Digital Three-Dimensional Visualization of Intrabony Periodontal Defects for Surgical Planning (Pilot Case Study)

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Research article

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Abstract

Background: In the regenerative treatment of intrabony periodontal defects, surgical strategies are determined by defect morphologies. Clinical direct measurements and intraoral radiographs are the main tools in periodontal diagnostics and surgical planning, however in certain cases they don't provide sufficient amount of information. Therefore, the application of cone-beam computed tomography (CBCT) in diagnosis and treatment planning of periodontally involved patients has been proposed. The aim of this study is to present a novel method for 3D visualization of intrabony periodontal defects on digital models reconstructed from CBCT datasets for diagnostics and treatment planning.

Methods: 4 patients with a total of 6 intrabony periodontal defects were enrolled in the present study. 2 months following initial periodontal treatment CBCT scan is taken. Radiographic image processing (segmentation) of CBCT datasets were performed in a radiographic imaging software to acquire anatomically accurate, virtual three-dimensional polygon models of surgical areas. Intrasurgical and digital measurements were taken, and results were compared, to validate the accuracy of digital models.

Results: Difference between intrasurgical- and digital measurements in depth and width of intrabony components of periodontal defects were 0,31±0,21 mm and 0,41±0,44 mm respectively.

Conclusion: It can be concluded that, the described digital workflow is useful in the treatment of certain periodontal intrabony defect morphologies. However, to determine the exact use cases of such technology further studies and examination is necessary.

Trial Registration: Retrospective Ethics Approval

Background

Regenerative treatment of periodontal defects was first published in the early 1980’s (Nyman et al. 1982), but the concept of a new periodontal attachment formation in intrabony periodontal defects was emphasized from the 1970’s (Melcher 1976). Since the first concepts on regenerative periodontal therapy, many different approaches have been introduced to achieve periodontal regeneration. The introduction of various biomaterials has made regenerative surgery more predictable and more straightforward. Applied surgical modalities and regenerative strategies are determined by the morphology and the extent of the intrabony defect. Decision-trees (Cortellini 2012), described in the literature provide treatment options for different clinical scenarios.

Defect morphology is determined by (i) direct clinical measurements (probing pocket depth: PPD, gingival recession: GR, clinical attachment loss: CAL) and (ii) two-dimensional (2D) radiographic images (intraoral radiographs: IR, and panoramic x-rays: PX). These tools are used for diagnostics and treatment planning of periodontally involved patients. The aforementioned methods are considered the gold standard in periodontal diagnostics, however there are a few drawbacks and in certain cases they don't provide sufficient amount of information. Clinical studies have demonstrated, that clinicians constantly
underestimated the extent of intrabony defects during direct clinical measurements (Eickholz et al. 1998, Vrotsos 1999, Christiaens 2018). IRs provide two-dimensional (2D) image, where overlapping anatomical structures make it difficult to accurately determine the true three-dimensional (3D) defect morphology (Eickholz et al. 1998, Christiaens 2018). Since the primary determining factors when selecting the regenerative treatment modality for intrabony periodontal defects are the morphology and the extent of the defect, without an accurate knowledge of these features, an exact treatment plan cannot be determined.

The application of cone-beam computed tomography (CBCT) in periodontal diagnostics diagnosis has been proposed by many authors (Mish et al. 2006; Kasaj et al. 2007; Walter et al. 2009). Series of in vitro and in vivo studies have demonstrated, that in certain cases CBCT is superior in the detection of periodontal defects (i.e. furcation defects, three wall intrabony defects, midbuccal intrabony defects and dehiscence type defects) then IRs (Vandenberghhe et al. 2007; Vandenberghhe 2008; Grimard et al. 2009, de Faria Vasconcelos 2012; Bagis et al. 2015; Cetmili et al. 2019) (Figure 1.), however it is difficult to justify the cost-benefit ratio of higher irradiation dose (Woebler et al. 2018; Walter et al. 2016). Therefore, CBCT should only be used for periodontal diagnosis, if conventional radiographic methods do not provide sufficient amount of information, which is in line with the 2017 recommendation of the American Academy of Periodontology (AAP) (Mandelaris et al. 2017).

