

Mancini Leonardo (Orcid ID: 0000-0002-7030-155X)
Pirc Miha (Orcid ID: 0000-0003-0831-8905)
MARCHETTI ENRICO (Orcid ID: 0000-0001-6461-7876)
Tavelli Lorenzo (Orcid ID: 0000-0003-4864-3964)
Thoma Daniel S (Orcid ID: 0000-0002-1764-7447)

3D surface defect map for assessing buccolingual profile of single tooth gaps following alveolar ridge preservation.

Leonardo Mancini^{1,2,3}, Shayan Barootchi^{3,4,5*}, Miha Pirc^{1*}, Enrico Marchetti², Ronald E. Jung¹, Lorenzo Tavelli^{3,4}, Daniel S. Thoma¹

¹ Clinic of Reconstructive Dentistry, Center of Dental Medicine, University of Zurich, Zurich, Switzerland.

² Department of Life, Health and Environmental Sciences, University of L'Aquila, L'Aquila, Italy.

³ Center for Clinical Research and evidence synthesis in oral Tissue Regeneration (CRITERION), Ann Arbor, MI, USA and Boston, MA, USA.

⁴ Department of Oral Medicine, Infection, and Immunity, Division of Periodontology, Harvard School of Dental Medicine, Boston, Massachusetts, USA.

⁵ Department of Periodontics and Oral Medicine, University of Michigan School of Dentistry, Ann Arbor, Michigan, USA.

*Shayan Barootchi and Miha Pirc contributed equally to the manuscript and share second author position.

Corresponding author: Leonardo Mancini

Clinic of Reconstructive Dentistry, Center of Dental Medicine, University of Zurich, Zurich, Switzerland.

Address: Center of Dental Medicine, University of Zürich, Plattenstrasse 11 CH-8032 Zürich, Switzerland

Tel: +41 44 634 04 04

E-mail address: mancinileonardo94@gmail.com

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Abstract:

Aim: A new, non-invasive approach suggests using single intraoral optical scanning to analyze the ridge profile of single-tooth gaps following alveolar ridge preservation in the absence of a baseline scan. This method involves creating a three-dimensional (3D) surface map to identify and assess contour changes and ridge profile based on the adjacent teeth.

Materials and methods: The present study was designed as a cross-sectional pilot analysis on a convenience sample of patients undergoing alveolar ridge preservation. Intraoral optical scans were taken on 23 patients, capturing data from 30 edentulous sites. The digital models were then imported into an image analysis software for a 3D surface defect map analysis performed by one examiner. This analysis characterized the buccolingual profile of the single tooth gap relative to the adjacent teeth. Ten linear divergence points, spaced 0.5mm apart in a corono-apical direction, were identified at the midfacial aspect of the sites. Based on these points the sites were plotted and grouped in three different buccolingual profiles (linear, concave and convex). Clinical parameters including Keratinized mucosa Width (KMW), and soft tissue phenotype with Colorvue biotype probes were also recorded.

Results: Three different buccolingual patterns (linear, convex, and concave) were identified. Seven sites exhibited a linear profile, 10 sites displayed a concave shape, and 13 showed a convex profile. The linear profile had surface discrepancies similar to the neighboring teeth. In contrast, the convex profile revealed mid-buccal discrepancy localized only at the crestal aspect, while the concave had an extended divergence ranging from 1mm to 5mm below the soft tissue margin. Univariate and multiple logistic regression analyses did not reveal any statistically significant variables influencing profilometric analysis; however, when combining phenotype and KMW, thick phenotypes demonstrated a higher proportion of concavity (OR=4.83) compared to thin ones, suggesting a significant trend. With every 1 mm of increase in KMW, the probability of showing a concavity decreased ($p=0.057$).

Conclusion:

A three-dimensional (3D) surface defect map represents a useful tool for objectively quantifying ridge defects and profiles by assessing profilometric and surface differences compared to adjacent dentition using a single intraoral scan. This method also indicates that keratinized mucosa width may play a critical role in preventing concavity defects. The 3D defect map can guide decision-making during soft tissue augmentation procedures by emphasizing the specific location of the defect and providing more detailed insights into its localization. These parameters can enable the tailoring of flap management and soft tissue grafting strategies to address the patient's individual needs.

Summary box:

What is known?

- Soft tissue augmentation is becoming an important aspect of implant rehabilitation treatment. Studies have demonstrated how it can enhance long-term results, including patient-reported outcomes.
- Tailoring and standardizing surgical approaches is recommended to minimize invasiveness and offer patients effective, suitable treatment options.
- The application of 3D analysis has become a prevalent method for assessing procedures in periodontology and implantology. Nevertheless, it consistently necessitates baseline data to achieve overlap of the models and assess alterations. In scenarios where initial data is unavailable, it is feasible to utilize nearby teeth as clinical benchmarks to delineate the defect and determine contour values at the edentulous gap.

What this study adds?

- A 3D surface defect map, generated from a single STL file of the affected area, can effectively help clinicians highlight and analyze the defect's depth and location even when baseline data (STL and CBCT) from the extraction site are not available.
- Following alveolar ridge preservation, three different patterns were noted. Profilometric analysis can be utilized to describe the profile of the defect and plan a proper flap design and soft tissue grafting/ guided bone regeneration procedures, taking into consideration possible irregularities of the surface and expected tension points.
- Keratinized mucosa width might be a protective factor for concavity profiles.

Introduction:

The process of tooth extraction triggers a series of changes in the oral tissues, affecting both the hard and soft tissue structure¹. One of the most significant outcomes is the inevitable loss of alveolar bone and soft tissue volume at the extraction site^{2,3}. If these changes are not addressed, they can create substantial difficulties for subsequent dental implant placement and impact the overall aesthetic and functional results of restorative dentistry^{4,5}.

After tooth extraction, socket resorption occurs because of remodeling and resorption in the surrounding alveolar bone^{2,6}. This typically leads to a decrease in both horizontal and vertical dimensions of the alveolar ridge, resulting in insufficient bone volume and altered soft tissue contours^{7,8}. The reduction in bone and soft tissue volume can exacerbate aesthetic concerns further, making prosthetic rehabilitation more complex when dealing with edentulous space. A recent systematic review showed that the magnitude of bone resorption is around 3.79 ± 0.23 mm on the horizontal aspect while for the vertical component, a reduction of 1.24 ± 0.11 mm could be expected at 6 months after extraction, whereas when focusing on the soft tissue changes there is an interesting gain of soft tissue thickness that is estimated between the 0.4 and 0.5 mm⁹.

Soft tissue remodeling plays a critical role in post-extraction healing by significantly contributing to stability and appearance within peri-implant tissues^{10,11}. However, spontaneous healing (SH) following tooth extraction is often unpredictable which may cause irregularities or inadequate tissue volume leading to challenges for implant placement that could compromise long-term esthetic integration and treatment^{12,13}. According to a recent randomized clinical trial, the use of alveolar ridge preservation (ARP) showed significantly higher soft tissue thickness 3.00 mm and fewer invaginations of the soft tissues compared to SH 1.5 mm⁸. However, when focusing on the implant placement time point in both cases further soft tissue augmentation (STA) or guided bone regeneration (GBR) was required to improve and facilitate the prosthetic component¹².

Soft tissue augmentation techniques have become crucial in contemporary implant dentistry to address the challenges of post-extraction alveolar ridge resorption and soft tissue remodeling¹⁴⁻¹⁶. These techniques aim to restore and enhance the volume, contour, and quality of peri-implant tissues, creating an optimal environment for successful implant placement and prosthetic rehabilitation¹⁷⁻¹⁹. By addressing volume deficiencies and optimizing soft tissue contours, these procedures facilitate the achievement of natural-looking aesthetic outcomes.

Several methods evaluate buccal bone thickness, bone gain, and keratinized tissue thickness objectively^{9,20,21}. However, the description of the edentulous site and profilometric analysis of the soft tissue in that region have not yet been discussed in the literature. With the introduction of minimally invasive concepts today, there is increasing interest in using alternative methods for addressing volume discrepancies, implant positions, and soft tissue thickness^{22,23}.

