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Apical U-shape splitting technique for undercut areas of the anterior alveolar ridge: a prospective non-randomized controlled study

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Abstract. The aim of this study was to investigate a novel apical U-shape splitting technique for horizontal bone augmentation in undercut areas and to compare its efficacy with that of guided bone regeneration (GBR). This was a prospective non-randomized controlled clinical trial. A total of 36 patients, who presented with a labial undercut that was not able to house a normally inclined implant, underwent the new technique or GBR. Radiographic and clinical data were obtained preoperatively, immediately after surgery, and 12 months after surgery. Pairwise comparisons of changes in ridge width gain, marginal bone loss, and pink aesthetic score were performed; correlations with pristine ridge morphology were investigated. The results showed similar marginal bone loss in the two groups. The overall ridge width gains in the new technique group (2.56 ± 1.92 mm) and GBR group (0.73 ± 1.21 mm) differed significantly ($P < 0.05$). The pink aesthetic score was higher for the new technique group (11.75 ± 1.22) than for the GBR group (9.25 ± 1.86) ($P < 0.01$). The morphology of the concavity had different impacts on regeneration in the two groups. The apical U-shape splitting technique, as a safe and effective alternative to GBR, provided a significant increase in bone volume gain where labial fenestration was inevitable during implant placement.

Key words: horizontal bone augmentation; dental implant; ridge splitting technique.

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Alveolar bone loss after tooth extraction can prevent favourable positioning and angulation of the implant[1]. Various techniques are applied to overcome these problems, including guided bone regeneration (GBR), onlay bone grafting, and the ridge splitting technique (RST)[2,3]. RST with simultaneous implant placement is proposed as a reliable alternative to horizontal bone augmentation in the anterior maxil-

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la[4,5]. Advantages of this technique include a higher bone utilization ratio, simultaneous implant placement, and the requirement of less bone substitute. Compared with RST, GBR entails a longer healing time and may be complicated by exposure of the membranes, resulting in bone loss or even implant failure[6]. The onlay bone grafting procedure requires a second surgical site and a healing period of 6–12 months before implant placement, and the graft may sometimes fail to integrate at the augmented site[7].

The success of RST is heavily dependent on the morphology of the alveolar ridge. Concavity of the alveolar bone, due to the centripetal resorption pattern of the maxilla, can result in fenestration of the labial bone plate during implant placement, even when a significant facial flare is allowed in severely resorbed conditions[8]. When the alveolar ridge is split longitudinally into two parts, provoking a greenstick fracture in the concave area, fracture of the labial bone plate may occur during bone expansion or implant placement[9,10]. Other concerns are that marginal bone loss (MBL) occurs when RST is applied, because the buccal and lingual plates are thin after ridge splitting, and that mechanical trauma is inevitable during splitting[7]. Therefore, horizontal bone augmentation leaving the top of the crest intact and locating the greenstick fracture away from the thinnest area may be recommended when decreased bone thickness is only found away from the top of the crest.

GBR has been suggested when fenestration occurs in the labial undercut[11]. However, compromised outcomes may result due to the inadequate space-making ability of the particulate grafts and absorbable membranes[12]. Non-absorbable membranes and titanium mesh can help maintain bone volume[13,14]. However, a higher rate of complications, including infection, tissue inflammation, and healing deficiency, has been recorded[12].

To address these problems, an apical U-shape splitting technique (AUST) using piezoelectric surgery was developed for horizontal bone augmentation in the undercut area in order to achieve simultaneous implant placement and predictable bone volume maintenance. The aims of this study were (1) to present the AUST and compare its efficacy with that of GBR, and (2) to assess the influence of labial bone morphology on the amount of horizontal bone augmentation achieved with the new technique.

