Journal of Dental Sciences 18 (2023) 1517–1526

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Original Article

# Autogenous bone ring augmentation around single tooth implantation in the esthetic zone: A retrospective case series study with 2–3 years of follow-up

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Received 4 January 2023; Final revision received 6 March 2023
Available online 26 March 2023

**KEYWORDS**
Alveolar ridge augmentation;
Autograft;
Bone ring technique;
Esthetic zone;
Maxillary incisor

**Abstract** *Background: /purpose*: Bone ring technique (BRT) is an effective method to reconstruct alveolar bone defects with simultaneous implant placement. This study aimed to evaluate the efficacy of the BRT in single maxillary anterior tooth implantation and its esthetic outcomes over 2–3 years of follow-up.

*Materials and methods:* Fifteen patients with single maxillary incisor loss received autogenous BRT with simultaneous implant placement. The vertical/horizontal bone gain, remaining vertical bone height (RVBH), remaining buccal bone width (RBBW), and vertical/horizontal bone resorption around implant over 2–3 years of follow-up were measured by using cone-beam computed tomography. Esthetic results including white esthetic score (WES), pink esthetic score (PES), and papilla index (PI) were evaluated by clinical recorded photographs.

*Results:* All implants showed evidence of osseointegration, and the mean vertical and horizontal bone gain of 14 sites was 5.55 ± 0.87 mm and 4.73 ± 0.70 mm, respectively. During 2–3 years of follow-up, all mean values of RBBW were more than 2 mm. Main vertical bone loss appeared within 4 months after surgery and the RVBH value decreased as the follow-up duration continued. Maximum buccal bone thickness resorption mostly appeared in the middle level of

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https://doi.org/10.1016/j.jds.2023.03.006

the implant during the primary two follow-up periods ($P < 0.05$). Esthetic results showed that the mean WES/PES was higher than 17, and more than half cases demonstrated relatively high PI (3 points) throughout the follow-up.
*Conclusion:* BRT could achieve excellent bone augmentation effect and can offer predictable esthetic outcomes for single tooth implant restoration in the esthetic zone.


## Introduction

Most alveolar sockets have a thin buccal wall, which is often absorbed within the healing period after tooth extraction. Changes such as soft- and hard-tissue collapse ultimately achieve equilibrium as the result of a 40%—60% decrease in alveolar height and width over 3—4 months, leading to severe horizontal/vertical alveolar bone defects.[1] Bone augmentation is often required to place the implant in a prosthetic-driven manner and to achieve long-term predictable esthetic outcomes. Several alveolar bone augmentation techniques are based on guided bone regeneration (GBR) for horizontal/vertical alveolar ridge deficiencies, among which autologous onlay grafts are considered the gold standard.[2] However, the procedure of onlay bone graft is complex and requires a second stage of implant placement after a healing period, which is overly invasive and increases the overall treatment time.[3]

The "bone ring technique" (BRT) was developed to overcome this issue based on bone augmentation with simultaneous implant placement.[4] BRT provides a three-dimensional reconstruction of alveolar bone defects with ring-shaped autogenous bone grafts or allogenic/xenogeneic bone substitutes fixed by dental implants. BRT is a reliable alternative method for the management of severe socket defects, knife-edge ridges, and many other types of bone defects.[5] BRT has been clinically applied and documented in several case reports showing excellent outcomes for dimensional bone augmentation.[6,7] A recent systematic review including 16 BRT studies revealed superior bone ring and implant survival rates (97.26% and 94.97%, respectively), as well as remarkable vertical bone gain of 4.94 mm and acceptable bone resorption and marginal bone loss (MBL) (0.83 mm and 0.57 mm, respectively) after an average follow-up of 13.35 months.[8] However, there is not enough evidence for the long-term effect of BRT, and different studies have demonstrated independent bone augmentation results compared with other GBR-based methods. Chandra et al. found autogenous BRT seemed to confer additional benefits over GBR using the sticky bone technique, while Wychowansky et al. reported similar long-term clinical regeneration outcomes of vertical bone defects when using autogenous BRT compared with traditional GBR.[9,10] Animal studies have indicated that the one-stage BRT procedure demonstrated better osseointegration and left behind more residual cortical bone than the two-stage procedure.[11,12] However, other studies proposed that this one-stage approach offers lower predictability due to the potential cortical bone graft resorption around the implant.[13] Another animal study using different bone substitutes for BRT in sheep mandibles found that only autogenous bone maintained bone volume around the dental implant, and the augmented area showed low bone-to-implant contact values.[14]

There is a lack of study investigation into BRT's effectiveness on horizontal/vertical bone augmentation as well as esthetic outcome in the esthetic zone over the long term. Ideally, successful esthetic single implant-supported restoration should imitate the natural tooth and be symmetrical with the reference tooth, which is mainly presented by a consistent gingival margin with a filled gingival papilla or by pink esthetic score (PES) is higher than 8 (maximum score, 10).[15] Therefore, this retrospective study aimed to evaluate BRT's efficacy on bone augmentation in single maxillary anterior tooth implantation and its esthetic outcome over 2—3 years of follow-up. The null hypothesis of this study was that single-stage BRT provides stable horizontal/vertical bone augmentation and maintain good esthetic outcome over 2—3 years of follow-up.

## Materials and methods

### Study subjects

This retrospective study evaluated data collected at the Department of West China Hospital of Stomatology, Sichuan University (Chengdu, China) between January 2016 and April 2022. The study was conducted by the Declaration of Helsinki and was approved by the Clinical Research Ethics Committee of West China Hospital of Stomatology, Sichuan University (permission number: WCHSIRB-D-2022-188).