The use of 3D analysis has revolutionized various areas of dentistry, especially in assessing and treating changes in the alveolar bone and soft tissue after tooth extraction^{6,14,24,25}. Traditional methods for evaluating post-extraction volume deficiency usually rely on two-dimensional radiographic imaging, which may provide limited information and miss the intricacies of three-dimensional changes^{6,21,24}. In contrast, 3D analysis techniques

offer enhanced accuracy, precision, and comprehensive evaluation of alveolar bone and soft tissue morphology.

Cone beam computed tomography imaging is commonly used for 3D analysis in post-extraction volume deficiency assessment ²⁶⁻²⁸. It provides high-resolution, detailed images of the alveolar ridge, facilitating bone morphology, density, and volume evaluation. By delineating extraction socket and surrounding bone boundaries precisely, CBCT enables accurate measurement of volume loss and identification of potential areas for bone resorption or remodeling ²⁶. Precise mapping of the dimensions and contours of the extraction site using 3D analysis empowers clinicians to design customized treatment strategies tailored to each patient's anatomical characteristics. However, increased invasiveness and costs need to be considered when performing this type of analysis ^{29,30}.

In addition to evaluating bone volume deficiency, 3D analysis can also assess soft tissue contours and dynamics after tooth extraction ^{15,20,23,31-35}. Surface scanning technologies such as intraoral scanners and digital impression systems capture detailed three-dimensional images of the soft tissue architecture. These images allow for precise tailoring of soft tissue augmentation techniques to complement bone grafting procedures and optimize the aesthetic integration of dental implants within the surrounding oral environment ³⁵. Moreover, sequential 3D analysis enables clinicians to longitudinally monitor post-treatment changes, evaluate treatment outcomes, and refine therapeutic approaches as needed while maintaining a minimally invasive concept ³⁶⁻³⁸.

This cross-sectional pilot study employed a three-dimensional surface mapping technique to identify and evaluate ridge variations and profilometric patterns, which were subsequently correlated with relevant clinical characteristics, such as tissue phenotype and keratinized mucosa width (KMW). This approach may offer insights into the potential profilometric discrepancies that can arise following alveolar ridge preservation procedures, utilizing a novel 3D analytical tool and a single intraoral scan without the need for superimposition methods.

Material and methods

Study design and participants.

The present study was designed as a cross-sectional pilot analysis on a convenience sample of patients undergoing alveolar ridge preservation. Subjects with at least one single tooth gap undergoing ARP were identified and invited to participate. The rationale for inviting patients with single tooth gaps was to minimize the influence of soft tissue shrinkage due to multiple teeth extractions. The study aimed to describe and analyze the buccolingual profile of the ridge in single tooth gaps using a novel digital method in relation to the neighboring teeth.

After obtaining an informed consent, patients were recruited, and intraoral optical scans were performed 4 months after ARP. The study protocol adhered to the Declaration of Helsinki of 1975, as revised in Fortaleza in 2013, and was approved by the Institutional Review Board of the University of L'Aquila (N.20/2021).

The inclusion criteria were: i) systemically and periodontally healthy subjects, ii) having at least one single tooth gap and undergoing ARP iii) buccal bone wall $\geq 50\%$ iv) tooth-bound extraction sites v) patient receiving standardized ARP procedure with deproteinized bovine bone mineral with 10% collagen (Geistlich Bio-Oss Collagen; Geistlich Pharma AG, Wolhusen, Switzerland) and collagen membrane (Geistlich Bio-Gide, Geistlich Pharma AG, Wolhusen, Switzerland)

Exclusion criteria: i) extended edentulous sites, ii) absence of a mesial or distal natural tooth; iii) ARP in conjunction with soft tissue augmentation iv) smokers.

Clinical Measurements

For each edentulous site, the following clinical parameters related to the soft tissues were evaluated:

- Soft tissue phenotype was screened, in thin ($<0.5\text{mm}$) moderate ($0.5\text{--}0.8\text{mm}$), and thick ($>0.8\text{mm}$) groups using a Colorvue biotype probes on the adjacent teeth ³⁹.
- Keratinized tissue width: Corono-apical width/height measured from the soft tissue margin to the mucogingival junction at the mid-facial aspect with a periodontal probe (PC NC15; HuFriedy;USA) after stretching the mucosa several times.

Intraoral scanning and STL file acquisition

The site of interest (figure 1A), together with their whole arch, were scanned with an intraoral optical scanner (Trios, 3Shape, Denmark). The generated digital models were exported and saved as STL files. Then, the digital files were imported into an image analysis software (GOM Inspect, GOM, Germany) (Figure. 1B) where an examiner with extensive expertise in 3D volumetric assessment (L.M.) performed the 3D surface defect map analysis.

3D surface defect map

A plane was designed to pass through the midfacial aspect of the edentulous ridge. Then, two planes were created for the midfacial aspect of the two adjacent teeth, parallel to the previously designed plan (Figure. 1C). A horizontal cutting plane, perpendicular to the vertical planes identified on the midfacial aspect of the gingival margin of adjacent teeth, was traced to define the direction of a cutting section (Figure. 1D-E). A region of interest (ROI) based on the vertical planes of the adjacent teeth, encompassing the mesial and distal papillae of the edentulous site was drawn. Subsequently, an automated function within image analysis software was used to generate a surface defect map (Figure. 1F). The 3D surface defect map allowed visualization of all points within these planes and quantified their divergence inside or outside from a horizontal cutting plan perpendicular to those vertical lines (more lingual/palatal or more buccal) at this region (Figure. 1G-H).

To report the outcomes of interest from the 3D surface defect map, 10 linear divergence points (LDPs) on the vertical plane designed at the midfacial aspect of the edentulous ridge were identified (Figure.2). These points started from the soft tissue margin and extended 0.5 mm apart in a corona-apical direction. Positive values of LDPs indicated that

the soft tissues were positioned more buccally ("outside") compared to the parallel point of the adjacent dentition profiles, while negative LDPs denoted that soft tissues were located more lingually/palatally ("inside") than the adjacent teeth profile. We recorded ten LDPs for each edentulous site and plotted them to explore possible patterns describing the bucco-lingual position of soft tissues relative to adjacent dentition profiles. Then, we grouped sites based on their pattern of 3D surface defect map and LDP outcomes. The method was previously described ³³.

Statistical Analysis

Categorical variables were reported in absolute and relative frequencies and continuous variables in means, standard deviation (SD), medians and interquartile range (IQR). Regarding the inferential analysis: The variable profile (measured in ordinal scale) was associated with independent factors and covariates using simple ordinal logistic regression. Raw odds ratio and 95% confidence intervals were obtained from the Wald's Chi² statistic. Then, a multiple model was estimated to adjust by potential confounding factors. A test of parallel lines was conducted in order to assure the hypothesis of proportional odds, the significance level used in the analysis has been 5% ($\alpha=0.05$). The analyses were conducted by an author with extensive expertise in statistics (SB) using the R software package (Version 1.3.959, Rstudio, Boston, MA, USA).

Results

A total of 27 patients with a mean age of 56.03 ± 12.05 were included, among which 16 were male and 11 were female (supplementary table 1). A total of 30 edentulous sites were screened and analyzed, with 13 in the mandible and 17 in the maxilla as detailed in Table 1. The phenotypes observed were thin in 9 patients, moderate in 9, and thick in 12. The keratinized mucosa width was measured at an average of 2.22 ± 0.79 mm overall, with values for the mandible at 1.66 ± 0.62 mm and for the maxilla at 2.66 ± 0.59 mm). When the LDPs were plotted, three different patterns were observed:

	Total	Maxilla	Mandible
<i>Patient (n.)</i>	27	16	11
<i>Age</i>	56.03 ± 12.05	54 ± 12.52	59 ± 10.03
<i>Sex (n.)</i>	Male 16	10	6
	Female 11	6	5
<i>Site (n.)</i>	Anterior 13	9	4
	Posterior 17	8	9
<i>Phenotype (n.)</i>	Thin <0.5mm	6	3
	Moderate $0.5 < 0.8$ mm	4	5
	Thick >0.8mm	7	5
<i>KMW (mm)</i>	2.22 ± 0.79 mm	2.66 ± 0.59 mm	1.66 ± 0.62 mm

Table 1. Overall data regarding included patients, sites, and clinical parameters related to the soft tissue, phenotype and keratinized mucosa width (KMW).

seven sites (4 mandible;3 maxilla) showed a linear progression pattern (R^2 of the linear functions ranging between 0.76 and 0.96), 10 sites (4 mandible, 6 maxilla) showed a concave progression pattern (R^2 of the linear functions ranging between 0.11 and 0.96) while 13 sites (5 mandible, 8 maxilla) showed a convex pattern (R^2 of the linear functions ranging between 0.48 and 0.95). Table 2 depicts the mean LDPs for the three identified groups. The linear profile showed a constant surface discrepancy similar to the adjacent teeth Regarding the convex profile the surface map revealed a discrepancy localized to the first 2mm mid-buccal (4 points from the LDPs) while the concave had a reduced soft tissue divergence localized from the 1mm to 5mm below the soft tissue margin (Figure 3).

