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ORIGINAL ARTICLE

Influence of suturing technique on marginal flap stability following coronally advanced flap: a cadaver study

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Abstract

Objectives The outcomes of periodontal soft tissue root coverage procedures can be influenced by a variety of different factors. Following coronally advanced flap (CAF), the impact of marginal flap stability (MFS) through the employment of specific suturing techniques has not yet been investigated. The purpose of this study was to compare the MFS of CAF following three different suture techniques.

Methods Fifty-six CAF procedures were performed on seven fresh human cadaver heads. The MFS following simple interrupted, single sling or sling and tag (SAT) suture techniques were investigated through a specific tool involving a load cell-based recording device.

Results A highly statistically significant MFS was observed for sling and SAT sutures compared to the simple interrupted suture ($p < 0.001$). SAT suture technique was related to the greatest MFS ($p < 0.001$). The addition of sutures to the vertical releasing incision was able to provide a greater MFS compared to the suturing of the papillae alone ($p < 0.001$). No statistically significant difference was observed with regard to the suturing sequence between the two sling groups when the vertical incisions were sutured before or after the surgical papillae ($p > 0.05$). Linear regression model showed a positive correlation between thicker gingival tissue and MFS changes ($p < 0.001$).

Conclusions Suturing technique highly affects the MFS following CAF on cadavers. Flap thickness was shown to be a positive predictor for flap stability.

Clinical relevance Within the limitation of this study, the suturing of CAF with the SAT technique may provide higher MFS. However, clinical studies are necessary to validate these findings.

Keywords Suture techniques · Sutures · Cadaver · Gingival recession

One sentence summary: Suturing technique affects the marginal flap stability following coronally advanced flap on cadavers

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Introduction

Gingival recession is often associated with dental hypersensitivity, discomfort, esthetic complications, and potentially, root caries [1–3]. The success of root coverage procedures depends on many factors such as (i) patient-related factors (e.g., oral hygiene, tooth brushing technique, smoking habit…etc.); (ii) site-related factors (e.g., interproximal attachment loss, tooth type and position, amount of keratinized tissue (KT), dimension of the recession defect, vestibular depth, height of papilla, root convexity, flap thickness); and (iii) technique-related factors (such as flap tension and its post-surgical position) [4, 5].

Since 1968, with the introduction of the first grafting procedure for the treatment of gingival recessions [6], several other flap designs have been developed providing successful outcomes [7–9]. Among these newer techniques, the coronally advanced flap (CAF), initially described by Norberg [10] and later modified by other authors [8, 11, 12], has showed to have higher predictability especially when combined with a connective tissue graft positioned over the exposed root, underneath the primary flap [13–15].

As a result, many researchers have meticulously investigated the factors influencing the final outcomes of CAF, such as the dimension of the papillae [16], initial recession depth [17], the defect size [18], tissue thickness [19, 20], flap design [8, 21], root mechanical instrumentation [22], the tension before suturing and the final suturing position of the flap related to CEJ [23]. Studies have also investigated the possibility to predict the final complete root coverage of CAF based on anatomical factors [24, 25].

However, so far to the best of our knowledge, no study has investigated the impact of suturing techniques on the stability of the flap and the adaptation of gingival margin against the tooth surface, which is a crucial factor for promoting optimum healing. Indeed, according to Burkhardt and Lang, the success of surgical procedures is profoundly influenced by proper closure and stabilization of the flap in the correct position [26]. Additionally, an appropriate suturing technique that closely adapts the coronal flap margin against the tooth would protect the blood clot lead to an improved healing capacity [26].

Three main approaches to suturing CAF have been utilized. The simple interrupted suture, one at each adjacent papilla [27], the sling suture [28], and the Sling and Tag (SAT) suture [29]. The aim of this study was evaluating the stability of CAF on the cemento-enamel junction (CEJ) area through the utilization of the following suturing techniques: (i) the simple interrupted suture, (ii) the sling suture, and (iii) the sling and tag (SAT) suturing technique. The second objective was to assess whether the sequence of suturing the vertical incisions before the surgical papillae or after has an effect on the marginal flap stability (MFS).

Material and methods

Study design

The study design consisted of 7 cadaver heads (58 included sites). Forty-six tooth sites were designated to the first part of the study and 12 sites for the second division of the experiment. Detailed explanation of the protocol is illustrated in Fig. 1.

Study population

Seven fresh human cadaver heads with a full or partial dentition of ages ranging from 63 to 82 years were donated to the Department of Periodontics and Oral Medicine, University of Michigan. All heads were preserved in a controlled −20 °C environment, without fixation in formalin to ensure minimal structural changes in the tissues. They were thawed to room temperature before being utilized in the study.

