigs. They found that implants with a sandblasted and acid-etched surface could integrate at a faster rate compared to implants with Osseotite and machined surfaces. Cochran and coworkers[25] evaluated the effect of the SLA surface in the canine mandible radiographically and found that this surface appeared to promote greater osseous contact at earlier time points compared to titanium plasma sprayed implants. Sykaras and associates[9] also found increasing percentages of BIC at 2, 4, 8, and 12 weeks. It seemed reasonable, therefore, to evaluate the osseointegration in the augmented sites at 8 weeks postimplantation.

A few quantitative histomorphometric investigations have suggested that osseointegrated implants can be apposed by as little as 35% bone.[26] A study by Lazzara and colleagues[27] revealed a percent BIC in the 50th percentile for all treatment groups; however, increased percent BIC was expected over time. Ericsson and associates[28] reported a 50% increase in BIC from 6 to 12 weeks when using implants with a roughened surface. One of the caveats in the evaluation of implants is the lack of standardization for osseointegration based on the implant surface, manufacturer, and histomorphometric techniques. The present study revealed that at 8 weeks all treatment groups appeared to have similar levels of osseointegration. This suggests that integration was completed and that the bone surrounding the implants was in a remodeling phase.

A significant difference was found in this study when the BIC values in the upper, middle, and lower regions of the implants were compared. The lower third of the control implant was found to have significantly less BIC compared to the lower thirds for both treatment groups. There are several possible reasons for this result. The control site was located in the second and third molar region, which may have resulted in a more cancellous bony housing as the extraction sites healed. Also, the augmented sites may have healed with a denser cortical pattern compared to the control site. The time of specimen collection must also be considered. The difference in percent BIC might have changed had the osseointegration period been extended. The examination of static time points during osseointegration is 1 problem of comparing the histologic results of dental implant studies.

The rationale for placing implants in the distracted bone at the end of the consolidation period was twofold. A consolidation period had to be

allowed before implants could be placed in the onlay-grafted bone; placing implants in the distracted bone at the same time allowed comparison of the 2 groups. It also allowed the comparison of the degree of integration of implants in both distracted and onlay sites that were being actively remodeled. Given that the implants became equally well integrated in both distracted bone and onlay grafted bone, it will now be worthwhile to attempt to place implants in distracted bone at the onset of the consolidation period. Further research is required to determine whether implants can be placed into distracted bone at earlier time points than those used in this study, which are earlier than the time points routinely used for implant placement in onlay grafted bone.

CONCLUSION

In conclusion, vertical augmentation of simulated atrophic ridges can be successfully achieved in the canine model using either distraction osteogenesis or onlay grafting. Implant placement and successful osseointegration in sites augmented by distraction osteogenesis and onlay graft were comparable in this investigation. No significant differences in overall BIC existed for implants placed into augmented sites using distraction osteogenesis or onlay graft compared to control sites. However, a statistically significant difference was found for the apical third of the control implants compared to experimental implants. The difference in integration in the apical third may be the result of greater bone density in the healed extraction socket than in the augmented sites.

Future studies are needed to evaluate the mineral apposition rate for onlay grafts and vertical distraction osteogenesis. If the mineral apposition rates were established for both methods of augmentation, the optimal time for implant placement could be determined using these rates. It will also be important to do a variety of pull-out and torsion tests to determine whether the degree of bony integration seen by histology translates into a clinically stable implant site. The present study provides new information comparing onlay graft and distraction osteogenesis, as the 2 techniques have not previously been compared in a single study. However, more information is needed regarding the remodeling characteristics of peri-implant bone to provide the clinician with information on the successful placement of dental implants into augmented sites.

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