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# Linear and volumetric gain after vertical bone augmentation in the posterior mandible using an autologous cortical tenting method

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*Abstract.* This study was performed to evaluate the linear and volumetric effects of a technique for reconstruction of the posterior atrophic mandible, including the final bone gain of the graft, by three-dimensional assessment. Thirteen individuals were recruited into the study and submitted to a total of 15 mandibular autogenous bone block surgeries. Cone beam computed tomography images were obtained at three different times. Bone graft length and thickness, and the volume, height, and width of the graft were measured. Data were compared statistically among the time points using the Friedman test, and cluster analysis was performed to identify the association between the study variables and the resorption rate ($\alpha = 0.05$). Linear analysis of the width and height of the recipient area at the different time points revealed a statistically significant difference. The final average increase in height was 1.6 mm; all subjects showed an average volume gain of 3.412 $mm^3$, and 77% of the subjects showed an average graft resorption of 0.688 $mm^3$ construction of three-dimensional vertical defects of the posterior mandible resulted in good healing with minimal complications and minimal bone graft resorption, favouring vertical bone gain.

Key words: bone transplantation; bone regeneration; cone beam computed tomography; mandible.

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A sufficient bone volume is a prerequisite for a favourable long-term prognosis in patients treated with osseointegrated implants. To achieve adequate implant stability, especially when horizontal defects of the alveolar ridge occur, bone grafts have been used to increase the alveolar crest[1–4]. Several surgical materials and methods for bone augmentation have been employed, such as autogenous block and particulate grafts, as well as alloys, xenogeneic grafts, and alloplastic materials[5–8]. Autogenous bone grafts are considered the gold standard for the rehabilitation of atrophic areas[1,2,6,7], with good reliability and predictability for the posterior placement of implants, independent of the donor area[1,2,9,10]. Moreover, the use of a split block graft with vertical and horizontal bone gain in the posterior mandibular region has been reported as an alternative to the conventional autogenous grafts and bone grafts from extraoral origins over the long term[7].

Intraoral donor areas have the advantages of easy surgical access and low morbidity, in addition to the proximity of the donor and recipient sites. Furthermore, the patients do not require hospitalization. Corticocancellous blocks are preferred for two-dimensional (2D) and three-dimensional (3D) reconstruction of the atrophic alveolar ridge, and these may be obtained from the mandibular symphysis, retromolar and paramolar region, or edentulous areas[7]. Bone block graft techniques using the oblique ridge as the donor area for the restoration of the atrophic posterior mandible are well-documented. However, few studies have assessed the horizontal and vertical bone condition of autogenous 3D grafts in the posterior mandible.

Recent studies have shown that cone beam computed tomography (CBCT) is a viable and accurate method to check the available bone volume and the results of bone resorption and neoformation in bone graft surgical procedures[11–14]. Thus, the objective of this study was to investigate the effects of reconstruction of the posterior atrophic mandible in terms of resorption and bone gain in the recipient area using a 3D technique and CBCT analysis. The null hypothesis was that no bone change in the recipient area would be observed after surgery. The information obtained from this study could be used to expand the therapeutic options for the effective rehabilitation of patients with an atrophic posterior mandible.

## Materials and methods

### Ethical issues and patients

The study was approved by the Ethics Committee of the Universidade Federal de Minas Gerais (UFMG), and the participants gave written informed consent in agreement with the Declaration of Helsinki. The Strengthening the Reporting of Observational Studies in Epidemiology statement was followed[15].

Patients with an indication for oral rehabilitation by means of osseointegrated implants were selected from among the individuals attending the Service of Oral Surgery and Implantology of the School of Dentistry, UFMG (Belo Horizonte, Brazil) between July and December 2017. The following inclusion criteria were applied: patients with an edentulous posterior mandibular region on panoramic radiography and CBCT analysis, a baseline defect situation (remaining bone) with a valley-shaped height, a minimum depth of 2 mm between the crest of the alveolar ridge and the roof of the mandibular canal, and a width space allowing the placement of dental implants with a minimum diameter of 2.8 mm (Fig. 1A and B). Exclusion criteria were general contraindication to the surgical procedures, being under treatment or taking medications that interfere with tissue repair, smokers and alcoholics, the presence of an active infectious process in the region to be operated, and a history of implant or graft installation in the mandible.

