Quintessence International

Manuscript:	QI-2024-246 - (15555)
Title:	Relationship between flap microcirculation and hard tissue changes following alveolar ridge augmentation: a prospective case series
Author(s)	Réka Fazekas, Bálint Molnár, Eleonóra Sólyom, Kristóf Somodi, Dániel Palkovics, Eszter Molnár, Anton Sculean, János Vág
Keywords:	Bone graft, Case-report/series, Guided Bone Regeneration, Membranes, Ridge augmentation
Type:	Original Article

This article has been accepted for publication and undergone full peer review but has not been through the copyediting, typesetting, pagination, and proofreading process, which may lead to difference between this version and the Version of Record.

Please cite this article as doi: ###############

Submitted: 13 Aug 2024

Accepted: 24 Aug 2024

Relationship between flap microcirculation and hard tissue changes following alveolar ridge augmentation - A prospective case series

Réka Fazekas DMD, PhD[1*], Bálint Molnár DMD, PhD[2*], Eleonóra Sólyom DMD[2], Kristóf Somodi DMD[2], Dániel Palkovics DMD, PhD[2], Eszter Molnár DMD, PhD[1], Anton Sculean, Prof. DMD, MS, PhD, Dr hc[3], János Vág Prof. DMD, PhD[1]

[1]Department of Restorative Dentistry and Endodontics, Faculty of Dentistry, Semmelweis University, Budapest, Hungary

[2]Department of Periodontology, Faculty of Dentistry, Semmelweis University, Budapest, Hungary

[3]Department of Periodontology, School of Dental Medicine, University of Bern, Switzerland

* Authors contributed to this manuscript equally

Corresponding author:

Anton Sculean, DMD, MS, PhD, Dr Med Dent, Dr hc (mult.)

Professor and Chair

Department of Periodontology, School of Dental Medicine, University of Bern

Freiburgstrasse 7

3010 Bern

Switzerland

Email: anton.sculean@gmx.de

Abstract

Objectives: To assess blood flow alterations after horizontal Guided Bone Regeneration (GBR) and to evaluate correlations between blood flow and hard tissue changes.

Method and Materials: Twelve mandibular surgical sites were involved in the current case series. GBR was carried out using a split-thickness flap design. Blood circulation was assessed with Laser Speckle Contrast Imaging at baseline as well as 1, 4, 6, 11, 13, 20, 27, and 34 days after the surgery, subsequently on a monthly basis until 6 months. Hard tissue alterations were measured horizontally and vertically using linear measurements. The first measurement point was 2 mm distal to the distal surface of the last tooth; additional measurement points were placed every 3 mm up to the 15th mm. Volumetric hard tissue loss and gain were also assessed.

Results: Baseline blood circulation was statistically significantly higher on the buccal side. On the first postoperative day, all regions presented a statistically significant decrease in blood flow circulation. The buccal-inner region presented significant ischemia on day 6. Mean volumetric hard tissue gain and loss were 712.62 ± 317.08 mm^3 and 222.431 ± 103.19 mm^3, respectively. Mean baseline alveolar ridge width was 4.82 ± 1.02 mm, 6 months ridge width averaged 7.21 ± 0.99 mm. Vertical resorption measured 1.24 ± 0.5 mm. Correlations between blood flow changes and hard tissue alterations were only found on Day 34 and Day 60.

Conclusion: Laser Speckle Contrast Imaging is an efficient method to measure flap microcirculation. No correlation was found between flap microcirculation changes hard tissue and alterations.

Introduction

Following tooth loss, severe alveolar ridge resorption can occur, which results in insufficient hard tissue dimensions for implant placement. [1-6] To overcome this challenge, various methods have been introduced for alveolar ridge augmentation. Among these methods, Guided Bone Regeneration (GBR) is the most commonly used procedure and is supported by extensive evidence.[6-10]

Since its introduction in the 1990s, different flap techniques and materials have been suggested for horizontal GBR. The full-thickness flap design, described by Tinti et al.[11] is considered the gold standard method. In this technique authors used vertical and periosteal releasing incisions for proper flap advancement. However, these incisions may disrupt vascular structures, potentially negatively impacting flap blood circulation. Therefore, alternative flap designs have also been proposed.[12-14] A recently proposed split-thickness flap design, introduced by Windisch et al. in 2017[15], aims to maintain periosteal blood circulation by avoiding vertical releasing incisions and periosteal incisions.

Recent studies have reported favorable outcomes with resorbable collagen membranes in horizontal GBR. Collagen membranes proved to have favorable clinical handling compared to non-resorbable membranes, with fewer complications.[16-18] According to state-of-the-art protocols for GBR, a 1:1 mixture of autogenous bone and deproteinized bovine bone mineral (DBBM) may result in optimal new hard tissue formation, even in different clinical scenarios. [17,19]

Postoperative wound healing is vastly influenced by the revascularization of the surgical area in case this process is compromised by either an infection or suture failure, it may result in flap dehiscence and graft exposure. Laser Speckle Contrast Imaging (LSCI), a high-resolution and high-contrast optical assessment method, is capable of non-invasive capillary blood flow evaluation with rapid recording over extended areas.[20] These features make it feasible to assess the spatial and temporal dynamics of tissue microcirculation. In our previous research, LSCI proved to be a valuable tool to evaluate soft tissue microcirculation following gingival recession coverage and augmentation of the keratinized mucosa[21] as well as a reliable predictive factor of tissue maturation.[22-24]

Hard tissue alterations after horizontal ridge augmentation procedures can be evaluated with various methods. Radiographic evaluation with Cone Beam Computed Tomography (CBCT) is considered a non-invasive, efficient, and accurate method. [25-27] In a previous paper, our research group described a semi-automatic CBCT segmentation approach to generate virtual 3D models. With these models, volumetric alterations can be assessed, and previously unreported aspects of alveolar ridge dimensional changes can be examined.[26-30]

The primary aim of this study was to assess postoperative blood flow after horizontal alveolar ridge augmentation utilizing a split-thickness flap design via LSCI during a 6-month healing period. The secondary aim was to reveal any possible correlation between blood flow alterations at the surgical site and radiographically analyzed hard tissue changes.

Method and Materials

Experimental design

This observational study is a case series including 12 surgical sites in 10 patients from an ongoing prospective randomized controlled trial investigating the efficacy of different surgical techniques for horizontal GBR prior to dental implant placement. The ethical approval of the study protocol was granted by the Semmelweis University Regional and Institutional Committee of Science and Research Ethics (approval number: SE RKEB 145/2018), and it was registered in the U.S. National Library of Medicine (www.clinicaltrials.gov; trial registration number: NCT05538715; registration date: 09/09/2022). The study was carried out in accordance with the Declaration of Helsinki of 1975, revised in 2013. [31] All subjects gave written informed consent before any procedure was conducted.

Participants

Ten female patients (ages ranged from 39 to 68 years, with an average age of 57 years) were selected from those attending the Department of Periodontology at Semmelweis University exhibiting posterior partial edentulism of the mandible or maxilla, with residual horizontal ridge thickness of 4 mm or less (Cawood-Howell Class IV.), who were scheduled for horizontal ridge augmentation to allow for second stage implant placement. Only non-smoking, periodontally and systematically healthy patients with good oral hygiene and high compliance were recruited. Exclusion criteria were: extraction or other surgical intervention at the study site within 6 months prior to surgery, suffering any systemic disease that would adversely influence wound healing, medication interfering with postoperative wound healing, previous bisphosphonate treatment, previous irradiation therapy in the maxillofacial area, smoking, pregnancy. Before enrollment, all patients underwent professional prophylactic treatment and received oral hygiene instructions. A total of 12 surgical sites on the mandible were examined in the present case series.

Surgical procedure

Alveolar ridge augmentation was performed with a partial thickness flap design described by Windisch and al.[15]. After appropriate local anesthesia (Ultracain DS forte, Sanofi Aventis, Paris) a midcrestal incision on the edentulous ridge was made and extended by intrasulcular incisions at two neighboring teeth (if any). On the lingual side a full-thickness flap was elevated down to the level of the mylohyoid line. On the buccal side, the flap was elevated in full thickness from the midcrestal incision down to the mucogingival junction. Subsequently, flap elevation was continued in partial thickness by sharp dissection towards the apical direction. No vertical releasing incisions were made. A combination of locally harvested particulate autogenous bone and DBBM (Bio-Oss®, Geistlich AG, Wolhusen, Switzerland) mixed in 1:1 ratio was covered by a resorbable collagen membrane (Bio-Gide®, Geistlich AG, Wolhusen, Switzerland) for bone augmentation. Titanium pins (Master pin, Hager&Meisinger, Neuss, Germany) were used for membrane fixation. The lingual flap and the buccal periosteal layer were sutured with orally positioned horizontal mattress sutures using a 3–0 non-resorbable expanded polytetrafuoroethylene suturing material (“periosteal sutures”; e-PTFE; Cytoplast sutures, Osteogenics Biomedical, Lubbock, Texas, USA*)*. The buccal mucosal layer was sutured to the oral flap above the periosteal layer with buccally positioned horizontal mattress sutures using a 3–0 non-resorbable e-PTFE suturing material (“mucosal sutures”). Finally, flap margins were adapted with single sutures using a 4–0 non-resorbable e-PTFE suturing material (“marginal sutures”) to achieve complete primary closure. (Fig.1.)

