Comparative Assessment of Flap-Advancing Techniques in an Ex Vivo Cadaverous Porcine Model

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Purpose: Since flap advancement is a prerequisite for tension-free primary closure and successful regenerative procedures, the aim of this study was to test the efficacy of six surgical approaches for flap advancement in an ex vivo porcine model. ***Materials and Methods:*** A total of 60 fresh mandibles from pigs were randomized into one of six groups: *(1)* trapezoidal full-thickness flap design with two vertical releasing incisions (control), *(2)* trapezoidal flap with linear periosteal scoring, *(3)* mucosal detachment technique, *(4)* mucosal detachment with horizontal extension, *(5)* mucosal detachment with horizontal and vertical extension, and *(6)* mucosal detachment with horizontal vertical and cutback extension. Coronal advancement of the flap was recorded as the primary variable; the surface area of exposed mucosa and the tear strength were recorded as secondary variables. ***Results:*** Homogeneity existed among groups for preoperative keratinized tissue width and tissue thickness. Mucosal detachment with horizontal, vertical, and, cutback extensions achieved the highest amount of advancement. All remaining groups achieved a statistically higher advancement compared with the trapezoidal full-thickness flap (control). Pairwise comparison demonstrated statistical significance between any two groups ($P < .001$). A positive correlation was noted between exposed mucosa and flap advancement; the advancement increased 0.62 mm for each 10 mm^2 of increase in the exposed mucosal surface. Strength at tear stress was the highest in the trapezoidal full-thickness flap (control) and mucosal detachment with horizontal-vertical-cutback incisions ($P < .001$). ***Conclusion:*** Coronal flap advancement was maximized in the mucosal detachment techniques and positively correlated with the area of exposed mucosa. *Int J Oral Maxillofac Implants 2022;37:823–829. doi: 10.11607/jomi.9382*

Keywords: bone regeneration, oral surgical procedures, plastic surgery, surgical flaps

Postextraction bone loss in the horizontal and vertical dimensions is inevitable, and the amount of loss is related to the extent of surgical trauma, local anatomy, and possible tissue phenotype.[1] As severe ridge resorption might impair placement of dental implants in a restorable position, guided bone regeneration (GBR) was introduced to provide sufficient bone volume for implant positioning and long-term biologic stability. GBR has evolved over the past decades and is today considered the most documented procedure for bone augmentation.[2] Although widely applied, it is still associated with a high prevalence of postoperative complications that can negatively influence the outcome.[3] Wound opening is one of the most commonly reported complications, with an occurrence ranging between 16% and 30%[4,5] depending upon systemic, local, and surgical factors.[6,7] Among systemic conditions, diabetes mellitus increases the overall risk of complications (odds ratio [OR]: 6.1). Smoking increases the risk for infection (OR: 10.8) and membrane exposure (OR: 9.5).[8] Local factors known to influence the surgical outcomes include defect features, defect extent, and soft tissue characteristics.[9]

Among the surgical-related factors, tension-free primary closure is considered a prerequisite for uneventful successful healing.[10,11] Therefore, several techniques have been proposed to improve the extent of flap advancement. Common approaches include vertical releasing incision, periosteal scoring, and split-thickness flap.[12–14] The disadvantages of these techniques are the increased tissue trauma with postoperative morbidity and the limited amount of flap advancement. To alleviate the described limitations, multiple techniques and modifications have been proposed and tested.[14–18] Urban et al proposed a location-specific technique to coronally advance the mucosa in mandibular posterior areas. With the aid of a tunneling dissection of the retromolar area and detachment of the mylohyoid muscle, the authors achieved significant advancement in sensitive anatomical areas. Kim et al also proposed a coronal