### Surgical protocol

All subjects underwent examinations including blood count, coagulation test, determination of urea, creatinine, fasting glucose, parathyroid hormone, calcium, phosphorus, calcitonin, alkaline phosphatase, and vitamin D, and bone densitometry. The procedures were performed by the same senior maxillofacial surgeon according to recommended surgical techniques[6,7]. Connective tissue surgery was performed in advance in order to improve the keratinized tissue pattern of the bone graft region, thereby preventing exposure of the graft[16]. The autogenous bone grafts were obtained from the oblique external ridge using the technique of Khoury et al.[6], with some modifications.

The following medications were used: amoxicillin (875 mg, 1 hour prior to surgery and twice daily for 7 days postoperative), tenoxicam (20 mg, 1 hour prior to surgery and twice daily for 5 days postoperative), dexamethasone (8 mg, 12 hours prior to surgery; 8 mg, 2 hours prior to surgery; and 8 mg twice daily for 5 days postoperative), and paracetamol (750 mg, 1 hour prior to surgery and three times daily for 5 days postoperative).

Perforations were punched in the previously anaesthetized donor area with an NR699 drill (Solidor Ind., Bauru, SP, Brazil) in parallel to the external oblique area, reaching the full thickness of cortical bone. Two vertical osteotomy lines were made under constant irrigation with chilled saline, mesial and distal to the initial osteotomy, determining the length of the graft. The vertical osteotomies were then joined with a horizontal osteotomy at the basal level with a diamond disc (5 mm; NeoBiotech, Pasadena, CA, USA). Particulate bone was obtained from a region adjacent to the donor bed using an ACM drill (NeoBiotech). The bone block obtained was carefully removed with a chisel and divided longitudinally into two thin parts with a diamond disc. The edges were then rounded with spherical diamond tips under irrigation with saline. The thin blocks were stabilized in the recipient region and maintained with titanium screws (1.5 mm; NeoBiotech). The first block was positioned in the occlusal region resting on the bone crest of the adjacent tooth, and the space below this first block was filled with particulate bone. The second block was then installed on the vestibular surface. The stability of the structure in the recipient area was evaluated clinically so that it would remain static (Fig. 2A–H).

The surgical wound in the recipient area was then closed with Donati type stitches and simple non-restorable sutures (Nylon 6–0, Ethicon, NJ, USA) (Fig. 2I). The same suture and only simple stitches were used in the donor area. The number of anaesthetic tubes used, the surgical time, and any intraoperative complications were recorded after each procedure.

### CBCT analysis

CBCT scans were performed using an i-CAT Next Generation scanner (Imaging Sciences International, Hatfield, PA, USA), with an 8-cm high field of view (FOV) measuring 16 cm in diameter, an isotropic voxel size of 0.20 mm, and an acquisition time of 26.9 seconds. To standardize the pre- and postoperative measurements made in the same region of interest (ROI), tomographic guides were made on 1-mm thick acetate plates with 2-mm wide lead sheets, surrounding the crown of the teeth, from the diagnostic waxing. Steel wires 1-mm in diameter were also positioned, delimiting the proximal surfaces of the waxed teeth[11,14] (Fig. 3A).

The CBCT examinations were performed at three different time points, i.e., 1–4 months before the bone graft was performed to confirm the requirement for grafting (T1), 14 days after the bone graft procedure, allowing postsurgical evaluation of the grafted bone (T2), and at 4 months after the graft surgery to evaluate the neoformed bone tissue and to plan implant installation (T3) (Fig. 1C–G). The images were exported in DICOM