LDP	Mean $\pm$ SD, mm		
	Linear Pattern (n=7)	Concave Pattern (n=10)	Convex Pattern (n=13)
LDP1	-0.32 $\pm$ 0.32	-0.66 $\pm$ 0.25	-0.52 $\pm$ 0.40
LDP2	-0.29 $\pm$ 0.48	-0.75 $\pm$ 0.34	-0.34 $\pm$ 0.35
LDP3	-0.36 $\pm$ 0.54	-0.71 $\pm$ 0.32	-0.30 $\pm$ 0.35
LDP4	-0.26 $\pm$ 0.35	-0.69 $\pm$ 0.26	-0.23 $\pm$ 0.25
LDP5	-0.32 $\pm$ 0.23	-0.56 $\pm$ 0.19	-0.08 $\pm$ 0.22
LDP6	-0.23 $\pm$ 0.14	-0.55 $\pm$ 0.16	-0.07 $\pm$ 0.18
LDP7	-0.17 $\pm$ 0.13	-0.48 $\pm$ 0.12	-0.07 $\pm$ 0.17
LDP8	-0.12 $\pm$ 0.09	-0.44 $\pm$ 0.11	-0.11 $\pm$ 0.14
LDP9	-0.08 $\pm$ 0.08	-0.19 $\pm$ 0.11	-0.15 $\pm$ 0.11
LDP10	-0.05 $\pm$ 0.08	-0.07 $\pm$ 0.11	-0.10 $\pm$ 0.11

Table 2. linear divergence points for each pattern. Every two points represent 1mm.

Simple ordinal logistic regression analysis revealed no statistically significant variables influencing the profilometric analysis, as presented in (Table 3). The likelihood of a higher concavity compared to a thin phenotype was not impacted by the moderate phenotype (OR=1.00; $p=1.000$). Nevertheless, it is noteworthy that thicker phenotype led to an increased proportion of concavity with an odds ratio of 3.62 (>1), although statistical significance was not attained ($p=0.132$).

In terms of KMW, for every additional 1mm of KMW, the probability of concavity in higher categories decreased by -45%. Once again, statistical significance was not observed ($p=0.133$).

When a combined model involving both Phenotype and KMW was used, findings showed no significant results (supplementary table 2), the strength of connections was more noticeable than in previous unadjusted models. Thick phenotypes were associated with increased proportions of concavity (OR=4.83) compared to thin ones ($p=0.083$), indicating a notable trend. For every 1mm increase in KMW, the likelihood of concavity (higher categories) decreased by 57%, approaching statistical significance ($p=0.057$). The hypothesis of proportional odds was accepted ($p=0.997$) and (Figure 4) represents each category's estimated probability according to KMW and phenotype. probability of concave

reduced when KMW increased. On the contrary, probability of convex increased when KMW increased. Moreover, probability of concave was somehow higher in the thick group compared to thin/moderate.

	OR	95% CI	p-value
PHENOTYPE			0.191
Thin	1		
Moderate	1.00	0.17 – 5.93	1.000
Thick	3.62	0.68 – 19.3	0.132
KMW	0.55	0.25 – 1.20	0.133
AGE	1.04	0.98 – 1.10	0.236
GENDER			
Male	1		
Female	1.02	0.26 – 4.04	0.981
TOOTH TYPE			0.278
Incisor	1		
Canine	2.81	0.30 – 26.0	0.364
Premolar	7.13	0.94 – 54.1	0.058
Molar	4.14	0.59 – 28.9	0.152
JAW			
Maxilla	1		
Mandible	1.11	0.29 – 4.26	0.874

Table 3. Defect's profile by independent factors and covariates. Results of simple ordinal logistic regression (OR and 95%CI, p-value), There were not found significant variables influencing on defect's profile. *p<0.05.

Discussion

The current study on the analysis of soft tissue deficiencies at single tooth gaps primarily revealed:

- The 3D surface defect map on single STL is a valuable method for localizing and quantifying ridge deficiencies following ARP when baseline information is missing.
- Following ARP, three different profilometric healing patterns can be expected (linear, concave and convex).
- The increase in KMW reduced the probability of a concave profile (p=0.057).

The field of dentistry has been significantly influenced by technological advancements, and one notable innovation in the past ten years is the emergence of intraoral optical scanning. These scanners were initially created to replace traditional impressions by capturing digital images of teeth, implants, and surrounding soft tissue, which are then saved as STL files^{27,40}. Ongoing developments in both the technology and its related software have allowed clinicians to use these scanners for evaluating volumetric changes in different clinical situations^{31,32,34,40}. Nevertheless, this process requires multiple scans of the same area to overlay the STL files and analyze changes using imaging software. The authors in the current study detailed how they utilized intraoral optical scanning to analyze the soft tissue profile of edentulous ridges and examine surface defects through 3D surface defect map analysis at a single time point. The proposed approach offers several advantages, including noninvasiveness of optical scanning, rapid data acquisition, and high patient acceptance and comfort levels. Furthermore, the authors demonstrated the ability to objectively visualize and define profiles deficiencies.

It is reasonable to consider that this factor could also influence the healing process and surgical outcomes of grafting procedures. In periodontal and peri-implants plastic surgery the recipient site anatomy is one of the factors that affects the stability of the graft and flap design⁴¹⁻⁴⁴. It can be postulated that the ridge profile may play a critical role in soft tissue augmentation during the grafting procedure and flap design phase. It is hypothesized that grafts and flaps placed closer to the tongue/roof of the mouth in relation to the horizontal plane of the ridge may receive a more substantial blood supply during healing compared to those positioned nearer to the cheek side; however, further research is needed to validate this assertion. The 3D surface defect maps revealed three distinct patterns in this group of patients. It is important to note that 3D scanners only capture the profile of the alveolar ridge STL without distinguishing between bone and soft tissue. Despite being a limitation, the selection of patients who underwent previous alveolar ridge preservation helped minimize potential confounding factors in this study. In line with previous studies on soft tissue remodeling after alveolar ridge preservation⁴⁵.

As supported by existing literature, only when combining STL files with CBCT data it is able to clearly delineate different tissues and their involvement in the defects⁴⁶. The 3D surface defect map can be utilized to assess defect extent, anatomy, and grafting site. For instance, deficiencies limited to the first millimeter of the crest should be managed differently from an extensive defect. It is also essential to emphasize that this method enables clinicians not just to locate but also determine a depth for each defect which may impact treatment planning and guide surgeons towards either a substitute or connective tissue graft⁴⁷. As denoted in the results a single tooth gap after ridge preservation might require a graft (concave profile) localized between the 1 and the 5mm from the crest or in case of a linear/convex profile the edentulous ridge may not need any type of correction.

A 3D map shows surface defects related to flap preparation/elevation. Color codes make it easier to identify changes in tissue, indicating bone irregularities, papilla invagination, or exostoses near neighboring teeth⁴⁰. These observations highlight the challenges of flap elevation and the increased risk of soft tissue damage or compression^{48,49}. It could be suggested that a convex profile necessitates a more extensive flap design and releasing incisions, as opposed to a concave profile where the surface lies between the adjacent teeth, reducing tension during flap elevation but future studies are needed to validate this assumption^{48,49}.