Patients were given antibiotics (amoxicillin with clavulanic acid 3x625 mg/die; in case of penicillin allergy: clindamycin 3x300 mg/die) for 7 days and non-steroid inflammatory drugs (ibuprofen maximum 3x400 mg/die according to individual needs). Patients were instructed to rinse with a 0.2% chlorhexidine mouth rinse (Corsodyl 0,2%, GSK) twice daily for 2 weeks. The wound had to be handled with gentle care; chewing on the surgical area until suture removal or wearing any mucosally supported removable dentures at the augmented sites until reentry were not allowed. Sutures were removed 14 days after surgery.

Circulatory parameters

Blood flow and blood pressure measurements were done before the operation (baseline) and postoperatively on the following days: 1, 4, 6, 11, 13, 20, 27 and 34, then every month until the sixth month of healing. Systolic and diastolic blood pressure and pulse rate were measured with an automatic blood pressure monitor (Omron M4, Omron Healthcare Inc., Kyoto, Japan) before and after the LSCI measurements. Mean Arterial Pressure (MAP) was calculated from these values. Blood flow was measured by LSCI instrument (785 nm PeriCam PSI HR System, Perimed AB, Stockholm, Sweden) at the alveolar mucosa of the augmented sites. Depending on the extent of the surgery, the measurement area either covered the whole surgical field or the mesial part of the surgical area corresponding to 3 teeth. The detailed method of oral mucosal blood flow measurement with LSCI instrument has been described earlier.[22,23] The instrument was set to take snapshots. A snapshot captures 20 images in two seconds, the average of which is used to build the snapshot. At least three measurements were performed on each session, as our previous studies[32] suggest that inter-day reproducibility of gingival LSCI measurements can be significantly improved by within-session repetitions.

LSCI images were analyzed using PimSoft software (PeriCam PSI-HR, Perimed AB, Stockholm, Sweden). Four Region of Interest (ROI) were determined in the area of the augmented site, starting 0.2 mm from the distal surface of the last tooth and were 15 mm in length. Four nearly equal rectangular zones were defined on both sides of the suture line, buccally and lingually (sides). Two in the area of the keratinized mucosa (buccal-inner and lingual-inner) and two in the area of the mucosa (buccal-outer and lingual-outer) (Fig.2.) All the pixel perfusion values were averaged over within these ROIs, and defined as blood flow value of the ROI, which was expressed in an arbitrary value called Laser Speckle Perfusion Unit (LSPU).

Three-dimensional radiographic analysis

For the radiographic assessment, baseline, and 6-month postoperative Cone Beam Computed Tomography (CBCT) scans were acquired. The segmentation and subtraction analysis method was described in detail elsewhere.[29] Briefly, the Digital Imaging and Communications in Medicine (DICOM) files were imported into an open-source imaging software (3D Slicer).[33] 3D virtual models were made with a semi-automatic segmentation method.[34] Anatomic structures had to be segmented separately (bone, teeth). After spatial registration, both linear and volumetric measurements were performed. The CBCT scans were oriented so that the sagittal axis became parallel, and the coronal axis became perpendicular to the surgical site. The linear measurements were performed in the coronal window, where a cross-sectional view was acquired. The previously described regions of interest were manually placed on the 3D models, and the linear horizontal and vertical measurements were performed at six planes. The first plane was at the most mesial border of the regions of interest (at the distal surface of the last tooth), and a new plane is taken every 3 mm distally from this point, so the six planes were taken at 0, 3, 6, 9, 12, 15 mm. A grid with 1 mm intervals was overlaid on the coronal window view for more precise measurements. The horizontal alveolar ridge alterations were measured at each plane, 2 mm apically from the most coronal point of the 6-month follow-up alveolar crest. Vertical hard tissue changes were measured between the most coronal point of the baseline alveolar ridge and, at the same plane, the coronal point of the postoperative ridge. (Fig. 3.)

Statistical analysis

The data in the text and in the figures are presented as mean ± 95% confidence intervals (95% CI*)*. The factors affecting blood flow were analyzed using a linear mixed model. For preoperative blood flow comparison, the fixed factors were as follows. The outer and inner sides of the flap were the two levels for the factor area, and the buccal and lingual flaps were the levels for the factor side. The two-way interaction of area * side was also included. For assessing the effect of surgery on the postoperative blood flow, the area, the side, and the postoperative days were the main fixed factors with all interaction combinations. The residuals were normally distributed in both models. The random intercept was the subject, and the random slope was the day. The p values were adjusted for multiple comparisons using the sequential Bonferroni method. Statistical evaluation was carried out by Statistical Package for the Social Sciences (Version 29.0. Armonk, NY: IBM Corp).

Results

Wound healing events

Ten female patients with twelve surgical sites in the posterior mandible were analyzed; two patients had bilateral defects. In all cases, wound healing was uneventful with no membrane exposure. During the first week after surgery, patients reported pain that peaked on days 3-4. Swelling was observed in all cases, while hematoma was observed in only one-third of the mandibular surgeries. Sutures were removed at 14 days postoperatively, primary intention wound healing occurred in all cases, soft tissues integrity over grafted areas was maintained over the 6 months healing period in all cases.

Postoperative blood flow changes

There was no significant change in the MAP during the half-year experiment and in the MAP before *(93.38±1.2 mm Hg) and after (92.32±1.2 mmHg, $p<0.01$)* the blood flow measurements per session.

Significant variations of preoperative blood flow (day 0) were found between areas and sides. Preoperative blood flow was significantly higher on the buccal side compared to the lingual side in the inner area, but significantly lower on the buccal side than on the lingual side in the outer area. (Fig.4.)

On the first postoperative day, blood flow was significantly reduced in all regions. On the fourth day, buccal-outer, buccal-inner and lingual-inner blood flow was still significantly lower than preoperatively. Furthermore, blood flow in the buccal-inner region was still significantly lower on day 6. In the inner regions, blood flow returned to baseline after the initial ischemia. Significant hyperemia was only found on day 11 in the lingual-outer region. Interestingly, at day 180, blood flow was significantly below baseline in the lingual-outer region, although no clinical complication occurred. (Fig. 5.)

Since preoperative blood flow differed between regions, absolute changes in postoperative blood flow relative to preoperative blood flow were calculated and compared between regions Changes in blood flow on the buccal and lingual sides were similar throughout the investigation period both in the inner and outer areas. The only exception was on the first postoperative day, when a significantly greater reduction in blood flow was observed in the buccal-outer region compared to the lingual-outer region. (Fig. 6).

No difference in blood flow change was observed between the inner and outer areas of the buccal side during the follow-up period, except on day 6, when the blood flow reduction buccally was significantly higher in the inner than in the outer area The change in blood flow on the lingual side was significantly higher in the inner than in the outer area on postoperative days 1, 4, 6, but significantly lower on postoperative day 11. (Fig. 7.)

Radiographic hard tissue changes

Volumetric hard tissue gain averaged 712.62 ± 317.08 mm^3. Volumetric hard tissue loss was also observed on the lingual aspect, average resorption was 222.431 ± 103.19 mm^3. The mean linear hard tissue width, measured 2 mm apically from the most coronal point of the postoperative alveolar crest, was 4.82 ± 1.02 mm. Mean follow-up ridge width was 7,21 ± 0.99 mm. Vertical hard tissue resorption occurred at the area of the lingual ROI and averaged 1.24 ± 0.5 mm. (Fig. 8.) (Table 1.)

Correlation between postoperative blood flow and radiographic hard tissue changes

Throughout the 180 day healing period, correlations were found only on 2 days: Day 34 and Day 60. *Volumetric hard tissue gain* (measured on day 180) was significantly correlated with postoperative blood flow changes (relative to preoperative blood flow) in the lingual-inner ($r=0.63$, $p<0.05$), lingual-outer ($r=0.64$, $p<0.05$) and buccal-outer ($r=0.75$, $p<0.01$) regions on day 34. The *volumetric hard tissue gain* was also significantly correlated with the postoperative blood flow changes in the lingual-inner ($r=0.69$, $p<0.05$) and buccal-outer ($r=0.70$, $p<0.05$) regions on day 60. (Fig. 6.) On the other 178 days of healing, no correlations were found. (Fig.9.)