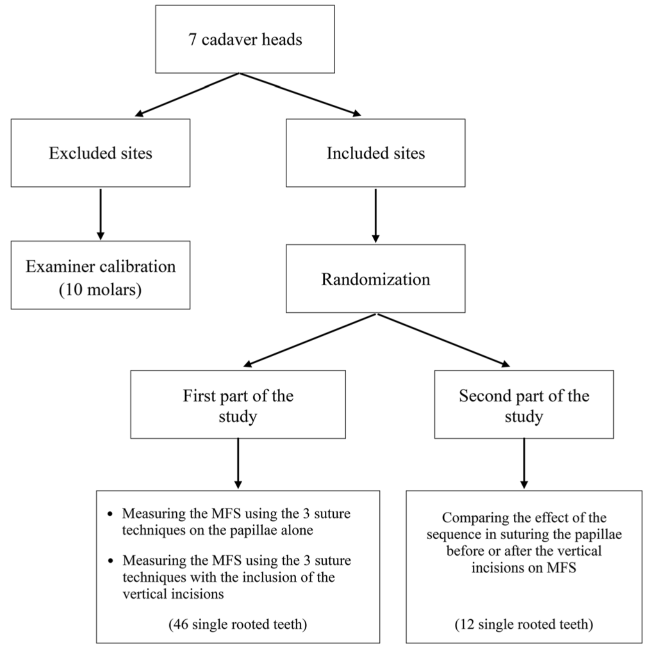

Fig. 1 Protocol of the study

The following inclusion criteria had to be met for each tooth site to be included in the study: (i) the presence of at least 3 mm of KT and (ii) a recession of no more than 3 mm on the buccal aspect of the tooth. While any of the following was considered as a criterion for exclusion from the study: (i) presence of missing adjacent teeth at the inclusion site; (ii) KT less than 3 mm; (iii) interproximal attachment loss of greater than 3 mm; (iv) presence of cervical decay or missing tooth structure that made the identification of the CEJ impossible; (v) gingival recession greater than 3 mm; (vi) class IV gingival recession as described by Miller [30] or RT3 as described by Cairo [25], and lastly, (vii) molar teeth on both maxilla and the mandible.

Clinical measurements

The following clinical measurements were registered at baseline using a periodontal probe PCP UNC 15.[1]

- REC 0: The initial recession of the tooth at the time of inclusion in the study.
- REC 1: The recession that was created on the tooth to reach a final depth of 3 mm using a 15c scalpel blade; the distance from the CEJ to the most apical point of the recession defect, measured on the mid-buccal aspect of the tooth.

[1] Hu-Friedy, Chicago, IL, USA

- KT: Keratinized tissue height measured from the gingival margin to the mucogingival junction at the mid-buccal aspect of the tooth.
- GT: Gingival thickness measured 2 mm from the most coronal part of the flap using a caliper[2] accurate to 0.1 mm.
- FT: Residual tension of the flap, measured after flap reflection by using the SMARTFLAP device.[3]
- TM-CEJ: The distance from the coronal/occlusal margin of the tooth (incisal edge/cuspal tip, along the long axis on the buccal aspect of the tooth) and the cement-enamel junction (CEJ) at the mid-buccal area. This measurement served as a reference point to illustrate the post-surgical position of the flap. When the CEJ was not detectable, the best estimation was done based on the adjacent teeth. A blue marker was used to highlight the proposed CEJ.
- TM-FM: The distance from the coronal margin of the tooth and the position of the flap after suturing, measured at the mid-buccal aspect of the tooth to compare with TM-CEJ and measure the flap advancement.
- MFS: Marginal flap stability as measured by the force required to elicit an apical displacement of the mid-coronal portion of the flap exposing the blue line drawn on the CEJ.

Randomization

Based on the random number function in Microsoft Excel, 46 sites in the cadaver heads were allocated to either of the "simple", "sling", or the "SAT" groups. Additional 12 sites were designated to assess whether the sequence in suturing the vertical releasing before or after the surgical papillae influences the marginal flap stability (MFS). After the reflection of the flap, the method of suturing technique was extracted from the computer-generated table for each site. All measurements for MFS were carried out by a single calibrated blinded examiner (S.B.) who was not present at the time of suturing. .

Examiner reproducibility

Calibration of the examiner was performed on 10 M teeth, two times for each tooth. The examiner repeated the measurement of the forces that led to the apical displacement of the flap exposing the blue-marked-CEJ. Calibration successfully achieved a reproducibility of 86%. In addition, this test also illustrated that no or very minimal changes are expected after the second attempt with the instrument to measure the forces at each site.

[2] Henry Schein, Melville, N.Y., USA
[3] Meta, Reggio Emilia, Italy

Surgical procedure

For easier manipulation of tissues, facilitation in registering the data and increased visibility of the surgical site, adjacent structures were cut and retracted carefully, without jeopardizing the alveolar mucosa. The location of the CEJ was identified prior to starting each procedure. If the tooth showed a pre-existing recession (REC 0), a deeper recession was created using a 15c scalpel blade on buccal sides of the teeth in order to attain REC 1, of 3 mm. If the tooth did not display gingival recession, gingivectomy was performed to obtain a 3 mm REC 1. After the creation of the REC1, the CEJ was highlighted with a blue marker (0.5 mm tip). The CAF for localized gingival recession was designed as described by De Sanctis and Zucchelli [8]. Briefly, two horizontal beveled incisions, approximately 3 mm, mesial and distal to the recession were performed beginning 4 mm from the tip of the papillae (REC 1 + 1 mm). Two beveled oblique slightly divergent incisions were placed starting at the end of the two horizontal incisions extending 2–3 mm into the alveolar mucosa. Given the reduced thickness of the mucosa in cadavers, a full thickness trapezoidal flap was then elevated contrary to the conventional split-full-split approach [8]. The elevation was achieved by using a small periosteum elevator until approximately 4 mm of bone apical to the created recession was exposed. The elevation proceeded split thickness with the blade before parallel to the bone plate and then parallel to the external mucosal surface to eliminate all muscle insertions.