Materials and methods

Study design and patients

This study was designed as a prospective non-randomized controlled clinical trial. Over a 1-year period, 36 patients attending the Implant Department of the West China Hospital of Stomatology, who were scheduled for horizontal bone augmentation in the anterior maxillary area, were enrolled consecutively into the study. The inclusion criteria were as follows: (1) at least one tooth missing in the anterior maxilla, (2) the presence of a labial undercut >2 mm in thickness but that was not able to house an implant with a minimum length of 8.0 mm and a minimum diameter of 3.3 mm, (3) the presence of adequate bone width near the alveolar bone crest, and (4) the absence of a vertical bone defect. The exclusion criteria were as follows: age <18 years, a history of any systemic disease that would contraindicate surgery, uncontrolled diabetes, pregnancy or lactation, long-term amino-bisphosphonate therapy, and smoking more than 10 cigarettes per day. The protocol was approved by the Ethics Committee of the West China Hospital of Stomatology. The study was reported in accordance with the CONSORT 2010 checklist.

Surgery and prosthetic procedures

All patients provided informed consent prior to treatment. The morphology of the residual alveolar ridge at baseline was assessed using data collected from cone beam computed tomography (CBCT) images. The alveolar ridges were divided into two categories: type I, which allowed virtual implant placement without bone augmentation, and type II, which required GBR or AUST for horizontal bone augmentation in the premaxillary undercuts (Fig. 1). Patients with type I ridges were excluded from the study and underwent implant placement without bone augmentation. Type II patients were re-enrolled consecu-

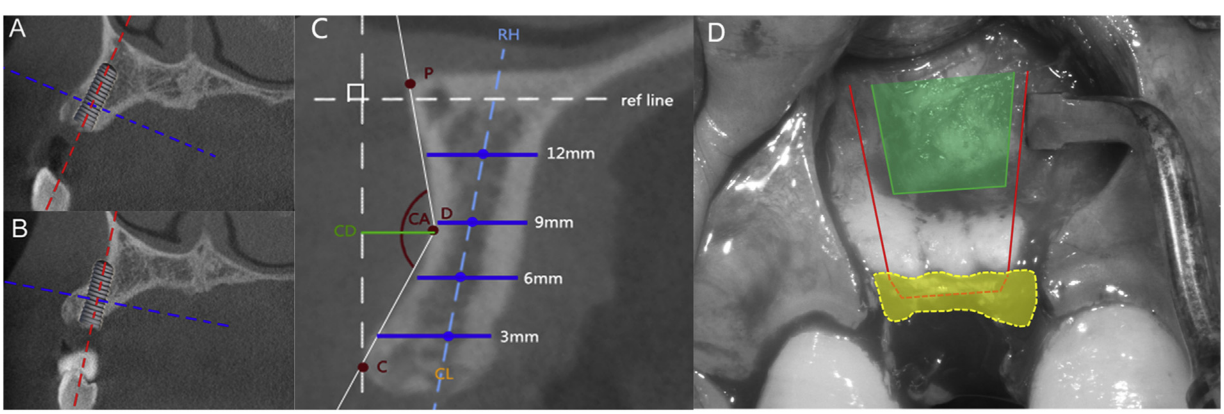

Fig. 1. Classification of alveolar ridges and assessment of ridge morphology. (A) Type I, allowing virtual implant placement without bone augmentation. (B) Type II, requiring horizontal bone augmentation in the undercut area. (C) Assessment of the ridge morphology at baseline: point D = the deepest point of the buccal plate; point C = the most external point of the buccal plate; point P = the most external point of the buccal plate coronal to point D; CD = concavity depth, i.e. the horizontal distance between point D and a vertical reference line perpendicular to the reference line passing through point C; CA = concavity angulation, i.e. the angle between line D–C and line D–P; CL = concavity location, i.e. the vertical distance between point D and the alveolar crest. (D) Osteotomies of the apical U-shape splitting technique (AUST) and conventional ridge splitting: the yellow area indicates the top of the crest; the red solid lines indicate the vertical cuts on the labial surface of conventional ridge splitting; the red dotted line indicates the mid-crestal bone cut of conventional ridge splitting; the green line indicates the bone cuts of the AUST; the green area indicates the bony flap elevated in the AUST.

tively and numbered in chronological order. Patients with an even number were assigned to GBR, while those with an odd number were assigned to AUST.