Inclusion criteria were as follows: (1) healthy patients aged 18—60 years; (2) single central maxillary incisor loss due to trauma or tooth decay for at least 6—8 weeks, with 2—3 wall defects detected via cone-beam computed tomography (CBCT; Morita Corp., Osaka, Japan) examination; (3) sign acceptable written consent; (4) complete final restoration within one year after the operation. Exclusion criteria were as follows: (1) presence of systemic diseases; (2) heavy smoking (more than 10 cigarettes a day); (3) untreated periodontitis; (4) no compliance with periodontal follow-up.

### Surgical protocol

One experienced surgeon conducted all procedures, and the surgical procedures are shown in Fig. 1. To make the bone ring match different bone defects and ensure the best implant position, it was prepared either centrally or

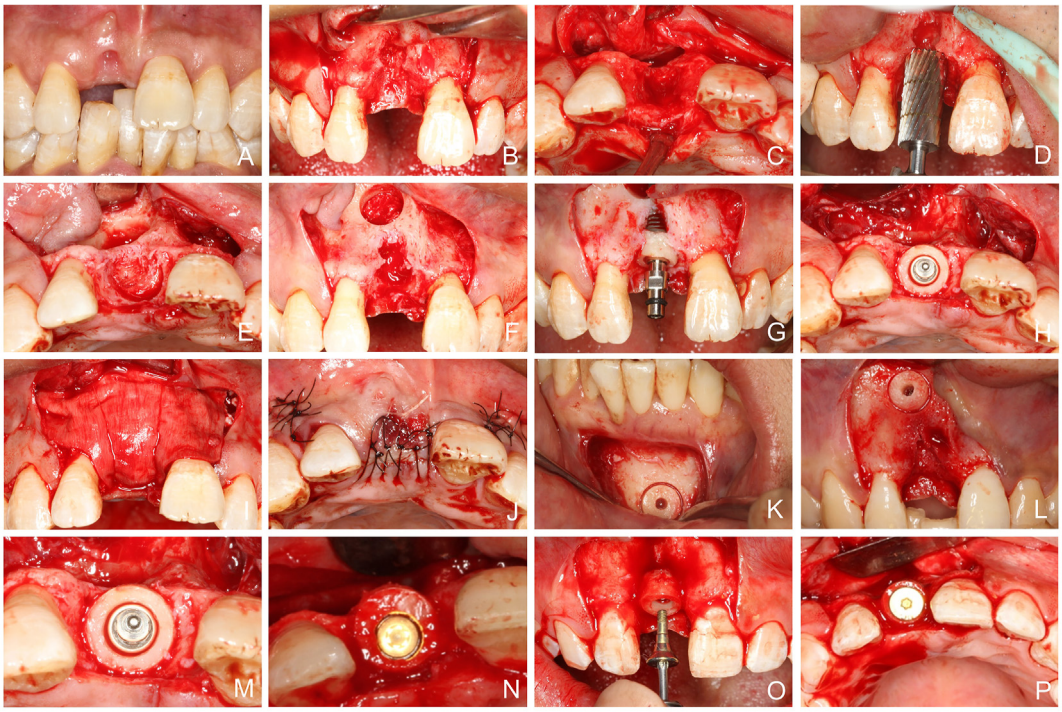


**Figure 1** BRT surgical procedure in different conditions. A. Single maxillary right incisor lost with soft tissue collapse. B. Mid-crestal incision with two vertical releasing incisions. C. Circular two-to three-wall defects. D. Recipient site measured and prepared with a solid bone grinding drill. E&F. Recipient and donor site after preparation. G. Bone ring fixed by the implant. H. Implant in the appropriate position. I. GBR. J. Soft tissue closure. K. Ring bone harvested from the chin region. L. Ring bone harvested in situ. M. A concentric type of central bone ring preparation. N. An eccentric type of central bone ring preparation. O&P. A healing cap with a large diameter and low height was used to fix the bone ring. BRT, bone ring technique; GBR, guided bone regeneration.

eccentrically (Fig. 1M and N). The position of implant placement was by the 3A2B principle in the esthetic zone.[16] The cover screw was secured generally, and when the bone ring was not stable enough, a healing abutment was used (Fig. 1O and P). The standard GBR procedure was performed with a bovine bone substitute (Bio-Oss; Geistlich Pharma AG, Wolhusen, Switzerland) and resorbable collagen membrane (Bio-guide; Geistlich Pharma AG). The surgical sites were left to heal for 4 months, and a second-stage surgery was performed. One month later, a temporary CAD/CAM screw-retained resin crown was used to reconstruct a natural gingival appearance. The personalized definitive all-ceramic crown was placed after 6 months. Patients were recalled for regular follow-ups of 1 year-, 2 year- and 3 year-postoperative.

## Radiological assessment

Vertical and horizontal bone gain and bone volume changes were assessed according to a modified method based on previous protocols.[17] Using Mevislab software (MeVis Research, Bremen, Germany) to overlap the presurgical CBCT data with those obtained 4 months after surgery (Fig. 2A&2B). The implant's long axis (ILA) line and the implant platform line perpendicular to the ILA were drawn at the same sagittal section. The difference between the vertical/horizontal lines (red line) before and after implantation was regarded as the vertical/horizontal bone gain value (Fig. 2C).

The coronal and sagittal orientation axes were adjusted through One Volume Viewer software (Ver.1.5.0, Morita Corp.) (Fig. 2D). In the coronal slice, two parallel lines (one coincided with the implant platform, the other tangential to the apex) perpendicular to the ILA was drawn, and two parallel lines along the implant mesial/distal surface coincided with the ILA were drawn. To assess the remaining vertical bone height (RVBH), the length from the intersecting points in the apical to the point where the next two lines intersected with the coronal marginal bone was recorded as the mesial vertical bone height (MVBH) and distal vertical bone height (DVBH) respectively (Fig. 2E). The same lines were drawn on the sagittal slice, and the buccal vertical bone height (BVBH) and lingual vertical bone height (LVBH) were recorded in the same manner (Fig. 2F). The RVBH at the implant platform could be obtained by subtracting the DVBH, MVBH, BVBH, and LVBH values from the implant length. For vertical bone resorption in different aspects around the implant, the subtraction values of DVBH, MVBH, BVBH, and LVBH between each time point (month 4 -Year 1, Year 1-Year 2, and Year 2-Year 3) were calculated.