The thickness of the flap (GT) was measured with a caliper at the keratinized mucosa, approximately 2 mm from the gingival margin (Fig. 2b). The flap tension was then tested with the SMARTFLAP device[3] (Fig. 2a). The flap was considered tension-free when the following circumstances were achieved: (1) it was able to passively reach a position 2 mm coronal to the CEJ; (2) A tension value of less than 5 g (0.049 N) was recorded by the SMARTFLAP device [31, 32]. Next, the anatomical papillae were de-epithelialized, and based on the randomization, the surgical papillae of the flap were then sutured according to either of the following techniques:

Group 1: The Simple Interrupted Suture. Two simple interrupted sutures (5–0 Vicryl, 13 mm 3/8 conventional cutting needle[4]) were placed at each adjacent papilla. The needle penetrates the outer surface of the mesial surgical papilla, passing through and engaging the anatomical papilla on the same side anchoring the surgical to the anatomical papillae. Next, the undersurface on the opposite side is engaged by the needle and the suture returns to the buccal side by passing underneath the mesial contact point without penetrating the

[4] Ethicon US., LLC, Somercille, New Jersey, USA

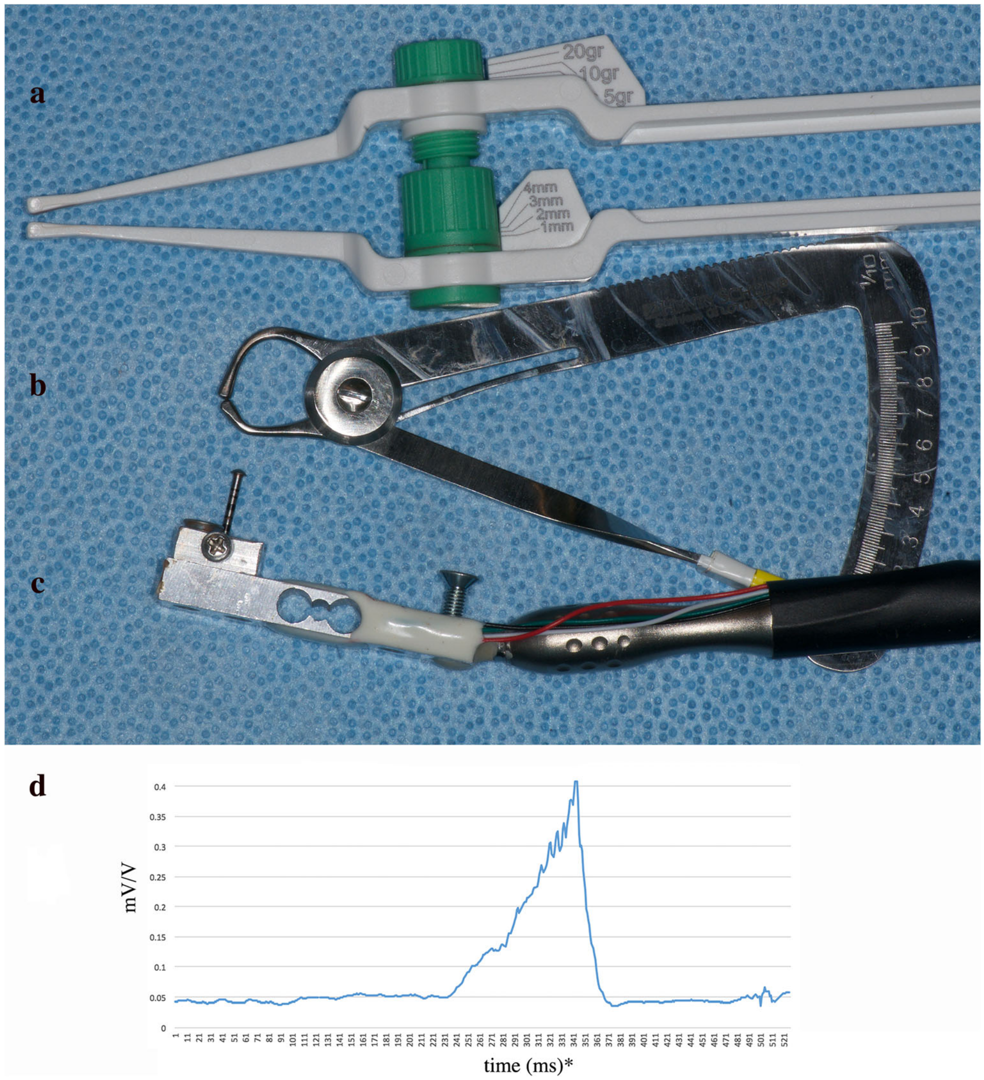

Fig. 2 **a** SMARTFLAP device, **b** Caliper, **c** measuring device incorporating a single-point load cell, **d** an example of the recorded values when testing the MFS

papilla or the flap. The knot is then performed on the mesial papilla. The same procedure is done on the distal for suturing the distal papilla (Figs.3a and 4a).