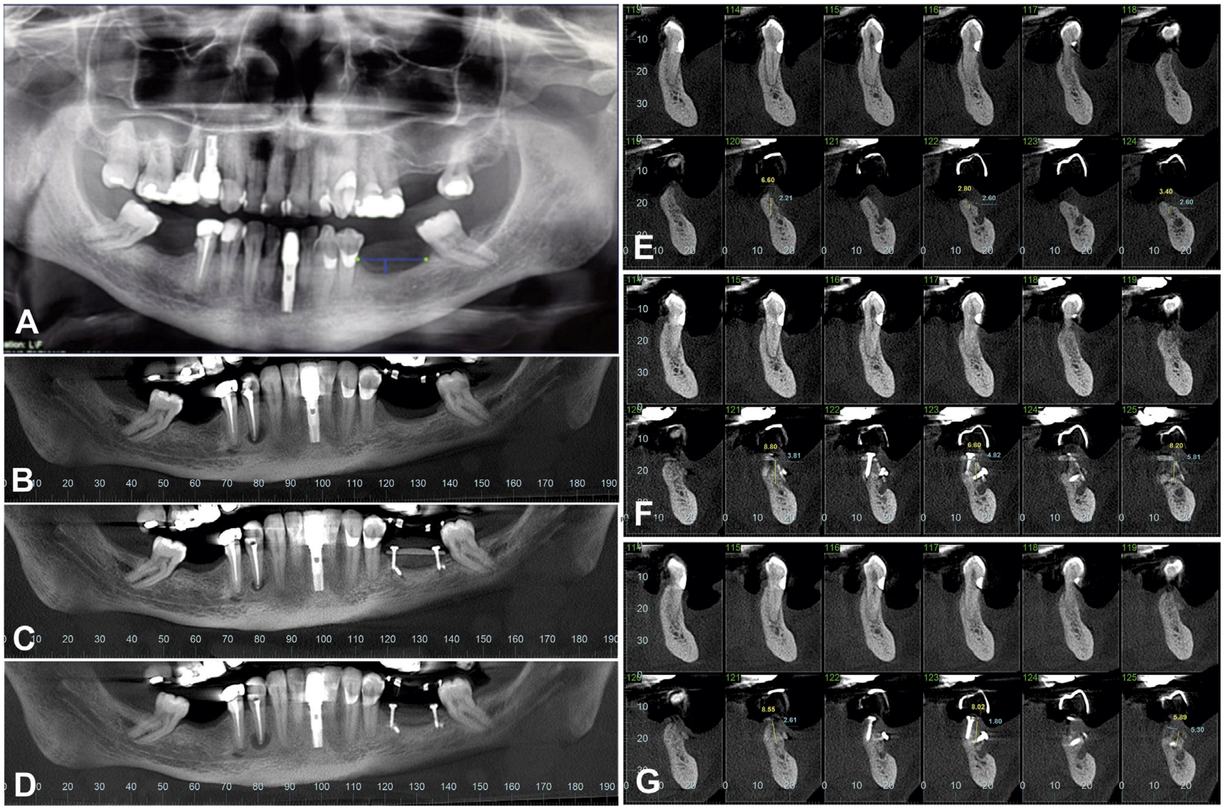


*Fig. 1*. (A) Initial panoramic radiograph. (B)–(G) Cone beam computed tomography (CBCT): initial scan (B and E), 14 days after surgery (C and F), and 4 months after surgery (D and G).