All procedures were performed by the same surgeon under local anaesthesia on an outpatient basis. A full-thickness mucoperiosteal flap was elevated bilaterally and reflected buccally to obtain adequate visibility of the undercut area (Fig. 2A, E). In the GBR group, no bone cuts were made in the undercut area. In the AUST group, a U-shaped bone cut, down to the cancellous bone, was made in the undercut area with a piezoelectric device. The horizontal bone cut was made apical (in the presence of a concavity location <6 mm; Fig. 2A–D) or coronal (in the presence of a concavity location ≥6 mm; Fig. 1D, Fig. 2E, F) to the most concave point in the undercut area with a distance of 3 mm. The two vertical bone cuts were placed at least 1 mm away from the adjacent roots and extended beyond the undercut area (Fig. 2B, F). Then, the released bone end was gently levelled out using a periosteotome through a greenstick fracture so as to create enough space for implant placement (Fig. 2C, G).

All implants were installed with the implant shoulders flush to the bone level using a low-speed drilling procedure. Almost no implant surface was exposed in the AUST group (Fig. 2D, H), while buccal fenestrations were found in the GBR group. The autologous bone obtained during the drilling process was used to cover any exposed implant surface. An inorganic bovine bone substitute (Bio-Oss; Geistlich Pharma AG, Wolhusen, Switzerland) was placed over the concave surface to cover the fenestration in the GBR group and to overcorrect the labial contour in the AUST group in anticipation of subsequent resorption. Passive primary closure was achieved by adequate periosteal releases and careful interrupted sutures. Routine anti-inflammatory therapy and prophylactic antibiotics were prescribed. The second-stage surgery was performed 3 months postoperative. An interim prosthesis was fabricated and screwed in immediately, for soft tissue conditioning over the next 3 months. The definitive restoration was placed 6 months after surgery (Fig. 3).

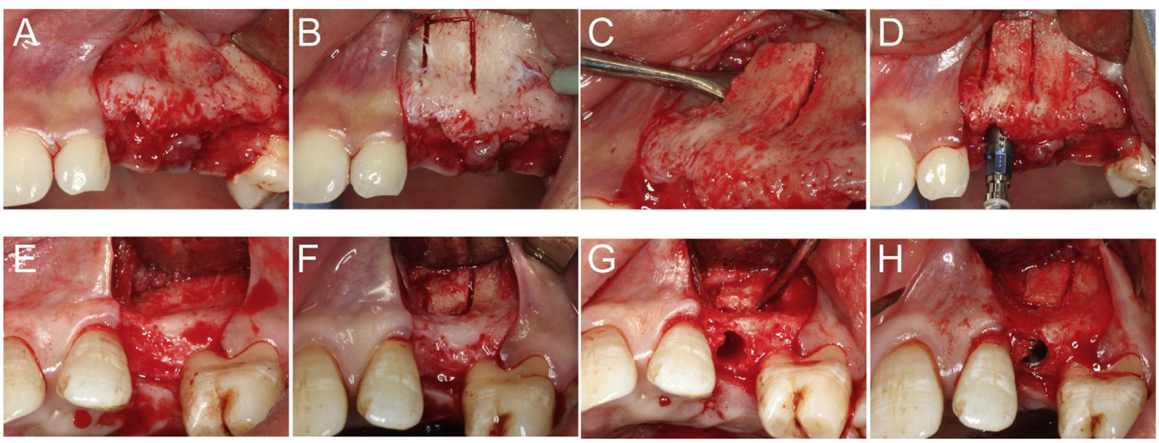

Fig. 2. Surgical procedure for the apical U-shape splitting technique. (A, E) Concave buccal area; (B, F) U-shaped bone cut, with the horizontal bone cut apical (B) or coronal (F) to the most concave point; (C, G) elevated bone flap; and (D, H) implant placement without exposure.