To assess the horizontal bone width, buccolingual bone width (BLBW), as well as remaining buccal bone width (RBBW), were both measured in the sagittal slice. BLBW was recorded as the length between the intersections of the coronal marginal bone and the line coinciding with the implant platform (Fig. 2C). RBBW was measured by drawing a line along the implant surface parallel to the ILA from the implant platform to the apical. Using five points to divide the line into five equal parts, and the distances from the

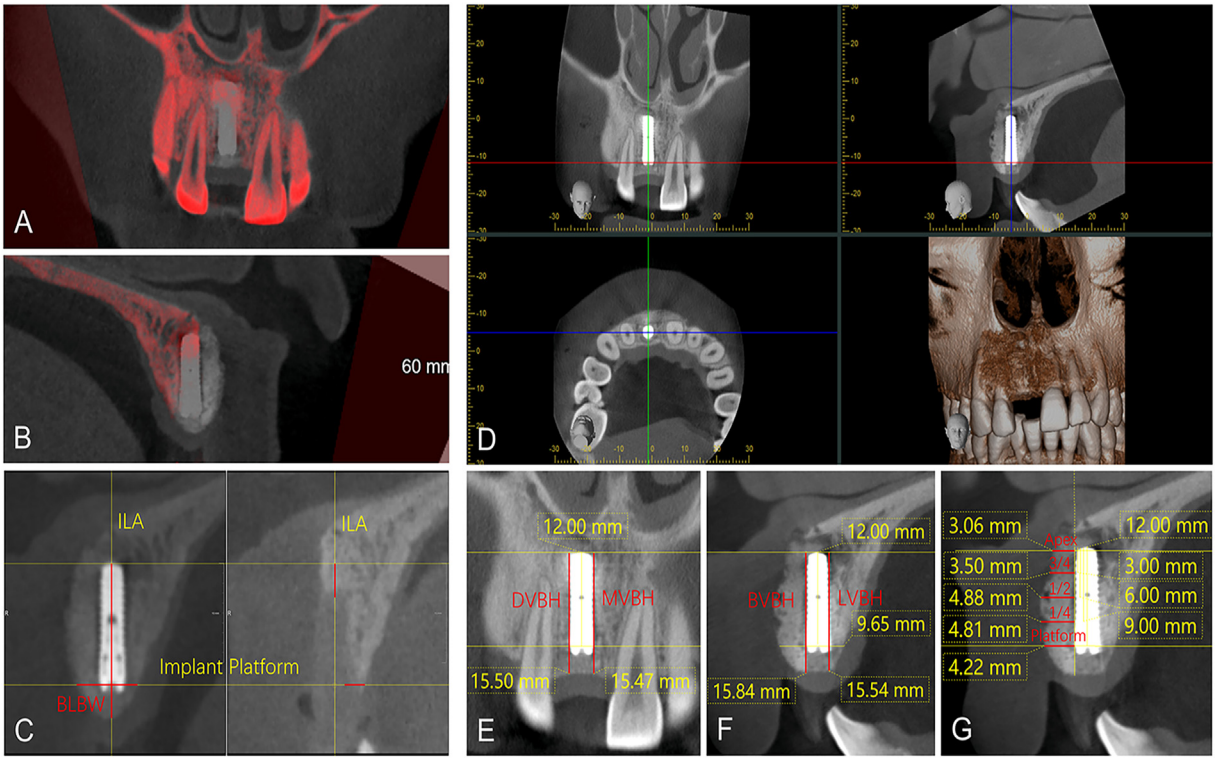


**Figure 2** Measurement of the bone around the implant. A&B. CBCT data pre-surgery and 4 months post-surgery overlapped using Mevislab software. C. Vertical bone height and buccolingual horizontal bone width as measured by CBCT. D. Adjustment snapshot of XYZ screen in One Volume Viewer software. E. Measurement of mesial (MVBH) and distal (DVBH) bone height. F. Measurement of buccal (BVBH) and lingual (LVBH) bone height. G. Measurement of implant buccal bone thickness on a different plane. Platform = implant platform, 1/4 = 3 mm apically from the platform of implant, 1/2 = 6 mm apically from the implant platform, 3/4 = 9 mm apically from the implant platform, Apex = apex of the implant.
BVBH, buccal vertical bone height; CBCT, cone-beam computed tomography; DVBH, distal vertical bone height; ILA, implant's long axis; LVBH, lingual vertical bone height; MVBH, mesial vertical bone height.

implant surface of the five points to the intersecting point of the bone surface at each line were recorded as the RBBW of Platform, 1/4, 1/2, 3/4, and Apex (Fig. 2G). For horizontal/buccal bone resorption, the subtraction values of BLBW and RBBW between each time point were also recorded in the same manner.

### Esthetic assessment

Photographs were taken immediately to record the soft tissue status on the day of definitive crown restoration and at each follow-up. White esthetic score (WES), PES, and papilla index score (PI) were used to assess the soft tissue around the single-tooth implants following a standard evaluation method.[18,19] The assessment was performed by three experienced dentists who had not been involved in the prosthetic treatment. These assessments were carried out twice on different days to reduce bias and ensure optimal reproducibility.

### Statistical analysis

All data were subjected to statistical analysis using SPSS version 26.0 software (SPSS Inc., Armonk, NY, USA). Continuous variables were represented as the means ± standard deviations (Mean ± SDs). The results and frequency distribution analysis are presented as tables, histograms, and boxplots. Data were proven to be normally distributed and variance homogeneity and analyzed through analysis of variance (ANOVA). A statistically significant bone height/width change over time was defined as a P value less than 0.05.