Group 2: The sling suture. Starting from the buccal side a 5–0 Vicryl (13 mm 3/8 conventional cutting needle)[4] suture is used to advance through the base of mesial surgical papilla, passing through the anatomical papilla and exiting on the opposing (lingual) side. The suture then encircles the tooth, going to the distal side, passes below the contact points and returns to the buccal side. Next, the needle engages the outer surface on the buccal side of the distal surgical papilla, through the anatomical papilla, advancing towards the opposite side. After encircling the tooth back to the mesio-lingual side, the suture, once again, passes underneath the contact points without engaging any tissues, returning to the buccal side. Lastly, a knot is made on the mesial papilla (Figs. 3b and 4b).

Group 3: Sling and tag (SAT) suture involves a double sling suture on the papillae of the flap, 2 mm from all margins, followed by two simple interrupted tag sutures, one at each papilla, coronal to the previous sutures at the center of the papilla to facilitate flap adaptation (Figs. 3c and 4c–d). From the buccal aspect, a 5–0 Vicryl (13 mm 3/8 conventional cutting needle)[4] suture engages the outer surface at the base of mesial surgical papilla, 2 mm below the tip, passing through the anatomical papilla, exiting on the opposite side. The suture then encircles the tooth towards the distal side and returns to the buccal side while passing underneath the contact points. Next, the needle penetrates the inner surface of the distal surgical papilla and returns to engage the buccal side again, approximately 1 mm lateral to the previous exit point. The suture, passing through the anatomical papillae, arrives at the palatal side, where it encircles the tooth back to the mesial side where it passes underneath the contact points back to the buccal side. Finally, it exits from the inner surface of the buccal surgical papilla, approximately 1 mm lateral to the previous entrance point and a knot is made. Subsequently, two simple interrupted sutures (6/0 Vicryl,

Fig. 3 Suture techniques after creating a 3-mm recession defect. **a** Two simple interrupted sutures; **b** the sling suture; **c** the SAT suture

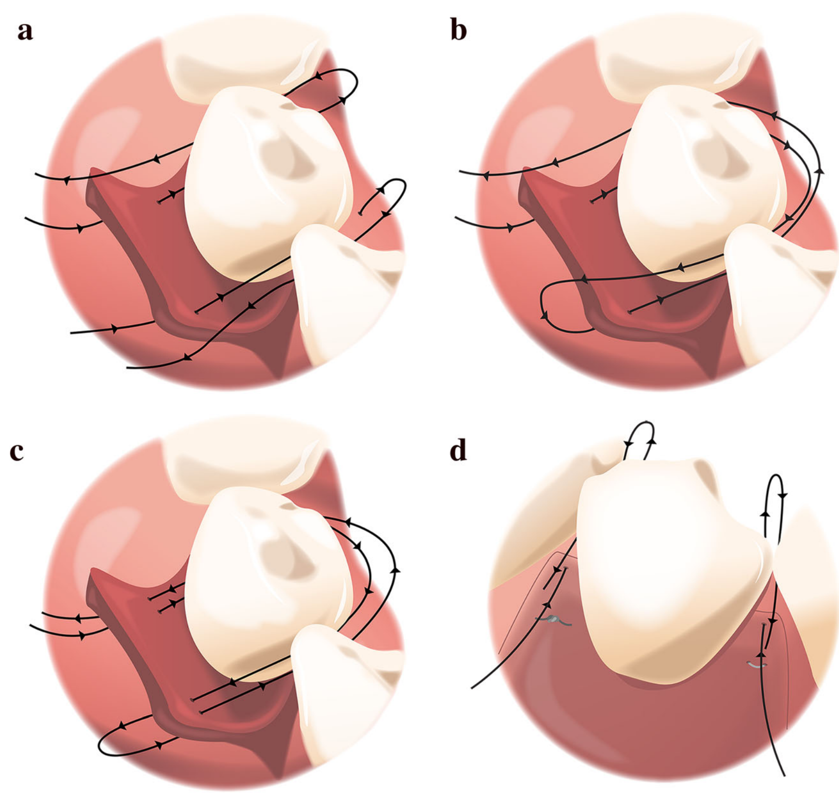

Fig. 4 **a** Two simple interrupted sutures; **b** sling suture technique; **c** first part of the SAT technique; **d** second part of the SAT technique

13 mm 3/8 conventional cutting needle[4]), one at each papilla, are made coronal to the double sling sutures, at the center of the surgical papillae.

For all groups, after suturing, the TM-FM was measured and compared to the TM-CEJ to make sure that the flap was sutured 1 mm beyond the CEJ [23].

