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Association of crown emergence angle and profile with dental plaque and inflammation at dental implants

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Abstract

Background: The shape of implant restorations is critical for function and aesthetics. It may also be important in peri-implant tissue health preservation. This study aimed to associate the restorative contour of a single crown with marginal dental plaque accumulation, tissue inflammation and probing depths.

Methods: Subjects with a single screw-retained implant restoration were clinically examined. The presence of dental biofilm, tissue inflammation and probing pocket depths were the dependent variables. The emergence angle, profile and depth of the mucosal tunnel were measured on superimposed digital scans of the crown soft-tissue complex, the removed crown mounted on an analogue and the soft tissue.

Results: One hundred twenty two subjects (46.7% female, 68.9% never smokers, 77% with treated periodontitis and 52.5% participating in regular supportive peri-implant care) were examined. The emergence angles at the mucosal margin were $15.3 \pm 9.4°$, $12.7 \pm 8.5°$, $31.3 \pm 11.8°$ and $19.2 \pm 9.8°$ for the mesial, distal, vestibular and oral aspects of the crowns. The largest emergence profile angles were observed on the vestibular aspect (74.6% of cases), reaching a maximum of 61.7°, and profiles were convex in 59% of cases. Generalized estimating equations indicated that the site-specific platform-level emergence angle and profile and depth of the mucosal tunnel were significantly associated with the presence of detectable plaque accumulation ($p < .01$) and bleeding on probing ($p < .02$).

Conclusions: Subtle variations in the shape of the restorative crown are associated with biofilm accumulation and mucosal inflammation. These findings are important for 3D implant planning/positioning and preservation of peri-implant tissue health.

KEYWORDS
dental implant, peri-implant mucositis, peri-implant tissue health, prevention, prosthesis

George Pelekos and Bonnie Chin contributed equally to this work.

1 | INTRODUCTION

The shape of dental restorations is essential for function, aesthetics, periodontal health and quality of life. Among the many parameters, significant attention has been paid to the contour of the tooth as it traverses the soft tissues to achieve its replication when restorations are placed (Stein & Kuwata, 1977). Both over and under-contouring have been associated with adverse health outcomes driven by plaque accumulation and marginal tissue inflammation (Du et al., 2011). Reproduction of an optimal contour for tooth restorations continues to be more of an art than an exact science. Achieving such a goal with implant-supported reconstructions poses specific additional challenges mainly arising from (i) the geometrical discrepancy between the shape of dental roots and the endosteal portion of implants and (ii) the lack of periodontal attachment in the supracrestal area of dental implants. In the clinic, specific efforts are routinely made to replicate the tooth's natural contour (Croll, 1989, 1990) while designing the abutment-crown complex as it arises from the implant restorative platform and emerges through the peri-implant soft tissues (Chu et al., 2019). To rationalize and simplify the clinical approach, specific topographic areas have been identified: the critical and subcritical contours with different functional and morphologic characteristics (Chu et al., 2019; Su et al., 2010). The subcritical contour provides a gradual and harmonious transition from the implant platform to the critical contour and supports the soft tissues. In contrast, the critical contour impacts the level of the soft-tissue margin, its architecture and the size and morphology of the clinical crown. So far, most analyses focused on the impact of morphology on aesthetics rather than tissue health.

Recent studies have shown that the contour of the restoration is associated with peri-implant health status (Katafuchi et al., 2018; Soulami et al., 2022; Yi et al., 2020) and that changes in the restoration shape, with the primary aim to increase access for oral hygiene practice in the context of non-surgical treatment of peri-implant mucositis, lead to better control of inflammation and treatment outcomes (de Tapia et al., 2019, 2022). Related to the importance of access for oral hygiene are also the observations pointing to the significance of the depth of the mucosal tunnel in the resolution of experimental peri-implant mucositis (Chan et al., 2019).

In implant dentistry, the ideal parameters still need to be clarified, which allow optimal aesthetics and maintenance of health/cleanability. Indeed, significant controversy remains about which measurements are genuinely associated with tissue health. It has been suggested that the deeper sub-mucosal part of the restoration and the more superficial, transmucosal portion may differentially contribute to the maintenance of tissue health. Specifically, it can be hypothesized that the restorative transmucosal profiles may be significant in the susceptibility to the earlier biofilm-associated inflammatory events, while the deeper shape may be associated with the progression of the lesions into peri-implantitis. The ease of measurement of the subcritical contour, additionally, may have biased measures away from aspects of the transmucosal profile (Mattheos et al., 2021). Lastly, analyses have not been able to fully account for the hierarchical structure of the sources of variability of tissue health parameters. This study focuses on the association of the platform level and transmucosal profile of implant single crowns on biofilm accumulation and marginal inflammation. The specific objectives of this retrospective study comprise (i) assessing the reproducibility of a method for measuring the transmucosal emergence angles and compare it with restoration level measures; (ii) characterizing the transmucosal and platform-level emergence angle and emergence profile of restorations, the depth of the mucosal tunnel and total tissue thickness in a population of successfully restored patients; (iii) associating the emergence angle, the restoration profile and the height of the mucosal tunnel with the presence of detectable microbial biofilms, marginal tissue inflammation and probing pocket depths.

2 | MATERIALS AND METHODS

2.1 | Study design and experimental population

This was a cross-sectional clinical study. Subjects with screw-retained single implant restorations were recruited from Prince Philip Dental Hospital, Faculty of Dentistry, The University of Hong Kong, between September 2019 and June 2021. The study is registered in the HKU Clinical Trial Registry (HKUCTR-2988). It has been approved by the Institutional Review Board of the University of Hong Kong/ Hospital Authority Hong Kong West Cluster (UW 19–505). All subjects provided written informed consent. This manuscript follows the STROBE guideline for reporting observational studies.