## Results

Fifteen patients (mean age, 35 years; age range, 18—64 years; 6 females, 9 males) enroll in the study and received 15 implants. Table 1 listed the detailed information of the included patients. A total of 15 bone rings were harvested with 10 in situ and 5 from the chin. All patients had slight postoperative edema on the day after surgery, which subsided completely after 4—6 days. During the subsequent healing period, none of the patients complained of numbness, pain, or any other symptom at the donor or recipient site. All 15 implant sites showed evidence of osseointegration by CBCT after 4 months and all bone rings healed uneventfully. However, one bone ring was found exposed at the 4 months post-surgery, which was excluded from the final statistical analysis. This bone ring survived but had some resorption, and the exposed part healed well after

**Table 1** Detailed information of 15 cases.

| No. | Gender | Age | Tooth | Bone defect | Implant | Donor site | Bone ring (mm) | Follow-up (year) |
|---|---|---|---|---|---|---|---|---|
| 1 | Female | 45 | 21 | 2.5-wall | Straumann BL, 3.3 × 12 mm | Chin | 5 | 2 |
| 2 | Male | 29 | 11 | 3-wall | Anthogyr REG, 3.4 × 12 mm | Chin | 5 | 2 |
| 3 | Male | 49 | 21 | 2.5-wall | Straumann BL, 3.3 × 12 mm | In situ | 5 | 3 |
| 4 | Female | 23 | 21 | 3-wall | Straumann BL, 3.3 × 12 mm | In situ | 5 | 3 |
| 5 | Male | 47 | 11 | 3-wall | WEGO, 3.4 × 12 mm | In situ | 5 | 3 |
| 6 | Male | 18 | 11 | 3-wall | Straumann BL, 3.3 × 12 mm | In situ | 5 | 3 |
| 7 | Female | 24 | 11 | 2-wall | Straumann BL, 3.3 × 12 mm | Chin | 5 | 2 |
| 8 | Male | 54 | 21 | 2.5-wall | Straumann BL, 3.3 × 12 mm | In situ | 5 | 3 |
| 9 | Male | 64 | 12 | 2.5-wall | Anthogyr REG, 3.4 × 12 mm | In situ | 5 | 3 |
| 10 | Male | 20 | 21 | 3-wall | Straumann BL, 3.3 × 12 mm | Chin | 5 | 2 |
| 11 | Female | 28 | 11 | 2-wall | Anthogyr REG, 3.4 × 12 mm | Chin | 5 | 2 |
| 12 | Male | 22 | 21 | 2-wall | Anthogyr REG, 3.4 × 12 mm | In situ | 5 | 2 |
| 13 | Female | 32 | 11 | 3-wall | Straumann BL, 3.3 × 12 mm | In situ | 5 | 2 |
| 14 | Male | 45 | 11 | 3-wall | Anthogyr REG, 3.4 × 12 mm | In situ | 5 | 2 |
| 15 | Female | 25 | 11 | 3-wall | Anthogyr REG, 3.4 × 12 mm | In situ | 5 | 2 |

careful treatment (Fig. 3). The overall bone ring survival rate was 100% and the complication rate was 6.67%. Throughout the follow-up period (average 2.4 years), no implant site demonstrated signs of acute infection or peri-implantitis, and a success and survival rate of 100% was achieved in this study. All the patients were satisfied with the esthetic results of the final restoration.

Through BRT the surgery sites get satisfactory bone augmentation to reconstruct 2–3 wall defects (Fig. 4A). The mean vertical bone gain was 5.55 ± 0.87 mm (Min: 3.81 mm, Max: 6.69 mm), and the mean horizontal bone gain was 4.73 ± 0.7 mm (Min: 3.39 mm, Max: 5.81 mm), indicating significant horizontal and vertical bone volume augmentation after BRT (Fig. 4B&C).

Horizontal bone width changes as follow-ups were shown in Table 2 and Fig. 5B, and RBBW at different levels were estimated independently, as it is related to the esthetic outcome (Table 3 and Fig. 5C). Significant bone loss