CBCT images provide images in multiple orientations (sagittal, axial, coronal), however only one slice can be viewed at a time. DICOM (Digital Imaging and Communications in Medicine) imaging software automatically generated three-dimensional volume renders of datasets, but the reconstruction is done with basic threshold algorithms based on gray values of each voxel, and not based on anatomical structures. Due to the nature of cone beam tomography, artefacts and scattering, caused by teeth and metal restorations, compromise image quality (Queiroz et al. 2018), consequently visualization of small and delicate areas, such as the periodontium could be difficult.

Various surgical fields in general medicine such as: cardiac surgery, orthopedic surgery and cranio-maxillofacial surgery have utilized different radiographic image segmentation techniques to create patient specific digital three-dimensional anatomical renders and 3D printed models for diagnostics and treatment planning.

Aim of this study is to present a method for 3D visualization of intrabony periodontal defects with the help of virtual, patients specific models reconstructed from CBCT datasets and to evaluate the accuracy of the models, by comparing the results with direct intrasurgical measurements.

**Methods**

**Patient selection and Image Acquisition**

4 patients with 6 intrabony periodontal defects were enrolled in this preliminary study. Selected patients were diagnosed with Stage III/ Grade B periodontitis and were in need of complex perio-prosthetic
rehabilitation. 2 months following initial periodontal treatment, CBCT scans were taken with I-CAT FLX® (KaVo Dental GmbH, Bieberach an der Riß, Germany) /300 µm voxel size; 120 kV anode voltage; 36 mA x-ray tube current/. In all cases prosthetic rehabilitation of all patients was planned with implant retained fixed partial dentures (FPD). To acquire the best possible image quality, all metal restorations, that would be changed during the treatment were removed. If the patient had permanent metal restoration and implants, metal artifact reduction was applied. To reduce scatter at the occlusal plane, patients were instructed to bite on cotton rolls. The study was conducted with full accordance to the declaration of Helsinki (2008) and were approved by the local ethical committee (Semmelweis University Regional and Institutional Committee of Science and Reasearch Ethitcs, ref. no. 195/2017). Surgical interventions were performed with the understanding and written consent of each participant.

**Radiographic image processing - Segmentation**

DICOM datasets were imported into an open source medical image processing software (3D Slicer©) for image segmentation. The goal of segmentation was to create 3D reconstructions of alveolar bone and teeth to allow easier analysis. Combination of semi-automatic thresholding tools (*Level tracing*), interpolation algorithms (*Fill between slices*) and manual segmentation tools (*Draw, Erase*), found in the Segment editor module were utilized to create separate regions of interest (ROI) for teeth and for alveolar bone (*Figure 2.*). Three-dimensional polygon models are generated from the ROIs and were exported as stereolithographic (.stl) files. Further refinement and occasional mesh repairs were done with an open source CAD based mesh modelling software (Meshmixer®, Autodesk, San Rafael, California, USA) (*Figure 3.*). For more accurate digitalization of the clinical situation soft tissue model derived from an intraoral scan can be superimposed over the 3D model created from the CBCT dataset (*Figure 4.*).

**Surgical Procedure and Validation**

With the advancement of minimally invasive surgical procedures (Harrel 1999; Cortellini & Tonetti 2007, 2009; Trombelli et al. 2009; Aslan et al. 2017) relatively large defects can be treated with relatively small flap designs. The improved blood clot and wound stability, achieved with minimal flap elevation during surgery, enhance regenerative capabilities (Chiu et al. 2013; Schincaglia et al. 2015; Azuma et al. 2017). Disadvantage of minimally invasive techniques is the impaired direct visualization of the surgical area. 3D reconstruction of the surgical area allowed for better understanding of the defect morphology, overcoming the limitations of reduced visibility. Periodontal defects were treated with either single flap approach (SFA) (Trombelli et al. 2009) or modified-minimally invasive surgical technique (M-MIST) (Cortellini & Tonetti 2009). Flap elevation was made either on the buccal or oral aspect, depending on the easiest access, which was predetermined on the virtual model. Regenerative strategy was determined by to defect morphology (*Figure 5.*). Applied surgical procedures and regenerative strategies are shown in Table 1.
Table 1