Discussion

The present study is the first to report on postoperative blood flow analysis utilizing LSCI following alveolar ridge augmentation. Hereby, we delivered evidence that this methodology is feasible for assessment of flap microcirculation on edentulous sites in the posterior mandible. During LSCI analysis, indirect visualization using photographic mirrors presented a challenge, nevertheless precise and reproducible data acquisition was possible in each case.

All documented cases exhibited uneventful wound healing, with no complications observed throughout the entire 180-day healing period. Consequently, our observations reflect blood flow changes during uncompromised healing processes, and the effect of adverse events could not be evaluated in the present study. Previous studies[21-24,35] have shown that flap circulation is restored between 2 and 8 weeks postoperatively, depending on the surgical procedure used and individual variations.

During the first 4 days of healing after alveolar ridge augmentation, blood flow was statistically significantly reduced in most regions, including the buccal-outer, buccal-inner, and lingual-inner areas. In the inner regions, blood flow returned to baseline after the initial ischemia, followed by significant hyperemia on day 11 in the lingual-outer region. These changes align well with previous observations following root coverage and vestibuloplasty procedures.[22,24] These observations may be explained by the injection of epinephrine containing local anesthetic solutions, as well as the inevitable disruption of vascular structures during tissue dissection and by the tissue compression caused by suturing.

Blood flow alterations on the buccal and lingual sides were similar throughout the investigation period both in the inner and outer areas, except for Day 1, when a statistically significantly greater reduction in blood flow was observed in the buccal-outer region compared to the lingual-outer region. This phenomenon can be explained by the fact that on the lingual side, full-thickness flap elevation was performed utilizing blunt instruments, as opposed to sharp dissection of the buccal mucosa and the underlying periosteal layer.

No difference was registered in blood flow change between the inner and outer areas of the buccal side during the follow-up period, except on day 6, which is not in line with the tendency of the majority of data registered. These observations indicate that the rebound of buccal flap circulation occurs simultaneously in the keratinized area on top of the augmented ridge and the mobile mucosa in the buccal vestibule, indicating the benefit of preserving vascular structures by a minimally invasive flap mobilization.

On the contrary, the reduction in blood flow on the lingual side was significantly higher in the inner than in the outer area on postoperative days 1, 4, 6. This indicates that due to the rotation of the lingual flap towards the buccal periosteum, initial compression of vascular structures might occur.

Assessment of hard tissue changes revealed favorable outcomes in all treated cases. At baseline, on average, 4.82 ± 1.02 mm horizontal ridge width was detected, which increased to 7.21 ± 0.99 mm at 6 months; this allowed for successful implant placement at reentry in all sites. Interestingly, minor vertical hard tissue resorption occurred lingually 1.24 ± 0.5 mm. This is a phenomenon that was first presented by our group elsewhere. [29] It can be hypothesized that the compression of lingual tissues due to flap mobilization, as well as the high density of lingual and crestal cortical bone with scarce vasculature, may lead to negative remodeling in this area.

Regarding the potential influence of postoperative blood flow changes on hard tissue alterations, significant correlations were observed only on Day 34 and Day 60. These data may be considered outliers, as none of the other days during the 180-day follow-up period showed similar tendencies. This suggests that the initially observed ischemia and subsequent blood flow rebound can be regarded as normal consequences of flap management during alveolar ridge augmentation. However, different conclusions might be drawn in cases with postoperative adverse events, such as suture failures, infections, or membrane exposures, leading to secondary intention wound healing. None of these complications were observed in the present study.

Conclusions

Within the limits of this case series, it can be concluded that LSCI is a feasible method for assessing postoperative changes in flap microcirculation following alveolar ridge augmentation. Additionally, in cases with uneventful primary intention wound healing, no correlations were observed between postoperative blood flow changes and the amount of newly formed hard tissue 6 months postoperatively. Further studies are needed to determine the prognostic efficacy of LSCI on new hard tissue formation in cases with compromised wound healing.

Acknowledgements

The study was supported by the Ministry of Innovation and Technology and by the Hungarian National Research, Development and Innovation Office /NKFIH/: FK_OTKA 2020 135348; Hungarian Academy of Sciences János Bolyai Research Scholarship, New National Excellence Programme. The study received material support from Geistlich Pharma AG, Wolhusen, Switzerland and Dicomlab Kft., Szeged, Hungary

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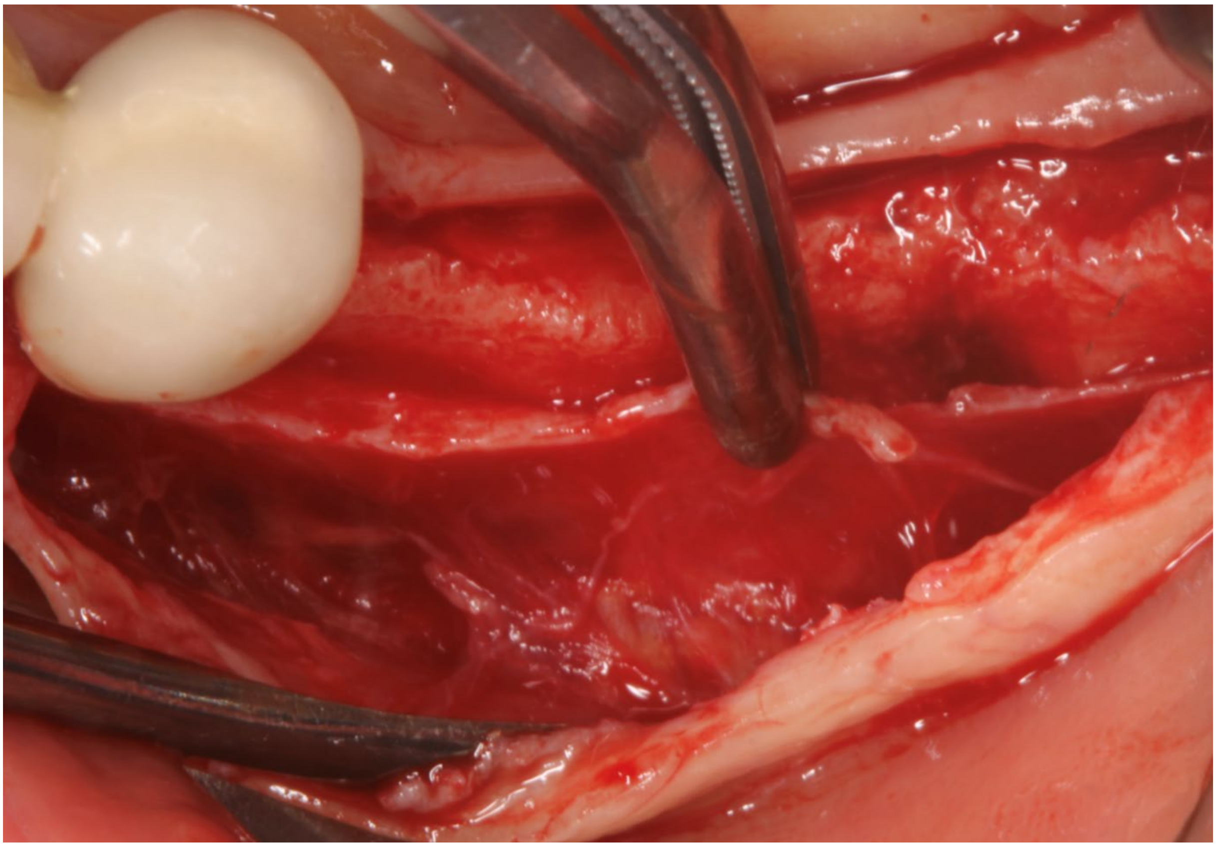