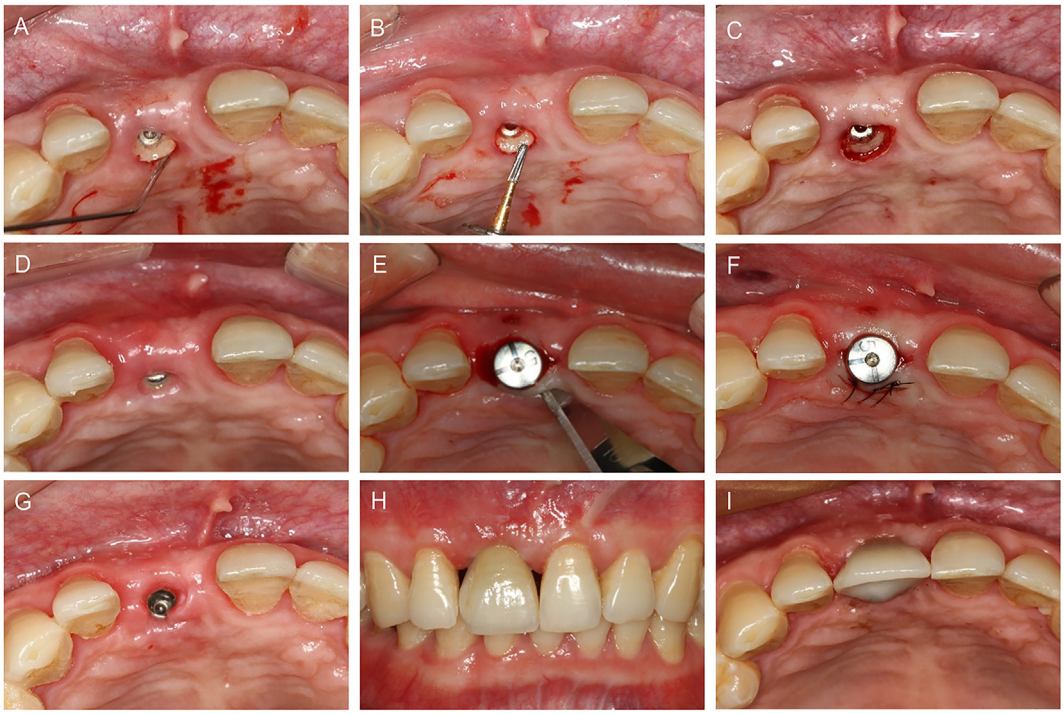


**Figure 3** Dealing with bone ring exposure. A. Bone ring exposure on the lingual side 4 months post-surgery. The bone ring survived and was stable. B. 0.05% chlorhexidine was used to rinse the exposed part, and we removed the exposed bone and cornified mucosa with a tungsten steel drill. C. Completing the entire treatment. D. Exposed part was reduced 2 weeks post-treatment. E. Removing the exposed bone and the cornified mucosa with a tungsten steel drill. F. Second phase surgery was performed, with suturing of the exposed part. G. The exposed part had healed well 1 week later. H&I, The final ceramic crown.

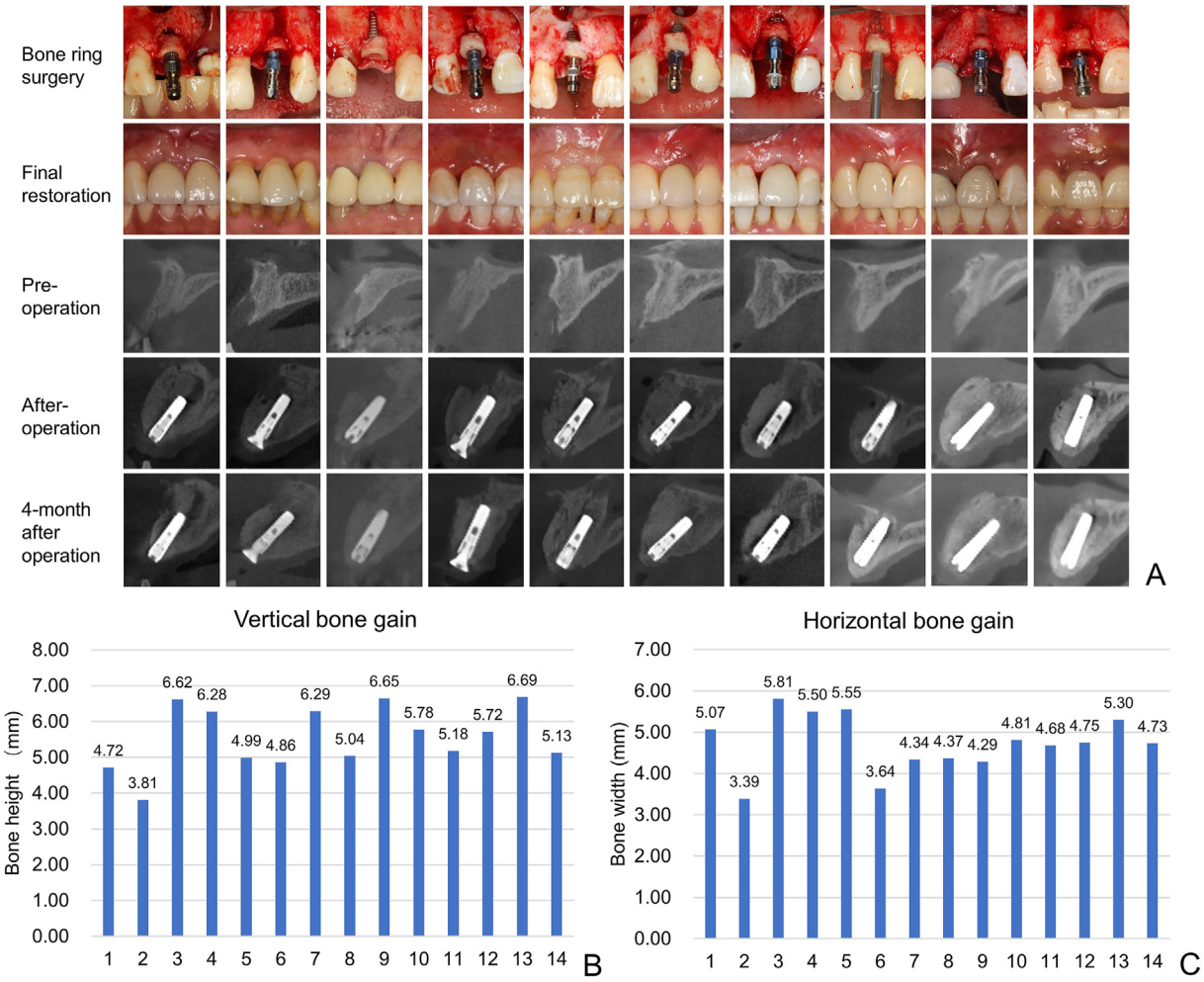


**Figure 4** BRT treatment procedure and vertical/horizontal bone gain in each patient included in the analysis. A. Representative photos from these patients' surgeries and radiographs during different follow-up periods. B. Vertical bone gain values after 4 months post-surgery as measured by CBCT. C. Horizontal bone gain values 4 months post-surgery. BRT, bone ring technique; CBCT, cone-beam computed tomography.