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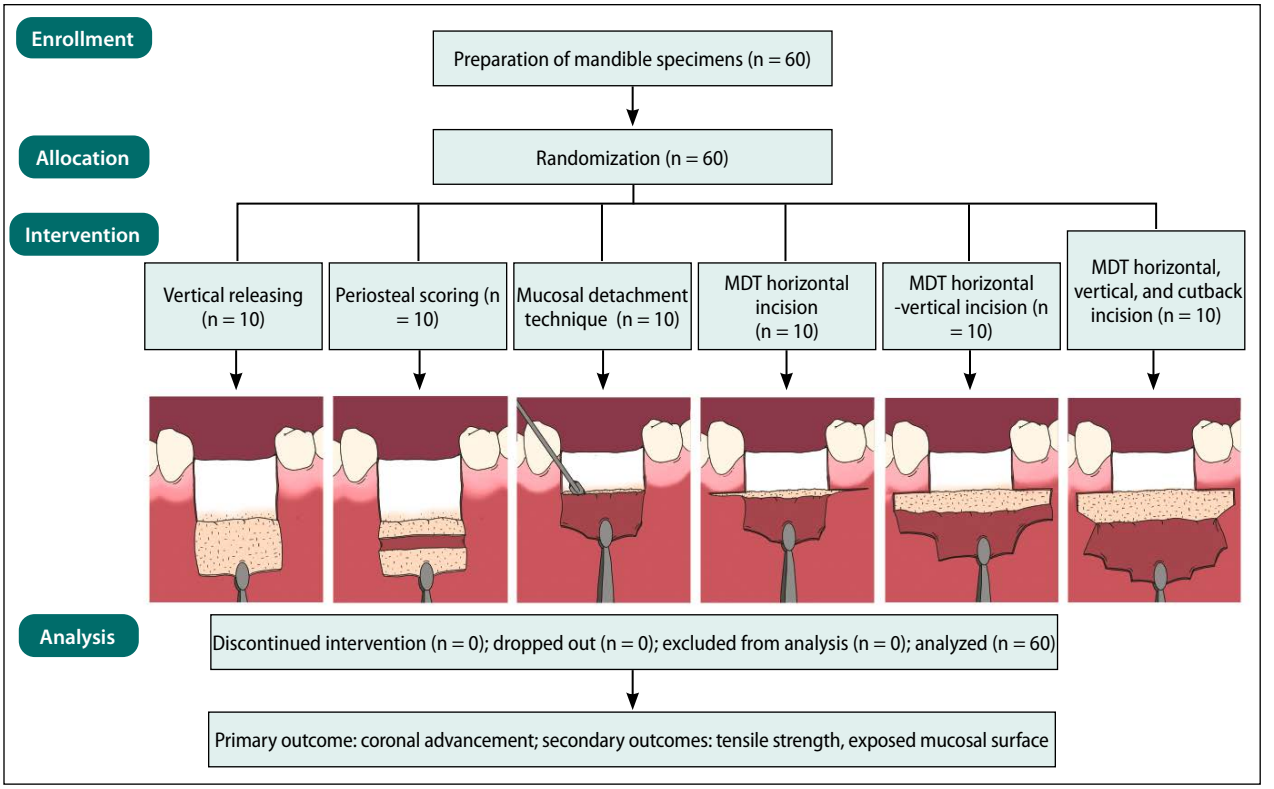


Fig 1 Flowchart of study design with schematic illustration of surgical methods.

advancement technique without vertical releasing incisions. Removal of the facial muscles was used to break the flap tension, and application of this technique showed > 7 mm of advancement. Despite the multitude of proposed techniques, soft tissue dehiscence is a prevalent finding of research articles and clinical practice, especially in patients with thin phenotypes. Burkhardt and Lang (2010) demonstrated an increased rate of flap dehiscence in thin vs thick flaps and that the prevalence of wound dehiscence was associated with flap tension. Thin flaps (< 1 mm) are more sensitive to the applied forces compared to thick flaps (> 1 mm), as a 100% rate of wound dehiscence was observed when forces > 0.15 N were applied to thin flaps.[19]

The mucosal detachment technique is a surgical approach for safe and effective flap release in thin tissue phenotypes that separates most of the mucosal connective tissue while leaving the underlying periosteum on the bone.[20] The mucosal detachment technique showed a favorable effect to achieve adequate dimensions of flap flexibility while allowing maintenance of vascularization and force distribution among the advanced flap.[20] In light of the limited information comparing different techniques for flap advancement, this study aimed to investigate the effectiveness of six surgical techniques in flap mobilization: *(1)* the trapezoidal full-thickness flap design with two vertical incisions; *(2)* trapezoidal flap with periosteal releasing; and *(3)* the mucosal detachment technique, as well as three modifications of the mucosal detachment technique with *(4)* horizontal; *(5)* horizontal and vertical; and (6) horizontal, vertical, and cutback additional extensions in an ex vivo cadaverous porcine model with thin tissue phenotype.