Defect morphologies and Surgical procedures

| Patients | Defect morphology | Defect Localization | Surgical Technique | Regenerative strategy       |
|----------|-------------------|---------------------|--------------------|-----------------------------|
| ÉTM      | 3 wall, pseudocircumdental | tooth 11, palatal | SFA                | EMD + collagen matrix (Fibroguide) |
| KA       | 1 wall            | tooth 44 distal    | M-MIST             | EMD + collagen matrix (Lyostypt) |
|          | 2 wall            | tooth 42 distal    | M-MIST             | EMD + collagen matrix (Lyostypt) |
|          | 1 wall            | tooth 36 mesial    | M-MIST             | EMD                         |
| KL       | 1 wall, furcation II | tooth 16 palatal | SFA                | EMD + collagen matrix (Lyostypt) |
| ZB       | Interdental crater, furcation II | tooth 27 palatal | SFA                | EMD + collagen matrix (Lyostypt) + FGG |

Following intrasurgical measurements were made: (i) CEJ-BD: vertical distance from cemento-enamel junction (CEJ) to the base of the defect (BD); (ii) CEJ-BC (suprabony component): the vertical distance from the CEJ to the marginal bone crest (BC); (iii) INTRA (intrabony component) : the vertical distance from marginal bone crest to the base of the defect; (iv) WIDTH (Root surface-bone crest): the horizontal distance from root surface to the most coronal point of the bone crest (Cortellini et al. 1993). Measurements were done digitally on the virtual models at the same points as well, to validate the accuracy of the models. *(Figure 6.)*

**Results**

**Clinical Measurements**

Clinical measurements (PPD, GR, CAL) were taken prior and 6 months following regenerative surgery. Probing pocket depths of $8.00 \pm 1.26$ mm and clinical attachment loss of $9.67 \pm 1.21$ mm was recorded at baseline. At 6 months follow-up $2.83 \pm 0.41$ mm probing depth value and $5.33 \pm 1.75$ mm clinical attachment level was registered. Differences in PPD and CAL values between baseline and 6 months follow-up averaged $5.17 \pm 1.17$ mm and $4.33 \pm 1.21$ mm respectively. Difference between baseline and follow-up PPD and CAL values was statistically significant ($P<0.001$). Changes in PPD, CAL and GR values are shown in Table 2.
### Table 2
Baseline and follow-up clinical measurement values

| Defect | PPD (mm) | GR (mm) | CAL (mm) |
|--------|----------|---------|----------|
|        | Baseline | 6 mths  | Baseline | 6 mths  | Baseline | 6 mths  |
| 1      | 7        | 2       | 2        | 2       | 9        | 4       |
| 2      | 7        | 3       | 2        | 1       | 9        | 4       |
| 3      | 10       | 3       | 2        | 4       | 12       | 7       |
| 4      | 8        | 3       | 1        | 2       | 9        | 5       |
| 5      | 7        | 3       | 3        | 5       | 10       | 8       |
| 6      | 9        | 3       | 0        | 1       | 9        | 4       |
|        | 8,00±1,26| 2,83±0,41| 1,67±1,03| 2,502±1,64| 9,67±1,21| 5,33±1,75|

### Intrasurgical and Digital measurements

Intrasurgical measurements (CEJ-BD, CEJ-BC, INTRA, WIDTH) were taken at multiple aspects of defects. On the digital models the CEJ is not clearly visible, therefore only the intrabony component and the width of the defects could be assessed accurately. Intrasurgically, the vertical distance from the marginal bone crest to the base of the defect averaged 4.22 ± 1.67 mm. On digital models the distance was 4.05 ± 1.51 mm. Horizontal distances between the marginal bone crest and the tooth surface measured at 3.17 ± 0.98 mm intrasurgically and 3.50 ± 1.02 mm on digital models. Difference between the intrasurgical measurements and digital measurements of intrabony components and the width of the defect were 0.31 ± 0.21 mm and 0.41 ± 0.44 mm respectively. Difference between intrasurgical measurements and digital measurements regarding the width and the depth of the intrabony component of periodontal defects was statistically not significant (P>0.001). Values and differences in intrasurgical and digital measurements are shown in Table 3.
Table 3
Intrasurgical and digital measurements

