The Influence of Different Graft Designs of Intraoral Bone Blocks on Volume Gain in Bone Augmentation Procedures: An In Vitro Study

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Purpose: Intraoral bone blocks from the external oblique are the gold standard for alveolar ridge bone grafting, but the limited amount of available bone limits their use for larger defects. The objective of this study was to compare whether different graft designs of intraoral bone blocks could affect the amount of bone gain. Materials and Methods: In this in vitro study, 20 pig jaws were used to harvest bone blocks and subsequently augment single-wall bone defects. Each bone graft was first used as a full block, and then the same block was divided lengthwise into two blocks, with one block fixed at a distance as a cortical shell and the second block particulated to fill the gap between graft and bone. Three stereolithographic (STL) files (pre-OP, full block, split block) were generated using an intraoral scanner. All STL files were evaluated for volume gain and horizontal bone dimensions. Results: A mean volume gain of 0.36 cm² (SD: 0.09) was achieved for the full block and 0.78 cm² (SD: 0.14) for the split block using the same block. The difference was statistically significant (P < .0001). A mean horizontal bone gain of 4.37 mm (SD: 0.93) was achieved with a full block and 5.77 mm (SD: 0.85) with the shell technique (P < .0001). Conclusion: With the same amount of bone removed, first as a full block and then as a split block, the split-block technique achieved a significantly higher bone gain compared with the full-block design. Int J Oral Maxillofac Implants 2020;35:1083–1089. doi: 10.11607/jomi.8368

Keywords: autogenous bone, bone augmentation, bone blocks, bone regeneration, graft design, intraoral bone graft

Alveolar ridge resorption may result in insufficient bone volume, preventing the placement of dental implants. Different bone augmentation procedures have been described to resolve this problem.1 The use of autogenous bone remains the gold standard in alveolar ridge grafting. Bone blocks are the treatment of choice, especially if the morphology of the bone defect is not optimal, as with single-wall bone defects.2 Mandibular harvesting sites are often defined as the site of choice due to the intramembranous origin of the bone, the simple harvesting procedure, proximity to the recipient site, minimal resorption, and minimal morbidity. However, the limited amount of bone available is the major drawback of this site.3,4

Furthermore, it has been reported that in a typical full bone block design, the number of vital cells is very small, even after uneventful healing. Zerbo et al stated that the majority of osteocytes within bone blocks do not survive grafting.5 Acocella et al also reported that after histologic evaluation of healed mandibular ramus bone block grafts, these bone grafts contained significant amounts of nonvital bone, and generally weak neovascularization was observed regardless of the time of biopsy.6 They also noted that a large proportion of osteocytes in the monocortical bone did not survive and that neovascularization of nonvital grafted bone was difficult due to the slow remodeling process.

On the other hand, it is known that cancellous grafts are revascularized more rapidly and completely than cortical grafts. Burchardt reported that cancellous grafts tended to repair completely with time, whereas cortical grafts remained as admixtures of necrotic and viable bone.7

One study described a technique in which the harvested intraoral bone block was further processed.8 The blocks were subsequently divided lengthwise into two blocks and further processed to obtain bone particles. The thin cortical plates were then fixed with osteosynthesis screws at a distance from the bone of...
the recipient site, and the space in between was filled with the particles. Using this split bone technique, the amount of cortical bone required was reduced to a minimal thickness. This cortical shell was only used to define the outer dimension of the graft and to provide the necessary stability for the bone particles to achieve successful bone healing.

It was hypothesized that a greater bone volume could be obtained using this split bone technique compared with the full-block technique when grafting the same defect with the same amount of bone.

**MATERIALS AND METHODS**

Twenty pig mandibles were treated with autogenous bone blocks from the retromolar area for horizontal bone augmentation. A one-wall bone defect in the premolar region was selected as the recipient site. Each recipient site was treated in such a way that each site received both types of treatment consecutively.