Fig 1a

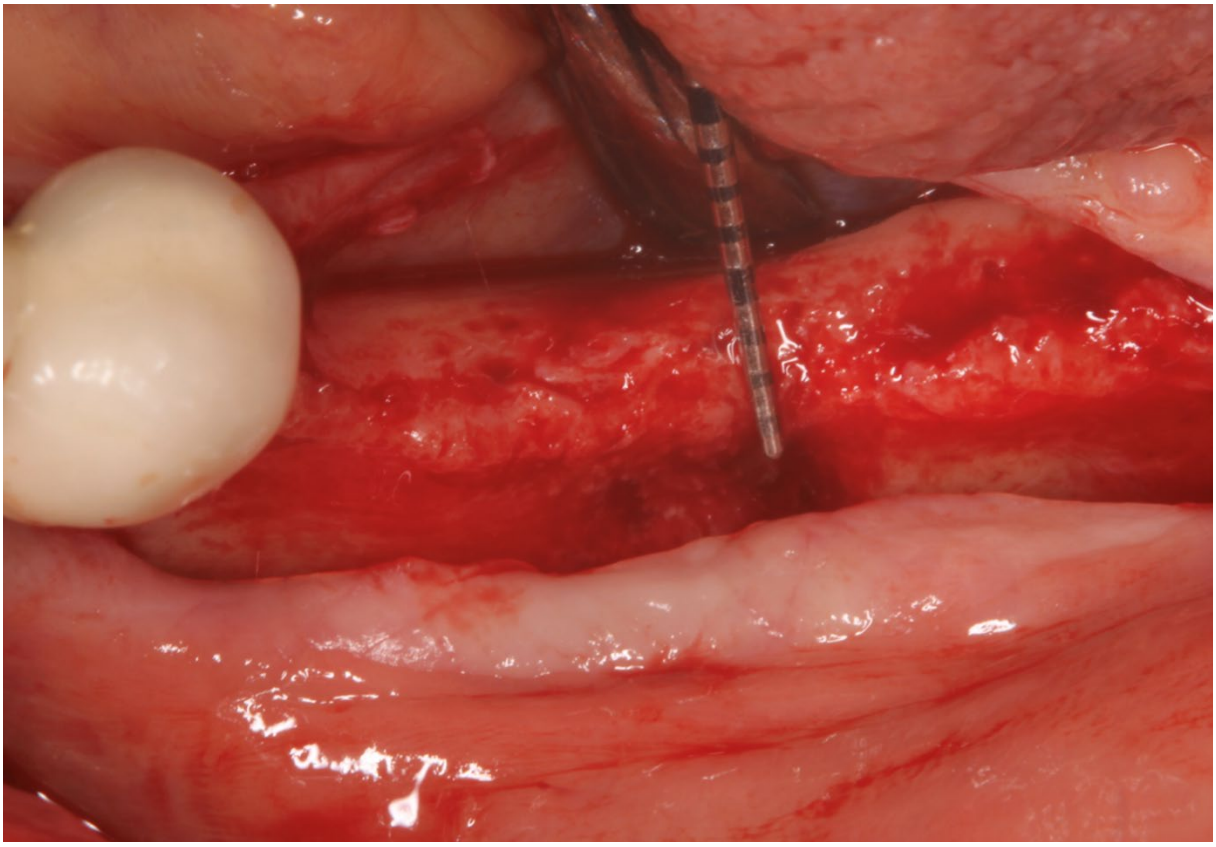

Fig 1b

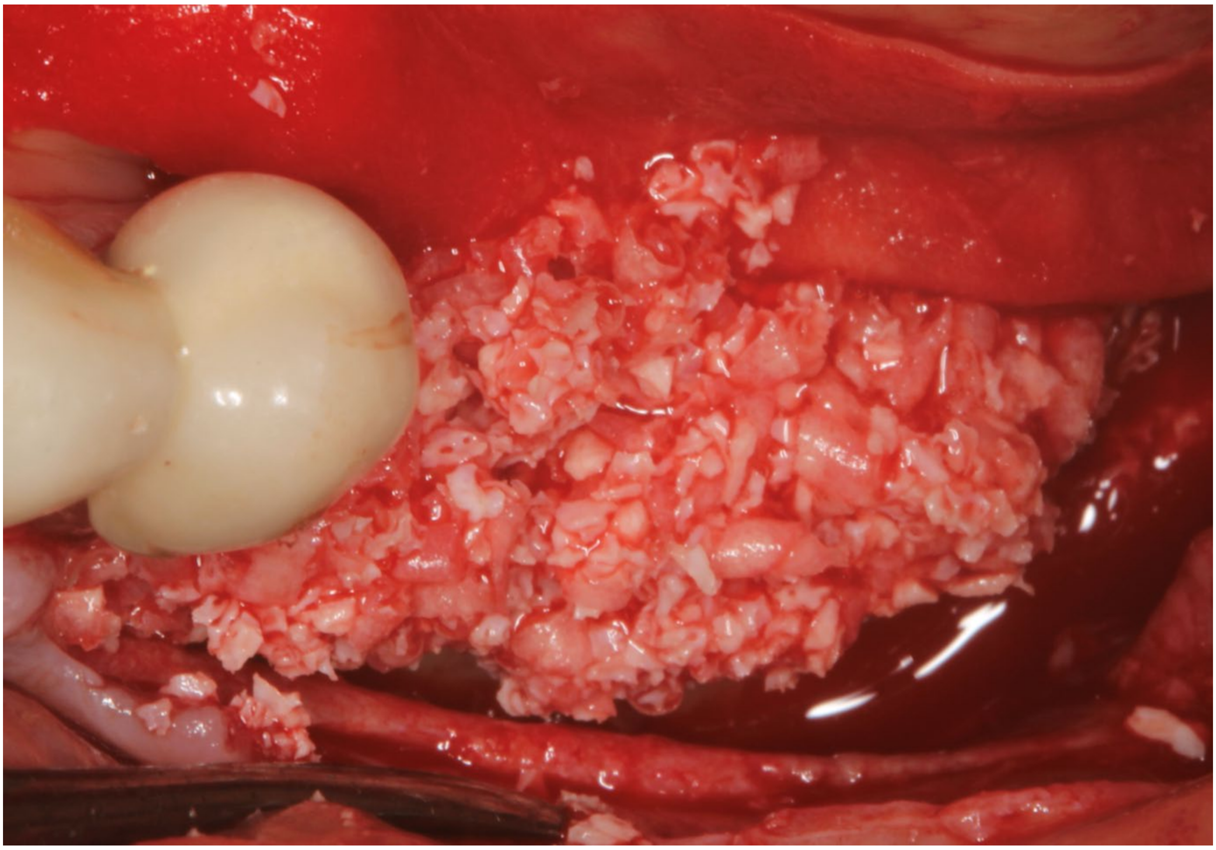

Fig 1c

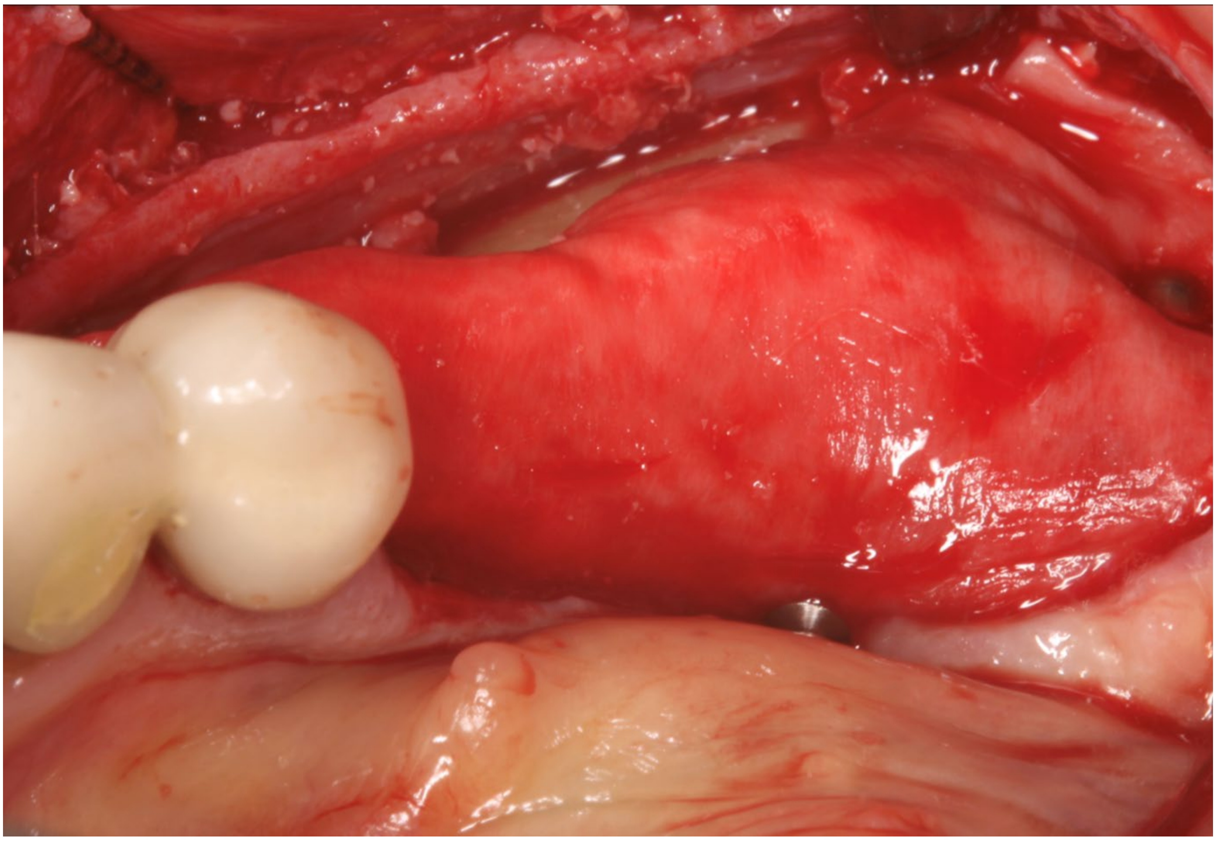

Fig 1d

