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The 3D emergence profile on implant-supported restorations: A method for evaluating restorative angles

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Title: **The 3D emergence profile on implant-supported restorations: a method for evaluating restorative angles**

Abstract:

Statement of Problem: There has been recent evidence that the emergence profile can have a significant impact on clinical outcomes as well as on the onset and progression of peri-implant disease. Restorations were traditionally measured by two-dimensional analysis of periapical x-rays at both mesial and distal portions of the restoration to determine their angle and impact on surrounding tissues. However, there were no reliable data available on the buccal aspect, which is the main site of soft tissue recession and bone remodeling.

Purpose: To describe a novel 3D method to estimate the emergence profile and restorative angles around single implant-supported crowns.

Material and methods: A total of 30 implant-supported crowns (11 molars, 8 premolars, 8 central incisors and 1 canine) were extra-orally scanned using an intraoral scanner and the STL files produced were imported into a 3D software. The crown/abutment interface of each crown was delineated, and apico-coronal lines were automatically drawn following the shape of the crown. Three reference points were defined on the apico-coronal lines at the transition edge of the biological (BC) and the esthetic zone (EC) and the resulting angles were then calculated. The reliability of the measurements (2D and 3D) were assessed using the intraclass correlation coefficient (ICC).

Results: In anterior restorations, the mean angle of the esthetic zone amounted to 162±14° at mesial sites, to 140±10° at buccal sites and to 163± 11° at distal sites. The corresponding angles at the biological zones, amounted to 155±13° at mesial sites, 139±15° at buccal sites and 157±5° at distal sites. In posterior zone, the mean angle of the esthetic zone amounted to 162±12° at mesial sites, to 157±13 at buccal sites and to 162±11 at distal sites. The corresponding angles at the biological zone, amounted to 158±8 at mesial sites, 150±15° at buccal sites and 156±10 at distal sites. The ICC for all measurements ranged between 0.77 and 0.99 indicating a good intra-examiner reliability.

Conclusion: Within the limitations of the present study, the 3D analysis seems to be a reliable and applicable method for the quantitative evaluation of the emergence profile in daily practice. Future randomized clinical trials are needed to assess whether a 3D analysis with the ensuing the emergence profile serves as a predictor for clinical outcomes.

Figure 1. Ideal Emergence profile around implant crown.

Background and Rationale

The long-term success of prosthetic reconstructions using osseointegrated dental implants is well-documented (1–5). Albrektsson et al. established criteria for implant success, which includes minimal bone loss (no more than 1mm in the first year and 0.2mm annually thereafter), absence of clinical mobility, peri-implant radiolucency, pain, discomfort, or infection (6). Smith et al. expanded these criteria to include an aesthetic component, emphasizing the importance of allowing for the placement of an esthetic restoration to consider an implant successful (7).

The success of an implant restoration, especially a single implant crown (SIC), hinges on several critical factors, including treatment planning, the quality and quantity of bone at the recipient site, surgical technique, the type of restoration (Fig.1), and proper oral hygiene and follow-up (8). Recent research has also linked the long-term survival of osseointegrated implants to the stability of transmucosal tissue around the implant collar (9).