| Defect | INTRA (mm) | WIDTH (mm) | CEJ-BD (mm) | CEJ-BC (mm) |
|--------|------------|------------|-------------|-------------|
|        | Surgical   | Digital    | Surgical    | Digital     |
| 1      | 3          | 2,28       | 2           | 2,17        | 10          | 7           |
|        | 3          | 3,27       |             |             | 9           | 6           |
|        | 4          | 3,86       |             |             | 10          | 6           |
| 2      | 8          | 7,41       | 4           | 4,36        | 9           | 1           |
| 3      | 3          | 3,23       | 2           | 2,25        | 8           | 5           |
|        | 4          | 4,13       |             |             | 9           | 5           |
| 4      | 5          | 4,72       | 4           | 3,75        | 8           | 3           |
| 5      | 3          | 2,80       | 4           | 4,15        | 7           | 4           |
| 6      | 5          | 4,79       | 3           | 4,30        | 11          | 6           |

\[4.22\pm1.64 \quad 4.05\pm1.51 \quad 3.17\pm0.98 \quad 3.50\pm1.02 \quad 9.00\pm1.22 \quad 4.78\pm1.86\]

Discussion

CBCT scans have been used in periodontal diagnostics and treatment planning for certain use cases, such as furcation defects, three wall intrabony defects, midbuccal intrabony defects and dehiscence type defects (Vandenberghe et al. 2007; Vandenberghe 2008; Grimard et al. 2009, de Faria Vasconcelos 2012; Bagis et al. 2015; Cetmili et al. 2019). But application of radiographic image processing and creation of anatomically accurate 3D models of periodontal defects has never been proposed. The biggest drawback of computed tomography compared to conventional radiographic methods is the increased radiation dose and unprocessed CBCT images give relatively little additional information compared to conventional radiographic methods. Therefore, the increased radiation dose is difficult to justify. This novel method for radiographic image processing in periodontal diagnostics allows for clinicians to view periodontal defects in 3D, rotate the models, zoom in and out, measure distances and plan surgeries more precisely. If necessary, the models can be produced with additive manufacturing techniques.

This pilot study demonstrated that digital models created with this novel semi-automatic segmentation method represent an accurate clinical situation. Differences between intrasurgical and digital measurements were minor and did not have any clinical relevance. However, for further evaluation of this process prospective case study has to be carried out.

Utilizing anatomic 3D models of hard tissues is a useful tool in periodontal diagnostics, because clinicians are able to see the three-dimensional morphology of intrabony periodontal defects. However, not every case requires the application of CBCT based segmentation. Conventional diagnostic tools (direct
clinical measurements, IRs) should still be the number one method in treatment planning of periodontal regenerative surgery however, if these aforementioned methods do not provide sufficient amount of information, this novel digital method can be utilized as a third diagnostic modality.

To further expand on the concept of applying computer assisted technologies in periodontology, the method can help to create a digital workflow in periodontal regenerative surgery. Digital technologies can be utilized during surgical procedures, as well as in 3D postoperative evaluation. Individualized, 3D-printed stents can be used during surgical intervention as passive guides (Lei et al. 2019). With 3D bioprinting technologies defect specific implants can be used as grafting material (Rasperini et al. 2015). Digital models on the other hand can also be uploaded into an augmented reality (AR) setup and be used with an AR headset (Pellegrino et al. 2019), to further increase the visualization of the surgical field.

**Conclusions**

It can be concluded that, the described digital workflow is a useful diagnostic modality in the treatment of certain periodontal intrabony defects. However, to determine the exact use cases of such technology further studies and examination is necessary. With the aid of digital, anatomical models, intraoperative tools and postoperative validation methods can be developed to further expand the digital workflow in periodontal surgery.

**Abbreviations**

PPD: Probing pocket depth

GR: Gingival recession

CAL: Clinical attachment loss

IR: Intraoral radiographs

PX: Panoramic X-ray

2D: Two-dimensional

3D: Three-dimensional

CBCT: Cone-beam computed tomography

AAP: American Association of Periodontology

DICOM: Digital Imaging and Communications in Medicine

FPD: Fixed partial denture
Declarations

Ethics approval and consent to participate

Approved by Semmelweis University Regional and Institutional Committee of Science and Research Ethics (Ref. No. 195/2017).

Patients participating in the study were fully informed and were given written consent to the participation.

Consent for publication

The identifying images and other personal or clinical details of participants are presented without compromising anonymity.

Availability of data and materials

All data generated or analyzed during this study are included in this article.

Competing interests

Francesco Guido Mangano (Associate Editor) and Peter Windisch are members of BMC Oral Health editorial board. The authors declare that they have no competing interests.
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Authors’ contribution

All authors have read and approved the manuscript.