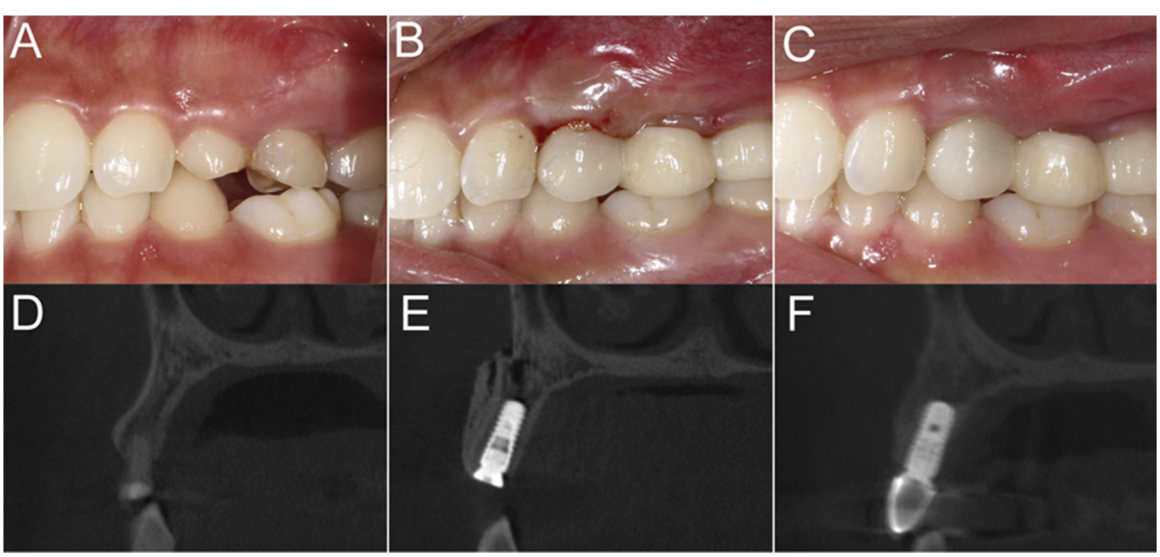

Fig. 3. Final restoration after apical U-shape splitting technique. Buccal view (A) at baseline, (B) immediately after the final restoration, and (C) 1 year after surgery. CBCT obtained (D) at baseline, (E) immediately after the final restoration, and (F) 1 year after surgery.

Clinical and radiographic evaluation

Clinical monitoring was conducted preoperatively (T0), immediately after implant placement (T1), and at the 1-year post-surgery visit (T2). The examiner was blinded to the patients' names, and the following variables were assessed: (1) Complications: fracture of the buccal bone. (2) Peri-implant health: presence of plaque, bleeding on probing (BOP), and probing depth (PD) at T2. The modified plaque index (mPI) was applied using the following scoring system: 0 = no plaque; 1 = non-visible thin film of plaque that can be detected by scraping the tooth surface with a probe; 2 = visible plaque; and 3 = massive amount of plaque that fills the interdental space. Scores of 0 (no bleeding) and 1 (bleeding) were used to record the presence or absence of peri-implant bleeding. Peri-implant probing was performed to the nearest 0.5 mm using a manual probe. (3) Baseline measurements for labial bone morphology (T0): ridge width (RW), concavity depth (CD), concavity angulation (CA), and concavity location (CL) (Fig. 1C). To standardize comparisons between the scans, the selected scans were reoriented according to Garaicoa et al.[15]. The line connecting the anterior and posterior nasal spine (maxillary plane) served as the reference line and was parallel to the ground. The maxilla was symmetrical and the reference arch was drawn in the transverse view at the level of crestal bone, with its centre corresponding to the centre of the ridge[15]. RW was the distance between the buccal and palatal bone plates at 3 mm, 6 mm, 9 mm, and 12 mm apical to the crestal bone. (4) Measurement of changes in horizontal dimensions: total bone gain in RW was calculated by subtracting the baseline value from the values at T2 at 3 mm, 6 mm, 9 mm, and 12 mm apical to the crestal bone. The volume of bone resorption after bone augmentation was calculated by subtracting the value at T2 from the values at T1 at 3 mm, 6 mm, 9 mm, and 12 mm apical to the crestal bone. (5) Measurement of peri-implant bone level: the distance from the implant shoulder to the most coronal point of bone-to-implant contact was recorded mesial and distal to the implant at T2.

Aesthetic evaluation

Objective evaluations of implant aesthetics were performed by two experienced examiners based on standardized intraoral photographs. The pink aesthetic scores (PESs) were recorded[16]. The soft tissue around implant-supported single teeth was evaluated by assigning a score of 0 to 2 for each variable, with 0 representing the poorest result and 2 representing the best result. The maximum score of 14 points reflects perfect peri-implant soft tissue aesthetics.