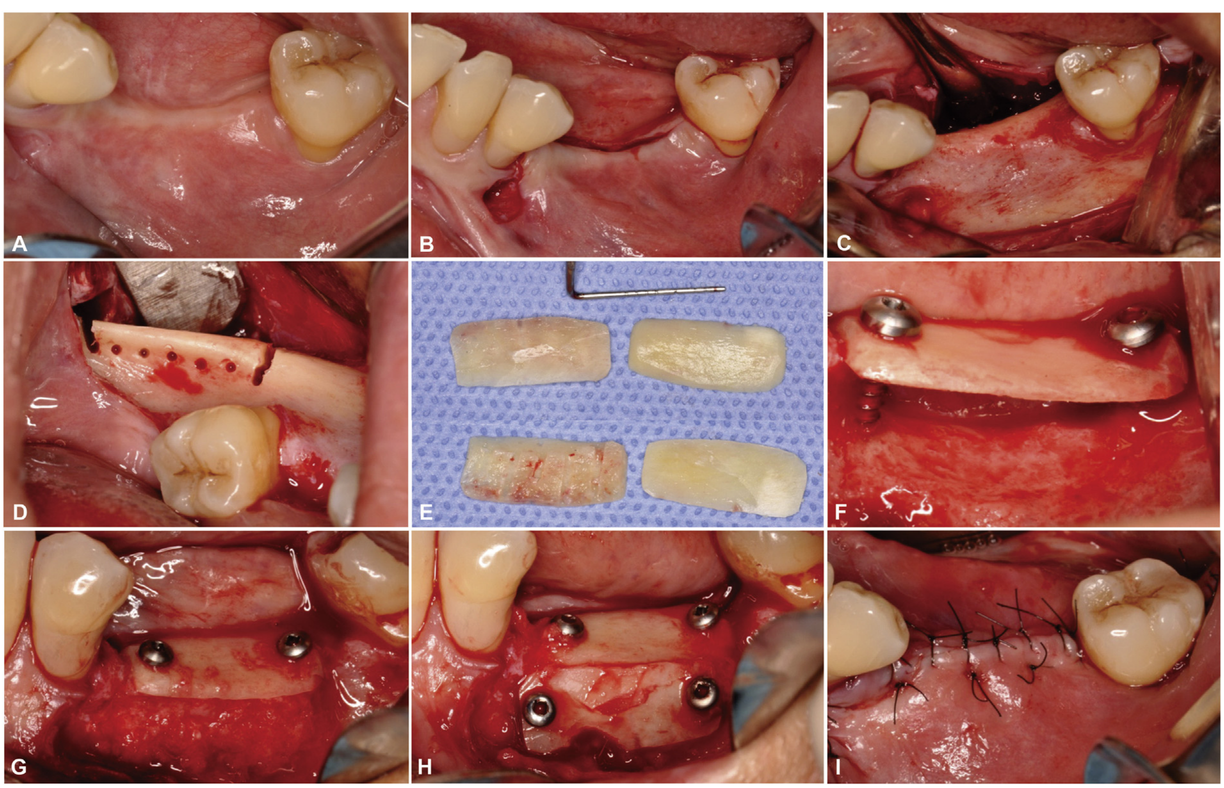


*Fig. 2*. (A) Posterior atrophic ridge. (B) Incision in the recipient area. (C) Full thickness detachment of the flap. (D) Donor area incised and detached with the osteotomies present. (E) Divided bone block, internal and external views. (F) Occlusal blade of the graft stabilized with two screws. (G) Filling of the space with particulate bone. (H) Bone graft with the bone tabs stabilized in position. (I) Sutured recipient area.

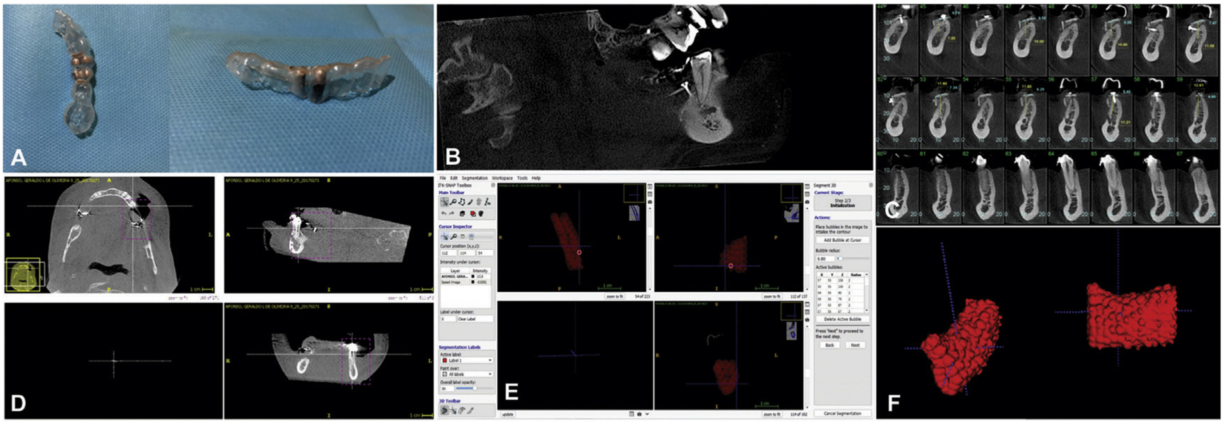

*Fig. 3.* (A) Tomographic guide for the vestibular and occlusal areas. (B) Reorientation by vertical alignment of the tooth adjacent to the recipient area. (C) Markings in orthoradial sections for linear analysis. (D) Determination of the region of interest (ROI) and marking for volumetric analysis. (E) (F) Volume generated after marking of the ROI in the anterior superior and vestibular views.