MATERIALS AND METHODS

Specimen Preparation

Ethical approval was not required for this study. Sixty mandibles from adult pigs freshly euthanized 1 hour before preparation from a local butcher's shop were used for the study. The edentulous ridge between the canine and premolar was used as the study site. To be included, the jaw phenotype needed to present a mucosal thickness (MT) of < 2 mm on the lingual side of the mandible, which was assessed by bone sounding with a probe (UNC probe, Hu-Friedy) at 1 mm apical to the mucogingival junction (MGJ) and with keratinized tissue width (KTW) ranging from 6 to 8 mm. A flowchart of study design and an illustration of surgical methods are provided in Fig 1.

Group Allocation

Each mandible specimen was randomly assigned to one of the six groups by the use of the random/sort function of software (Microsoft Excel):

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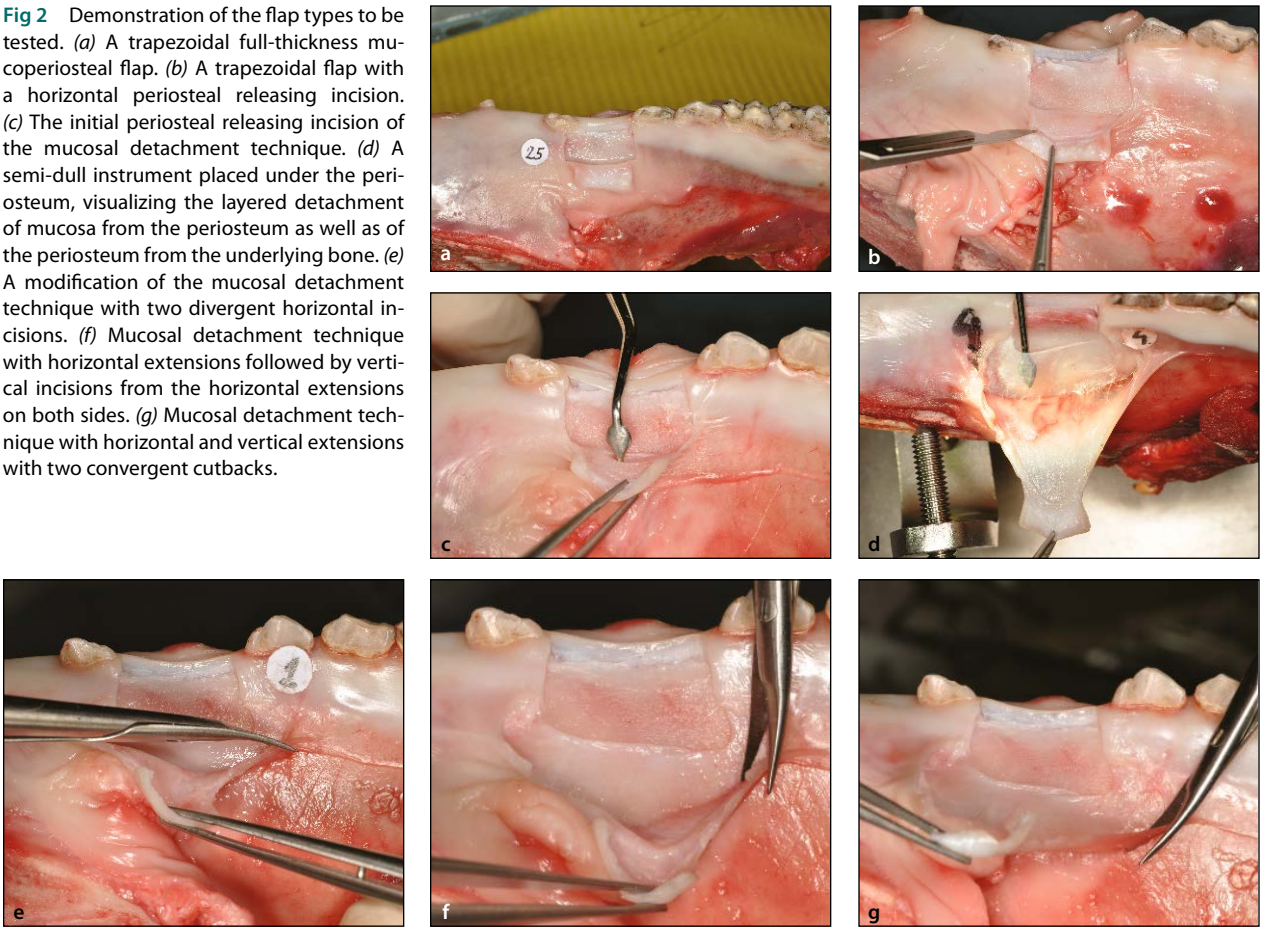