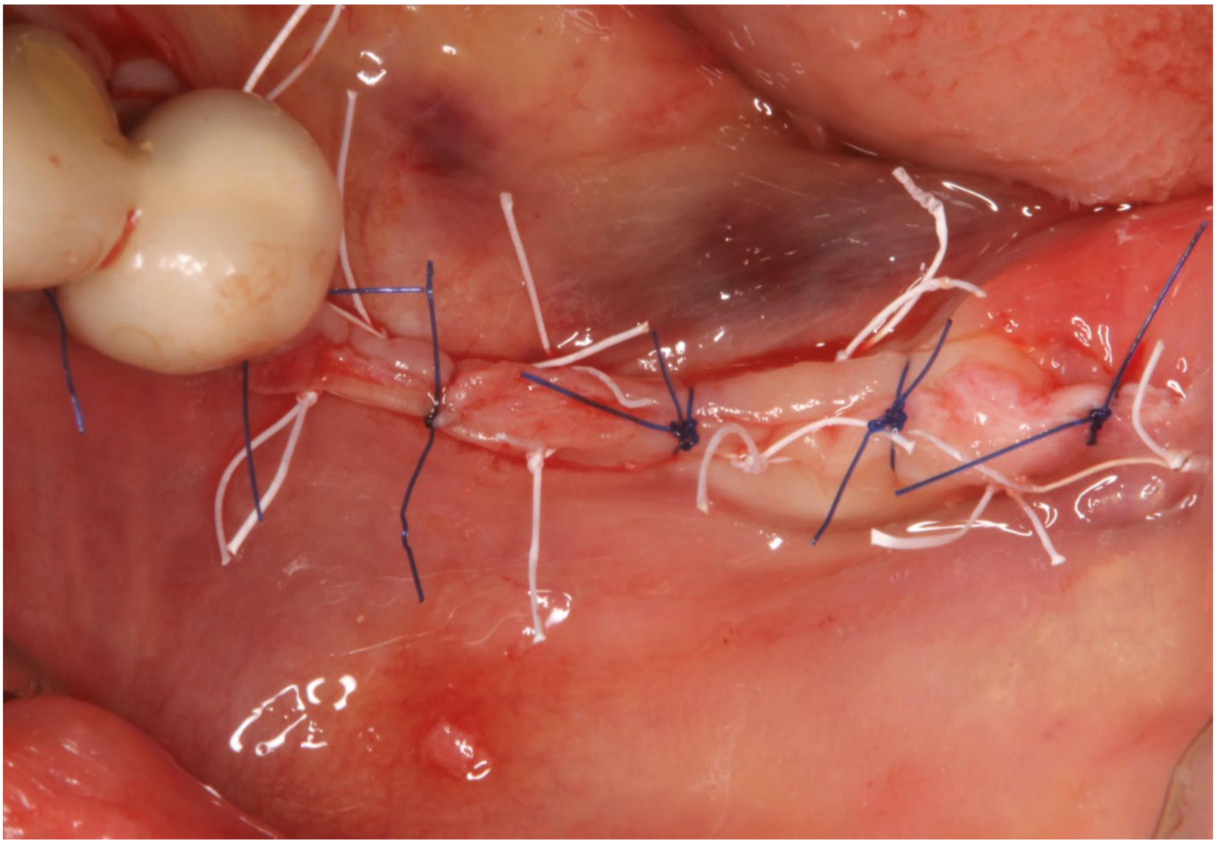

Fig 1e

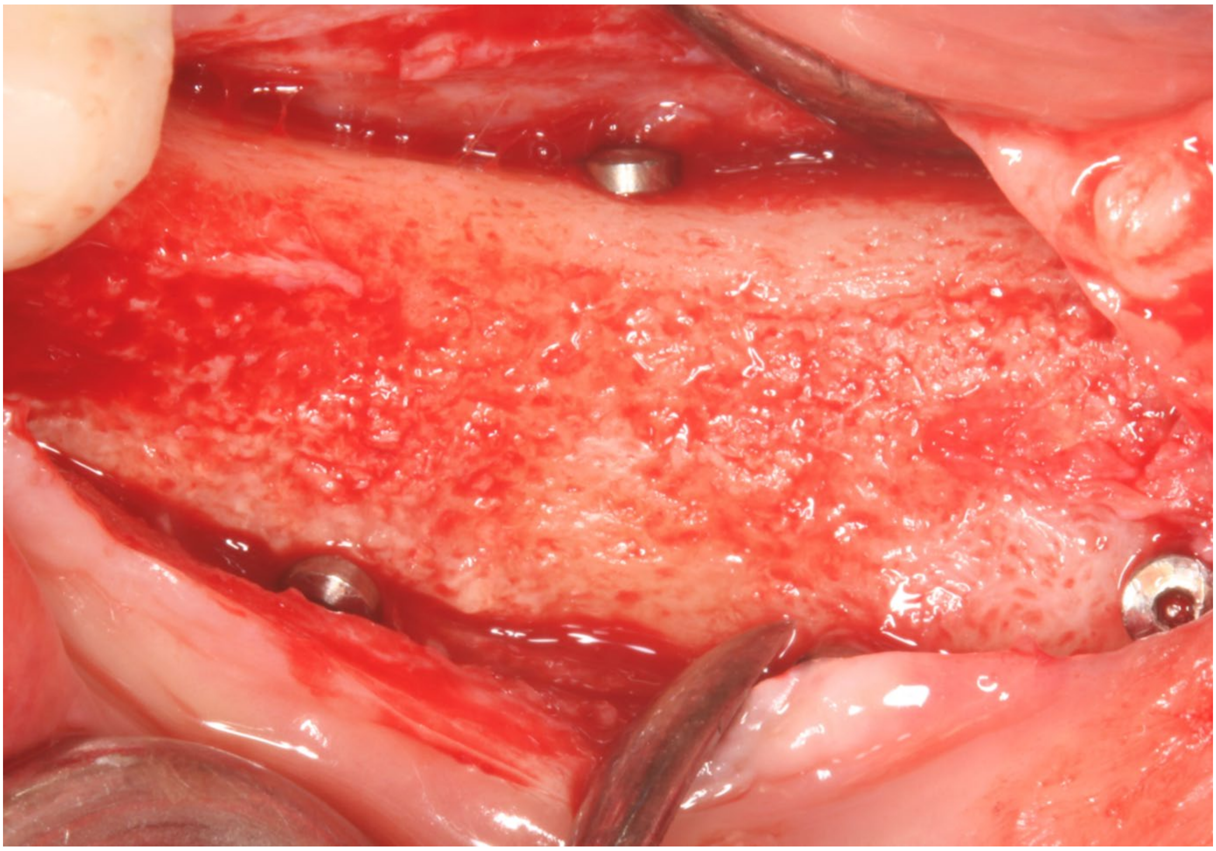

Fig 1f

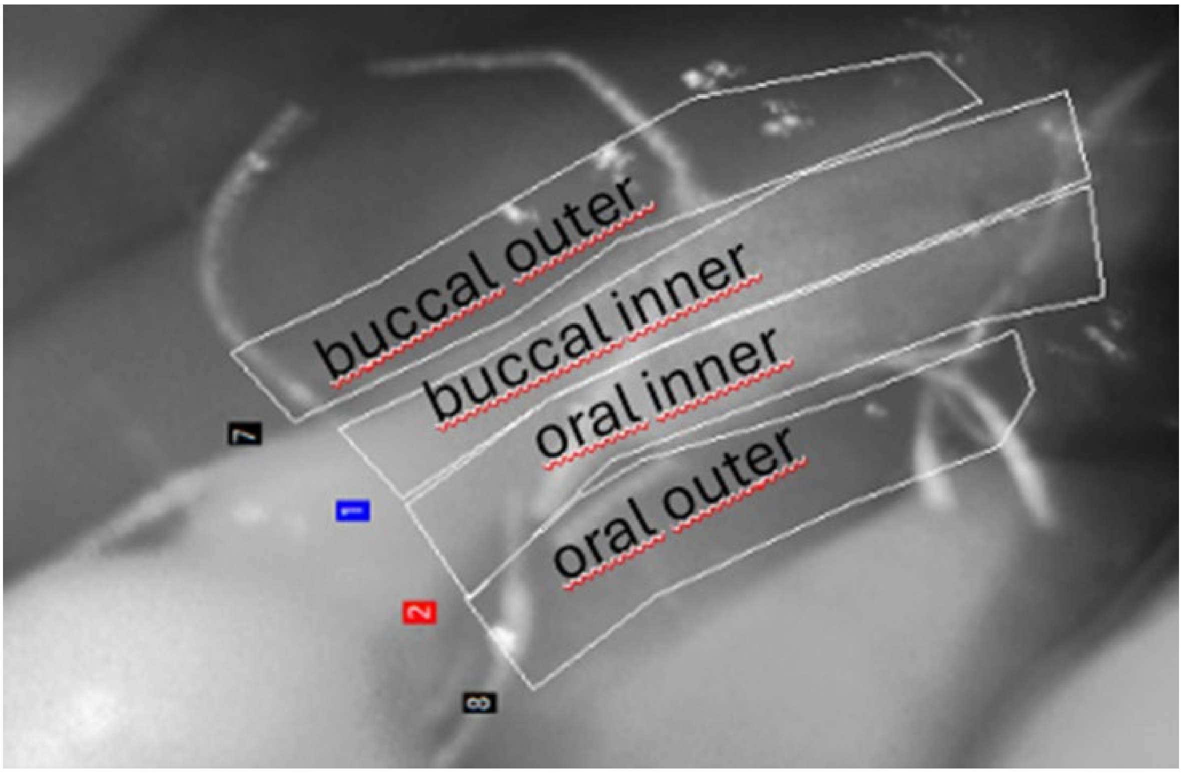

Fig 2a

Fig 2b-d