Preoperative 3D surface defect mapping is a valuable tool in clinical research for studying the impact of various biomaterials and flap approaches around edentulous sites, teeth, and implants. Factors such as the alveolar ridge profile at the site of interest and the buccolingual position of soft tissues should be considered in stratified randomization and statistical analysis from a methodological standpoint. The tool provides quick visualization of divergence profiles at the area of interest compared to adjacent regions, with data reported using different outcome measures such as linear points and volumetric data.

The potential impact of using this tool in the scientific field is demonstrated in this study, indicating that KMW may contribute to preventing concave defects and minimizing tissue remodeling. While there are numerous studies discussing how different phenotypes could result in varying healing and remodeling patterns, limited data exists on the extent of KMW. Over the past 20 years, the role of KM around teeth and implants has been a widely debated topic, highlighting its crucial role for long-term follow-up care for both teeth (root coverage procedures) and implants (as a protective factor against peri-implantitis development)^{18,50,51}. Data on the role of KMW in ridge preservation are scarce, but it is

well-known that thickness plays a significant role during the remodeling phase⁹. This particular study revealed that with each millimeter increase, there was a 57% reduction in the probability of developing a concave profile. Thus, it can be inferred that sites with extensive keratinized mucosa exhibit less remodelling after alveolar ridge preservation, potentially reducing the phenotype's impact during this phase.

When analyzing the findings of this research, it is crucial to take into account certain limitations such as the lack of data on bone position and bone thickness, the small sample size, and the inclusion of both single and multirooted teeth in the assessment. Nevertheless, the 3D surface defect map appears to be a promising tool for integration into everyday clinical practice and for use in future randomized clinical trials.

Conclusion

A 3D surface defect map generated from a single intraoral scan can be a valuable tool for objectively quantifying and evaluating profilometric and surface differences compared to adjacent teeth. By providing detailed insights into the precise location and depth of the defects, the 3D defect map could guide clinicians in decision-making during soft tissue augmentation procedures. These data-driven inputs may enable the implementation of tailored flap management and soft tissue grafting strategies, addressing the specific needs of each patient more effectively. However, given the limitations of this study, further clinical investigations leveraging this tool and correlating it with the type of implant placement and soft tissue augmentation procedures are needed.

References:

1. Tonetti MS, Steffen P, Muller-Campanile V, Suvan J, Lang NP. Initial extractions and tooth loss during supportive care in a periodontal population seeking comprehensive care. *J Clin Periodontol*. 2000;27(11):824-831.
2. Araujo MG, Lindhe J. Ridge alterations following tooth extraction with and without flap elevation: an experimental study in the dog. *Clin Oral Implants Res*. 2009;20(6):545-549.
3. Avila-Ortiz G, Elangovan S, Kramer KW, Blanchette D, Dawson DV. Effect of alveolar ridge preservation after tooth extraction: a systematic review and meta-analysis. *J Dent Res*. 2014;93(10):950-958.

4. Avila-Ortiz G, Gubler M, Romero-Bustillos M, Nicholas CL, Zimmerman MB, Barwacz CA. Efficacy of Alveolar Ridge Preservation: A Randomized Controlled Trial. *J Dent Res*. 2020;99(4):402-409.
5. Tonetti MS, Jung RE, Avila-Ortiz G, et al. Management of the extraction socket and timing of implant placement: Consensus report and clinical recommendations of group 3 of the XV European Workshop in Periodontology. *J Clin Periodontol*. 2019;46 Suppl 21:183-194.
6. Chappuis V, Engel O, Reyes M, Shahim K, Nolte LP, Buser D. Ridge alterations post-extraction in the esthetic zone: a 3D analysis with CBCT. *J Dent Res*. 2013;92(12 Suppl):195S-201S.
7. Barone A, Ricci M, Tonelli P, Santini S, Covani U. Tissue changes of extraction sockets in humans: a comparison of spontaneous healing vs. ridge preservation with secondary soft tissue healing. *Clin Oral Implants Res*. 2013;24(11):1231-1237.
8. Thoma DS, Bienz SP, Lim HC, Lee WZ, Hammerle CHF, Jung RE. Explorative randomized controlled study comparing soft tissue thickness, contour changes, and soft tissue handling of two ridge preservation techniques and spontaneous healing two months after tooth extraction. *Clin Oral Implants Res*. 2020;31(6):565-574.
9. Tan WL, Wong TL, Wong MC, Lang NP. A systematic review of post-extraction alveolar hard and soft tissue dimensional changes in humans. *Clin Oral Implants Res*. 2012;23 Suppl 5:1-21.
10. Cosyn J, Seyssens L, De Bruyckere T, et al. A multi-centre randomized controlled trial on alveolar ridge preservation with immediate or delayed implant placement: Need for soft-tissue augmentation. *J Clin Periodontol*. 2023.
11. Zuiderveld EG, Meijer HJA, Vissink A, Raghoobar GM. The influence of different soft-tissue grafting procedures at single implant placement on esthetics: A randomized controlled trial. *J Periodontol*. 2018;89(8):903-914.
12. Barootchi S, Tavelli L, Majzoub J, Stefanini M, Wang HL, Avila-Ortiz G. Alveolar ridge preservation: Complications and cost-effectiveness. *Periodontol 2000*. 2023;92(1):235-262.
13. Marconcini S, Giammarinaro E, Derchi G, Alfonsi F, Covani U, Barone A. Clinical outcomes of implants placed in ridge-preserved versus nonpreserved sites: A 4-year randomized clinical trial. *Clin Implant Dent Relat Res*. 2018;20(6):906-914.
14. Couso-Queiruga E, Garaicoa-Pazmino C, Fonseca M, Chappuis V, Gonzalez-Martin O, Avila-Ortiz G. Interproximal Soft Tissue Height Changes After Unassisted Socket Healing versus Alveolar Ridge Preservation Therapy. *Int J Periodontics Restorative Dent*. 2023.
15. Mancini L, Fratini A, Tarallo F, Americo LM, Marchetti E. 3D analysis at implant sites after soft tissue augmentation with two types of collagen matrices: a pilot study. *Plastic and Aesthetic Research*. 2021;8:26.
16. Mancini L, Simeone D, Roccuzzo A, Strauss FJ, Marchetti E. Timing of soft tissue augmentation around implants: A clinical review and decision tree. *Int J Oral Implantol (Berl)*. 2023;16(4):289-302.
17. Lim HC, Strauss FJ, Shin SI, Jung RE, Jung UW, Thoma DS. Augmentation of keratinized tissue using autogenous soft-tissue grafts and collagen-based soft-tissue substitutes at teeth and dental implants: Histological findings in a pilot pre-clinical study. *J Clin Periodontol*. 2024;51(5):665-677.
18. Mancini L, Strauss FJ, Lim HC, et al. Impact of keratinized mucosa on implant-health related parameters: A 10-year prospective re-analysis study. *Clin Implant Dent Relat Res*. 2024.
19. Seyssens L, Eghbali A, Christiaens V, De Bruyckere T, Doornewaard R, Cosyn J. A one-year prospective study on alveolar ridge preservation using collagen-enriched deproteinized bovine bone mineral and saddle connective tissue graft: A cone beam computed tomography analysis. *Clin Implant Dent Relat Res*. 2019;21(5):853-861.