Fig 2 Demonstration of the flap types to be tested. *(a)* A trapezoidal full-thickness mucoperiosteal flap. *(b)* A trapezoidal flap with a horizontal periosteal releasing incision. *(c)* The initial periosteal releasing incision of the mucosal detachment technique. *(d)* A semi-dull instrument placed under the periosteum, visualizing the layered detachment of mucosa from the periosteum as well as of the periosteum from the underlying bone. *(e)* A modification of the mucosal detachment technique with two divergent horizontal incisions. *(f)* Mucosal detachment technique with horizontal extensions followed by vertical incisions from the horizontal extensions on both sides. *(g)* Mucosal detachment technique with horizontal and vertical extensions with two convergent cutbacks.

- Group 1: A trapezoidal full-thickness flap with mesial and distal vertical releasing incisions was used as the control group. A uniform flap was initiated with a midcrestal incision of 15 mm, followed by two vertical incisions of 10 mm long each. The full-thickness mucoperiosteal flap was then elevated (Fig 2a).
- Group 2: The flap was initiated as for group 1, and an additional single horizontal periosteal scoring incision was performed at 2 to 3 mm apical to the MGJ after flap elevation (Fig 2b).
- Group 3: This procedure was performed according to the mucosal detachment technique as described by Steigmann et al.[20] A sharp dissection in the mucosal tissue from underneath the periosteum was performed, starting at 2 to 3 mm past the MGJ (Fig 2c). In the created space, an instrument with sharp angles but dull cutting edges was moved with mesiodistal motions in continuation of the initial periosteal releasing incision (Hu-Friedy #TKSTEIG2, Hu-Friedy #TKSTEIG). This created the separation of the mucosal tissue from the periosteum. A semi-dull instrument was then used horizontally along the entire flap width to improve the separation of the mucosal tissue from the periosteum (Fig 2d). The amount of the apical extension of the flap was the same as the other two groups (10 mm apically).
- Group 4: The same as the mucosal detachment technique with a divergent horizontal incision at the base of the flap in mucosal tissue on both sides (Fig 2e).
- Group 5: The same as the mucosal detachment technique with horizontal extensions plus a vertical incision extending apically into the mucosa on both sides (Fig 2f).
- Group 6: The same as the mucosal detachment technique with horizontal and vertical extensions plus a back-action convergent incision into the mucosa on both sides (Fig 2g).

All surgical procedures were completed by three trained and calibrated surgeons (M.S., G.S., C.P.) in 4 days.