format (Digital Imaging and Communications in Medicine) and reconstructed using the following programs: Xoran (Xoran Technologies, Ann Arbor, MI, USA) for linear measurements of the height and width of the region receiving the graft; ITK SNAP (https://www.itksnap.org/) for measurements of the initial and final volumes of the bone graft and the initial recipient area. The measurements were performed by a professor of oral and maxillofacial radiology.

### Linear analysis

For standardization of the examinations in order to obtain the same position at the different time points, positioning of the mandible was reoriented for vertical alignment of the long axis of the tooth adjacent to the graft receptor site in the sagittal and coronal sections. Initially, the ROI was determined and then the width (horizontal, in blue) was measured from one cortical surface to the other in the buccolingual direction and the height (vertical, in yellow) was measured from the roof of the mandibular canal, in the orthoradial plane. The mean values of three measurements for width and height (mesial, medial, distal) were calculated in the oblique sagittal sections, and the length of the graft was measured in the anteroposterior dimension. The minimum and maximum thickness of the graft was measured in the coronal sections, in millimetres (Fig. 3B and C).

### Volume analysis

After determination of the ROI, 3D segmentation of the image was performed and the graft volume was demarcated by means of a 0.8-mm radius cursor, delimiting the grafted area in each $1 \times 1$ mm section in the axial, coronal, and parasagittal planes (Fig. 3D–F).

### Data analysis

A descriptive statistical analysis was performed for the clinical, demographic, and CBCT data using IBM SPSS Statistics version 22.0 (IBM Corp., Armonk, NY, USA). The rates of bone resorption and gain for the linear and volumetric data were calculated from the differences in the measurements obtained at T2–T3 and T3–T1.

The bone volume and linear analysis values at the three time points were compared using the Friedman test ($\alpha = 0.05$). Post-hoc tests were applied using the PMCMR package of R software[17].

A cluster analysis was performed using the Ward method on the Euclidean distance scale[18], in order to identify groups of surgical sites formed from three quantitative variables: initial volume of the recipient area, length and thickness of the bone block. If the measurement scale was not the same, a subset analysis was performed. The most similar objects were first grouped and then merged according to their similarities for the variables of the study. In addition, the results showed homogeneous elements within each group.

The quantitative results for the bone resorption rate were dichotomized using the median ($<10.493\%$ or $\geq 10.493\%$). Fisher's exact test was used to determine the association between the groups defined by cluster analysis and other variables (graft between teeth, postoperative complications, osteopenia, vitamin D, and time of surgery) in relation to the rate of bone resorption. The following variables were dichotomized: postoperative complications (absent or present), osteopenia (absent or present), vitamin D (altered or normal), and surgical time ($\leq 120$ or $>120$ minutes).

## Results

Of 15 preselected patients, two were excluded from the study: one due to osteoporosis detected in the bone densitometry examination and the other because of failure to perform the clinical controls and imaging tests at the predetermined times. A total of 15 bone graft surgical procedures were performed in the posterior mandibular region of the remaining 13 patients [nine female (69.2%) and four male (30.8%)]. For two patients, surgeries were performed bilaterally in two different surgical sessions. The mean patient age was $53.4 \pm 11.7$ years. The mean duration of surgery was 127.6 minutes (range 95–180 minutes) and the mean number of anaesthetic cartridges used was 7.7 (range 6–10).

Four intraoperative complications were recorded: three lingual flap fenestrations and one oral mucosa burn. Four postoperative complications were observed, i.e., infections in the donor area (two cases), screw loss on the occlusal face of the recipient area (one case), and graft angle exposure (one case). Neurosensory dysfunction of the mental nerve after surgery was observed at five sites. Two sites showed complete recovery at 2 months after surgery, while three sites remained under observation for 3 months (Table 1).