20. Couso-Queiruga E, Weber HA, Garaicoa-Pazmino C, et al. Influence of healing time on the outcomes of alveolar ridge preservation using a collagenated bovine bone xenograft: A randomized clinical trial. *J Clin Periodontol*. 2023;50(2):132-146.
21. Jung RE, Philipp A, Annen BM, et al. Radiographic evaluation of different techniques for ridge preservation after tooth extraction: a randomized controlled clinical trial. *J Clin Periodontol*. 2013;40(1):90-98.
22. Saini RS, Bavabeedu SS, Quadri SA, et al. Impact of 3D imaging techniques and virtual patients on the accuracy of planning and surgical placement of dental implants: A systematic review. *Digit Health*. 2024;10:20552076241253550.
23. Tavelli L, Barootchi S, Vera Rodriguez M, et al. Early soft tissue changes following implant placement with or without soft tissue augmentation using a xenogeneic cross-link collagen scaffold: A volumetric comparative study. *J Esthet Restor Dent*. 2022;34(1):181-187.
24. Strauss FJ, Fukuba S, Naenni N, et al. Alveolar ridge changes 1-year after early implant placement, with or without alveolar ridge preservation at single-implant sites in the aesthetic region: A secondary analysis of radiographic and profilometric outcomes from a randomized controlled trial. *Clin Implant Dent Relat Res*. 2024;26(2):356-368.
25. Tavelli L, Majzoub J, Kauffmann F, et al. Coronally advanced flap versus tunnel technique for the treatment of peri-implant soft tissue dehiscences with the connective tissue graft: A randomized, controlled clinical trial. *J Clin Periodontol*. 2023;50(7):980-995.
26. Dos Santos JG, Oliveira Reis Durao AP, de Campos Felino AC, Casaleiro Lobo de Faria de Almeida RM. Analysis of the Buccal Bone Plate, Root Inclination and Alveolar Bone Dimensions in the Jawbone. A Descriptive Study Using Cone-Beam Computed Tomography. *J Oral Maxillofac Res*. 2019;10(2):e4.
27. Strauss FJ, Gil A, Smirani R, Rodriguez A, Jung R, Thoma D. The use of digital technologies in peri-implant soft tissue augmentation - A narrative review on planning, measurements, monitoring and aesthetics. *Clin Oral Implants Res*. 2024.
28. Tsigarida A, Toscano J, de Brito Bezerra B, et al. Buccal bone thickness of maxillary anterior teeth: A systematic review and meta-analysis. *J Clin Periodontol*. 2020;47(11):1326-1343.
29. Al-Okshi A, Lindh C, Sale H, Gunnarsson M, Rohlin M. Effective dose of cone beam CT (CBCT) of the facial skeleton: a systematic review. *Br J Radiol*. 2015;88(1045):20140658.
30. Schulze D, Heiland M, Thurmann H, Adam G. Radiation exposure during midfacial imaging using 4- and 16-slice computed tomography, cone beam computed tomography systems and conventional radiography. *Dentomaxillofac Radiol*. 2004;33(2):83-86.
31. Benic GI, Elmasry M, Hammerle CH. Novel digital imaging techniques to assess the outcome in oral rehabilitation with dental implants: a narrative review. *Clin Oral Implants Res*. 2015;26 Suppl 11:86-96.
32. Galarraga-Vinueza ME, Obreja K, Magini R, Sculean A, Sader R, Schwarz F. Volumetric assessment of tissue changes following combined surgical therapy of peri-implantitis: A pilot study. *J Clin Periodontol*. 2020;47(9):1159-1168.
33. Mancini L, Galarraga-Vinueza ME, Barootchi S, Tavelli L. 3D surface defect map for characterising the buccolingual profile of peri-implant tissues. *Int J Oral Implantol (Berl)*. 2023;16(2):105-113.
34. Parvini P, Galarraga-Vinueza ME, Obreja K, Magini RS, Sader R, Schwarz F. Prospective study assessing three-dimensional changes of mucosal healing following soft tissue augmentation using free gingival grafts. *J Periodontol*. 2021;92(3):400-408.
35. Tavelli L, Zucchelli G, Stefanini M, Rasperini G, Wang HL, Barootchi S. Vertical soft tissue augmentation to treat implant esthetic complications: A prospective clinical and volumetric case series. *Clin Implant Dent Relat Res*. 2023;25(2):204-214.

36. Limones A, Molinero-Mourelle P, Cakmak G, et al. Impact of the superimposition methods and the designated comparison area on accuracy analyses in dentate models. *J Dent*. 2024;145:104939.
37. Tomita Y, Uechi J, Konno M, Sasamoto S, Iijima M, Mizoguchi I. Accuracy of digital models generated by conventional impression/plaster-model methods and intraoral scanning. *Dent Mater J*. 2018;37(4):628-633.
38. Xue F, Zhang R, Cai Y, Zhang Y, Kang N, Luan Q. Three-dimensional quantitative measurement of buccal augmented tissue with modified coronally advanced tunnel technique and de-epithelialized gingival graft: a prospective case series. *BMC Oral Health*. 2021;21(1):157.
39. Nik-Azis NM, Razali M, Goh V, Ahmad Shuhaimi NN, Mohd Nazrin NAS. Assessment of gingival thickness in multi-ethnic subjects with different gingival pigmentation levels. *J Clin Periodontol*. 2023;50(1):80-89.
40. Tavelli L, Barootchi S, Majzoub J, Siqueira R, Mendonca G, Wang HL. Volumetric changes at implant sites: A systematic appraisal of traditional methods and optical scanning-based digital technologies. *J Clin Periodontol*. 2021;48(2):315-334.
41. Barootchi S, Mancini L, Heck T, et al. Reliability assessment of the classification for facial peri-implant soft tissue dehiscence/deficiencies (PSTDs): A multi-center inter-rater agreement study of different skill-level practitioners. *J Periodontol*. 2022;93(8):1173-1182.
42. Zucchelli G, Tavelli L, Barootchi S, Stefanini M, Wang HL, Cortellini P. Clinical Remarks on the Significance of Tooth Malposition and Papillae Dimension on the Prediction of Root Coverage. *Int J Periodontics Restorative Dent*. 2020;40(6):795-803.
43. Zucchelli G, Tavelli L, Stefanini M, et al. Classification of facial peri-implant soft tissue dehiscence/deficiencies at single implant sites in the esthetic zone. *J Periodontol*. 2019;90(10):1116-1124.
44. Zucchelli G, Testori T, De Sanctis M. Clinical and anatomical factors limiting treatment outcomes of gingival recession: a new method to predetermine the line of root coverage. *J Periodontol*. 2006;77(4):714-721.
45. Canullo L, Pesce P, Antonacci D, et al. Soft tissue dimensional changes after alveolar ridge preservation using different sealing materials: a systematic review and network meta-analysis. *Clin Oral Investig*. 2022;26(1):13-39.
46. Couso-Queiruga E, Tattan M, Ahmad U, Barwacz C, Gonzalez-Martin O, Avila-Ortiz G. Assessment of gingival thickness using digital file superimposition versus direct clinical measurements. *Clin Oral Investig*. 2021;25(4):2353-2361.
47. Tavelli L, Barootchi S, Avila-Ortiz G, Urban IA, Giannobile WV, Wang HL. Peri-implant soft tissue phenotype modification and its impact on peri-implant health: A systematic review and network meta-analysis. *J Periodontol*. 2021;92(1):21-44.
48. Bienz SP, Vaquette C, Ioannidis A, et al. Tissue integration and biodegradation of soft tissue substitutes with and without compression: an experimental study in the rat. *Clin Oral Investig*. 2023;27(1):313-328.
49. Chao YC, Chang PC, Fu JH, Wang HL, Chan HL. Surgical Site Assessment for Soft Tissue Management in Ridge Augmentation Procedures. *Int J Periodontics Restorative Dent*. 2015;35(5):e75-83.
50. Barootchi S, Tavelli L, Di Gianfilippo R, et al. Soft tissue phenotype modification predicts gingival margin long-term (10-year) stability: Longitudinal analysis of six randomized clinical trials. *J Clin Periodontol*. 2022;49(7):672-683.
51. Isler SC, Soysal F, Tunc S, Kaymaz Ö, Unsal B, Roccuzzo A. Impact of peri-implant keratinized mucosa width on the long-term reconstructive outcomes of peri-implantitis: A retrospective analysis with a follow-up up to 10 years. *Clin Implant Dent Relat Res*. Published online June 24, 2024. doi:10.1111/cid.13358.