The inclusion criteria comprise subjects who: (i) received a screw-retained single implant restoration at the anterior or premolar region from 2009 to 2018 at Prince Philip Dental Hospital; (ii) male or female, aged 18 years or above; (iii) willing and able to comply with all study requirements; (iv) presence of a diagnostically acceptable periapical radiograph after implant loading.

Subjects who were pregnant or lactating, used systemic antibiotics within 3 months, needed antibiotic prophylaxis, had radiation therapy in the head and neck area, had HIV, TB, Hepatitis with positive viremia or other infectious diseases, reported drug and alcohol abuse or had undergone therapy for peri-implantitis were excluded.

2.2 | Data collection

Details of implant placement, including the location, time since placement and crown insertion, implant brand, implant design, implant diameter, length, type of implant placement and presence of simultaneous bone augmentation, were collected from the clinical record of each subject.

2.3 | Clinical examination

All examinations were performed by a single calibrated and trained investigator (BC). Plaque Score was recorded dichotomously with the aid of disclosing agent (GC Tri plaque ID gel, GC Australia) at six sites around the implant before removing the clinical crown. Bleeding on Probing (BOP) was similarly assessed dichotomously at six sites around the implant using a UNC-15 periodontal probe (PCP-UNC15, Hu-Friedy) and light probing force (0.2–0.25 N). After removal of the screw-retained crown (García-García et al., 2021), the following were recorded: (i) Probing Pocket Depth (PPD) measured to the nearest millimetre at six sites around the implant with a periodontal probe (PCP-UNC 15, Hu-Friedy), (ii) Suppuration on Probing assessed dichotomously at six sites around the implant and (iii) the amount of keratinized tissue measured to the nearest millimetre at the buccal side of the implant at the thinnest area (Berglundh et al., 2018).

Other clinical information included self-reported smoking status, history of diabetes mellitus and maintenance care. In addition, the subjects were categorized as 'periodontitis patients' with the presence of Interdental CAL of ≥ 2 mm at ≥2 non-adjacent teeth or buccal CAL ≥ 3 mm with pocketing >3 mm at ≥2 teeth (Tonetti et al., 2018). The presence of sites with PPD ≥ 4 mm was also recorded (Chapple et al., 2018).

2.4 | Intraoral digital scans

Digital scans were performed using either a Primescan (CEREC Primescan; Dentsply Sirona) or 3shape (3shape TRIOS Intraoral scanners; 3Shape Global) intraoral scanner. In each subject, three digital scans were made: (i) An intraoral scan with the implant restoration in situ; (ii) An intraoral scan immediately after removal of the screw-retained restoration and placement of an implant scan body; (iii) An extraoral scan of the implant restoration on a corresponding implant analogue. The scans were exported as standard Tessellation Language (STL) files. The files were subsequently imported into Zfx Dental Design CAD software Version 6.0 (Zfx CAD software; GmbH). The three files were merged with a manual selection of three distinct points on each file with subsequent automatic alignment with the best-fit-matching function. The scan body reproduced the implant position. All three files were merged digitally. Buccolingual and mesiodistal cross-sectional images were made for measurements.

2.5 | Measurement of emergence angle and profile

All measurements were performed by a single calibrated examiner (BC). Images were analysed using a Dell Precision Tower 3620 workstation equipped with Dell Flatview Monitors P2717H with a resolution of 1920x1080 pixels in a room with standardized lighting. Coronal, sagittal and axial scan slices of the site of interest were displayed with the x7 zooming factor for performing measurements. Three different methods were used for measuring the emergence angle and profile. In the first method, measurements were performed at the radiographic restorative margin according to the methodology outlined by Katafuchi et al. (2018). The emergence angle was measured between the implant's long axis and a line tangent to the implant restoration at the mesial and distal surfaces (Figure 1a). The emergence profile was categorized as concave, straight, or convex (Katafuchi et al., 2018; Figure 1b). The second method was like the first, but with the extraoral scan of the implant restoration, which allowed us to additionally measure the buccal and oral angles (Figure 1c). The emergence profile was categorized accordingly on all four surfaces (Figure 1d). The third method described the emergence angle at the location where the implant restoration emerged from the gingival margin (Chu et al., 2019): the transmucosal emergence angle. This was