There was a statistically significant difference in the width of the recipient area between T1 and T2, and between T2 and T3; the height of the recipient area differed between T1 and T2, and between T1 and T3 ($P < 0.001$) (Fig. 4). The mean bone

*Table 1.* Clinical features of the patients undergoing vertical bone augmentation surgery[a].

| Variables | |
|---|---|
| Sex | |
| Female | 9 (69.2%) |
| Male | 4 (30.8%) |
| Age (years) | 53.4 ± 11.7 |
| Surgery time (min) | 127.6 (95–180) |
| Anaesthetic tubes | 7.7 (6–10) |
| Intraoperative complications | |
| No | 11 (73.3%) |
| Yes | 4 (26.7%) |
| Postoperative complications | |
| No | 11 (73.3%) |
| Yes | 4 (26.7%) |
| Neural disturbances | |
| None | 10 (66.7%) |
| Temporary | 2 (13.3%) |
| Present | 3 (20.0%) |

[a] Results are presented as the number (percentage), mean ± standard deviation, or mean value (confidence interval).

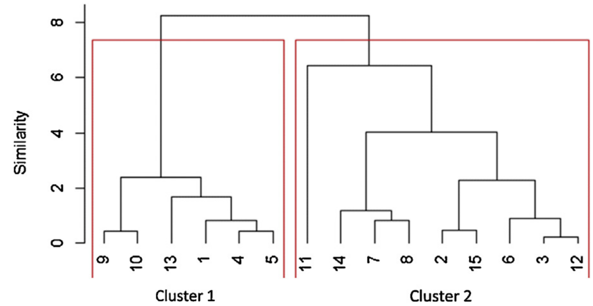


*Fig. 5.* Cluster dendrogram for cluster groups: cluster 1 ($n = 6$) and cluster 2 ($n = 9$). Each number on the horizontal line represents each surgical site, allocated to a specific group.

width was 4.3 ± 1.39 mm at T1, 6.6 ± 0.71 mm at T2, and 4.5 ± 1.06 mm at T3. The mean height values were 7.4 ± 2.61 mm at T1, 10.0 ± 2.53 mm at T2, and 9.0 ± 2.59 mm at T3, resulting in an initial average height increase of 2.6 ± 0.79 mm and a final increase of 1.6 ± 0.95 mm. The mean length and thickness of the bone block were 15.99 ± 4.03 mm and 1.0 ± 0.15 mm, respectively.

There was a statistically significant difference in bone volume in the recipient area at the time points evaluated ($P <$ 0.001), with a volume of 5.061 ± 1.39 $mm^3$ at T1, 9.161 ± 2.69 $mm^3$ at T2, and 8.473 ± 2.06 $mm^3$ at T3. The mean final volume gain was 3.412 ± 1.55 $mm^3$ in all subjects when comparing T1 and T3, and 10 of 13 (77%) of the patients showed a gain with a mean graft resorption of 0.688 ± 1.48 $mm^3$ between T2 and T3 (Fig. 4).

Cluster analysis identified two groups for the 15 surgical sites according to the percentage of variables included (Fig. 5). Cluster group 1 included participants with higher mean graft length and thickness values, while the volume of the initial recipient area was lower in relation to cluster group 2 (Table 2).

Table 3 shows the results of the analysis of the bone graft resorption rate between T2 and T3 and the associations with certain clinical variables. There was a strong association between the cluster groups and the resorption rate ($P <$ 0.05).

## Discussion

A significant change in bone volume was observed after surgery in this study. Autogenous bone grafts are osteoinductive, osteogenic, and osteoconductive, with a strong regenerative potential compared to other graft types. Thus, autogenous bone remains the gold standard for the repair of major lateral or vertical defects in the maxillofacial region[1,2,6,7]. Intraoral bone graft donor sites have the advantage of being close to the recipient site and having low morbidity[7].

Systematic reviews have reported several augmentation techniques that are able to increase bone in the vertical direction, resulting in a low failure rate of 10–15%[1,2]; however, there is insufficient evidence to indicate the techniques that could be used. Overall, these procedures have resulted in significantly more complications (rates ranging from 20% to 60%) such as pain, increased days of hospitalization, increased costs, and longer treatment times when compared to the use of short implants. Moreover, there is no scientific evidence justifying the vertical bone augmentation procedure for installing longer implants in resorbed jaws. However, the long-term prognosis of shorter implants is still unknown.