**Table 2** Horizontal bone width at different follow-up time points (mm).

| | Postoperative | 4 months | 1 year | 2 years | 3 years |
|---|---|---|---|---|---|
| **Horizontal bone width** | $9.04 \pm 0.73^{b,c,d,e}$ | $7.38 \pm 0.74^{a,c,d,e}$ | $6.60 \pm 0.74^{a,b}$ | $6.35 \pm 0.70^{a,b}$ | $6.32 \pm 0.89^{a,b}$ |

The characters a,b,c,d,e indicated significant difference found when comparing to groups postoperative, 4 months, 1 year, 2 years and 3 years respectively under Least Significance Difference test ($p < 0.05$).

appeared within 1 year after surgery ($P < 0.05$ for bone width of other groups compared with postoperative or 4 months groups), but the bone width at different planes decreased to a stable level after 1 year postoperative ($P > 0.05$ for 1, 2 and 3- year follow-up groups compared with each other). The remaining buccal bone at 3/4 and apical implant levels seem to show less bone resorption than other implant levels, and the main bone resorption occurred within the first 4 months after surgery ($P < 0.05$ for bone width of other groups compared with the post-operative group). At each observation time point, the minimum mean values were found on the plane of the implant platform, while most maximum mean values appeared on the plane of the 1/2 or 3/4 implant. After 3 years of follow-up, all mean values of RBBW in different planes maintained a stable bone volume that was more than 2 mm, which was of great importance for the esthetic area.

Main vertical bone resorption mostly appeared during the 4 months postoperative (range from $1.06 \pm 0.11$ mm to $1.16 \pm 0.27$ mm) and 4 months to the 1-year follow-up (range from $0.68 \pm 0.27$ mm to $0.81 \pm 0.22$ mm), then the value decreased as the follow-up period continued (Fig. 5A). In the case of RVBH, mean bone height values on the coronal side of the implant also decreased with observation time (max: $3.22 \pm 0.62$ mm, min: $0.35 \pm 0.76$ mm) (Table 4). Most mean

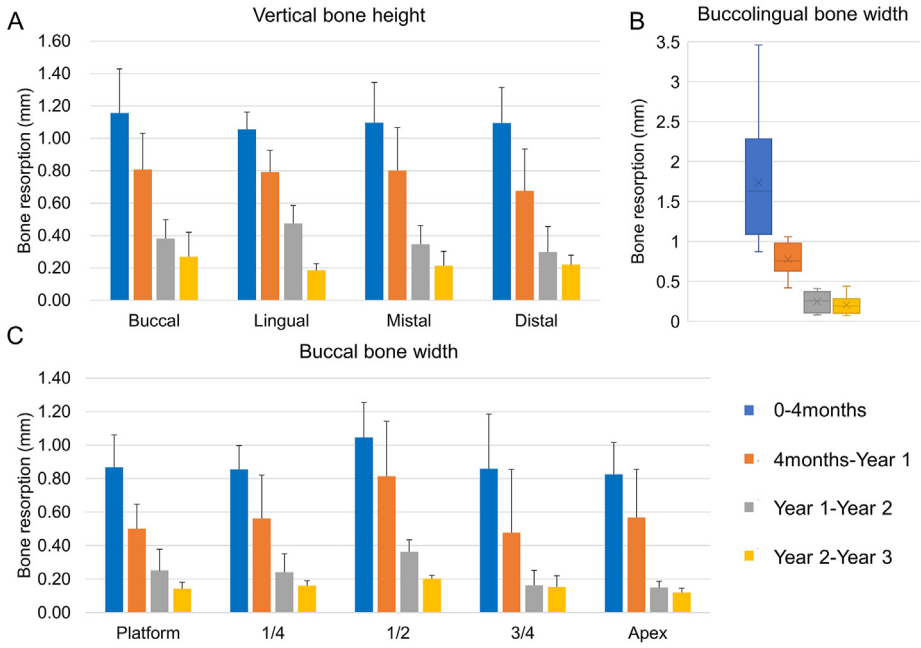


**Figure 5** Vertical and horizontal bone resorption within different follow-up periods. A. Decreases in vertical bone height within different follow-up periods. B. Decreases in buccolingual bone width at the implant platform within different follow-up periods. C. Decreases in buccal bone thickness at a different plane of the implant within different follow-up periods.

**Table 3** Remaining buccal bone width (RBBW) around the implant at different follow-up time points (mm).

| Implant level (plane) | Follow-up | | | | |
|---|---|---|---|---|---|
| | Postoperative | 4 months | 1 year | 2 years | 3 years |
| Platform | $3.86 \pm 0.39^{b,c,d,e}$ | $3.02 \pm 0.48^{a,c,d,e}$ | $2.49 \pm 0.47^{a,b}$ | $2.19 \pm 0.58^{a,b}$ | $2.25 \pm 0.29^{a,b}$ |
| 1/4 | $4.77 \pm 0.40^{b,c,d,e}$ | $3.89 \pm 0.40^{a,c,d,e}$ | $3.29 \pm 0.40^{a,b}$ | $3.09 \pm 0.40^{a,b}$ | $3.01 \pm 0.22^{a,b}$ |
| 1/2 | $5.46 \pm 0.81^{b,c,d,e}$ | $4.39 \pm 0.62^{a,c,d,e}$ | $3.56 \pm 0.62^{a,b,e}$ | $3.33 \pm 0.59^{a,b}$ | $2.81 \pm 0.29^{a,b,c}$ |
| 3/4 | $5.24 \pm 1.07^{b,c,d,e}$ | $4.37 \pm 1.00^{a}$ | $3.89 \pm 1.01^{a}$ | $3.78 \pm 1.09^{a}$ | $3.42 \pm 0.71^{a}$ |
| Apical | $4.63 \pm 1.30^{c,d,e}$ | $3.84 \pm 1.25$ | $3.25 \pm 1.21^{a}$ | $3.24 \pm 1.30^{a}$ | $3.28 \pm 1.02^{a}$ |

The characters a,b,c,d,e indicated significant difference found when comparing to groups postoperative, 4 months, 1 year, 2 years and 3 years respectively under Least Significance Difference test ($p < 0.05$).