Primary and Secondary Outcomes

Coronal advancement of the flap was defined as the primary outcome and was measured in millimeters (mm) with a periodontal probe positioned vertically and perpendicularly to the bone crest. Standardized force of 10 g was applied to measure the advancement. Flap tensile

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Table 1 Intergroup Comparisons (Unadjusted for Covariates, KTW, and MT) for Flap Advancement, Exposed Mucosal Surface, and Tensile Strength

Treatment groups	Flap advancement (mm)	Exposed mucosal surface (mm^2)	Tensile strength (g)
Group 1	0.60 ± 0.52	0.00 ± 0.00	1,626.00 ± 316.13
Group 2	3.80 ± 0.29	57.00 ± 11.83	381.00 ± 54.26
Group 3	8.80 ± 1.01	97.50 ± 14.18	928.00 ± 94.29
Group 4	10.90 ± 1.29	146.50 ± 14.92	979.50 ± 81.47
Group 5	13.30 ± 1.64	210.80 ± 24.45	1,234.00 ± 338.76
Group 6	15.00 ± 1.83	213.90 ± 22.87	1,371.00 ± 62.97
P value	< .001**	< .001**	< .001**

**Represents statistically significant difference ($P < .001$).
Data are presented as mean ± SD.

Table 2 Intergroup Comparisons (ANOVA) for Keratinized Tissue Width and Mucosal Thickness

Treatment groups	Keratinized tissue width (mm)	Mucosal thickness (mm)
Group 1	7.00 ± 0.47	1.05 ± 0. 16
Group 2	7.10 ± 0.57	1.15 ± 0.24
Group 3	7.15 ± 0.88	1.25 ± 0.34
Group 4	7.10 ± 0.99	1.15 ± 0.24
Group 5	7.40 ± 0.84	1.20 ± 0.26
Group 6	7.60 ± 0.97	1.20 ± 0. 27
P value	.57	.56

Data are presented as mean ± SD. ANOVA was used for statistical analysis.

strength in grams and the exposed mucosa surface in mm^2 were evaluated as secondary outcomes. For tensile strength evaluation, the flap edge was connected to a device applying incremental continuous tensile force. At the time of flap tearing, the applied force was recorded. The area of exposed mucosa was calculated clinically through the measurement of the height and width of the exposed mucosal surface with the use of a periodontal probe.

Statistical Analysis

All measurements were reported as adjusted mean ± standard error (SE). One-way analysis of variance (ANOVA) tests were used to test the significance of group effect on primary and secondary variables. Tukey post hoc pairwise comparison was performed. Pearson correlation test was used to provide the association between the amount of surface exposure area and the amount of flap advancement. Statistical significance was set for $P < .05$.

RESULTS

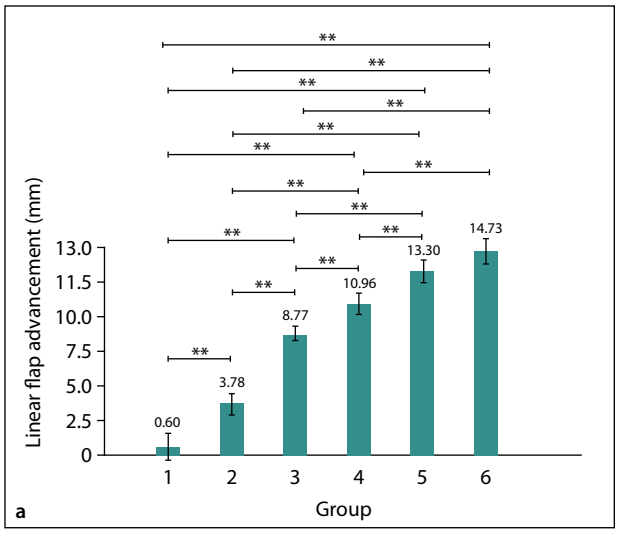
A total of 105 pig mandibles were screened, of which 60 fulfilled the inclusion criteria and were included in the present study. Baseline characteristics of the specimens showed homogeneity among groups. The mean ± SD of the primary outcome (coronal advancement of the flap [Adv]) and secondary outcomes (flap tensile strength [TS] and exposed periosteum surface area [ES]) are reported in Table 1. The two covariates (KTW and MT) at the baseline did not show a statistically significant difference in the intergroup comparison ($P > .05$; Table 2).