**Recipient Site**

In the premolar area of the mandible, a crestal incision was made with vertical releasing incisions. After flap elevation at the recipient site, a CBCT scan (Galileos Comfort Plus, Dentsply Sirona) with a spherical volume of 15.4 cm was recorded, and an intraoral scan (Omnicam, Dentsply Sirona) was performed to document the initial situation. These served as the baseline for further measurements.

**Donor Site**

To harvest the autogenous bone block, an incision was made in the retromolar region of the mandible, followed by elevation of a mucoperiosteal flap to expose the bone of the external oblique. The anterior-posterior and apicocoronal dimensions of the block were determined by the size of the defect. In this study, bone harvesting was performed using the microsaw protocol (Dentsply Sirona) due to the thin osteotomy cuts, because the thickness of the diamond disk was only 0.25 mm.8,9 Performing the harvesting procedure with thin piezosurgical saw blades would have been a valid alternative. After the distal and mesial vertical osteotomy cuts were performed with a handpiece with diamond disks, the apical connection was then also made with a diamond disk in a contra-angle handpiece. Subsequently, crestal perforations with a depth of 4 mm were made with a 1-mm drill bur, parallel to the external oblique at a distance of approximately 4 to 5 mm, connecting the mesial and distal vertical osteotomy lines. The perforations were connected with chisels, resulting in lateral dislocation of the block from the donor site (Figs 1a to 1d).

**Bone Augmentation Surgery**

**Treatment Type 1: Full Block.** For full-block grafting, the graft was placed in a manner such that the contact zone between bone graft and recipient site was maximized and fixed with two titanium screws (Fig 2a). A CBCT scan and an intraoral scan of the augmented situation were then performed.

**Treatment Type 2: Split Block.** After performing the full-block grafting procedure, the block graft was unscrewed again and divided longitudinally into two thin blocks using a diamond disk. Subsequently, the blocks were thinned out using a bone scraper (Safescrapper Twist, META) until a thickness of approximately 1 mm...
was achieved. This allowed a good quantity of bone chips to be obtained. One thin cortical block was fixed at a distance of approximately 5 mm from the bone defect using two osteosynthesis screws. The distance was chosen according to a clinical study by Khoury and Hanser showing reliable regenerative results in horizontal and vertical bone augmentation (mean horizontal bone gain: 5.2 mm, mean vertical bone gain: 7.6 mm). Furthermore, it was placed to fit the individual anatomy of the defect and the surrounding bone. The second block was further thinned out and particulated to gain additional bone chips to fill the space between the thin bone block and the native bone. Only autogenous bone chips and particles obtained by the described procedure were used. No biomaterials were added; the particulated bone volume was sufficient in all cases (Figs 2b to 2d). After dense condensation of the bone particles, a third CBCT and an intraoral scan were performed.

Measurement Technique
All acquired CBCT data were exported in the Digital Imaging and Communications in Medicine (DICOM) file format. All data captured by the intraoral scanner were exported as high-resolution stereolithographic (STL) format files. These data were then imported into implant-planning software (Simplant Pro 18.0, Dentsply Sirona), where the volumetric changes after bone grafting were analyzed (Figs 3 to 5).

For volumetric measurements of the DICOM data sets, all three scans (preoperative, full-block technique, split-block technique) were imported into the preoperative DICOM data set. The models were aligned using a three-point-matching process in which corresponding landmarks were placed on each STL surface. The teeth served as reference points for overlapping of the volumes to allow correct alignment of the models and accurate comparison. After overlapping the volumes of the individual data sets, the total volumetric bone gain and horizontal dimensions were evaluated. The now-visible differences between the STL data set of the initial situation and the condition after bone grafting were outlined manually in the corresponding layers (layer thickness: 0.25 mm). The total graft volume was automatically calculated in cm³.

Measurement of the maximum horizontal bone gain that could be achieved with each augmentation technique was performed after volumetric measurement on the respective DICOM and STL data sets. Once the appropriate layer had been selected, the distance in millimeters was displayed using an orthogonal line drawn manually between two points in the center of the grafts.

All radiographic and volumetric measurements were taken by the same calibrated examiner (L.K.) under identical conditions to ensure high reliability.