Legend:

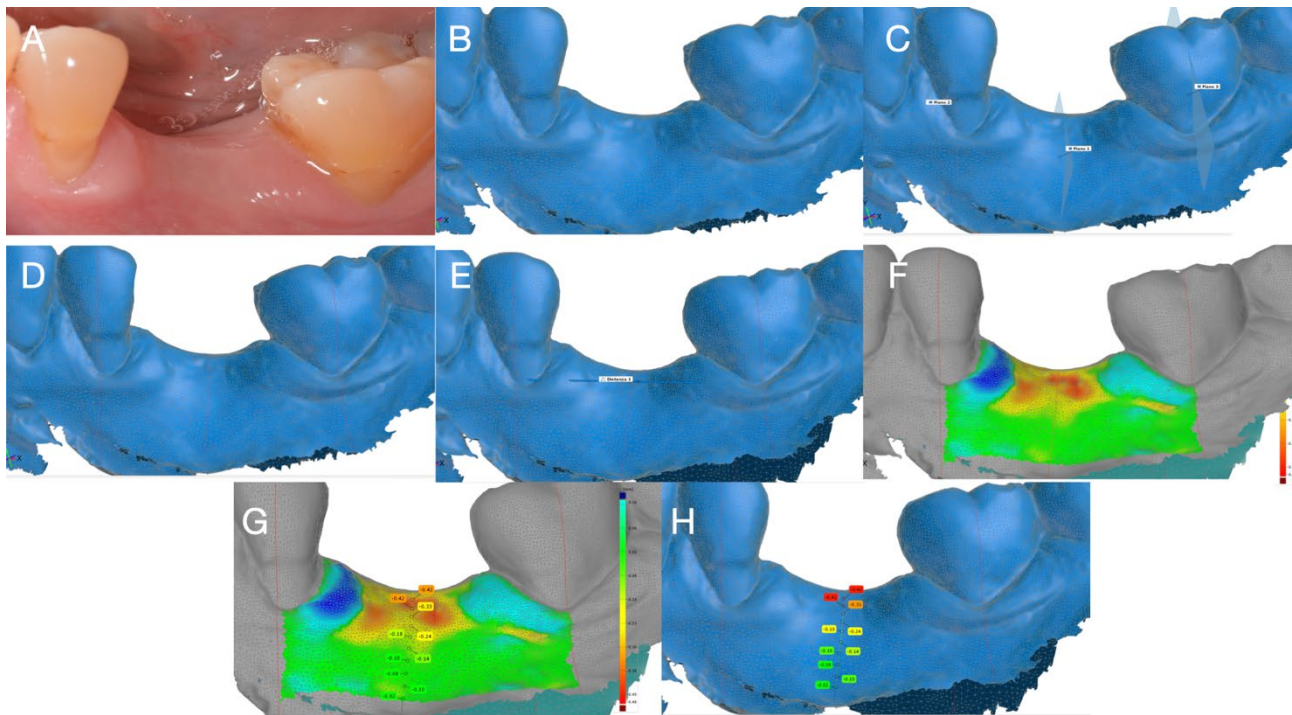


Figure 1 A-H. shows the creation of a 3D surface defect map around an edentulous site at the premolar region. **(A-B)** The clinical view and STL file are imported into the software. **(C-D)** Three vertical planes are defined at the midfacial aspect of the edentulous ridge and adjacent teeth. **(E)** A horizontal plane is created perpendicular to the vertical planes designed at the midfacial aspect of the adjacent teeth. **(F)** The 3D surface defect map is generated. **(G-H)** Ten linear divergence points on the midfacial aspect of the edentulous site representing volume differences compared to the previously traced horizontal plane are identified.

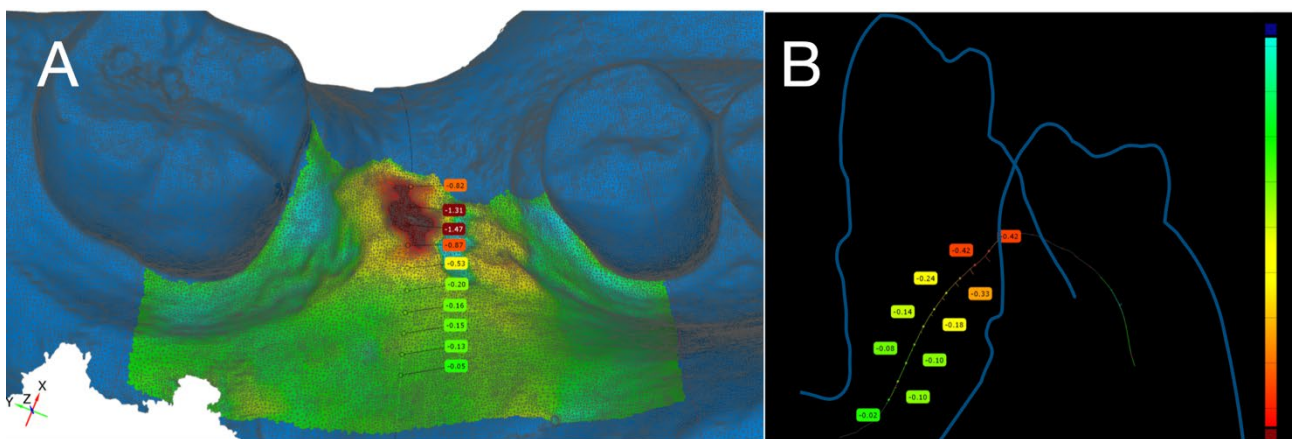


Figure 2. A) Identification and profilometric characterization of the 10 linear deviation points along the edentulous ridges. B) A discernible irregularity is observed within the initial 3 mm at the crestal aspect of the location in contrast to neighboring teeth.

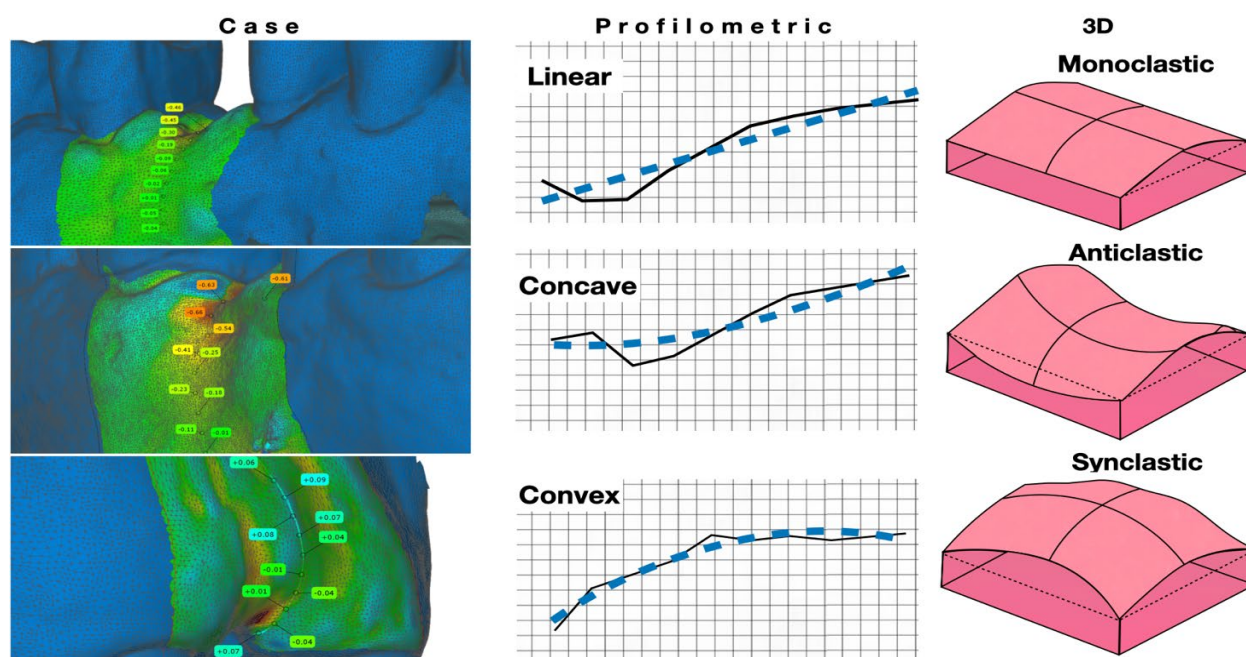


Figure 3. Schematic representation from the case overview to the profilometric analysis, including a 3D interpretation based on the surface curvature and color map. Monoclastic (or uniclasic) surfaces bend in only one direction at a time, while anticlastic surfaces have centers of curvature located on opposing sides. Synclastic curvatures have principal curvatures with the centers of curvature on the same side of the surface.