Statistical analysis

For continuous variables, the data are expressed as the mean ± standard deviation (SD). The Mann–Whitney *U*-test was applied to compare measurements, including BOP, mPI, PD, MBL, PES, CL, CA, and CD, between the studied groups. Pearson's χ^2 test was used to analyze the difference in sex distribution between the studied groups. The independent *t*-test was used to analyze bone gain (T2–T0) and bone loss (T1–T2) between the two study groups. The mean mesial and distal measurements were used unless stated otherwise. Possible correlations between CL, CA, CD, and the final RW gains at various measurement levels were plotted, and the results were analyzed with linear regression. To account for multiple testing (factors influencing horizontal dimensional changes), a Bonferroni correction was applied. The intra- and inter-examiner reliability of the measurements was analyzed using the kappa value. All tests were two-sided, and $P < 0.05$ was considered significant. Statistical analyses were performed using IBM SPSS Statistics for version 20.0 (IBM Corp., Armonk, NY, USA).

Results

A total of 36 patients (14 women and 22 men), aged between 25 and 58 years (mean age 35.4 years), were eligible for evaluation and met the inclusion criteria. There was no significant difference between the different treatment protocols with regard to the sex distribution ($P = 0.687$). Of the 36 patients, 20 had single teeth missing and 16 had multiple teeth missing. Eighteen patients underwent GBR and 18 patients underwent AUST. In cases of adjacent missing teeth, only the mesial tooth was included. A total of 36 implants were evaluated, including 10 NobelActive implants (Nobel Biocare AB, Göteborg, Sweden) and 26 ITI bone level implants (Institut Straumann AG, Basel, Switzerland), between January 2014 and March 2016. The GBR group and AUST group each included five NobelActive implants and 13 ITI bone level implants. There was no significant difference in the implant system used. Two experienced examiners independently measured the parameters 10 times on 10 randomized CBCT scans. The kappa values were calculated to be 0.81 and 0.84, respectively.

Horizontal bone augmentation was uneventful in the two groups. No evidence of swelling, redness, or exudate around the implants or symptoms of pain or sensitivity upon implant percussion were detected during the follow-up. No implants were lost during the 1-year follow-up. All patients had good oral hygiene as indicated by low plaque indices (GBR group 0.61 ± 0.70; AUST group 0.50 ± 0.70), bleeding scores (GBR group 0.11 ± 0.32; AUST group 0.16 ± 0.38), and probing depth (GBR group 2.51 ± 0.25; AUST group 2.44 ± 0.35). No significant differences between the two surgical protocols were found in terms of mPI ($P = 0.672$), PD ($P = 0.421$), BOP ($P = 0.847$), CD ($P = 0.92$), CA ($P = 0.882$), or CL ($P = 0.801$).

Table 1 shows the ridge morphology indices at T0, T1, and T2. Immediately after surgery, a significant increase in RW was evident in both groups at all levels (Fig. 4A).

Table 1. Mean bone width at different levels preoperatively (T0), immediately after surgery (T1), and 1 year after surgery (T2).

Intervals		Ridge width, mean ± SD (mm)				Baseline measurement, mean ± SD		
		3 mm	6 mm	9 mm	12 mm	Concavity depth	Concavity angle	Concavity location
GBR	T0	5.92 ± 0.80	5.65 ± 1.15	6.34 ± 1.20	8.77 ± 1.46	3.65 ± 0.62	135.26 ± 10.43	8.25 ± 2.26
	T1	7.03 ± 0.57	8.00 ± 0.73	9.04 ± 1.07	9.61 ± 1.62			
	T2	5.75 ± 0.92	6.76 ± 1.08	7.96 ± 1.47	9.13 ± 1.62			
AUST	T0	5.88 ± 0.57	5.10 ± 0.41	5.31 ± 1.62	6.57 ± 1.71	3.68 ± 0.89	135.98 ± 12.97	8.04 ± 1.88
	T1	7.58 ± 0.82	8.84 ± 1.26	9.49 ± 1.45	9.04 ± 1.82			
	T2	6.76 ± 0.92	8.29 ± 1.40	9.11 ± 1.60	8.93 ± 1.69			

AUST, apical U-shape splitting technique; GBR, guided bone regeneration; SD, standard deviation.