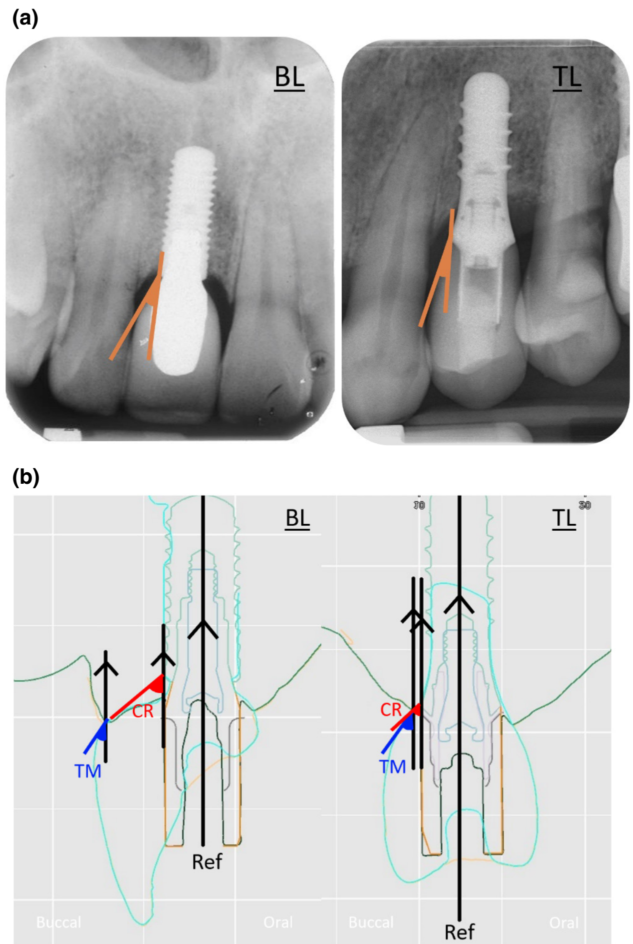

FIGURE 1 Illustration of the method of measurement of the emergence angle. (a) Examples of measurement of emergence angle at bone-level implant (BL) and tissue-level implant (TL) using method 1 (RAD) according to the method by Katafuchi et al.2018. (b) Examples of measurement of emergence angle at bone-level implant (BL) and tissue-level implant (TL) using method 2(CR) and method 3(TM). A reference line (Ref) was drawn along the long axis of the implant. The emergence angle at the base of the crown *(CR)* was measured between the line at outer surface of implant parallel to the implant's long axis and a line tangent to the implant crown defining the largest angle. The emergence angle at the tissue margin *(TM)* was measured with reference to the line parallel to the implant's long axis at transmucosal level and a line tangent to the implant crown defining the largest angle.

measured at one single restoration point at the mucosal margin using the combined intraoral and extraoral scans in the middle of the buccal, oral, mesial and distal surfaces (Figure 1e). The emergence profile was categorized accordingly at the gingival margin (Figure 1f). A high degree of intra-examiner reliability was found with a single measure intra-class correlation of 0.973, 0.988 and 0.984 for the three methods, respectively.

2.6 | Mucosal height and tissue thickness

The mucosal height (mucosal tunnel) depth was measured as the soft-tissue height from the gingival margin to the endosseous portion of the implant according to its long axis. At bone-level implants, a reference line was drawn at the level of the most coronal level of the endosseous portion of the implant perpendicular to the implant long axis. The mucosal height was the vertical distance between the most coronal point of the gingiva in contact with the implant prosthesis and the drawn line. For tissue-level implants, the reference line was set by first drawing another line at the level of the implant shoulder, then moving it apically according to the height of its smooth collar, which is 1.8 mm or 2.8 mm. Measurements were performed at the buccal, oral, mesial and distal surfaces. The thickness of tissue is the distance between the mucosal surface to the implant surface along the drawn line at the buccal and oral surfaces (Figure 2b). A high degree of intra-examiner reliability was also found for the depth of the mucosal height (ICC $r=.998$) and mucosal thickness (ICC $r=.995$) (Figure 3).

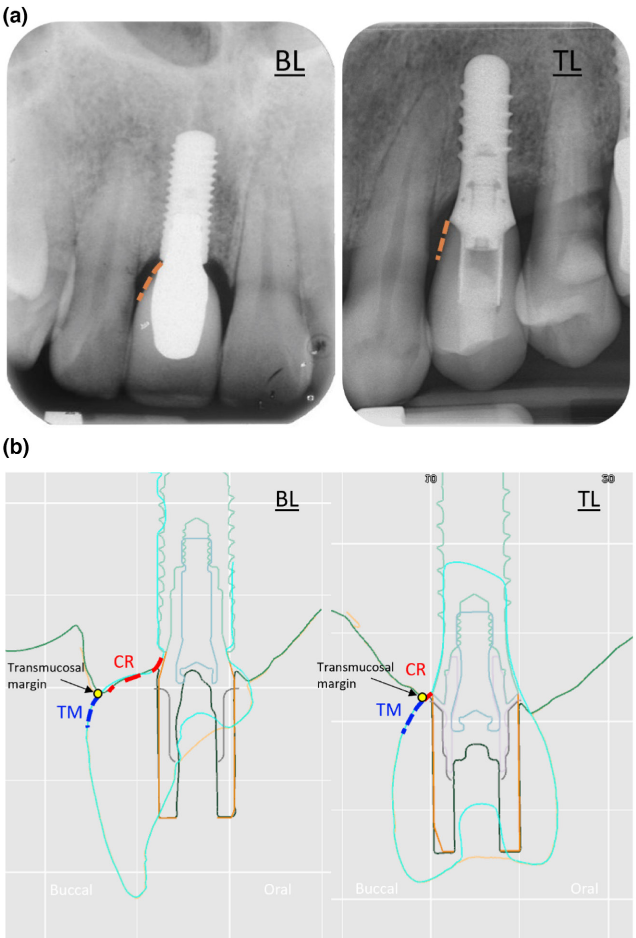

FIGURE 2 Illustration of the method of measurement of the emergence profile. (a) Examples of measurement of emergence profile at bone-level implant (BL) and tissue-level implant (TL) using method 1 (RAD) according to the method outlined by Katafuchi et al., 2018. (b) Examples of measurement of emergence profile at bone-level implant (BL) and tissue-level implant (TL) using method 2 (CR) and method 3 (TM). The emergence profile at the base of the crown *(CR)* was the emergence from the endosseous portion of the implant at a bone-level implant (BL) and the shoulder of the implant at a tissue-level implant (TL), categorized as concave, straight or convex. The emergence profile at the tissue margin *(TM)* was the emergence at the transmucosal margin, categorized as concave, straight or convex.

2.7 | Statistical analysis

Sample size calculation by G*power software (G*Power version 3.1.9.2) indicated that a minimum of 122 samples would be necessary to detect a correlation of MBL and EA at $r=.25$ (Reference was