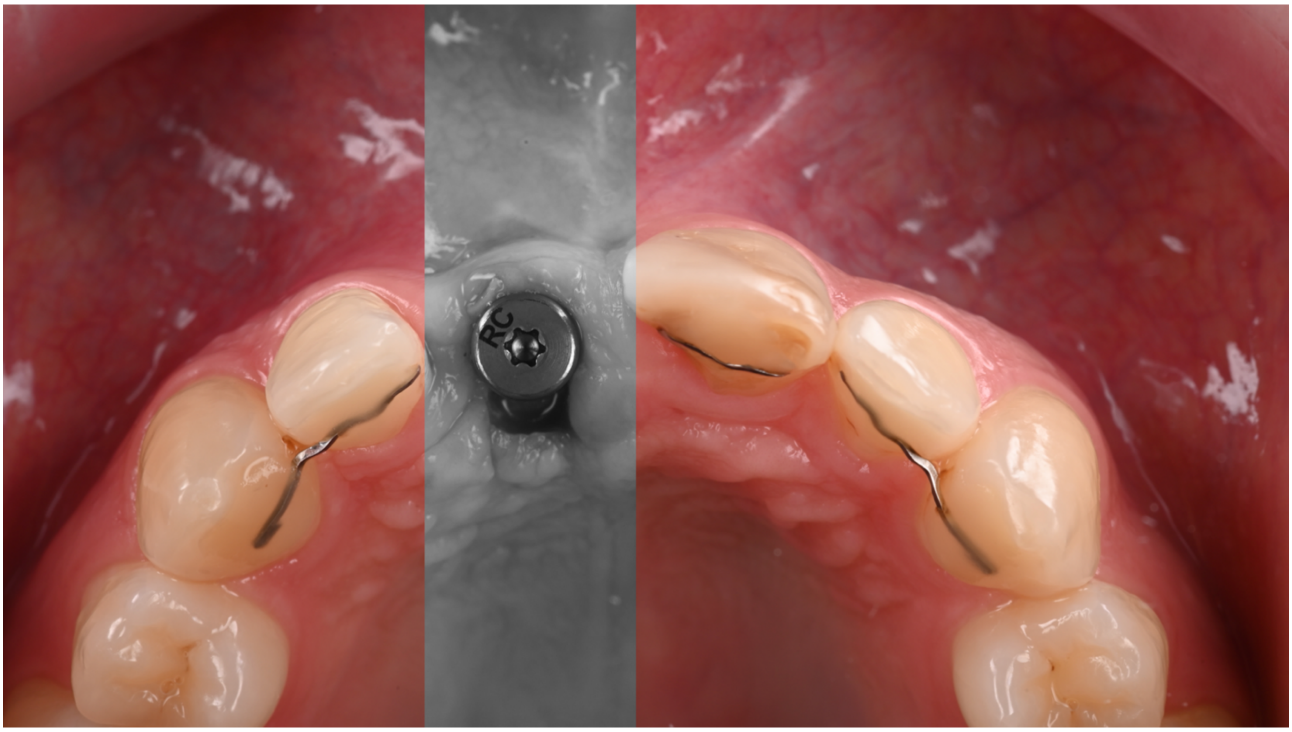

Figure 2. Implant position and soft tissue contour around the implant after healing abutment connection.

Phillips et al. stressed the need for implant restorations to harmonize with the crown form of adjacent natural teeth and the contralateral natural tooth (10). The color, texture, and location of peri-implant soft tissue, as well as the cervical profile of the implant restoration, play vital roles in the fabrication of implant-supported restorations (10,11).

To ensure a favorable prognosis, the artificial crown's form should closely mimic natural tooth morphology (12,13). Deviating from the natural tooth form can subject dental tissue to excessive stress and make it more vulnerable to disease. The primary etiological factors for caries and periodontal disease in natural dentition involve microbial plaque adjacent to the gingival tissue (12,14). Notably, plaque retention is prominent in the interproximal, lingual, and facial cervical surfaces of the teeth. Therefore, creating an ideal cervical contour for an artificial restoration that doesn't provide ecological niches for plaque is essential for the long-term prognosis of the restoration (Fig.2) (15).

Figure 3. The provisional crown lacks the necessary marginal contour, which should be crafted and shaped by the dentist during the provisional delivery.

To fabricate a restoration that promotes the health of the surrounding soft tissue, it's crucial to study the emergence profile of natural teeth. Croll described the emergence profile of a tooth as the axial tooth contour extending from the base of the gingival sulcus beyond the free margin of the gingiva into the oral environment (16). Buccally and lingually, the emergence profile extends to the height of contour of the clinical crown, while interproximally, it extends from the base of the gingival sulcus at the cemento-enamel junction (CEJ) to the contact area (16,17). Healthy natural teeth typically exhibit straight emergence profiles in the gingival third, with an emergence angle of approximately 15 degrees relative to the long axis of the tooth (Fig.3) . Contact areas are situated approximately 4 to 5 mm above the interproximal bone, and the embrasure area is filled with the interdental papilla (18,19).

Figure 4. After adjusting the emergence profile, the provisional crown supports the surrounding tissues and shapes them for the final restoration.

It's worth noting that over-contoured restorations can be more detrimental to gingival health than under-contoured ones. Excessive crown contours can act as plaque niches (12,20). Under-contoured restorations may result in hyperplastic gingival tissue. However, under-contoured restorations can be maintained with proper plaque removal procedures and circular tooth brushing techniques (12,20). When the emergence profile of a restoration is over-contoured, especially in the gingival third, it becomes challenging to remove bacterial plaque from the tooth surface that contacts the gingival sulcus below the height of contour (21).

To achieve an ideal emergence profile in a single implant crown (SIC), precise implant placement in a three-dimensional space is crucial. The utilization of custom abutments for restoration further enhances the restoration's form. Custom abutments provide support to the peri-implant tissue and allow for customized placement of the crown margin in cement-retained SICs (22). The location of the gingival margin of the future restoration serves as a guide to determine the depth of implant placement (Fig.4) . The angle of emergence also plays a significant role in establishing aesthetics and maintaining stable gingival architecture. For the emergence angle to be greater than 120 degrees, the depth of implant placement should be roughly equivalent to the horizontal distance between the buccal edge of the implant and the height of contour of the SIC. In other words, for every millimeter the implant is placed lingually, it should also be placed in an apical direction (23). Ideally, the placement of the implant platform should be approximately 3 mm below the CEJ of adjacent teeth to provide the required distance for establishing the correct emergence of the restoration (24).