Statistical Methods

Sample Size Calculation. The sample size calculation was based on the comparison of the means of “maximum horizontal bone gain” between the two treatment groups (full block/split block). A total of 20 pig jaws were needed to achieve a power of 90% by means of paired t test with a two-sided significance level of 5%, when
assuming a mean “maximum horizontal bone gain” of 5.2 and 4.18 mm for the split- and full-block designs, respectively. Additionally, equal variance of 1.28 mm in both treatment groups was assumed. Sample size calculation was performed using PASS 16.0.3.

Due to the lack of available literature for measurement type STL, sample size calculation was performed for the factor treatment group alone (full block/split block). Because this study examined whether different measurement types (DICOM/STL) influenced the outcome, two-way analyses (ANOVAs) for repeated measurements were chosen for the analysis.

Statistical Analysis. Both outcomes, volume gain and maximum horizontal bone gain, were described using descriptive measures for each treatment group including number of nonmissing values, mean, standard deviation, median, Q1, Q3, minimum, and maximum.

The endpoint, whether the treatment group (full block/split block) or measurement type (DICOM/STL) influence the volume gain or maximum horizontal bone gain, was analyzed via two-way ANOVAs for repeated measurements with interaction effect. In addition, due to the repeated measurements, a random error term was included in the analysis to account for natural variation between the animals. With the help of these analyses, it was possible to investigate whether the treatment group (factor A) and/or the measurement type (factor B) significantly influenced the outcome measures. Moreover, the interaction term could be used to assess whether a measurement type might be more advantageous for a specific treatment group.

Due to the exploratory character of the trial, P values could only be interpreted descriptively, so that no formal adjustment was made for multiple testing. P values smaller than .05 were considered to be statistically significant. Statistical analyses were conducted using the statistical software R (R Core Team, 2019 R Foundation for Statistical Computing), and figures were produced using the package ggplot2.

RESULTS

When evaluating the outcome maximum horizontal bone gain, the full-block treatment group achieved a mean maximum horizontal bone gain of 4.37 mm (± 0.93) when evaluated using the STL measurement and 4.28 mm (± 0.81) using the CBCT measurement. The split-block treatment group achieved a mean maximum horizontal bone gain of 5.77 mm (± 0.85) using the STL measurement and 5.44 mm (± 0.60) using the CBCT measurement (Table 1).

The results of two-way ANOVA for repeated measurements showed that the split-block treatment group had significantly greater maximum horizontal bone gain than the full-block treatment group (P < .0001). This difference was also seen in corresponding box plots (Fig 6). Additionally, the type of measurement showed no significant effect on the maximum horizontal bone gain (P = .0974). It was also evident that there was no significant interaction effect between the two independent variables (P = .2247).
When evaluating the outcome volume gain, the full-block treatment group achieved a mean volume gain of 0.36 cm² (± 0.09) for the STL measurement and 0.37 cm² (± 0.14) for the CBCT measurement. The split-block treatment group achieved a mean volume gain of 0.78 cm² (± 0.09) for the STL measurement and 0.76 cm² (± 0.14) for the CBCT measurement (Table 1).

The results of two-way ANOVA for repeated measurements showed that the split-block treatment group had a significantly larger volume gain than the full-block treatment group ($P < .0001$). This difference was also seen in corresponding box plots (Fig 7). Additionally, the type of measurement showed no significant effect on the volume gain ($P = .7949$). It was also found that there was no significant interaction effect between the two independent variables ($P = .2832$).

### DISCUSSION

The use of autogenous bone blocks from the retromolar region for performing bone augmentation procedures provides a very reliable graft with low morbidity compared with other donor sites. In addition, this method has the advantages of low bone resorption and the ability to harvest and transplant bone under local anesthesia. The only disadvantage of this site is the limited amount of available bone.

The aim of this study, therefore, was to compare two different graft designs and investigate their influence on the bone volume obtained. It was hypothesized that a greater bone volume could be generated using a split-block design compared with a full-block design. This hypothesis was clearly confirmed by the present study. Not only was the bone volume gain significantly...
greater, but the horizontal dimension of the grafted areas was also larger.