Marginal flap stability measurement

A device that incorporates a single-point load cell[5] (Fig. 2c) was used to accurately measure the applied forces by the examiner. The measuring device was specifically designed for the purposes of this experiment at the Department of Mechanical Engineering of Politecnico, Milan, Italy. The load cell (45 × 9.3 × 6 mm in dimension) can record forces between 0 and 7.65 N and connects the hand piece to the tip. To accurately measure the forces, the tip must be perpendicularly attached to the load cell (Fig. 2c). Vibrations are perceived as tension (m*V*/V) and transmitted to an interface (wheatstone bridge-based sensor)[5]. The interface is connected to a computer where the software Phyton Launcer (version 2.7.11) is used to record the output with specific lines of codes, at a sampling rate of 8 milliseconds (ms) (Fig. 2d). In order to gain the equivalent values in Newton, the load cell was strictly calibrated with standardized weights at the Department of Mechanical Engineering, Politecnico of Milan, Milan, Italy. Consequently, a calibration curve and a specific formula and were used to correlate the output in m*V*/V to the applied force (N).

After the flaps were sutured according to the randomization, a single horizontal suture (4/0 silk[4]) was made at the central part of the flap 3 mm apical to the free gingival margin. Careful attention was paid in identifying the entrance and exit points of the needle making sure the suture was symmetrically placed at the long axis to the tooth (approximately 3 mm from the flap margin and the exit and entrance points 2 mm lateral to the tooth axis) (Fig. 5a). Following the primary knot on the flap, the long head of the suture was fastened around the base of the tip on the measuring device (Fig. 5b). This allowed for real-time measurements of the MFS when tension was applied. The measuring device was cautiously held in the position without applying any forces for the first 10 s to determine the background noise. Next, the device was moved apically in a steady manner, parallel to the long axis of the tooth until the first sight of the blue line at the CEJ was noticed. Immediately, the downward forces stopped and the data were recorded and saved. MFS was then calculated as the difference between the forces registered at the highest peak (the first sight of the blue line) and the average numerical value during the first 10 s when the instrument was held in position without any movements. Each suturing technique was evaluated initially without the additional sutures at the vertical incisions, and subsequently, with the addition of sutures on the vertical incisions. Each vertical incision was sutured with three oblique simple interrupted sutures from the flap to the adjacent mucosa in the apico-coronal direction. The MFS was registered again at a second time by using the previously described steps.

For the second part of the study, the effect in sequence of suturing the vertical incisions before or after the surgical papillae on the MFS was assessed. Two sites in each cadaver head were assigned to CAF where vertical releasing incisions were sutured before the papillae. Three simple interrupted sutures were placed for each vertical incision. The surgical papillae were then sutured using the sling method alone. For two specimens, only one site per head could be used, resulting in a total of 12 teeth for this section in the experiment. The resultant MFS values were compared to the initial observations where the papillae were sutured preceding the vertical incisions with the sling suturing technique.

Statistical analysis

The primary outcome was the force required to elicit an apical displacement of the mid-coronal portion of the flap expositing the CEJ among the three groups, with and without the additional suturing on the vertical incisions. The secondary outcome was to assess whether suturing the vertical incisions before or after the surgical papillae can affect the MFS and to investigate the influence of the gingival thickness on the MFS.

The characteristics across the treatment groups were analyzed using SPSS version 24.00.[6] Student's t test was used to compare the mean flap thickness within the three investigated suturing techniques. The multiple random effects regression model was applied to evaluate the influence of flap thickness on the MFS among the groups. MFS of the three groups were compared by using a one-way ANOVA test and the Tukey HSD post hoc test. Student's t test was performed for comparing the benefits of the addition of vertical incision sutures and to assess the influence of the order in suturing the papillae and the vertical incisions on MFS. Linear regression was used to investigate the correlation between flap thickness and MFS.

Results

A total of 58 CAF were performed on 58 teeth of 7 fresh human cadaver heads (6 male and one female; 5 Caucasian and 2 Asian in ethnicity, and ages between 63 and 80 years) (Table 1). The average flap thickness was 0.21 ± 0.09 mm. No statistically significant differences in flap thickness were found within the investigated groups ($p > 0.05$).

[5] Robot Italy, Rome, Italy

[6] IBM Corp., Armonk, NY, USA

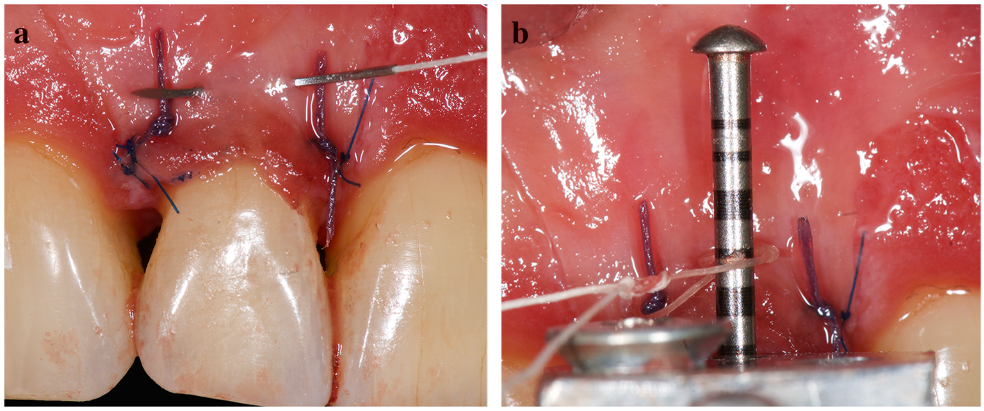

Fig. 5 A single horizontal suture (4/0 silk) performed at the central part of the flap (**a**) that secures the tip of the measuring device to the flap (**b**)

Characteristics of the treated sites in the three groups are depicted in Table 2.