The procedure chosen for ridge augmentation should be the simplest and least invasive, involving the lowest risk of complications within the shortest period of time. Both the surgeon and the patient should assess the pros and cons of the procedures to be selected[1,2,19]. The combination of 3D reconstruction using a bone block graft divided into two thin layers and filled with particulate bone is a simple and effective treatment that offers good short-term results, minimal complications, and good stability over time[6,7,20–23].

Four postoperative complications occurred in the present study patients, a rate similar to that observed in previous studies[19,20] (4/15 = 26.7%). However, a systematic review of bone grafts in atrophic jaws reported a higher complication rate (44%)[20]. In the present study patients, the grafts were obtained from the ipsilateral retromolar area of the recipient area, avoiding the need for a second donor site,

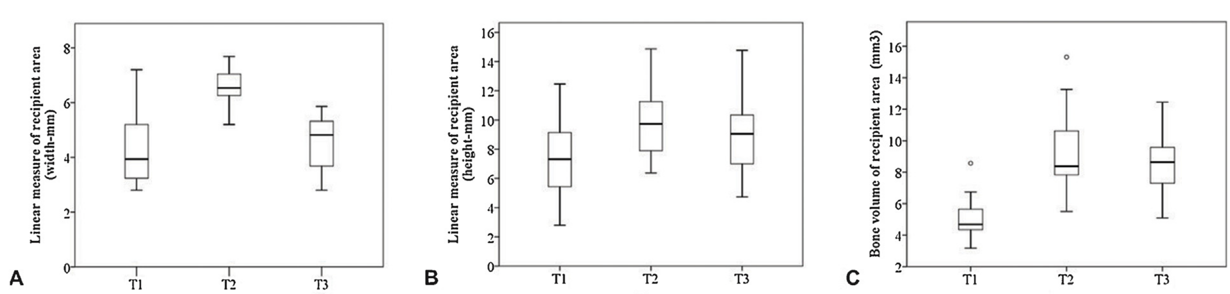


*Fig. 4.* Box plots of the dimensions of the recipient area at the different time points; Friedman test (α = 0.05). (A) Linear width (mm), (B) linear height (mm), (C) bone volume ($mm^3$).

*Table 2*. Cluster groups based on variables of CBCT measurements.

| Cluster groups | Initial volume ($mm^3$) | Initial graft length (mm) | Initial graft thickness (mm) |
|---|---|---|---|
| 1 | 4.547 | 17.017 | 1.186 |
| 2 | 5.404 | 15.306 | 0.905 |

CBCT, cone beam computed tomography.

*Table 3*. Associations between variables and resorption.

| Variables | Resorption % | | | | Total | | *P*-value[c] |
|---|---|---|---|---|---|---|---|
| | <10.493% | | ≥10.493% | | | | |
| | *n* | %[a] | *n* | %[a] | *n* | %[b] | |
| Cluster | | | | | | | |
| 1 | 5 | 83.3 | 1 | 16.7 | 6 | 33.3 | 0.04[*] |
| 2 | 2 | 22.2 | 7 | 77.8 | 9 | 66.7 | |
| Graft between teeth | | | | | | | |
| No | 2 | 50.0 | 2 | 50.0 | 4 | 26.7 | 1.000 |
| Yes | 5 | 45.5 | 6 | 54.5 | 11 | 73.3 | |
| Postoperative complications | | | | | | | |
| Absent | 7 | 63.6 | 4 | 36.4 | 11 | 73.3 | 0.200 |
| Present | 0 | 0 | 4 | 100 | 4 | 26.7 | |
| Osteopenia | | | | | | | |
| Absent | 4 | 50.0 | 4 | 50.0 | 8 | 53.3 | 1.000 |
| Present | 3 | 42.9 | 4 | 57.1 | 7 | 46.7 | |
| Vitamin D | | | | | | | |
| Normal | 5 | 55.6 | 4 | 44.4 | 9 | 60.0 | 0.608 |
| Altered | 2 | 33.3 | 4 | 66.7 | 6 | 40.0 | |
| Surgery time | | | | | | | |
| >120 min | 3 | 37.5 | 5 | 62.5 | 8 | 53.3 | 0.619 |
| ≤120 min | 4 | 57.1 | 3 | 42.9 | 7 | 46.7 | |
| Total | 7 | 46.7 | 8 | 53.3 | 15 | 100.0 | |

[a] Values expressed as the in-line percentage.
[b] Values expressed as the percentage.
[c] Fisher's test.
[*] Significant at $P < 0.05$.

with the advantage of only one surgical field, thereby reducing the general morbidity rate and postoperative complications. These findings are in agreement with data reported elsewhere[6,7,19].