The greater the horizontal distance between the buccal edge of the implant and the SIC contour at the level of the gingival margin, the more likely the emergence angle will approach 90 degrees. Severe angles of emergence require ridge-lap contours to create a coronal tooth form that conforms to adjacent teeth and mimics its natural counterpart (Fig.5) . Ridge-lap contours of an implant restoration result in increased plaque accumulation, hindering the maintenance of adequate oral hygiene around the implant restorations, often resulting in inflammation of peri-implant soft tissue, apical migration of the gingiva, and exposure of the implant abutment junction and/or implant threads (23). Over-contoured restorations usually have more plaque, often leading to gingival degradation and inflammation over time. It has also been shown that more extensive plaque accumulates on an artificial crown compared to a contralateral unrestored tooth. In a study conducted on natural teeth, it was found that a 170-degree emergence angle allowed for superior

Figure 5. Clinical steps from healing abutment connection to the definitive contour.

cleaning around the accessible margin compared to a 165 or 140-degree emergence angle (25). Radiographically determined bone changes and probing depth (PD) changes are commonly used to estimate the stability of sites or the progression of disease around natural teeth. These parameters have been extended for use with implants and may provide valuable information concerning periodontal stability, despite certain diagnostic limitations (26–29). Additionally, parameters like the presence or absence of bleeding on probing (BOP), suppuration, and visible plaque have been applied for implant site evaluation during maintenance (30,31). Although BOP may have limited predictive value for disease progression (32), these parameters offer additional insights into implant health.

Emergence profile

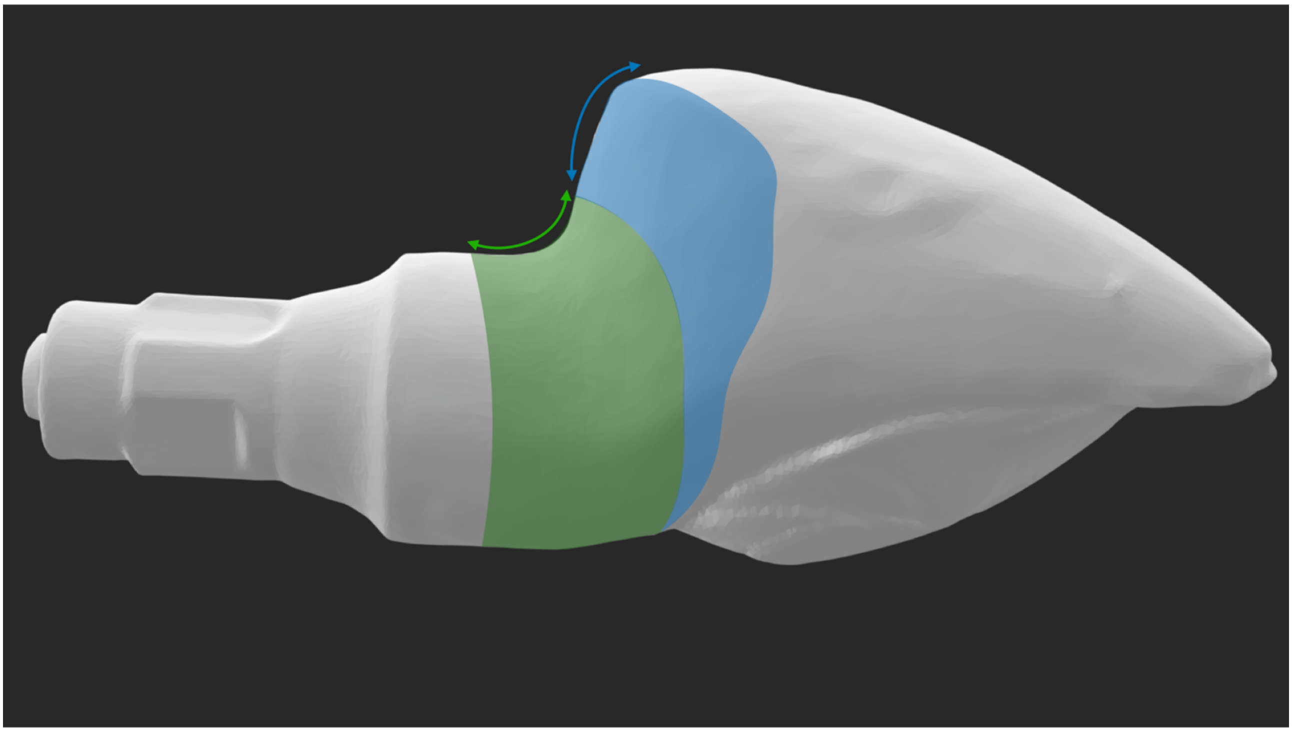

Figure 6. The green and blue areas are associated with different effects on the surrounding tissues. The green area represents the biological zone, while the blue area represents the aesthetic zone.