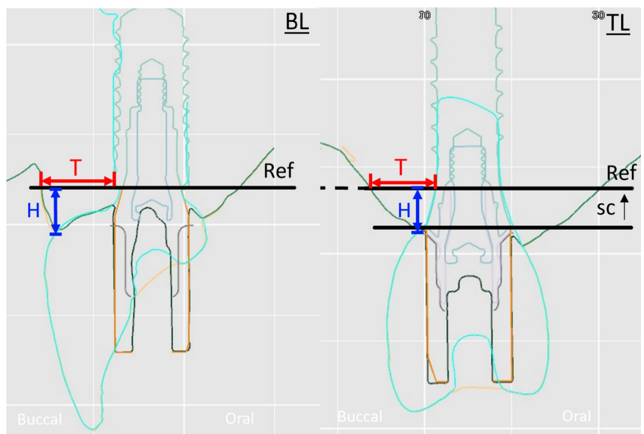

FIGURE 3 Illustration of the measurement of the peri-implant soft-tissue height and of the thickness of the combined peri-implant soft and hard tissue. Examples of measurement of peri-implant soft-tissue height and thickness of combined peri-implant soft and hard tissue at bone-level implant (BL) and tissue-level implant (TL). *Ref at BL*: A reference line was drawn perpendicular to the long axis of the implant and at the most coronal level of the endosseous portion of the implant (bone-level platform). *Ref at TL*: A reference line was drawn perpendicular to the long axis of the implant and at the level of most coronal level of endosseous portion of the implant, by first drawing a line at the shoulder of the implant, then moving it apically according to the height of its smooth collar (*sc*). *H*: The peri-implant soft-tissue height was measured as the vertical distance between most coronal point of peri-implant mucosa in contact with the prosthesis and the reference line. *T*: The thickness of the combined peri-implant soft- and hard-tissues was measured as the horizontal distance along the reference line from the mucosal surface to the implant surface.

taken from Pearson's $r = .23$ in Yi et al., 2020) with statistical significance set at p-value <.05 and 80% power.

All data were analysed using the IBM statistical Package for Social Sciences, Version 27.0 (IBM SPSS). The interclass correlation coefficient was used to compare three measuring methods of emergence angle. Mann–Whitney U or Kruskal-Wallis tests were used to compare the mucosal height and thickness of combined hard and soft tissue across implant location, implant design, implant length and tooth type. A multilevel analysis was performed to analyse the effect of the emergence angle, emergence profile and the mucosal height on plaque score, PPD and BOP at four sites within the same implant using generalized estimating equations with unstructured correlation assumption between multiple sites within each implant. A p-value <.05 was considered statistically significant in all tests. A sensitivity analysis was performed to explore the effect of tissue- and bone-level implants.

3 | RESULTS

3.1 | Patient population

A list comprising 676 subjects who received implants in the anterior/premolar area between 2008 and 2018 was identified. Of these, 197 individuals met the inclusion criteria of having a single screw-retained crown and had a diagnostic quality radiograph taken at the loading time. Forty-one could not be reached, while 34 refused to participate, were deceased, or reported having lost their implant. Consequently, 122 subjects were included in the study. Table 1 shows the characteristic of the included subjects. The median duration of the patient's follow up period was 5.6 years, with a range of 2.8–11.2 years. The location and type of included implants are illustrated in Figure 4.

3.2 | Emergence angle, profile

A descriptive analysis of the experimental population's emergence angle and profile at the level of the implant platform and the transmucosal margin is shown in Tables 2 and 3. Parameters are shown following the three different measurement techniques for the four aspects of each implant-supported crown. The radiographic method allows reporting only the mesial and distal aspects, while the digital scanning methods also provide information for the buccal and oral surfaces. Comparing the three measurement techniques, intra-class correlation coefficients were 0.694 (95% CI: 0.590–0.776, $p < .001$) and 0.660 (95% CI: 0.547–0.749, $p < .001$) for mesial and distal radiographic and crown scan measurements, respectively. The same values were 0.254 (95% CI: 0.022–0.449, $p < .001$) and 0.316 (95% CI: 0.049–0.521, $p < .001$) comparing radiographic and soft-tissue margin measurements and 0.236 (95% CI: 0.002–0.435, $p < .001$) and 0.242 (95% CI: 0.014–0.436, $p < .001$) comparing the digital scanning measurements at the level of the implant platform with those at the transmucosal margin.

TABLE 1 Subject characteristics.

Age	Median (IQR)	122	60 (42–78)
Gender	Count (%)	122	
Male			65 (53.28%)
Female			57 (46.72%)
Smoking history	Count (%)	122	
No smoking history			84 (68.85%)
Current smoker			15 (12.30%)
Former smoker			23 (18.85%)
History of Diabetes Mellitus	Count (%)	122	
Yes			11 (9.00%)
No			111 (91.00%)
Periodontitis patient (2017 World workshop)	Count (%)	122	
Yes			94 (77.00%)
No			28 (23.00%)
Patient with presence of site with PPD ≥ 4 mm	Count (%)	122	
Yes			46 (37.70%)
No			76 (62.30%)
Periodontal maintenance	Count (%)	122	
Yes			64 (52.50%)
No			58 (47.50%)

Abbreviations: IQR, interquartile range; PPD, probing pocket depth.

3.3 | Mucosal height and tissue thickness

Table 4 shows the height of the peri-implant soft tissues and the thickness of the combined soft and hard tissue assessed on the digital scan on the buccal and oral aspects. Significant differences in peri-implant soft-tissue height were observed comparing maxillary and mandibular implants (Figure S1, $p = .01$). In contrast, no significant differences were observed comparing anterior and posterior implants, bone-level and tissue-level implants, or implants replacing incisors/canines/premolars. Details of combined soft and hard tissue thickness are illustrated in Figure S2. Significant differences were observed for bone- and tissue-level implants (greater thickness for bone level, $p = .04$), maxillary and mandibular implants (greater thickness for maxillary, $p < .001$), and incisor, canine and premolar location (less thickness for canine, $p = .027$).