DP: surgical procedures, intrasurgical measurements, segmentation, digital measurements, preparation of manuscript

FGM: Supervisor and assistance in the creation of digital models

KN: Supervisor of the research process and assistance in the composition of the text

PW: Suprevisor of patient selection and surgical procedures clinical measurements

References

1. Nyman S, Lindhe J, Karring T, Rylander H. New attachment following surgical treatment of human periodontal disease. J Clin Periodontol. 1982 Jul;9(4):290–6.

2. Melcher AH. On the repair potential of periodontal tissues. J Periodontol. 1976 May;47(5):256–60.

3. Cortellini P. Minimally invasive surgical techniques in periodontal regeneration. J Evid Based Dent Pract. 2012 Sep;12(3 Suppl):89–100.

4. Eickholz P, Kim TS, Benn DK, Staehle HJ. Validity of radiographic measurement of interproximal bone loss. Oral Surg Oral Med Oral Pathol Oral Radiol Endod. 1998 Jan;85(1):99–106.

5. Christiaens V, De Bruyn H, Thevissen E, Koole S, Dierens M, Cosyn J. Assessment of periodontal bone level revisited: a controlled study on the diagnostic accuracy of clinical evaluation methods and intra-oral radiography. Clin Oral Investig. 2018 Jan;22(1):425–31.

6. Misch KA, Yi ES, Sarment DP. Accuracy of cone beam computed tomography for periodontal defect measurements. J Periodontol. 2006 Jul;77(7):1261–6.

7. Kasaj A, Willershausen B. Digital volume tomography for diagnostics in periodontology. Int J Comput Dent. 2007 Apr;10(2):155–68.

8. Walter C, Kaner D, Berndt DC, Weiger R, Zitzmann NU. Three-dimensional imaging as a pre-operative tool in decision making for furcation surgery. J Clin Periodontol. 2009 Mar;36(3):250–7.

9. Woelber JP, Fleiner J, Rau J, Ratka-Krüger P, Hannig C. Accuracy and Usefulness of CBCT in Periodontology: A Systematic Review of the Literature. Int J Periodontics Restorative Dent. 2018 Mar/Apr;38(2):289–97.

10. Walter C, Schmidt JC, Dula K, Sculean A. Cone beam computed tomography (CBCT) for diagnosis and treatment planning in periodontology: A systematic review. Quintessence Int. 2016
11. Vandenberghe B, Jacobs R, Yang J. Diagnostic validity (or acuity) of 2D CCD versus 3D CBCT-images for assessing periodontal breakdown. Oral Surg Oral Med Oral Pathol Oral Radiol Endod. 2007 Sep;104(3):395–401.

12. Vandenberghe B, Jacobs R, Yang J. Detection of periodontal bone loss using digital intraoral and cone beam computed tomography images: an in vitro assessment of bony and/or infrabony defects. Dentomaxillofac Radiol. 2008 Jul;37(5):252–60.

13. Grimard BA, Hoidal MJ, Mills MP, Mellonig JT, Nummikoski PV, Mealey BL. Comparison of clinical, periapical radiograph, and cone-beam volume tomography measurement techniques for assessing bone level changes following regenerative periodontal therapy. J Periodontol. 2009 Jan;80(1):48–55.

14. de Faria Vasconcelos K, Evangelista KM, Rodrigues CD, Estrela C, de Sousa TO, Silva MA. Detection of periodontal bone loss using cone beam CT and intraoral radiography. Dentomaxillofac Radiol. 2012 Jan;41(1):64–9.

15. Bagis N, Kolsuz ME, Kursun S, Orhan K. Comparison of intraoral radiography and cone-beam computed tomography for the detection of periodontal defects: an in vitro study. BMC Oral Health. 2015 May;28:15:64.

16. Cetmili H, Tassoker M, Sener S. Comparison of cone-beam computed tomography with bitewing radiography for detection of periodontal bone loss and assessment of effects of different voxel resolutions: an in vitro study. Oral Radiol. 2019 May;35(2):177–83.

17. Mandelaris GA, Scheyer ET, Evans M, Kim D, McAllister B, Nevins ML, Rios HF, Sarment D. American Academy of Periodontology Best Evidence Consensus Statement on Selected Oral Applications for Cone-Beam Computed Tomography. J Periodontol. 2017 Oct;88(10):939–45.