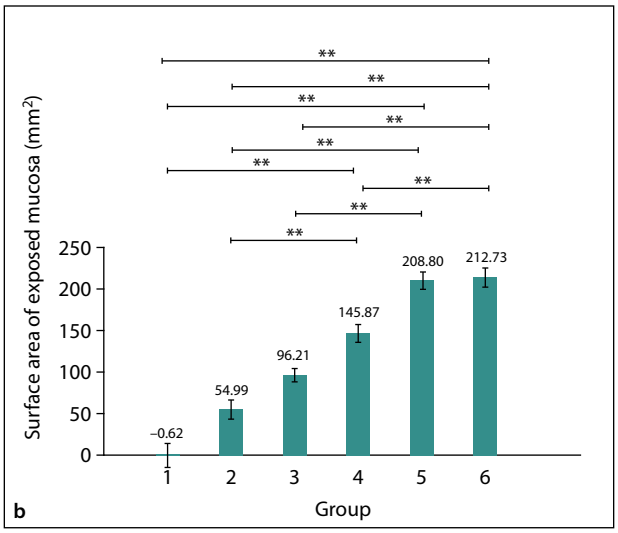
Among three outcome measures, intergroup comparisons were statistically significant if the covariates (KTW, MT) were not accounted for ($P < .001$). After adjustment for KTW and MT, there was still a statistically significant difference in the amount of flap advancement between six groups ($P < .001$). Group 6, namely, the mucosal detachment technique with modification with horizontal and vertical incision plus cutback, achieved the highest amount of advancement (14.73 ± 0.40 mm, adjusted mean ± SE), followed by group 5 (13.30 ± 0.37 mm), group 4 (10.96 ± 0.37 mm), group 3 (8.77 ± 0.25 mm), and group 2 (3.78 ± 0.37 mm) compared to group 1 (0.60 ± 0.49 mm; Fig 3a). Post hoc analysis was performed with a Bonferroni adjustment. The flap advancement of groups 4, 5, and 6 was statistically significantly greater compared to group 3 ($P < .001$), with mean differences of 2.19, 4.53, and 5.96 mm, respectively. The pairwise comparison demonstrated statistical significance between any two groups ($P < .001$), except between groups 5 and 6 (mean difference: 1.43 mm).

After adjustment for KTW and MT, there was a statistically significant difference in the surface area of exposed periosteum between six groups ($P < .001$; Fig 3b). Group 6 yielded the highest amount of exposed surface (212.73 ± 5.82 mm^2, adjusted mean ± SE), whereas the conventional approach (group 1) only yielded minimal mean exposed surface area (–0.62 ± 7.21). Post hoc analysis was performed with a Bonferroni adjustment. The surface of exposed mucosa in groups 4, 5, and 6 was statistically significantly greater compared to group 3 (mucosal detachment technique; $P < .001$), with mean differences of 49.67, 112.59, and 116.52 mm^2, respectively. The pairwise comparison did not reach significance between groups 3 and 4 (mean difference of 3.93 mm^2; $P > .05$).

After controlling for KTW and MT, a statistically significant difference for tensile strength among the groups was found ($P < .001$; Fig 3c). The highest tensile strength was found in group 1 (1,602.52 ± 87.74 g, mean ± SE), followed by group 6 (1,384.29 ± 70.76 g), group 5 (1,234.68 ± 65.19 g), group 4 (978.18 ± 65.13 g), group 3 (927.94 ± 44.34 g), and group 2 (393.10 ± 65.62 g).

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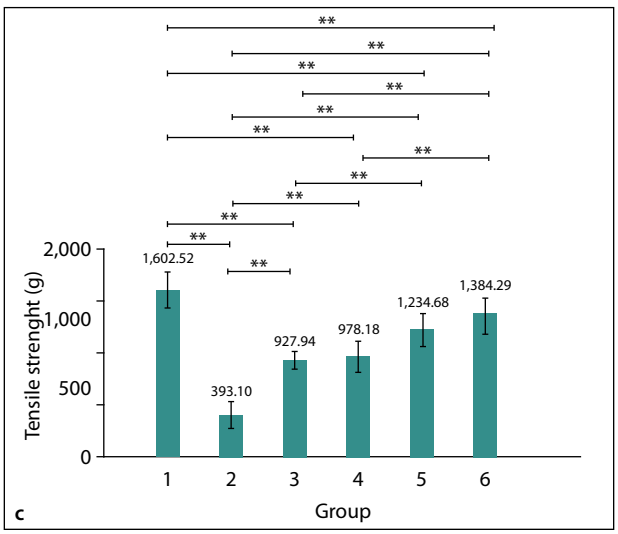