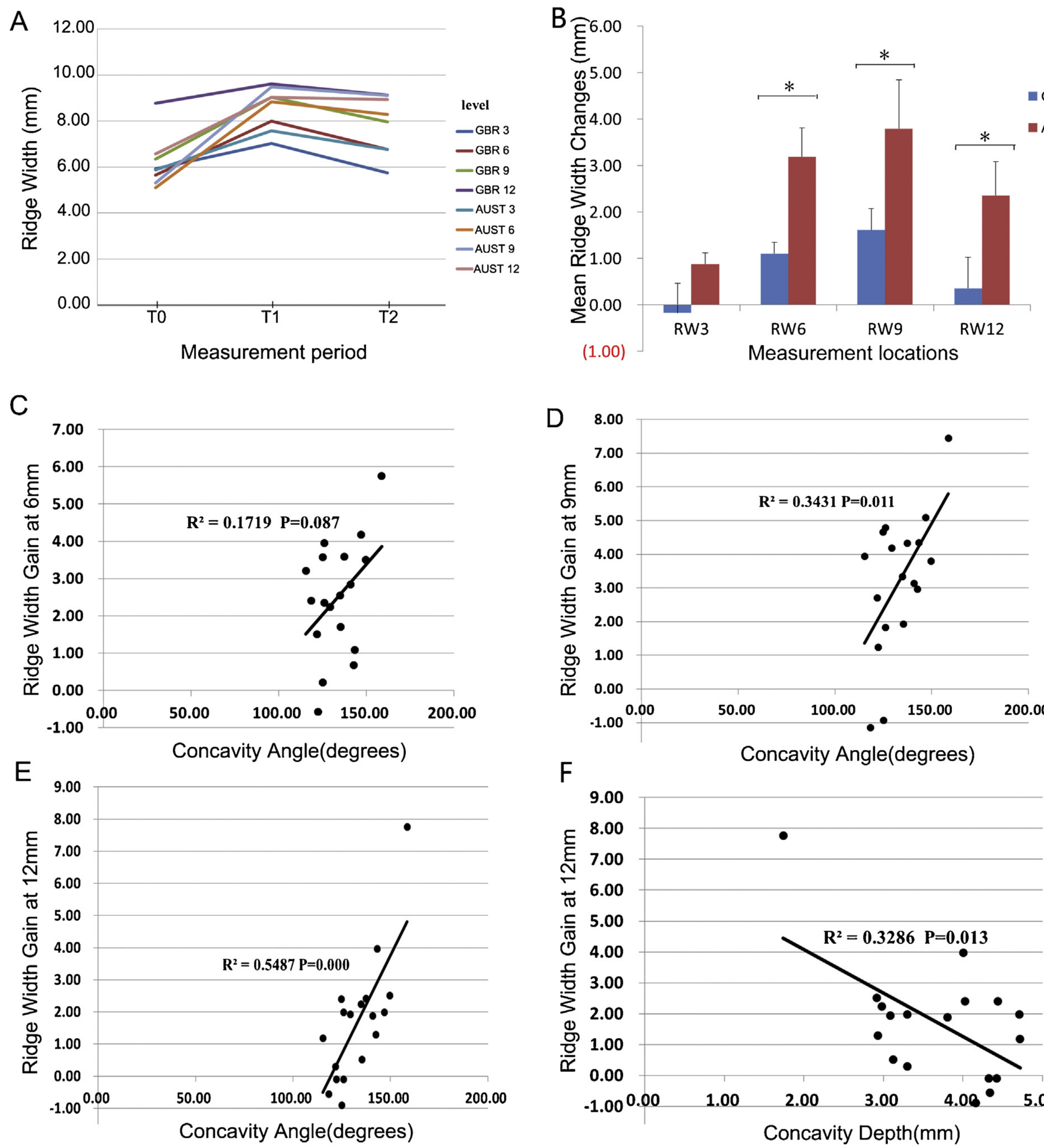

Fig. 4. Graphic representation of the mean ridge widths and changes in mean ridge width: (A) mean ridge widths of the GBR and AUST groups at different measurement levels; (B) comparison of changes in mean ridge width at 3 mm (RW3), 6 mm (RW6), 9 mm (RW9), and 12 mm (RW12) using GBR and AUST (*$P < 0.05$). The effect of ridge morphological characteristics on mean ridge width gain at: (C) 6 mm, (D) 9 mm, and (E, F) 12 mm apical to the bone crest in AUST group. (AUST, apical U-shape splitting technique; GBR, guided bone regeneration.).