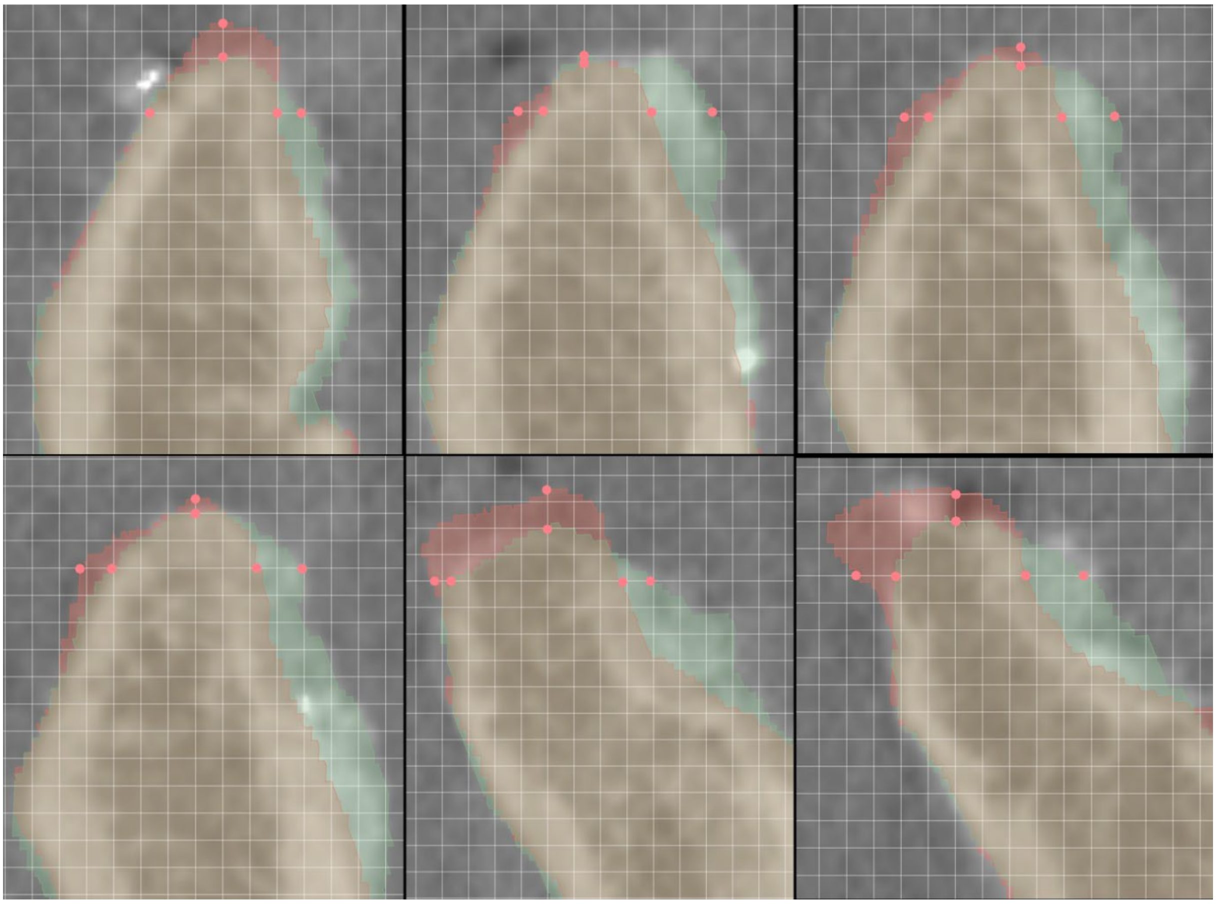

Fig 3

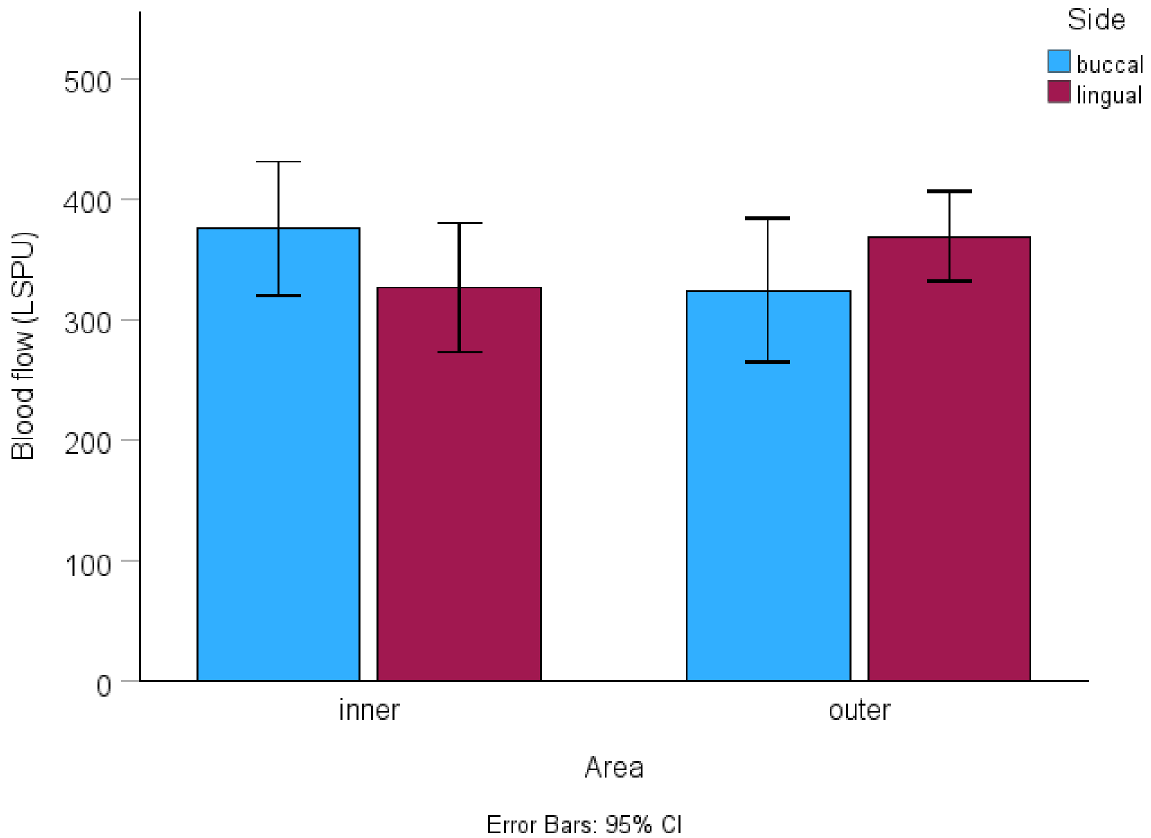
Side
buccal
lingual
Blood flow (LSPU)
500
400
300
200
100
0
inner
outer
Area
Error Bars: 95% CI