There are several procedures for vertical bone augmentation and guided bone regeneration that provide vertical bone gains of 2–8 mm, with the most common complication being membrane exposure[20]. Osteogenic distraction promotes bone gain of 5–15 mm; however, it entails a high complication rate (10–75.7%)[20]. For onlay bone grafts, a mean gain ranging from 4.2 mm to 4.6 mm has been reported, but with a significant rate of block resorption (42%)[21]. In the present study, statistically significant differences in linear measures of width and height were observed between the different time points, proving the effectiveness of the technique. A significant width increase was expected between T1 and T3 and a non-significant resorption between T2 and T3. Nevertheless, the presence of a residual ridge with regions of greater width than the graft and the difficulty of visual identification of the border of the graft after 4 months may have influenced the accuracy of the measurements. However, a mean $1.6 \pm 0.95$ mm linear vertical increase was found.

Using a similar technique, Restoy-Lozano et al. evaluated the outcomes of mandibular vertical defect restoration with autologous bone through a sub-periosteal tunnel approach, in preparation for dental implant insertion[19]. A mean 5.2 mm increase in bone height was observed. This higher average was possibly due to the measurement method employed, which used the lowest point from the residual border to the upper edge of the mandibular canal as the reference, while the present study used the mean mesial, medial, and distal measurements. In the cited study[19], the final measurements were performed on panoramic radiographs, while in the present study the initial and final measurements were performed on CBCT scans. Domingues et al. used CBCT to compare vertical and volumetric bone augmentation after interpositional grafting with Bio-Oss or Bone-Ceramic for the reconstruction of the atrophic posterior mandible through segmental osteotomy, and obtained a maximum vertical linear bone gain of 2.10 mm and 2.17 mm, respectively[23].

Few studies have examined the volumetric measurement of bone gain and resorption after 3D grafting in the posterior region of the mandible[23,24]. Using biomaterial interposed in autogenous bone, Domingues et al. reported a final volume gain of 82% and 58% and a resorption rate of 11% and 22%, for Bio-Oss and Bone-Ceramic, respectively[23]. Barone et al. reported a final volume gain of 61% and 40% and resorption rate of 29% and 35% for biomaterial of equine origin and iliac crest, respectively, based on 3D computed tomography analysis[24].

The results of this study demonstrated that a recipient bone graft area with a greater volume, in conjunction with a lower graft length and thickness, is associated with a greater bone resorption rate. Despite speculation that the association between the lower volume of the recipient bed and a larger graft may favour resorption due to the lower nutrition of the graft, the thickness of the occlusal bone board determined the degree of graft resorption in the present study, perhaps because a thinner bone board suffers a lower influence of soft tissue pressure. In addition, the other variables investigated were expected to be significantly associated with the rate of graft resorption, although the reduced sample size may have impaired this observation.

The limitations of this study are due to the aspects inherent to the design of a prospective study, so the evaluations of the subjects must be systematically understood and controlled. Suggested perspectives for future investigations are longitudinal studies monitoring patients with chronic diseases submitted to bone graft surgeries.

Within the limitations of this study, it is concluded that through clinical and CBCT analysis with follow-up of 4 months, almost 77% of the patients had a final volume gain with a low resorption rate. Vertical bone augmentation was obtained, allowing stability and a satisfactory crown/implant relationship as provided by dental implants.

## Funding

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## Competing interests

The authors declare no conflict of interest.

## Ethical approval

The study was approved by the Ethics Committee of the Universidade Federal de Minas Gerais (Approval No. 67497617.7.0000.5149).

## Patient consent

The patients gave written informed consent for the publication of the study in agreement with the Declaration of Helsinki.

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