Fig 3 Bar charts representing the primary and secondary results. *(a)* Linear flap advancement in millimeters. *(b)* Surface area of exposed mucosa in square millimeters. *(c)* Tensile strength in grams among the three surgical flap techniques. Data are presented as adjusted means with error bars representing the ± 2 standard errors of the mean values. ***P* < .001 in the post hoc pairwise comparison with a Bonferroni adjustment for KTW and mucosal thickness. Group 1: trapezoidal full-thickness flap; group 2: trapezoidal flap with linear horizontal periosteal scoring; group 3: mucosal detachment technique; group 4: mucosal detachment with horizontal extension; group 5: mucosal detachment with horizontal and vertical extension; group 6: mucosal detachment with horizontal, vertical, and cutback extensions.

Bonferroni post hoc analysis revealed that the tensile strength in the conventional group (group 1) was significantly higher than groups 2, 3, 4, and 5, with mean differences of 1,209.42, 674.57, 624.34, and 367.84 g, respectively ($P < .005$). Interestingly, group 6 also led to a high tensile strength, which was statistically significantly higher than groups 4 and 3 (mucosal detachment technique, with a mean difference of 406.11 g [$P < .001$] and 456.34 mg [$P = .001$], respectively). The mean difference of flap tensile strength between groups 1 and 6, between groups 3 and 4, or between groups 5 and 6 did not reach statistical significance ($P > .05$).

A strong positive correlation was found between the exposed periosteal surface and flap advancement ($r = 0.96$, $R^2 = 0.91$, two-tail $P < .001$; Fig 4). It was estimated in the linear regression model that the flap advancement increased by 0.62 mm for every 10 mm^2 increase in the exposed mucosal surface (slope coefficient: 0.062 mm/10 mm^2; $P < .001$). The regression equation was: Flap advancement = 1.42 + (0.06 × exposed mucosal surface).

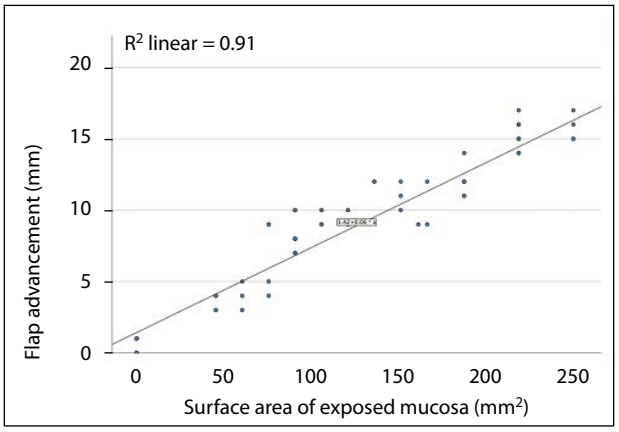


Fig 4 A correlation plot of the exposed mucosa surface and flap advancement amount. Each specimen is represented by a dot. Specimens with same mucosal exposure and coronal advancement are represented within a single dot. A strong positive correlation was found between exposed mucosal surface and flap advancement. For each 10 mm^2 of increased exposed mucosal surface, there was an estimated additional 0.62 mm of flap advancement (slope coefficient: 0.062 mm/10 mm^2; $P < .001$).