When comparing the forces necessary to apically displace the coronal margin of the flap, the simple interrupted suture technique (one at each papilla) showed a MFS of 1.3 ± 0.45 N, while the sling and SAT sutures illustrated a higher MFS of 3.19 ± 0.7 and 4.68 ± 1.33 N, respectively. The SAT suturing technique displayed a greater MFS than the sling and simple interrupted sutures ($p < 0.001$), whereas the sling suture revealed an increased MFS than the simple suture group ($p < 0.001$) (Fig.6, Table 3).

The completion of suturing the flaps with the vertical releasing incision sutures was able to provide a better MFS compared to suturing the surgical papillae alone. This result was statistically significant for each of the investigated groups ($p < 0.001$). For group 1, after suturing the vertical releasing incisions, a mean value of 2.83 ± 1.02 N for MFS was obtained. Similarly, the MFS of groups 2 and 3 with the addition of the vertical incision sutures was 3.86 ± 0.79 and 5.33 ± 1.02 N, respectively. The increase in MFS due to the presence of sutures at the vertical incisions was 51.2% for the simple sutures, 16.8% for sling suture, and 13.2% for SAT suture (Fig. 6, Table 3). No statistically significant difference was observed with regard to the suturing sequence between the two sling groups when vertical incisions were sutured before or after the surgical papillae ($p > 0.05$). Linear regression model showed a positive correlation between flap thickness and MFS changes. Thicker flaps were indeed associated with higher MFS ($p < 0.001$) (Fig. 7).

Table 1 Characteristics of the population

Cadaver ID	Gender	Race	Age	BMI
1	M	Asian	67	28.29
2	M	Caucasian	75	25.49
3	M	Caucasian	63	22.78
4	F	Caucasian	71	27.95
5	M	Asian	68	24.31
6	M	Caucasian	71	23.97
7	M	Caucasian	80	26.94

Discussion

The success of gingival recession coverage procedures is primarily based on the resolution of recession defects. Nonetheless, several other parameters are also evaluated such as the KT gain, PD reduction, restoration of the natural soft tissue texture and color, marginal tissue contour, and mucogingival alignment together with patient satisfaction [8, 33, 34]. It has been demonstrated that CAF, either alone or in combination with other soft tissue grafting materials, is the most effective and predictable technique for achieving these outcomes [13, 35]. However, the success of CAF relies on many factors. Some of them are not dependent on the clinician (e.g., attachment loss, tooth position, etc.) [36]; however, other factors such as flap tension [31] and the post-surgical position of the gingival margin in relation to CEJ [23] are dictated by the clinician. Pini-Prato et al. observed that minimal flap tension does not affect the final outcome of CAF; however, increasing flap tension was associated to reduced root coverage [31]. The results of the present study clearly demonstrate the paramount role of suturing on flap stability. Both the sling and SAT techniques allowed for an increased MFS compared to simple interrupted sutures ($p < 0.001$) with the highest MFS obtained with the SAT suturing technique ($p < 0.001$). It can be concluded that the double sling suture of the SAT technique, which also engages the lingual aspect of the papillae, provides a stronger adaptation of the flap to the root surface and, thus, a greater MFS compared to the other groups.

Despite the fact that a direct correlation between MFS and higher chance for achieving complete root coverage has not yet been demonstrated, it may be logical to assume that a stable flap, closely adapted to the root surface by sutures, might better resist eventual tensile forces during the healing period. Moreover, MFS may be able to maintain the position

Table 2 Characteristics of the treated sites in the three groups

Suture technique	N of incisors Maxilla/mandible	N of canines Maxilla/mandible	N of premolars Maxilla/mandible	Total number of teeth
Simple interrupted	3/1	3/4	3/1	15
Sling	4/1	4/2	2/2	15
SAT	5/2	2/4	1/2	16
Total	12/4	9/10	6/5	46

of the gingival margin coronal to the CEJ, which is a crucial factor strongly associated with complete root coverage. It has been shown that during the initial phases of healing, the presence of blood clot is not sufficient for maintaining the flap against the root surface [37, 38]. According to Hiatt et al., the functional stability of the flap is achieved approximately after 14 days post-surgery [37]. Indeed, a superior complete root coverage following CAF was found when sutures were removed after 10 days compared to earlier removal during the healing process [39]. The concept of wound stability has been comprehensively studied by Wikesjo et al. that demonstrated that compromised blot clot adhesion can result in gingival recession and healing by long junctional epithelium [40, 41]. Therefore, an effective suturing technique that properly stabilizes the flap is essential for countering the tensile forces present in the oral cavity providing an undisturbed wound maturation [42, 43].