**Table 4** Remaining vertical bone height (RVBH) around the implant at different follow-up time points (mm).

| Implant level (plane) | Follow-up | | | | |
|---|---|---|---|---|---|
| | Postoperative | 4 months | 1 year | 2 years | 3 years |
| Buccal | $3.22 \pm 0.62^{b,c,d,e}$ | $2.06 \pm 0.61^{a,c,d,e}$ | $1.25 \pm 0.62^{a,b}$ | $0.86 \pm 0.70^{a,b}$ | $0.64 \pm 0.83^{a,b}$ |
| Lingual | $3.01 \pm 0.54^{b,c,d,e}$ | $1.95 \pm 0.51^{a,c,d,e}$ | $1.16 \pm 0.51^{a,b,d,e}$ | $0.73 \pm 0.51^{a,b,c}$ | $0.59 \pm 0.56^{a,b,c}$ |
| Mesial | $3.03 \pm 0.77^{b,c,d,e}$ | $1.94 \pm 0.84^{a,c,d,e}$ | $1.14 \pm 0.82^{a,b}$ | $0.78 \pm 0.86^{a,b}$ | $0.35 \pm 0.76^{a,b}$ |
| Distal | $3.09 \pm 0.80^{b,c,d,e}$ | $2.00 \pm 0.86^{a,c,d,e}$ | $1.32 \pm 0.97^{a}$ | $1.08 \pm 1.07^{a,b}$ | $0.46 \pm 0.55^{a,b}$ |

The characters a,b,c,d,e indicated significant difference found when comparing to groups postoperative, 4 months, 1 year, 2 years and 3 years respectively under Least Significance Difference test ($p < 0.05$).

values in different aspects of the implant were higher than 0.5 mm, indicating that the bone ring around the implant stably maintained bone height throughout the 3-year follow-up.

PES/WES scores of the 14 examined single-tooth implants are summarized in Table 5. The mean total PES/WES was $17.14 \pm 1.35$, $17.29 \pm 1.33$, and $17.67 \pm 0.82$ at baseline (final restoration), 2-year, and 3-year follow-ups, respectively. No restorations had an overall score lower than 15, indicating highly satisfactory esthetic results. The clinical photos of 3-year follow-up patients are shown in Fig. 6A. Mean PES was $8.21 \pm 0.89$ (range, 7–10) at baseline and $8.50 \pm 0.55$ (range, 8–9) at the 3-year follow-up, indicating a stable soft tissue state throughout the follow-up. For those 5 variables that were used to estimate PES, the proportion of a high score of 2 for every variable was more than 50% at all follow-up

**Table 5** Mean pink esthetic score (PES) and white esthetic score (WES) (Variables and totals) for implant restorations at baseline and follow-ups.

| Time | PES | | | | WES | | | | Total | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Max | Min | Mean | SD | Max | Min | Mean | SD | Max | Min | Mean | SD |
| Baseline | 10 | 7 | 8.21 | 0.89 | 10 | 7 | 8.71 | 0.83 | 19 | 15 | 17.14 | 1.35 |
| 2 years | 10 | 7 | 8.57 | 0.76 | 10 | 7 | 8.60 | 0.84 | 19 | 15 | 17.29 | 1.33 |
| 3 years | 9 | 8 | 8.50 | 0.55 | 10 | 7 | 8.83 | 0.98 | 19 | 15 | 17.67 | 0.82 |

Max, maximum; Min, minimum; SD, standard deviation.

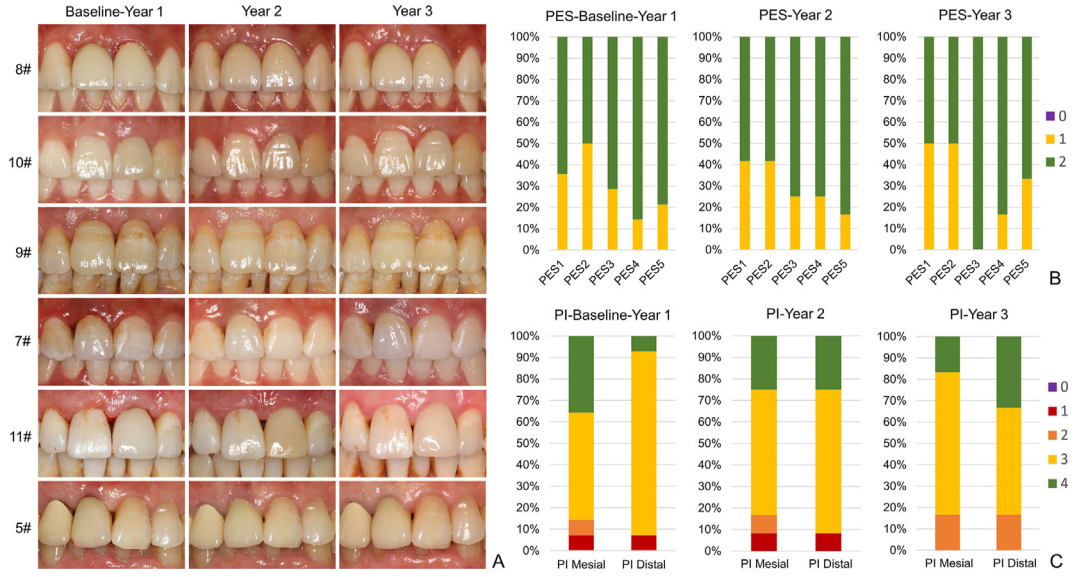


**Figure 6** A. Clinical photos of 6 BRT patients during 3-year follow-up. B. Frequency of PES assessment at baseline and follow-up of 5 variables (PES 1 = mesial papilla; PES 2 = distal papilla; PES 3 = curvature of the facial mucosa; PES 4 = level of the facial mucosa; PES 5 = root convexity/soft tissue color and texture); each was further rated with scores of 0–2 (2 = complete presence; 1 = incomplete presence; 0 = absence). C. Frequency of PI assessment at baseline and follow-up. PI ratings for the mesial and distal papilla (0 = no papilla present; 1 = less than half of the papilla height present [convex nature of the adjacent tissue]; 2 = more than half of the papilla height present, but not to the full extent of the contact point [papilla not in complete harmony]; 3 = papilla fills the entire proximal space and is in good harmony; 4 = papilla is hyperplastic). BRT, bone ring technique; PES, pink esthetic score; PI, papilla index.

durations (Fig. 6B). For PI, more than half of the cases demonstrated a relatively high score of 3 throughout the entire period, suggesting that most cases in this study obtained excellent soft tissue outcomes (Fig. 6C). All patients showed complete satisfaction with the final prosthesis concerning esthetics and function.