Fig 4

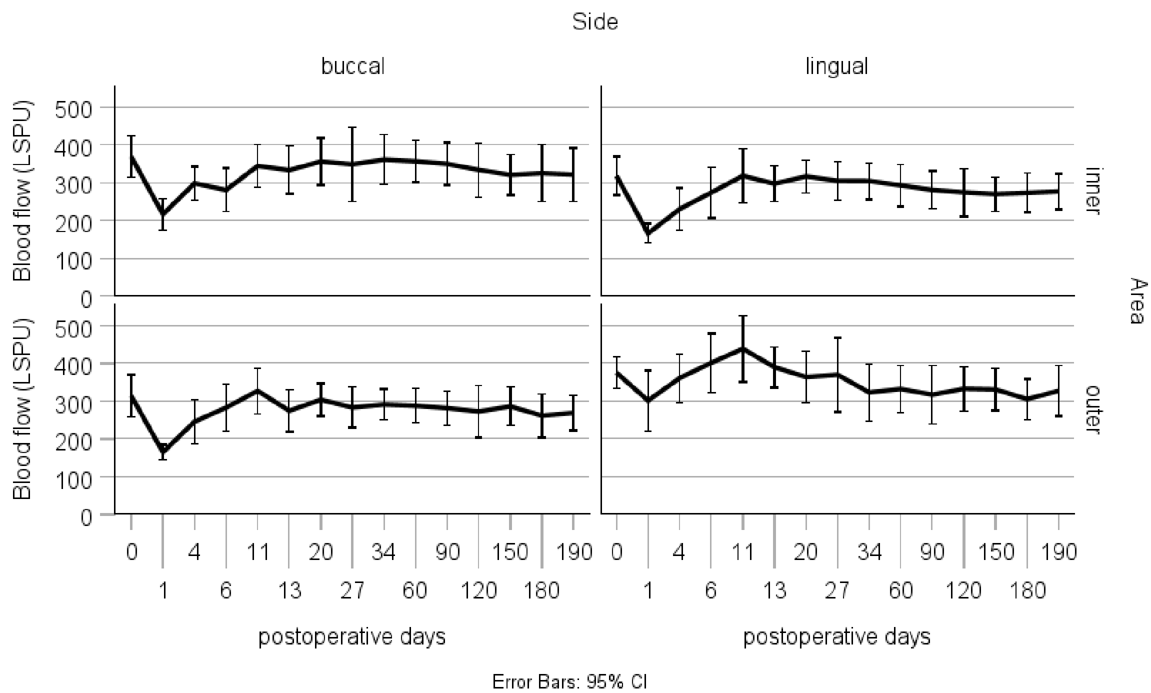
Side
buccal
lingual
Blood flow (LSPU)
500
400
300
200
100
0
inner
outer
Area
0 1 4 6 11 13 20 27 34 60 90 120 150 180 190
postoperative days
Error Bars: 95% CI

Fig 5

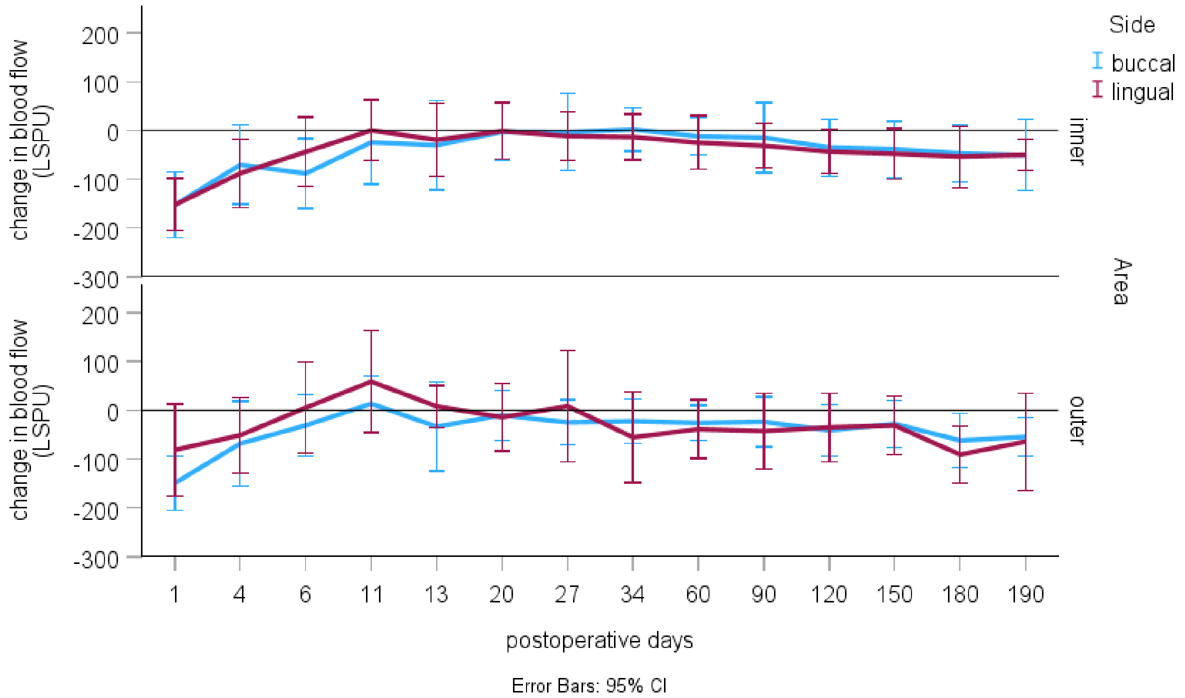
Side
buccal
lingual
Area
inner
outer
change in blood flow (LSPU)
200
100
0
-100
-200
-300
1
4
6
11
13
20
27
34
60
90
120
150
180
190
postoperative days
Error Bars: 95% CI

Fig 6

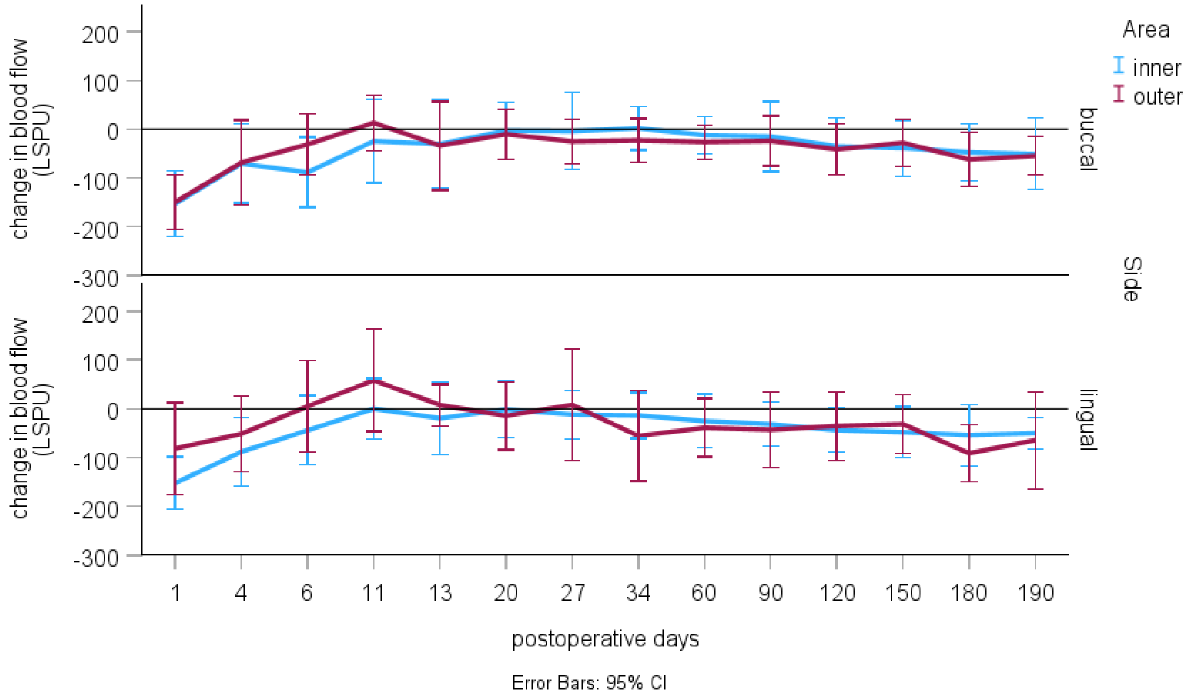
Area
inner
outer
Side
buccal
lingual
change in blood flow (LSPU)
200
100
0
-100
-200
-300
1
4
6
11
13
20
27
34
60
90
120
150
180
190
postoperative days
Error Bars: 95% CI