Huang and Wang suggested the uniform distribution of tension forces as one of the most important advantages of the SAT technique for CAF. This may render an eventual tensile force less likely to dislocate or lacerate the flap [29]. It is believed that a properly attached flap to the CEJ area may

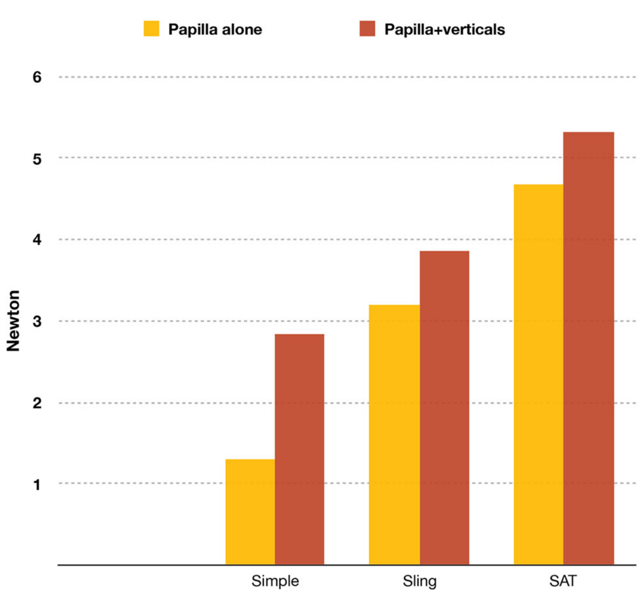

Fig. 6 Graph illustrating the mean MFS in the three groups after only suturing the papillae (orange) and after the addition of the vertical incision sutures (red)

provide a positive effect on blood clot maturation during healing, and the formation of a proper gingival margin in the desired coronally advanced position.

It is important to highlight that with the addition of the vertical sutures, a higher MFS can be attained for all the suturing techniques investigated ($p < 0.001$). However, the sequence in suturing the vertical incisions, before or after the surgical papillae, is controversial in the literature. De Sanctis and Zucchelli suggested that interrupted sutures in the apico-coronal direction of the vertical incisions facilitate the coronal advancement of the flap and reduce the tension of the sling suture at the surgical papillae [8]. Conversely, in order to achieve better marginal flap adaptation in the desired coronal position, some clinicians began suturing the papillae first, then proceeded to perform single interrupted sutures along the vertical releasing incisions [28]. Our results indicate that there is no difference between either sequence of suturing ($p > 0.05$), whereas the specific technique for papillae suturing strongly affects the MFS ($p < 0.001$).

To the best of our knowledge, no study has compared the effect of different suturing techniques, or the suturing sequence on flap stability after CAF. For ethical reasons, assessment of the MFS is only possible on cadavers. Although animal experiments allow for evaluation of wound healing over time [44], morphologic characteristics of the teeth and papillae widely vary among humans and animals. In an in vitro experimental study involving pig mucosal samples, Burkhardt et al. investigated the influence of the applied flap tension on tearing characteristics of mucosal tissues. It was observed that breakage can occur both at the tissue level or within the suture thread, depending on the suture diameter and strength applied. For 5–0 and 6–0 sutures, both events occurred in a range of forces between 7 and 20 N. It was concluded that finer suture diameters lead to thread breakage rather than tissue trauma and the mean breaking force for gingival samples with 5–0 and 6–0 sutures was approximately the same (10 N) [45].

A regression analysis of the data in the present study illustrated a high statistical correlation between thicker flap and high MFS ($p < 0.001$). The influence of flap thickness on complete root coverage has already been highlighted in the literature. Huang et al. found that an initial gingival thickness of greater than 1.2 mm, measured 2 mm apical to the gingival margin, was the most decisive factor for achieving complete

Table 3 Results of the MFS in each investigated group

Suture technique	Average flap thickness (mm) (SD)	MFS (papillae alone) (N) (SD)	MFS (papillae + verticals) (N) (SD)	Increase of MFS after verticals (%)	*p* value
Simple interrupted	0.2 (± 0.09)	1.3 (± 0.45)	2.83 (± 1.02)	51.2	$p < 0.001$†
Sling	0.24 (± 0.08)	3.19 (± 0.7)	3.86 (± 0.79)	16.8	$p < 0.001$†
SAT	0.23 (± 0.09)	4.68 (± 1.33)	5.33 (± 1.02)	13.2	$p < 0.001$†
p value	$p > 0.05$	$p < 0.001$*	$p < 0.001$*		

MFS marginal flap stability

**p* value favoring MFS of sling suture compared to MFS of simple interrupted suture and *p* value favoring MFS of SAT suture compared to sling and simple interrupted sutures

†*p* value favoring MFS (papillae + verticals) compared to MFS (only papillae)

root coverage [20]. Similarly, Baldi et al. reported a direct correlation between flap thickness measured at the alveolar mucosa and recession reduction [19]. It can be speculated that thicker flaps are more firmly attached to the CEJ area and are less affected from eventual dislocating forces during the first phases of healing.