3.4 | Multivariate analyses

Multilevel analyses using the transmucosal and platform-level emergence angle and profile, and mucosal height as independent variables and plaque score, and BOP, as dependent variables were performed using GEE. Results of the final model and are shown in

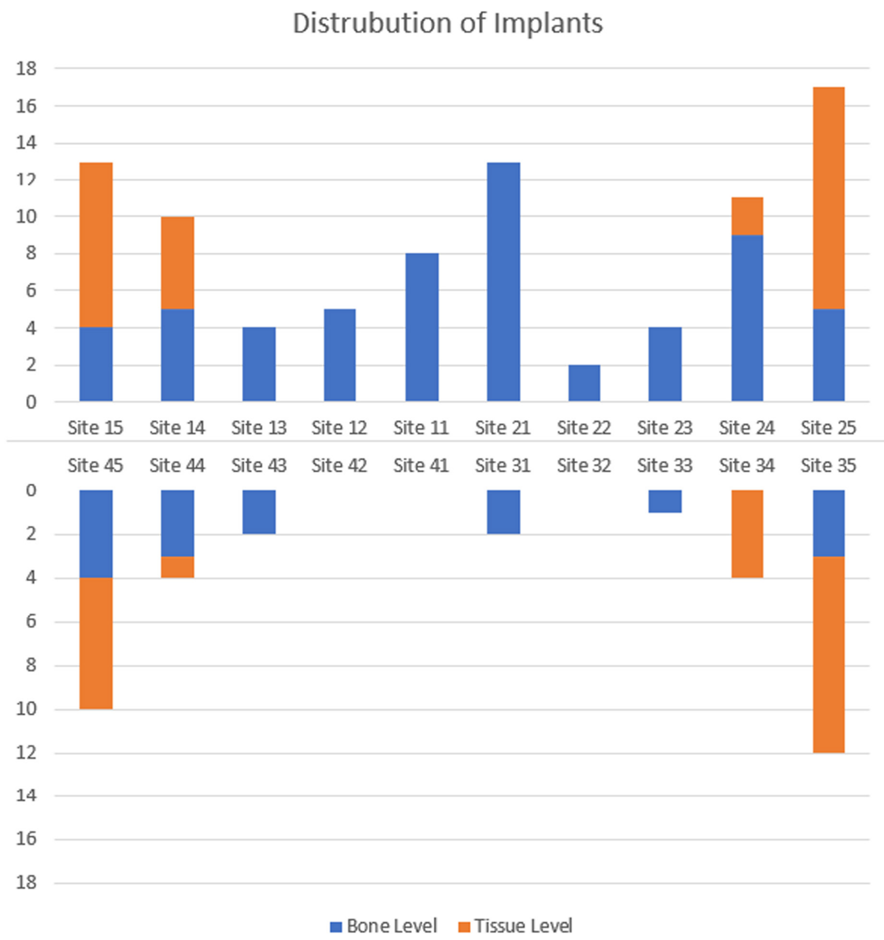

FIGURE 4 Location and type of included implants.

TABLE 2 Descriptive analysis of emergence angle (degrees).

		Method 1–RAD	Method 2–CR	Method 3–TM
Buccal	Mean° (SD)	–	33.9 (10.2)	31.3 (11.8)
Oral	Mean° (SD)	–	22.2 (7.4)	19.2 (9.8)
Mesial	Mean° (SD)	22.8 (9.0)	23.5 (9.1)	15.3 (9.4)
Distal	Mean° (SD)	19.1 (7.8)	19.7 (8.1)	12.7 (8.5)
p-value			<.01*	<.01*
Site with the greatest angle within the implant	Count (%)	Mesial, 79/122 (64.8%)	Buccal, 85/122 (69.7%)	Buccal, 91/122 (74.6%)
Greatest angle	Site, °	Mesial, 54.8	Buccal, 76.0	Buccal, 61.7

Note: RAD, Measurement on radiographic image (method 1); CR, Measurement on digital scan at the implant crown (method 2); TM, Measurement on digital scan at the transmucosal margin (method 3).

Abbreviation: SD, standard deviation.

*Friedman's test, significant result, *p*-value <.05.

Table 5. Dental plaque was detected significantly less frequently on the buccal and oral surfaces compared to the distal ones. Similarly, bleeding on probing was seen less frequently at the mesial, buccal and oral sites compared to the distal ones. The mucosal height and the platform-level emergence angle were significantly associated with plaque and bleeding on probing at the specific location. Probing depths were progressively significantly shallower at mesial, buccal and oral sites compared with the distal ones. The emergence profile had no significant effect on probing depths. The mucosal height was significantly associated with probing depths. Data are summarized in Figure 5. The combination of tissue- and bone-level implants may bias the association with probing depths. Table S1 shows the results of a model analysing separately the association of emergence angle and peri-implant soft tissue. Results of a sensitivity analysis

TABLE 3 Descriptive analysis of emergence profile.

		Method 1-RAD			Method 2-CR			Method 3-TM		
		Convex	Straight	Concave	Convex	Straight	Concave	Convex	Straight	Concave
Buccal	Count (%)	-	-	-	54 (44.3%)	31 (25.4%)	37 (30.3%)	72 (59.0%)	25 (20.5%)	25 (20.5%)
Oral	Count (%)	-	-	-	44 (36.1%)	70 (57.4%)	8 (6.6%)	43 (35.2%)	67 (54.9%)	12 (9.8%)
Mesial	Count (%)	65 (53.3%)	42 (34.4%)	15 (12.3%)	57 (46.7%)	49 (40.2%)	16 (13.1%)	25 (20.5%)	89 (73.0%)	8 (6.6%)
Distal	Count (%)	56 (45.9%)	51 (41.8%)	15 (12.3%)	44 (36.1%)	68 (55.7%)	10 (8.2%)	15(12.3%)	101 (82.8%)	6 (4.9%)

Note: RAD, Measurement on radiographic image (method 1); CR, Measurement on digital scan at the implant crown (method 2); TM, Measurement on digital scan at the transmucosal margin (method 3).

TABLE 4 Descriptive analysis of peri-implant soft-tissue height and thickness of the combined peri-implant soft and hard tissue.

	Peri-implant soft-tissue height, median (IQR)	Thickness of combined peri-implant soft and hard tissue, median (IQR)
Mean height (mm)	3.50 (1.14)	–
Buccal	2.70 (1.37)	3.10 (1.59)
Oral	2.97 (1.39)	9.45 (5.35)
Mesial	4.59 (1.92)	–
Distal	3.43 (1.50)	–
p-value	<.01*	

Abbreviation: IQR, interquartile range.