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DISCUSSION

The success of regenerative procedures relies on the ability to advance the flap for achieving tension-free primary closure. Flap designs and periosteal manipulation to improve the coronal flap advancement are currently an important topic.[14–18] Therefore, the aim of the present study was to test the efficacy for flap advancement of periosteal scoring and the mucosal detachment technique and its modifications compared to the trapezoidal full-thickness flap without periosteal manipulation. The present results reported improved efficacy of the mucosal detachment technique to gain flap mobilization compared to traditional techniques such as periosteal scoring and vertical incisions. Furthermore, when comparing mucosal detachment modifications (groups 4, 5, and 6), incremental improvement of flap advancement was noticed with each group increasingly from groups 3 to 6 (Fig 4).

An undisturbed closed environment allows a cascade of proliferative signaling and stabilization of an osteogenic matrix that is required for favorable regenerative outcomes.[21,22] Wang and Boyapati reviewed the relevant biologic principle for predictable clinical outcomes[10] and stressed the importance of tension-free primary wound closure and postoperative uninterrupted wound healing. Clinically, this principle is best achieved with soft tissue manipulation to gain sufficient flap advancement in a coronal direction. Park et al reported on the efficacy of flap advancement using vertical releasing incisions with or without the use of periosteal scoring.[12] Coronal displacement increased 1.1 mm after the first vertical incision, 1.9 mm after the second vertical incision, and 5.5 mm with the adjunct of periosteal scoring. These results confirmed the need for manipulation of the inner mucosa to achieve greater advancement, as also reported in the present study. Flap advancement and mucosal exposure were found to be linearly related, as coronal displacement increased by 0.62 mm for every 10 mm^2 of increase in exposed mucosal surface.

Another commonly used approach for flap advancement is the split-thickness flap,[13,23] which is traditionally performed as sharp dissections of the inner mucosal thickness. Split-thickness flaps are performed rather arbitrarily with sharp dissections that split the connective tissue, leaving part in the periosteum and part in the elevated flap. The disadvantages of this approach include increased operative bleeding and postoperative swelling and edema as a consequence of injuring the supraperiosteal blood vessels. Especially in thin phenotype patients, random incisions in the tissue may lead to perforation and acute tissue trauma. On the other hand, the mucosal detachment technique provides an alternative for a controlled detachment of the mucosa from the underlying periosteum. The mucosal detachment technique allows for a complete separation of the mucosa from the periosteum. The technique uses semi-blunt instruments for flap preparation to maintain the blood supply in the mucosa and offers an effective alternative to still achieve tension-free primary closure with minimal flap injury.

The experimental design of this study allowed for evaluation of biomechanical properties of surgical advancement procedures. When considering the tensile strength of the flaps, the trapezoidal full-thickness flap showed the highest values compared to flaps with periosteal manipulation techniques but offered marginal advantages for coronal advancement. Group 6 stands out by providing the highest flap advancement and yet maintaining comparable tensile strength to group 1 ($P > .05$). High tensile strength for group 1 can be explained by the retention of the whole tissue complex into the flap, including the periosteum. However, the absence of an exposed mucosal surface compromises its advancement. While periosteal scoring improved the amount of coronal advancement, it compromised flap tensile strength significantly. The mucosal detachment technique, in particular with modification of horizontal, vertical, and cutback incisions, provided the greatest advancement, while still maintaining optimal tensile strength. The biophysical spreading of mucosal surface distributed the forces more evenly and on a wider mucosal surface area.

A major limitation of the present study is related to the nature of the ex vivo preclinical model, which may not be completely translatable to humans, especially due to individual variability of healing potential and postoperative inflammatory response. Only one periosteal releasing technique has been included in the present study; therefore, no information could be drawn on the impact of multiple parallel periosteal incisions or of the apicocoronal location of the horizontal incision on the magnitude of flap advancement. In ex vivo studies, it is possible to measure coronal advancement while some important clinical outcomes such as pain score, swelling score, force of adjacent mastication muscles, reduction of keratinized tissue, and vestibular depth remain unassessed.

Further research is needed to validate the reported outcomes in human controlled prospective studies.

CONCLUSIONS

This study demonstrated flap advancement differences as a result of various periosteal manipulation approaches. Mucosal advancement was positively correlated with the surface of exposed mucosa, and both were maximized in the mucosal detachment techniques.

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