The authors are well aware of the limitations of the present study. First, the soft tissue in cadavers is thinner than living humans as demonstrated previously by CBCT, ultrasonography, and clinical measurements [46]. Second, cadaver soft tissues are dehydrated, and lack of vascularity may result in reduced elasticity of the flap. Similarly, muscle tension may be different in cadavers. In addition, the results of the current study are based on measurement units for MFS and not on clinical outcomes and so far, no study has demonstrated a correlation between MFS and a higher chance for achieving complete root coverage.

Lastly, power calculation was not performed in the present investigation. However, the authors believe that the number of cadaver heads and teeth were adequate for this pilot study.

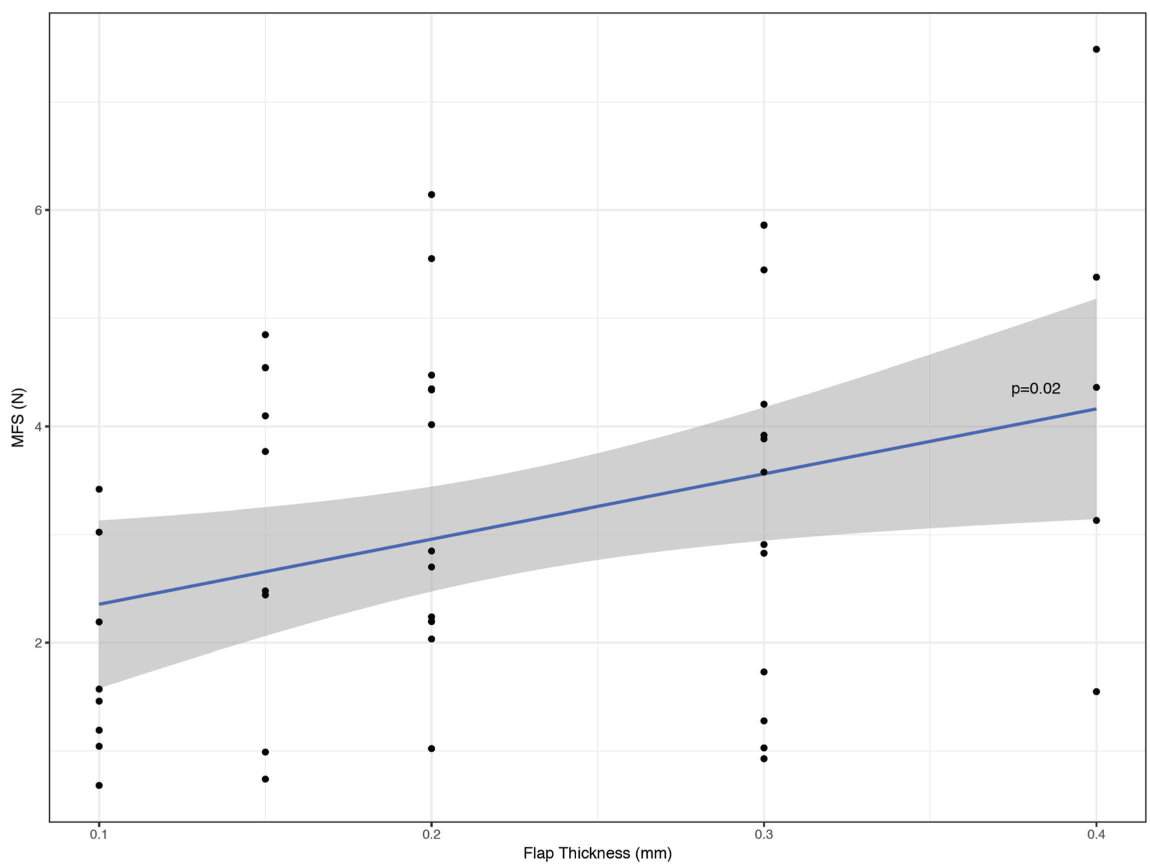

Fig. 7 Correlation between MFS (N) and the measured flap thickness (mm) among the treated sites

These limitations may create doubt whether the results of this study can be directly transferred to the clinical practice. However, our findings are purely based on comparisons between different suture techniques and may suggest that MFS can benefit when the SAT technique is performed and that flap thickness may also play a key role.

Conclusions

Within the limitations of this study, it can be concluded that different suturing techniques highly affected the marginal flap stability following coronally advanced flap on cadavers. The addition of sutures on vertical releasing incisions was able to provide further stability; however, no differences were found between the surgical sequence of suturing the vertical incisions before or after the surgical papillae. Lastly, flap thickness was shown to be a positive predictor for flap stability.

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Compliance with ethical standards

Conflict of interest The authors do not have any competing interests, either directly or indirectly in the products or information listed in the paper.

Ethical approval Due to the study design that involved human cadaver heads without any identifiable private information, The University of Michigan, School of Dentistry, does not require approval by the Institutional Review Board. All the consents for research and educational uses of the bodies were kept by the University of Michigan Donation Department.

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