Fig 7

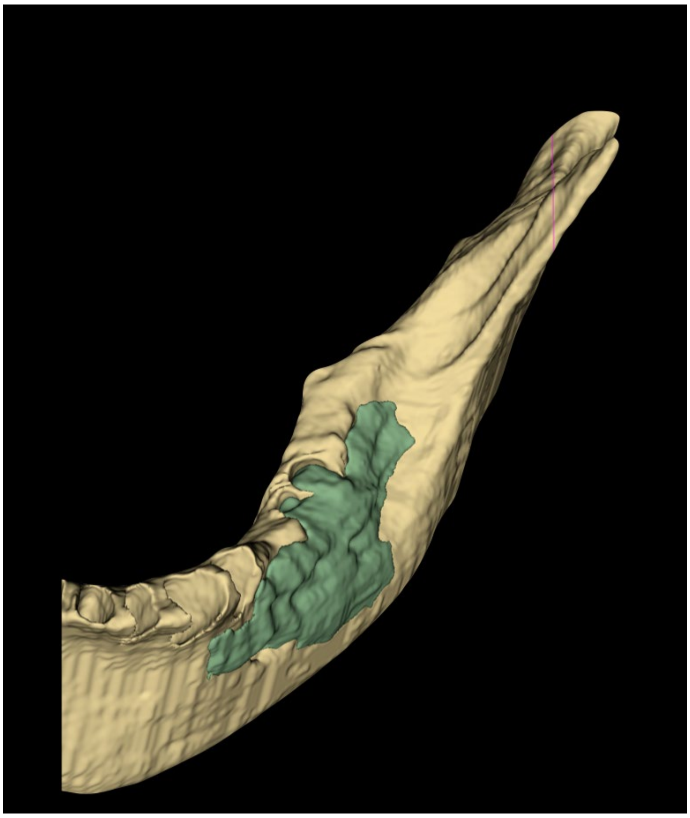

Fig 8a

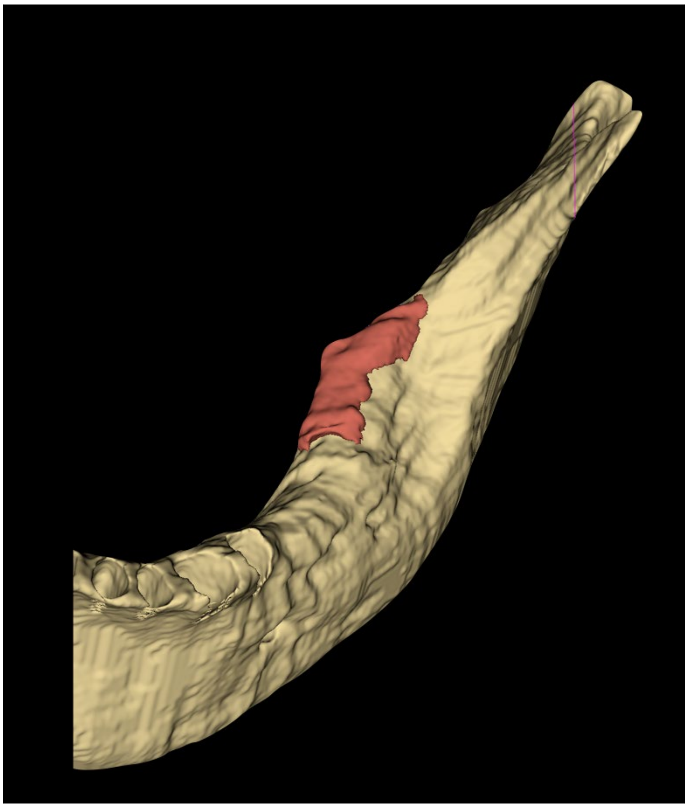

Fig 8b

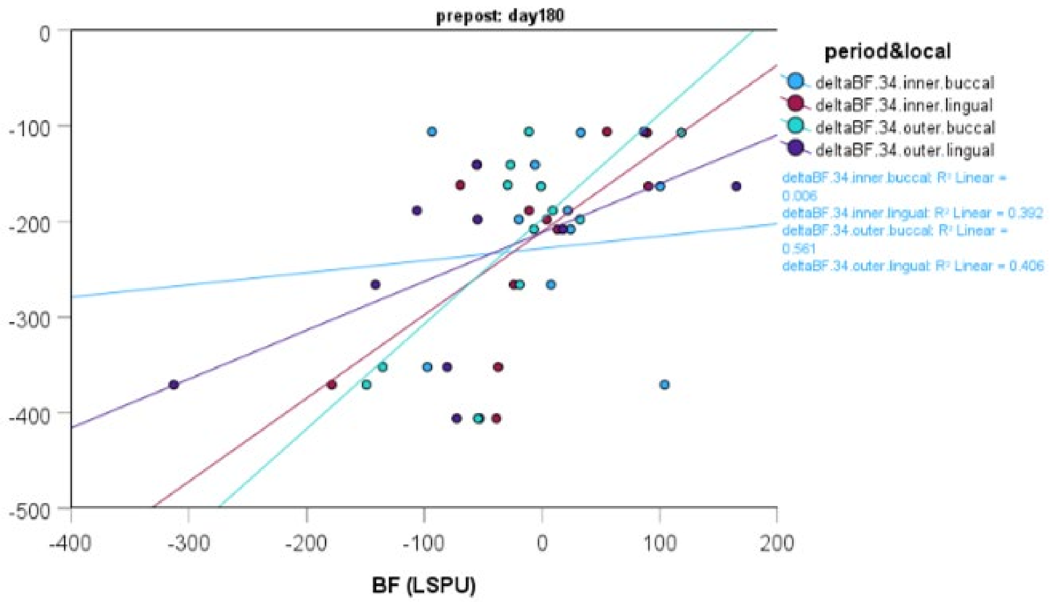
prepost: day180
period&local
deltaBF.34.inner.buccal
deltaBF.34.inner.lingual
deltaBF.34.outer.buccal
deltaBF.34.outer.lingual
deltaBF.34.inner.buccal: R² Linear = 0.006
deltaBF.34.inner.lingual: R² Linear = 0.392
deltaBF.34.outer.buccal: R² Linear = 0.561
deltaBF.34.outer.lingual: R² Linear = 0.406
0
-100
-200
-300
-400
-500
-400
-300
-200
-100
0
100
200
BF (LSPU)

Fig 9a

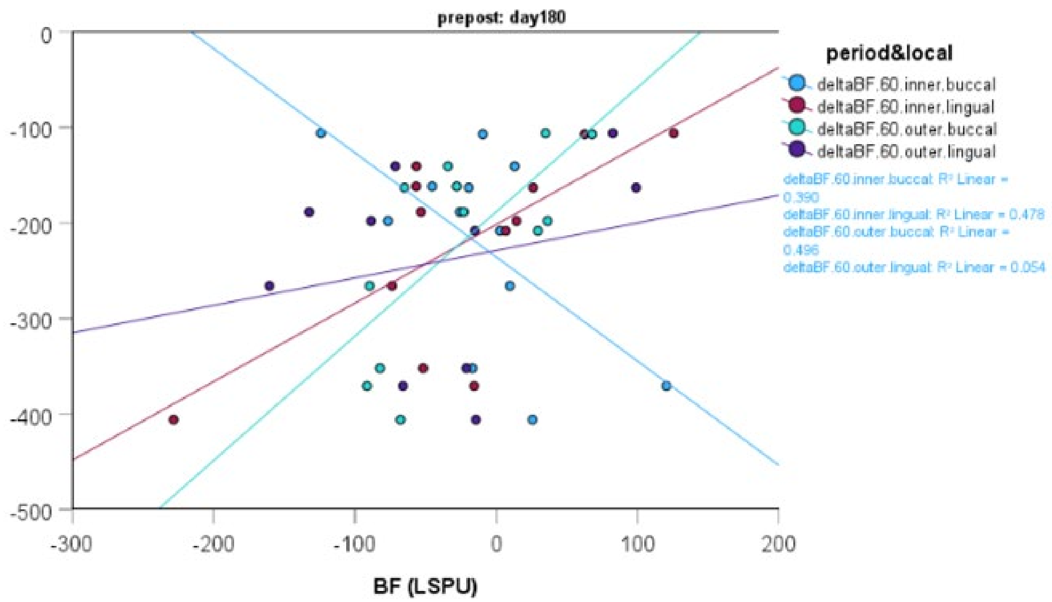
prepost: day180
period&local
deltaBF.60.inner.buccal
deltaBF.60.inner.lingual
deltaBF.60.outer.buccal
deltaBF.60.outer.lingual
deltaBF.60.inner.buccal: R² Linear = 0.390
deltaBF.60.inner.lingual: R² Linear = 0.478
deltaBF.60.outer.buccal: R² Linear = 0.496
deltaBF.60.outer.lingual: R² Linear = 0.054
0
-100
-200
-300
-400
-500
-300
-200
-100
0
100
200
BF (LSPU)

Fig 9b