This demonstrated effect could only be proven with the use of an in vitro study design, as the same defect sites always received both types of graft. Furthermore, the exact same amount of bone was used for both procedures, and no other material was added. As the full-block technique had to take place first, the sequence of the grafting procedures could not be randomized, because the split-block technique required further processing of the same block. Despite the fact that splitting the bone block led to a certain loss of bone, the bone volume achieved was higher after grafting in the split-block group.

In a clinical study, the repositioning of one split block to the donor site is described.\(^8\)

In addition, there is greater flexibility with the split-block technique, as the blocks do not have to be adapted to the surface of the bone at the recipient site. The thin cortical bone plates were intentionally placed at a distance to allow the gap to be filled with bone particles. The use of a cortical bone plate allowed good stabilization of the graft, while the use of bone chips allowed rapid revascularization and consolidation of the bone. Some reports have described bone-healing periods of only 3 to 4 months. Compared with studies using biomaterials, this value was significantly reduced.

In the classic guided bone regeneration (GBR) procedures with osteoconductive biomaterials and resorbable membranes, the defect morphology must ideally be self-containing, and the graft material must be space-maintaining. Therefore, the ideal defect morphology for this method is a three-wall bone defect. One-wall bone defects require further stabilization by the use of membrane pins, tenting screws, or nonresorbable, titanium-reinforced membranes,\(^12\) but this can lead to a higher rate of postoperative complications, such as exposure.

With the split-block technique, the particulated graft is completely stabilized by the cortical plate, so that one-wall bone defects can also be reliably treated. With a view to biology, the decision where to position the cortical plates should be based on the individual defect and the surrounding bone. The maximum distance that still allows vascularization is rather defined by graft stabilization, as shown in a study by Khoury and Hanser, who published 10-year prospective clinical data. After 3 months of bone healing, a vertical bone gain of 7.6 ± 3.4 mm was described with a maximum gain of 13 mm. The reported alveolar crest width after bone augmentation was described as 7.7 ± 1.7 mm in the same study.\(^9\)

According to these results, the authors of this study intended to achieve a horizontal bone gain of approximately 5 mm. The radiographic measurements confirmed that a mean horizontal bone gain of 5.44 mm could be achieved.

Furthermore, the present study showed that a significant increase in bone volume and horizontal bone dimension could be achieved by further processing of the harvested block graft compared with a conventional full block. With the split-block technique, sufficient condensation of the bone chips must be achieved, but with the protocol used, an adequate amount of bone particles could be obtained in all cases performed. This was possible by thinning the cortical plates to a thickness of 1 mm because the cortical plate was only required to define the outer dimension of the graft and to give the bone particles the stability required for successful bone healing.

In order to increase the reliability of the generated data, two different and independent measurement methods were used. CBCT data were obtained, as were surface scans generated by an optical scanner. Because CBCT data can be affected by artifacts, noise, and scatter,\(^13\) another measurement technique was used to improve the reliability of the study data. As intraoral scanners are now able to produce reliable and accurate images,\(^14\) this method was used as an additional measurement technique. However, data on the reliability of bone surface scans are not yet available. Nonetheless, in the present in vitro setting, this technique seemed to produce comparable data to a CBCT scan. The statistical evaluation showed no significant influence of the measurement technique on bone volume gain (\(P = .7949273\)). However, accuracy under real surgical conditions may be limited by blood on the bone surfaces.

**CONCLUSIONS**

Graft design had a significant influence on bone gain when autogenous block augmentations were performed. Total bone volume gain and horizontal bone dimensions were both significantly increased when the split-graft technique was used.

Measurement using either the CBCT or optical scanning techniques showed comparable results in this in vitro setting.

**ACKNOWLEDGMENTS**

The authors did not receive any external funding for this study. The authors have stated explicitly that there are no conflicts of interest in connection with this article.
REFERENCES