*Friedman's test, significant result, *p*-value <.05.

considering separately tissue- and bone-level implants are shown in Tables S2 and S3 and are summarized in Figure S3. Keeping in mind the loss of power, the overall results were largely confirmed.

4 | DISCUSSION

The main finding of this study is the site-specific association of the platform-level emergence angle of an implant-supported restoration and its associated mucosal tissue height with the odds of dental plaque accumulation and local inflammation. Linking subtle variations in the morphology of the contour of implant-supported crowns with oral hygiene and inflammation is potentially relevant as prevention/treatment of peri-implant mucositis is considered key for the prevention of peri-implantitis and long-term complication-free survival of dental implants (Herrera et al., 2023; Jepsen et al., 2015). Emerging evidence of improved resolution of inflammation incorporating prosthesis modification in the treatment protocol to manage peri-implant mucositis (de Tapia et al., 2019, 2022) and the impact of the depth of the mucosal tunnel on the resolution of experimental peri-implant mucositis (Chan et al., 2019) underline the importance of these parameters in the maintenance of peri-implant tissue health and potentially their significance in properly planning the ideal position of the implant. In this respect it is important to differentiate the concept of mucosal tissue height (mucosal tunnel as used in a previous publication, Chan et al., 2019) in this context to a similar one that has been used as predictor of marginal bone stability (Linkevicius et al., 2009; Puisys & Linkevicius, 2015). The recent EFP S3 clinical practice guideline for the prevention and management of peri-implant diseases has used the term mucosal sulcus (Herrera et al., 2023).

Overall, imprecision in implant position and its restorative sequelae have been retrospectively associated with peri-implantitis: deep implant positioning, asymmetric shape of the implant restoration, an emergence profile >30° and a convex form (Kumar et al., 2018). Conversely, the requirements of implant-supported

TABLE 5 Final model of generalized estimating equations analysing the influence of the emergence angle, profile and peri-implant soft-tissue height on plaque score, bleeding on probing and probing pocket depth.

	Presence of plaque					Presence of bleeding					Probing pocket depth				
	%	OR	95% CI	*p*-value	Pairwise Comparison	%	OR	95% CI	*p*-value	Pairwise Comparison	Mean(SD)	Estimated Mean	95% CI	*p*-value	Pairwise Comparison
Site															
Buccal	24.6	0.04	0.02–0.07	.00*	Distal, Mesial > Oral > Buccal[a]	46.7	0.06	0.03–0.15		Distal, Mesial > Oral > Buccal[a]	3.09 (1.08)	−1.86	−2.26 to −1.46		Distal > Mesial > Oral > Buccal[a]
Oral	36.1	0.10	0.05–0.18			59.8	0.16	0.08–0.32			3.61 (1.37)	−1.72	−2.27 to −1.17		
Mesial	84.4	1.55	0.70–3.43			83.6	0.37	0.16–0.82			4.75 (1.43)	-3.05×10^{-4}	-4.26×10^{-4} to -1.84×10^{-4}		
Distal	81.1	Ref				90.2	Ref				4.75 (1.43)	Ref			
Emergence angle		1.03	1.01–1.05	.01*			1.04	1.01–1.07	.01*			–	–	–	
Peri-implant soft-tissue height		0.78	0.65–0.93	.01*			1.24	1.03–1.49	.02*			8.72×10^{-5}	3.30×10^{-6} to 1.78×10^{-4}	.01*	

Note: Emergence angle refers to platform-level measurements. Mucosal level measurements were eliminated from the model together with the type of restoration profile (concave or convex) using a backward elimination approach of non-significant factors.

Abbreviations: CI, confidence interval; OR, Odds Ratio; SD, Standard Deviation.

[a]Multiple comparison by Bonferroni correction.

*Significant result, *p*-value <.05.

	Site	Emergence angle	Emergence profile	Peri-implant soft tissue height
Plaque Score	Distal, Mesial> Oral> Buccal	Increases as EA increases	No significant influence	Decreases as H increases
BOP	Distal, Mesial> Oral> Buccal	Increases as EA increases	No significant influence	Increases as H increases
PPD	Distal> Mesial> Oral> Buccal	No significant influence	No significant influence	Increases as H increases

FIGURE 5 Summary of multilevel analysis of the association of the emergence angle, the profile and tissue height on plaque score, BOP and PPD. BOP, bleeding on probing; EA, emergence angle; H, peri-implant soft-tissue height; PPD, probing pocket depth.

restorations have historically focused on achieving three primary objectives: the replacement of function (occlusal and phonetic), limiting food impaction and the achievement of acceptable aesthetics. Recent studies have associated the shape of the buccal contour of temporary crowns with changes in the buccal soft-tissue levels (Siegenthaler et al., 2022) and the interproximal contour with food impaction (Chanthasan et al., 2022). Obtaining a form compatible with the preservation of health by enabling appropriate biofilm control has remained implicit, and no clear parameters have been identified.

The lack of significance of the transmucosal emergence angle in the GEE analysis is noteworthy. A likely interpretation is that the platform-level emergence angle and the mucosal height may explain the majority of variance and are still highly correlated with the transmucosal angles (ICC = 0.24, $p < .001$). A sensitivity analysis with only the transmucosal angle, however, did not show a significant association in this study. Another sensitivity analysis with only tissue-level implants (Table S2) found a significant association of the transmucosal emergence angle and presence of plaque ($p < .01$). More research is needed to assess the relative importance of the platform-level and mucosal-level profiles.

The present results are also crucial in the context of the recent EFP clinical practice guidelines for preventing and treating peri-implant diseases (Herrera et al., 2023). Recommendations R5.2 and R5.3 regarding implant position and prosthesis design to reduce incident peri-implant disease are particularly relevant since they emphasize proper planning and access for optimal self-performed and professional plaque removal to prevent peri-implant diseases. Further, in these clinical practice guidelines, prosthesis modification is a key consideration in managing peri-implant mucositis and peri-implantitis.