At T2, MBL of 0.62 ± 0.33 mm was measured in the GBR group and 0.55 ± 0.48 mm in the AUST group ($P = 0.571$). The mean changes in bone width at the different levels are reported in Table 2. The comparisons of changes in ridge morphology at all measurement locations revealed an overall mean RW gain of 2.56 ± 1.92 mm after AUST and 0.73 ± 1.21 mm after GBR ($P = 0.022$) (Table 2). Significant differences in total bone gain (T2-T0) were observed between GBR group and AUST group at 6 mm and 9 mm ($P < 0.05$) (Fig. 4B). Bone resorption at T2 was significantly different between the GBR group and AUST group at 6 mm ($P = 0.041$) and 9 mm ($P = 0.032$) . The PESs at T2 were 9.25 ± 1.86 and 11.75 ± 1.22 in the GBR group and AUST group, respectively ($P = 0.001$).

When AUST was used, linear regression analysis revealed that a higher CA was related to a higher RW gain. The effect of CA on mean RW gain was only significant at 9 mm and 12 mm apical to the crest (Fig. 4C–E). A higher CD was possibly associated with a lower RW gain. The effect of CD on mean RW gain was only significant at 12 mm apical to the crest (Fig. 4F). No obvious

Table 2. Mean bone width changes at different levels preoperatively (T0), immediately after surgery (T1), and 1 year after surgery (T2).

Intervals[a]		Ridge width, mean ± SD (mm)				
		3 mm	6 mm	9 mm	12 mm	Average
GBR	T1–T0	1.11 ± 0.56	2.34 ± 0.87	2.70 ± 1.19	0.84 ± 0.99	1.75 ± 1.20
	T2–T0	−0.17 ± 0.84	1.11 ± 0.94	1.61 ± 1.37	0.36 ± 0.88	0.73 ± 1.21
	T1–T2	1.28 ± 0.91	1.24 ± 0.92	1.09 ± 1.09	0.48 ± 0.97	1.02 ± 1.00
AUST	T1–T0	1.70 ± 0.80	3.74 ± 1.10	4.19 ± 2.07	2.46 ± 2.15	2.22 ± 2.03
	T2–T0	0.88 ± 0.84	3.19 ± 1.22	3.80 ± 2.04	2.36 ± 2.04	2.56 ± 1.92
	T1–T2	0.82 ± 0.91	0.55 ± 0.60	0.39 ± 0.56	0.55 ± 0.60	0.46 ± 0.77

AUST, apical U-shape splitting technique; GBR, guided bone regeneration; SD, standard deviation.

[a] T1–T0 = increased bone width immediately after surgery; T2–T0 = increased bone width 1 year after surgery; T1–T2 = bone width resorption during the 1-year follow-up.

relationship was observed between CL and RW gain.

Discussion

This study was designed to evaluate the efficacy of the AUST in horizontal bone augmentation and to determine the influence of alveolar morphological characteristics on the dimensional changes. The new technique was found to be a safe and reliable alternative to GBR based on the higher RW gain, the stable marginal bone level, and the satisfactory aesthetic results. The depth and angle of the concavity may affect the final result, while the location of the deepest point has no effect on bone gain.

The presence of a labial undercut, common in the anterior maxilla, contraindicates the application of RST[9,10], possibly due to the higher risk of labial bone fracture. AUST, a new modification of RST, was designed exclusively for implant sites with labial undercuts. It minimizes the risk of labial bone fracture by starting the osteotomy in the labial area rather than in the usual midcrestal area. Thus the coronal portion of the implant is always surrounded by pristine bone, which decreases the vertical bone resorption associated with osteotomy.