18. Queiroz PM, Santaella GM, Groppo FC, Freitas DQ. Metal artifact production and reduction in CBCT with different numbers of basis images. Imaging Sci Dent. 2018 Mar;48(1):41–4.

19. Harrel SK. A minimally invasive surgical approach for periodontal regeneration: surgical technique and observations. J Periodontol. 1999 Dec;70(12):1547–57.

20. Cortellini P, Tonetti MS. A minimally invasive surgical technique with an enamel matrix derivative in the regenerative treatment of intra-bony defects: a novel approach to limit morbidity. J Clin Periodontol. 2007 Jan;34(1):87–93.

21. Cortellini P, Tonetti MS. Improved wound stability with a modified minimally invasive surgical technique in the regenerative treatment of isolated interdental intrabony defects. J Clin Periodontol. 2009 Feb;36(2):157–63.

22. Trombelli L, Farina R, Franceschetti G, Calura G. Single-flap approach with buccal access in periodontal reconstructive procedures. J Periodontol. 2009 Feb;80(2):353–60.

23. Aslan S, Buduneli N, Cortellini P. Entire Papilla Preservation Technique: A Novel Surgical Approach for Regenerative Treatment of Deep and Wide Intrabony Defects. Int J Periodontics Restorative Dent. 2017 Mar/Apr;37(2):227–33.
24. Chiu HC, Shen EC, Lin SJ, Susin C, Wikesjö UM, Fu E. Periodontal repair in dogs: space-provision supports alveolar bone and cementum formation. J Clin Periodontol. 2013 Apr;40(4):358–63.
25. Schincaglia GP, Hebert E, Farina R, Simonelli A, Trombelli L. Single versus double flap approach in periodontal regenerative treatment. J Clin Periodontol. 2015 Jun;42(6):557–66.
26. Azuma H, Kono T, Morita H, Tsumori N, Miki H, Shiomi K, Umeda M. Single Flap Periodontal Surgery Induces Early Fibrous Tissue Generation by Wound Stabilization. J Hard Tissue Biol. 2017;26(2):119–26.
27. Cortellini P, Pini Prato G, Tonetti MS. Periodontal regeneration of human infrabony defects. II. Re-entry procedures and bone measures. J Periodontol. 1993 Apr;64(4):261–8.
28. Rasperini G, Pilipchuk SP, Flanagan CL, Park CH, Pagni G, Hollister SJ. Giannobile WV. 3D-printed Bioreorbable Scaffold for Periodontal Repair. J Dent Res. 2015 Sep;94(9 Suppl):153S-7S.
29. Lei L, Yu Y, Ke T, Sun W, Chen L. The Application of Three-DimensionalPrinting Model and Platelet-Rich Fibrin Technology in Guided Tissue Regeneration Surgery for Severe Bone Defects. J Oral Implantol. 2019 Feb;45(1):35–43.
30. Pellegrino G, Mangano C, Mangano R, Ferri A, Taraschi V, Marchetti C. Augmented reality for dental implantology: a pilot clinical report of two cases. BMC Oral Health. 2019 Jul 19;19(1):158.

Figures
**Figure 1**

Visualization of periodontal defects on IRs and CBCT. 1a: Midpalatal defect of tooth 11 1b: Complex periodontal defect involving teeth 24, 25, and 26, with questionable prognosis
Figure 2

Regions of interest highlighted on CBCT datasets. ROI 1: alveolar bone, ROI 2: teeth
Figure 3

Anatomical, 3D digital model of periodontal defects, that aid the decision-making process prior to surgery. Horizonto-vertical defect at the palatal aspect of tooth 11, deep intrabony component at the mesial aspect, shallower towards the distal aspect, when eventually transitioning into the horizontal slope at the position of tooth 12.
Figure 4

Soft tissue model from intraoral, hard tissue model from CBCT Circumdental crater around tooth 24 and 25, Class III furcation involvement of tooth 26, soft tissue model derived from an intraoral scan superimposed over the segmented model derived from CBCT dataset
Figure 5

Regenerative periodontal surgery. 5a: Palatal single flap approach 5b: Volume stable collagen matrix (Fibroguide®) 5c: Enamel matrix derivatives placed into the defect 5d-e: Collagen matrix placed into the defect 5f: Double layer wound closure

Figure 6

Comparing intrasurgical measurements with digital measurements. 6a: Intrasurgical measurement 6b: Digital measurement