This work also reports on a methodological improvement to assess the impact of the morphology of the restorations on tissue health status by the superimposition of three digital scans: the soft tissue with the crown in situ, the soft tissues without the crown and the crown (Figure 1e,f). High levels of intra-examiner consistency were observed (ICC > 0.97) pointing to the reliability and precision of the measures. While the mesial and distal measures of the emergence angle of the conventional analysis based on intraoral periapical radiographs and those obtained using the digital scan of the crown on an implant analogue are very similar and highly correlated (Table 2), the digital scan of the crown allows extension of the analysis to the buccal and oral aspects that are not visible on conventional radiographs. Additionally, the novel method using the digital superimposition of the crown with the soft-tissue outline captures the angle at the level of the soft-tissue emergence. This latter parameter describes the critical contour (Chu et al., 2019; Su et al., 2010) and is immediately adjacent to the area where the presence of marginal dental biofilms is assessed and inflammation in response to their accumulation starts. Summary statistics and ICC data show that platform and mucosal-level measures capture different features. The reported method allows the study of the impact of subtle variations in the shape of restoration at the critical mucosal-restoration interface.

The main limitation of this study is its design, which is unsuitable for establishing chronological consistency and limiting potential bias. The two major features identified in this study, the emergence angle and the mucosal tissue height, likely are not independent; the relatively small sample size did not allow to study their interaction. Another limitation is the type and location of the studied implants (Figure 3). Implants positioned in the incisor/canine areas comprised only bone-level implants, while those in the premolar region were both bone and tissue level. It is clear that the challenges to compensate for the geometrical discrepancy between the implant platform in incisors, canines, or premolars are different and so are the potential impact of imprecision in implant positioning. Additionally, pooling tissue- and bone-level implants may provide a broader range of values and hence increase the power to detect the significance of the emergence angles and profiles. At the same time, the intrinsic anatomic variations of these two types of implants and their reconstructions may confound the association and particularly so for PPD. Due to sample size limitations, these potential confounders could not be fully explored in this study.

5 | CONCLUSION

Subtle variations in the restorative crown's shape, particularly the emergence profile can be measured in digital scans and are associated with site-specific biofilm accumulation and soft-tissue inflammation. The mucosal tissue height (depth of the mucosal tunnel) is also associated with these outcomes. More research is needed to confirm these findings and to identify a biologically acceptable range of values for the emergence profile and depth of the implant platform to use as a guideline to better plan precise dental implant placement and fabrication of the restoration.

AUTHOR CONTRIBUTIONS

MST generated the hypothesis, designed the work and provided funding. BC and MF performed the clinical examinations. MST, BC, XW, MF, JS and GP contributed to data analysis, interpretation and manuscript drafting. GP supervised the work and contributed to quality control.

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CONFLICT OF INTEREST STATEMENT

The authors declare no conflict of interest.

DATA AVAILABILITY STATEMENT

Research data are not shared.

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REFERENCES

Berglundh, T., Armitage, G., Araujo, M. G., Avila-Ortiz, G., Blanco, J., Camargo, P. M., Chen, S., Cochran, D., Derks, J., Figuero, E., Hämmerle, C. H. F., Heitz-Mayfield, L. J. A., Huynh-Ba, G., Iacono, V., Koo, K. T., Lambert, F., McCauley, L., Quirynen, M., Renvert, S., … Zitzmann, N. (2018). Peri-implant diseases and conditions: Consensus report of workgroup 4 of the 2017 world workshop on the classification of periodontal and peri-implant diseases and conditions. *Journal of Clinical Periodontology*, *45*(Suppl 20), S286–S291. https://doi.org/10.1111/jcpe.12957

Chan, D., Pelekos, G., Ho, D., Cortellini, P., & Tonetti, M. S. (2019). The depth of the implant mucosal tunnel modifies the development and resolution of experimental peri-implant mucositis: A case-control study. *Journal of Clinical Periodontology*, *46*(2), 248–255. https://doi.org/10.1111/jcpe.13066

Chanthasan, S., Mattheos, N., Pisarnturakit, P. P., Pimkhaokham, A., & Subbalekha, K. (2022). Influence of interproximal peri-implant tissue and prosthesis contours on food impaction, tissue health and patients' quality of life. *Clinical Oral Implants Research*, *33*(7), 768–781. https://doi.org/10.1111/clr.13958

Chapple, I. L. C., Mealey, B. L., Van Dyke, T. E., Bartold, P. M., Dommisch, H., Eickholz, P., Geisinger, M. L., Genco, R. J., Glogauer, M., Goldstein, M., Griffin, T. J., Holmstrup, P., Johnson, G. K., Kapila, Y., Lang, N. P., Meyle, J., Murakami, S., Plemons, J., Romito, G. A., … Yoshie, H. (2018). Periodontal health and gingival diseases and conditions on an intact and a reduced periodontium: Consensus report of workgroup 1 of the 2017 world workshop on the classification of periodontal and peri-implant diseases and conditions. *Journal of Clinical Periodontology*, *45*(Suppl 20), S68–S77. https://doi.org/10.1111/jcpe.12940

Chu, S. J., Kan, J. Y., Lee, E. A., Lin, G. H., Jahangiri, L., Nevins, M., & Wang, H. L. (2019). Restorative emergence profile for single-tooth implants in healthy periodontal patients: Clinical guidelines and decision-making strategies. *The International Journal of Periodontics & Restorative Dentistry*, *40*(1), 19–29. https://doi.org/10.11607/prd.3697

Croll, B. M. (1989). Emergence profiles in natural tooth contour. Part I: Photographic observations. *The Journal of Prosthetic Dentistry*, *62*(1), 4–10. https://doi.org/10.1016/0022-3913(89)90036-x