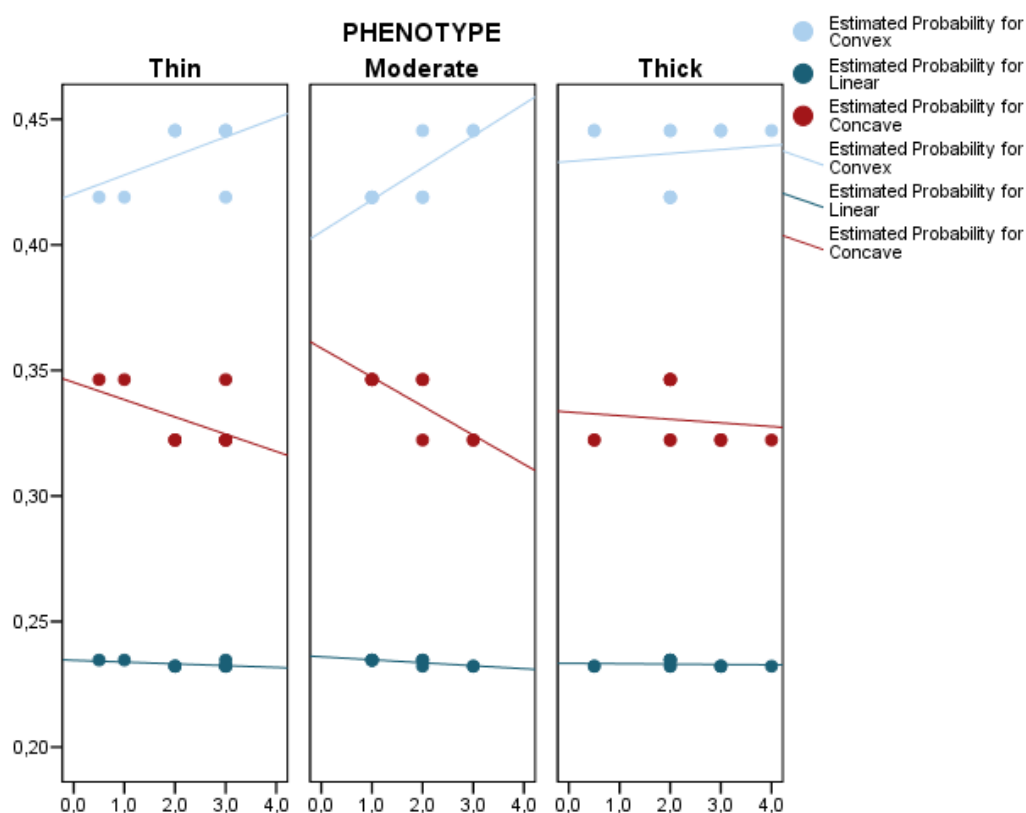


Figure 4. Graph representing the estimated probability of each category according to KMW and phenotype, it's noteworthy that as KMW increased, there was a decrease in the probability of concavity but an increase in the probability of convexity. Additionally, the

likelihood of concavity was relatively higher in the thick group than in the thin/moderate group.