## Discussion

The autogenous cortical bone block is the main choice for BRT which can be harvested from the chin, hard palate, or retromolar regions.[6,20] The chin region is the main intraoral donor site, but it still carries the disadvantage of a secondary surgical area, prolonged surgery time, and potential paresthesia in the symphyseal region.[21] In situ bone ring harvesting is another choice, bone rings harvested from the maxilla contain more cancellous bone tissues, supplying abundant osteoprogenitor cells and consequently encouraging the rapid ingrowth of local vessels as well as the revascularization process.[22,23] In this study, an in situ bone ring near the apical of the implant insertion area was the first choice. However, if the bone volume in situ is insufficient, the chin was considered as the donor site.

BRT is more suitable for two-to three-wall bone defects because the cortical ring bone has better contour support than the GBR technique alone can supply, leading to a better contour increment effect. In addition, graft/bed proximity can be easily achieved via this technique through host bone preparation, which is more conducive to graft survival compared with the traditional onlay graft technique.[4] During the bone ring obtainment and recipient site preparation, the internal diameter of the trephine bur was the same as that of the bone grinding drill to achieve a precise fit ("press fit") between the bone ring and bone defect.[24] Besides, to ensure the perfect three-dimensional implantation position, the central preparation of the bone ring can be either concentric or eccentric, enabling better application in different types of bone defects and increasing buccal alveolar bone thickness.

Previous studies have shown that single-stage implant placement using BRT seems to be as equally efficient as the two-stage procedure.[12] A study utilizing autogenetic bone ring reported a mean crestal bone resorption of 0.61 mm mesially and 0.64 mm distally at 6 months postoperative.[6] A recent retrospective clinical study using xenogeneic BRT reported that the MBL was 1.46 ± 0.38 mm on the buccal side of the implants one year after prosthetic restoration.[25] In this study, aa total of 14 implant sites showed a mean vertical bone gain of 5.55 ± 0.87 mm and a mean horizontal bone gain of 4.73 ± 0.70 mm at 4 months post-surgery. Vertical and horizontal bone loss significantly during the first 4 months post-surgery, but in the final follow-up period of 2—3 years, the bone loss values were only 0.22 ± 0.03 mm (vertical) and 0.21 ± 0.13 mm (horizontal). The values of bone gain and bone resorption in our study were in accordance with those reported in a recent systematic review, which included a total of 186 patients treated with 219 autogenetic or xenogenetic bone rings.[8] Remaining vertical bone and buccal bone were the most important factors affecting the final esthetic outcome. In this study, mean values of RVBH around the implant throughout the whole period were positive, suggesting that the implant platform was well protected by the newly forming bone without any exposure. In addition, mean values of RBBW were consistently higher than 2 mm, meeting the esthetic requirement of 2 mm thick buccal bone for implant placement in the esthetic zone.[16]

BRT complications occur during both surgery and the healing period; therefore, care should be taken when applying this technique. In this study, there is no bone ring fracture occurred in any of the cases. In one case that lost ring bone stability, we fixed the bone ring using a large diameter and low-height healing cap. To prevent ring bone exposure, we tried to smoothen the bone ring edge and make sure the wound was closed without tension. Only one case had palatal-bone graft exposure 4 months post-surgery, but the graft was stable and alive. After removing the exposed part of the bone ring and dealing with the soft tissue, the graft healed well.

Soft tissue esthetics is a major aspect of implant success and the main motivation for patients to undergo implant therapy in the esthetic zone. Bone support as well as the soft tissue dimensions around the implant restoration are two important factors affecting the esthetic outcome of implant therapy.[18] In this study, the average total PES/WES score of 14 cases was 17.14 at baseline, and 17.67 at the last follow-up (range, 15—19). All patients' PES was above 7, the frequency of every PES item scored 2 was more than 50% and no case showed a score of zero, which was defined as the threshold of clinical acceptability by Belser et al.[15] The frequency distribution of PI also demonstrated more than half cases had a relatively high score of 3, suggesting that most patients in this study obtained excellent stable soft tissue outcomes. The peri-implant soft tissue appearance depends on underlying bone topography and the surgical procedure that is applied to regenerate the peri-implant bone defects, while the height of peri-implant papillae primarily depends on the bone level height at adjacent root surfaces.[26] In this study, the excellent and stable soft tissue outcome was mainly due to the effective three-dimensional bone reconstruction and limited horizontal/vertical bone resorption obtained via BRT combined with GBR over 2—3 years of follow-up.

In conclusion, autogenous BRT demonstrated significant bone augmentation, acceptable vertical/horizontal bone resorption, pleasing esthetic outcomes, and stable soft tissue alteration. Therefore, autogenous BRT is an effective technique to reconstruct bone defects both horizontally and vertically and to offer predictable esthetic outcomes for single tooth implant restoration in the esthetic zone.

## Declaration of competing interest

The authors deny any conflicts of interest related to this study.

## Acknowledgments

This work was supported by Basic Research Project of Sichuan Provincial Department of Science and Technology [grant numbers 20YYJC3660].

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