Other techniques aiming at protecting the buccal bone have been described in previous studies[4,17–20]. Based on the classical RST, González-García et al.[4] tried to decrease the risk of buccal bone detachment by facilitating greenstick fracture through a horizontal osteotomy within the cortical bone at the pedicle of the buccal bone plate. However, this modified technique provides no protection against vertical resorption around the implant shoulder[4]. Santagata et al.[17] described a minimally invasive RST involving the elevation of a partial thickness flap to expose the alveolar crest, and performed only a midcrestal osteotomy. Without the buccal flap, the RST was performed blindly, thereby increasing the surgical difficulty[17]. Some studies managed to keep the periosteum attached to the buccal bone when performing RST by dividing the classical procedure into two steps[18–20]. This staged protocol increases the overall treatment time. All of these previous techniques were designed for patients with horizontal bone resorption all through the length of the implant site. None of them could be applied safely in patients with labial undercuts.

The results of the present study showed that greater RW gain was obtained using AUST compared with GBR, indicating the advantage of AUST over GBR in patients with labial undercuts. The ability to maintain the space is the most prominent advantage of AUST over GBR. The labial plate, which is elevated in AUST as a vascularized bone flap, acts as a tent to keep the grafting materials in place and to disperse the mucosal tension. The amount of bone gain with GBR remains questionable, complicated by the lack of mechanical stability of the absorbable membranes[21]. The elevated bone flap also provides osteogenic factors from the bone marrow, such as bone marrow stromal cells and growth factors, which are favourable for bone regeneration. Using elevation, the buccal bone in the undercut area can be preserved as a whole, while it would have been drilled off if GBR and simultaneous implant placement were performed. The extra space provided by buccal bone elevation increases the chance of achieving a normal implant inclination. The lateral compression exerted by the elevated labial bone during implant placement can increase bone density and cutting torque resistance of the implant, promoting primary retention and initial stability of the implant.

Implant aesthetics were better rehabilitated by AUST than by GBR. In this study, the crestal bone loss 1 year after implant placement was comparable to GBR and was much smaller than that reported in traditional RST studies[22]. AUST did not require any osteotomy in the coronal part of the ridge. The integrity of the coronal bone reduced the risk of peri-implant bone loss and subsequently kept the soft tissue margin stable and the PES favourable. In terms of aesthetics, particulate xenograft material was used to fill the gaps around the elevated bone flap to overcorrect the labial contour in anticipation of resorption. Additional xenografting may be unnecessary when the bony flap can be safely elevated to an overcorrected degree, making the technique less time-consuming and expensive.

The RW gains were less at 3 mm and 12 mm than those at 6 mm and 9 mm apical to the crest, using either AUST or GBR, and this may be attributed to the higher mucosal tension there. Furthermore, a more acute concavity angle was associated with a deeper defect. In the GBR group, the more contained the defect, the more bone gain was achieved, permitting better tenting of the barrier membrane for the purpose of maintaining space. Similar results have been reported in previous studies on GBR[15,23,24]. However, this was in discordance with the result for AUST; with this procedure, a more blunt concavity angle was associated with a shallower defect and greater bone gain. Rather than the concavity as a container, space-keeping with AUST was mostly provided by the elevated bone flap. In cases with deeper defects, the fracture risk of the bone flap was greater, consequently limiting the degree of elevation. In addition, a deeper defect necessitated a thinner elevated bony flap, which tended to resorb during follow-up. As such, there is a greater risk of contour collapse with a deeper concavity than with a shallow concavity, resulting in less bone regeneration. The results show that AUST works better than conventional GBR. Due to different space-keeping mechanisms, the morphology of the concavity has different impacts on regeneration. Whenever the possibility of fenestration exists and coronal bone width is abundant, AUST may be an appropriate alternative to GBR and RST, either with a concave or flat labial morphology.

This study had some limitations. Subjective patient evaluations were not conducted; therefore, the aesthetic evaluation was incomplete. The allocation method, with alternate patients being allocated to the two groups, is less preferable than true randomization. A controlled study with a longer follow-up and true randomization is needed to further assess this new technique. Within the limitations of the study, this new splitting technique appears to be highly effective. It provided an alternative strategy for the rehabilitation of function and aesthetics where labial fenestration was inevitable during implant placement.

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Competing interests

No conflict of interest existed.

Ethical approval

Ethical approval was given by the Human Ethics Committee of the West China School of Stomatology (WCHSIRB-ST-2013-104).

Patient consent

Written patient consent was obtained to publish the clinical photographs.

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