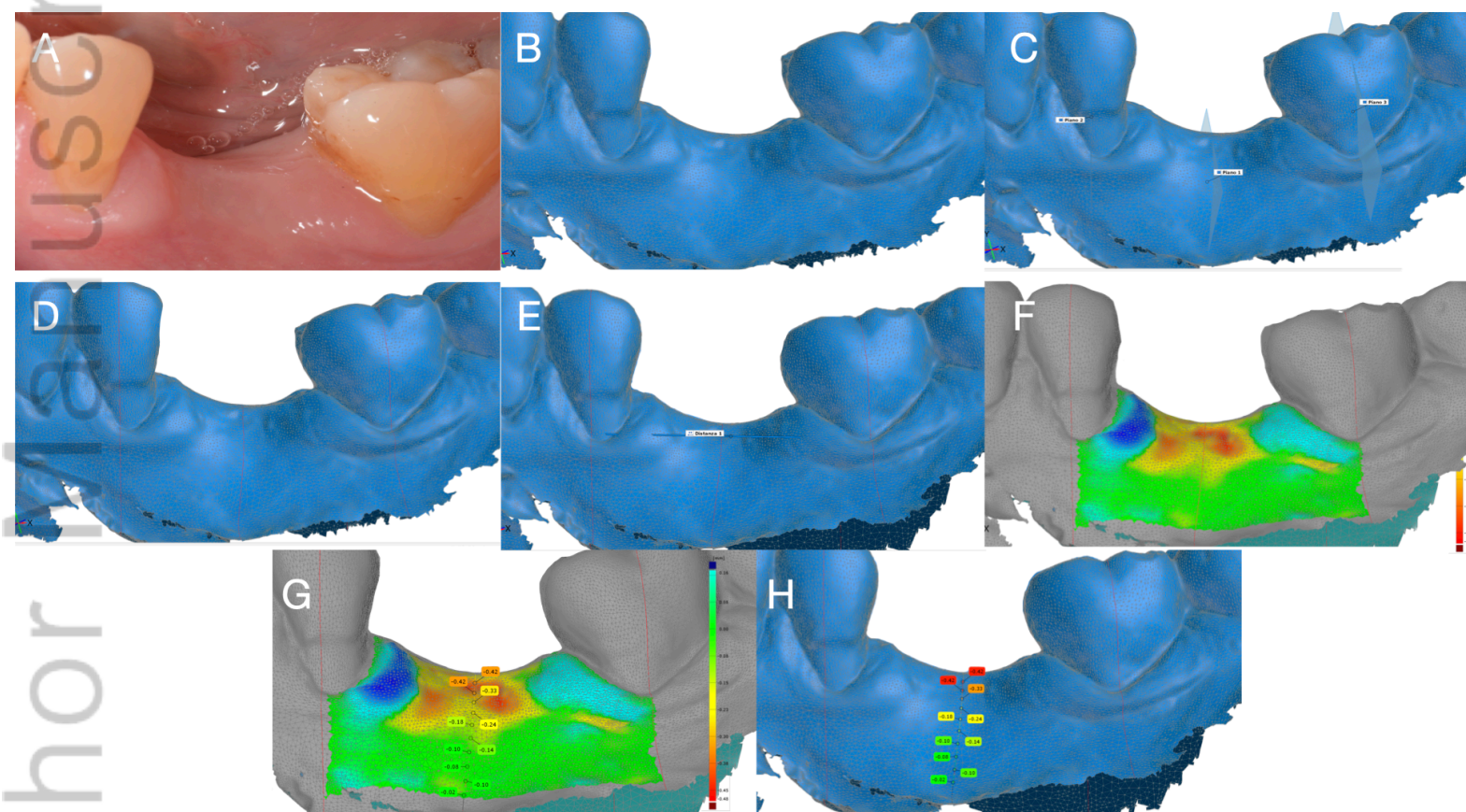


figure 1 .tiff

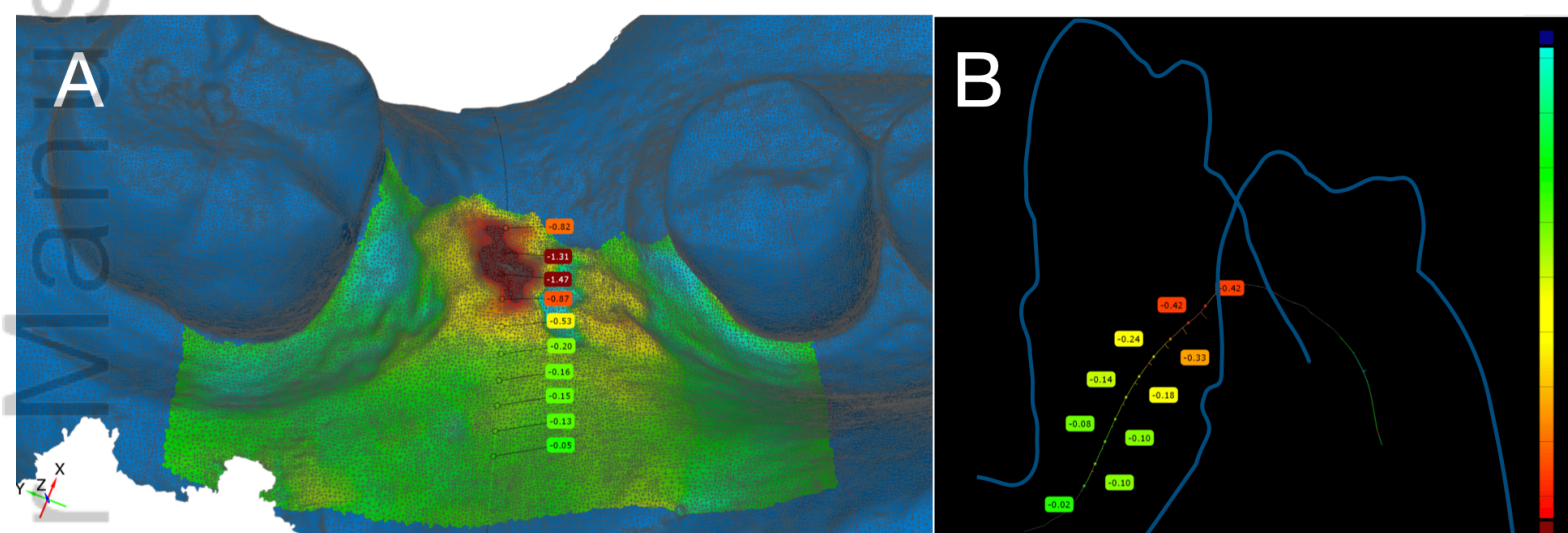


figure 2 .tiff

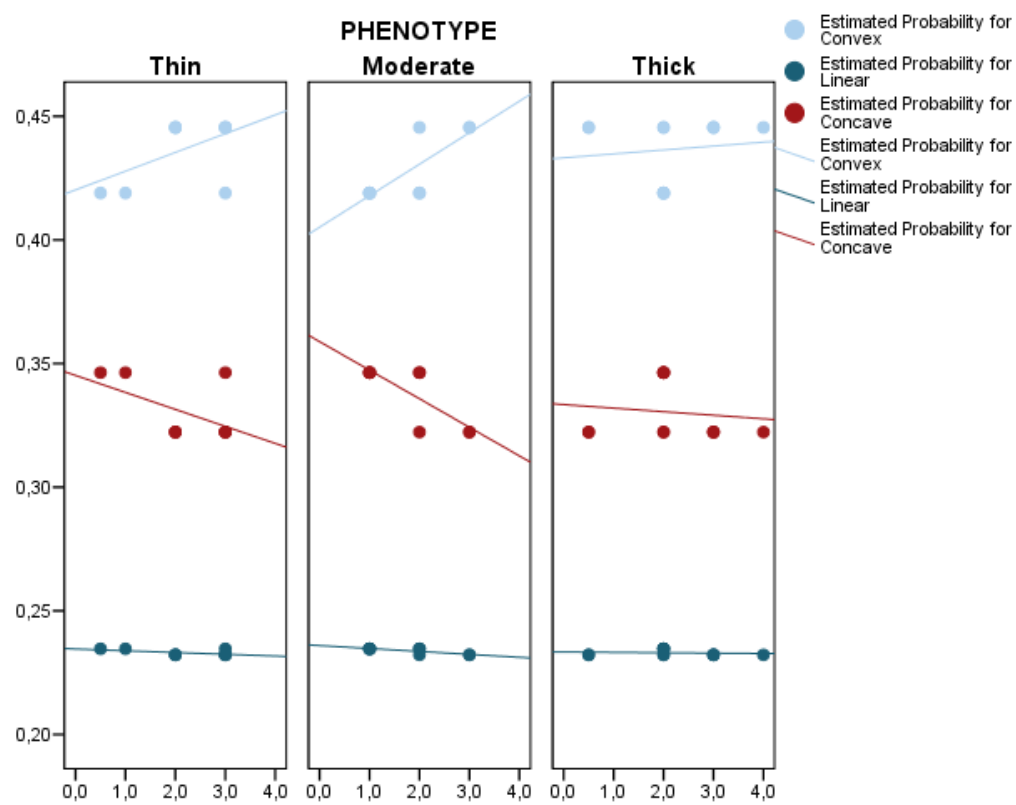


figure 4.TIF

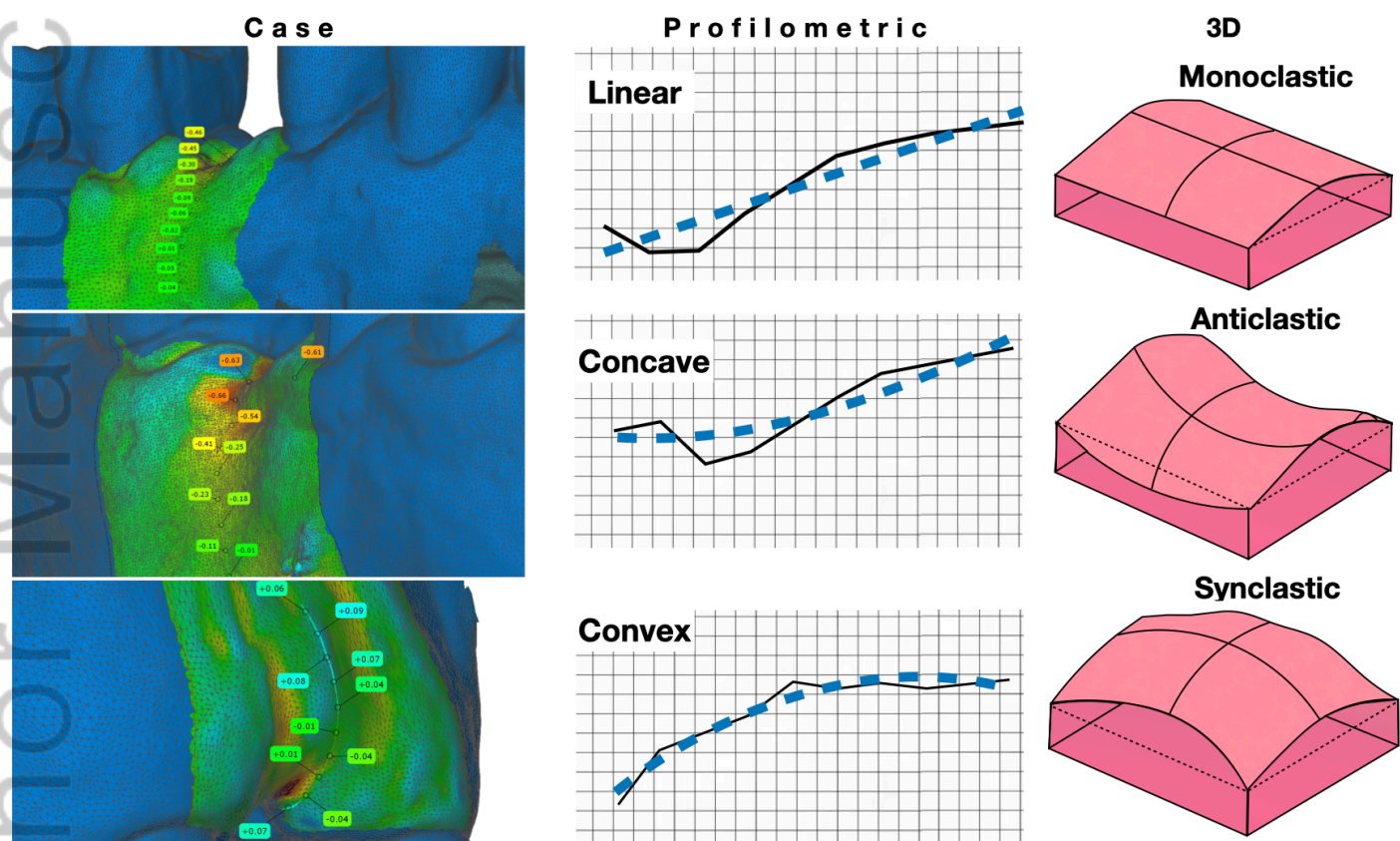


Figure 3 .tiff