Croll, B. M. (1990). Emergence profiles in natural tooth contour. Part II: Clinical considerations. *The Journal of Prosthetic Dentistry*, *63*(4), 374–379. https://doi.org/10.1016/0022-3913(90)90223-y

de Tapia, B., Bonnin, M., Valles, C., Mozas, C., Herrera, D., Sanz, M., & Nart, J. (2022). Clinical outcomes and associated factors in the treatment of peri-implant mucositis, combining mechanical debridement and prosthesis modification: A 30-month follow-up prospective case series. *Journal of Clinical Periodontology*, *49*(12), 1357–1365. https://doi.org/10.1111/jcpe.13711

de Tapia, B., Mozas, C., Valles, C., Nart, J., Sanz, M., & Herrera, D. (2019). Adjunctive effect of modifying the implant-supported prosthesis in the treatment of peri-implant mucositis. *Journal of Clinical Periodontology*, *46*(10), 1050–1060. https://doi.org/10.1111/jcpe.13169

Du, J. K., Li, H. Y., Wu, J. H., Lee, H. E., & Wang, C. H. (2011). Emergence angles of the cementoenamel junction in natural maxillary anterior teeth. *Journal of Esthetic and Restorative Dentistry*, *23*(6), 362–369. https://doi.org/10.1111/j.1708-8240.2011.00471.x

García-García, M., Mir-Mari, J., Figueiredo, R., & Valmaseda-Castellón, E. (2021). Probing single-tooth dental implants with and without prostheses: A cross-sectional study comparing healthy and peri-implant mucositis sites. *Journal of Clinical Periodontology*, *48*(4), 581–589. https://doi.org/10.1111/jcpe.13436

Herrera, D., Berglundh, T., Schwarz, F., Chapple, I., Jepsen, S., Sculean, A., Kebschull, M., Papapanou, P. N., Tonetti, M. S., Sanz, M., & EFP Workshop Participants and Methodological Consultant. (2023). Prevention and treatment of peri-implant diseases – The EFP S3 level clinical practice guideline. *Journal of Clinical Periodontology*, *50*, 4–76.

Jepsen, S., Berglundh, T., Genco, R., Aass, A. M., Demirel, K., Derks, J., Figuero, E., Giovannoli, J. L., Goldstein, M., Lambert, F., Ortiz-Vigon, A., Polyzois, I., Salvi, G. E., Schwarz, F., Serino, G., Tomasi, C., & Zitzmann, N. U. (2015). Primary prevention of peri-implantitis: Managing peri-implant mucositis. *Journal of Clinical Periodontology*, *42*(Suppl 16), S152–S157. https://doi.org/10.1111/jcpe.12369

Katafuchi, M., Weinstein, B. F., Leroux, B. G., Chen, Y. W., & Daubert, D. M. (2018). Restoration contour is a risk indicator for peri-implantitis: A cross-sectional radiographic analysis. *Journal of Clinical Periodontology*, *45*(2), 225–232. https://doi.org/10.1111/jcpe.12829

Kumar, P. S., Dabdoub, S. M., Hegde, R., Ranganathan, N., & Mariotti, A. (2018). Site-level risk predictors of peri-implantitis: A retrospective analysis. *Journal of Clinical Periodontology*, *45*(5), 597–604. https://doi.org/10.1111/jcpe.12892

Linkevicius, T., Apse, P., Grybauskas, S., & Puisys, A. (2009). The influence of soft tissue thickness on crestal bone changes around implants: A 1-year prospective controlled clinical trial. *The International Journal of Oral & Maxillofacial Implants*, *24*(4), 712–719.

Mattheos, N., Janda, M., Acharya, A., Pekarski, S., & Larsson, C. (2021). Impact of design elements of the implant supracrestal complex (ISC) on the risk of peri-implant mucositis and peri-implantitis: A critical review. *Clinical Oral Implants Research*, *32*(Suppl 21), 181–202. https://doi.org/10.1111/clr.13823

Puisys, A., & Linkevicius, T. (2015). The influence of mucosal tissue thickening on crestal bone stability around bone-level implants. A prospective controlled clinical trial. *Clinical Oral Implants Research*, *26*(2), 123–129. https://doi.org/10.1111/clr.12301

Siegenthaler, M., Strauss, F. J., Gamper, F., Hämmerle, C. H. F., Jung, R. E., & Thoma, D. S. (2022). Anterior implant restorations with a convex emergence profile increase the frequency of recession: 12-month results of a randomized controlled clinical trial. *Journal of Clinical Periodontology*, *49*(11), 1145–1157. https://doi.org/10.1111/jcpe.13696

Soulami, S., Slot, D. E., & van der Weijden, F. (2022). Implant-abutment emergence angle and profile in relation to peri-implantitis: A systematic review. *Clinical and Experimental Dental Research*, *8*(4), 795–806. https://doi.org/10.1002/cre2.594

Stein, R. S., & Kuwata, M. (1977). A dentist and a dental technologist analyze current ceramo-metal procedures. *Dental Clinics of North America*, *21*(4), 729–749.

Su, H., Gonzalez-Martin, O., Weisgold, A., & Lee, E. (2010). Considerations of implant abutment and crown contour: Critical contour and subcritical contour. *The International Journal of Periodontics & Restorative Dentistry*, *30*(4), 335–343.

Tonetti, M. S., Greenwell, H., & Kornman, K. S. (2018). Staging and grading of periodontitis: Framework and proposal of a new classification and case definition. *Journal of Clinical Periodontology*, *45*(Suppl 20), S149–S161. https://doi.org/10.1111/jcpe.12945

Yi, Y., Koo, K. T., Schwarz, F., Ben Amara, H., & Heo, S. J. (2020). Association of prosthetic features and peri-implantitis: A cross-sectional study. *Journal of Clinical Periodontology*, *47*(3), 392–403. https://doi.org/10.1111/jcpe.13251

SUPPORTING INFORMATION

Additional supporting information can be found online in the Supporting Information section at the end of this article.

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