The research conducted by B. M. Croll in 1989, which aimed to establish anatomical norms for emergence profiles in natural teeth, has had a profound impact on the field of dentistry. The emergence profile, or the way a tooth emerges from the gums and extends into the oral cavity, plays a vital role in maintaining gingival health, preventing the retention of plaque, and enabling effective oral hygiene. It also has a direct correlation with the longevity and success of dental prostheses. To achieve proper coronal contours, a combination of periodontal and prosthodontic principles is essential during prosthesis production (Fig.6).

Croll's observations of natural tooth contours revealed that most measured surfaces exhibit a straight emergence profile. Specifically, he noted that the lingual surfaces of mandibular posterior teeth have straight emergence profiles from the cemento-enamel junction (CEJ) to points located one-half to two-thirds of the distance to the occlusal surface. In contrast, the emergence profile on the buccal surface of mandibular posterior teeth comprises three straight lines, collectively forming the entire facial profile. Restorations created with these facial contours closely mimic the appearance of natural teeth, contributing to a more natural and esthetic outcome (16).

Parkinson et al., in their 1976 work, emphasized that the success of dental restorations hinges on meticulous consideration of psychological, mechanical, and biological factors. The contours of artificial crowns are pivotal for maintaining soft tissue health and minimizing iatrogenic dental disease. It is crucial that the artificial crown form closely approximates the morphology of a natural tooth. When the contours of a dental restoration exceed the natural curvature, the restoration may compromise the natural defensive capacity of the surrounding soft tissues. Parkinson and his colleagues concluded that inadequately contoured restorations can stress dental tissues beyond their capacity to resist disease and are closely linked to the etiology of dental disease. They noted that microbial plaque present adjacent to the host's gingival tissues is the most common etiological factor in the pathogenesis, severity, and prevalence of periodontal disease (33).

Jameson et al., in their 1982 study, examined the relationship between crown contours and gingival health. They concluded that overcontouring of restorations is likely more detrimental to gingival health than undercontouring because excessive crown contours can facilitate the retention of plaque, leading to the formation of endemic plaque niches. The common gingival response to an undercontoured restoration, particularly in mandibular molars, is the development of hyperplastic tissue. However, this condition can be less damaging to the health of soft tissues if adequate plaque removal procedures and circular tooth brushing techniques are employed (20).

Parkinson's 1976 study further emphasized that crown contour plays a mediating role in plaque accumulation and gingival health at the tissue-restoration interface. Specifically, they found that 60% to 70% of teeth with overcontoured axial buccal surfaces exhibited gingival degradation and inflammation over time (33).

Sundh et al., in their 2002 research, evaluated the effect of crowns with different emergence profiles on marginal plaque formation. They found that an emergence angle of 170 degrees on an artificial crown made the margin more accessible to active cleaning compared to angles of 165 and 140 degrees. However, the self-cleansing effect remained relatively similar regardless of the angle (25).

Neale et al., in their 1994 study, stressed the importance of an appropriate emergence profile for implant-supported restorations. They highlighted that a proper emergence profile should be considered in all three dimensions to avoid the development of a 'ball on a stick' restoration. The emergence profile's relevance is directly related to implant placement, with the length of the subgingival portion of the restoration being particularly critical. Guided gingival growth ultimately depends on the depth of the implant (35).

These studies collectively underscore the critical role of emergence profiles in dental restorations, emphasizing the importance of accurately replicating natural tooth contours to maintain gingival health, prevent plaque-related issues, and ensure the longevity and esthetics of dental prostheses (Fig.7).

Figure 7. The ideal emergence profile in the anterior zone entails maintaining intact papilla at both the mesial and distal aspects of the edentulous ridge.

Ideal Implant placement

The ideal position for placing the implant platform is typically recommended to be approximately 3 millimeters below the Cementoenamel Junction (CEJ) of the adjacent teeth. This positioning allows for the necessary space to ensure that the final restoration emerges from its position in a manner that appears natural and aesthetically pleasing.

In cases where this 3 mm depth can be achieved, a prefabricated abutment may be employed to create the definitive prosthesis, simplifying the restoration process. However, if the depth of the soft tissue exceeds the 3 mm guideline, a customized abutment may be required to replicate the existing gingival contour and topography accurately. Customized abutments are especially useful in more complex prosthetic scenarios (Fig.8) (36).

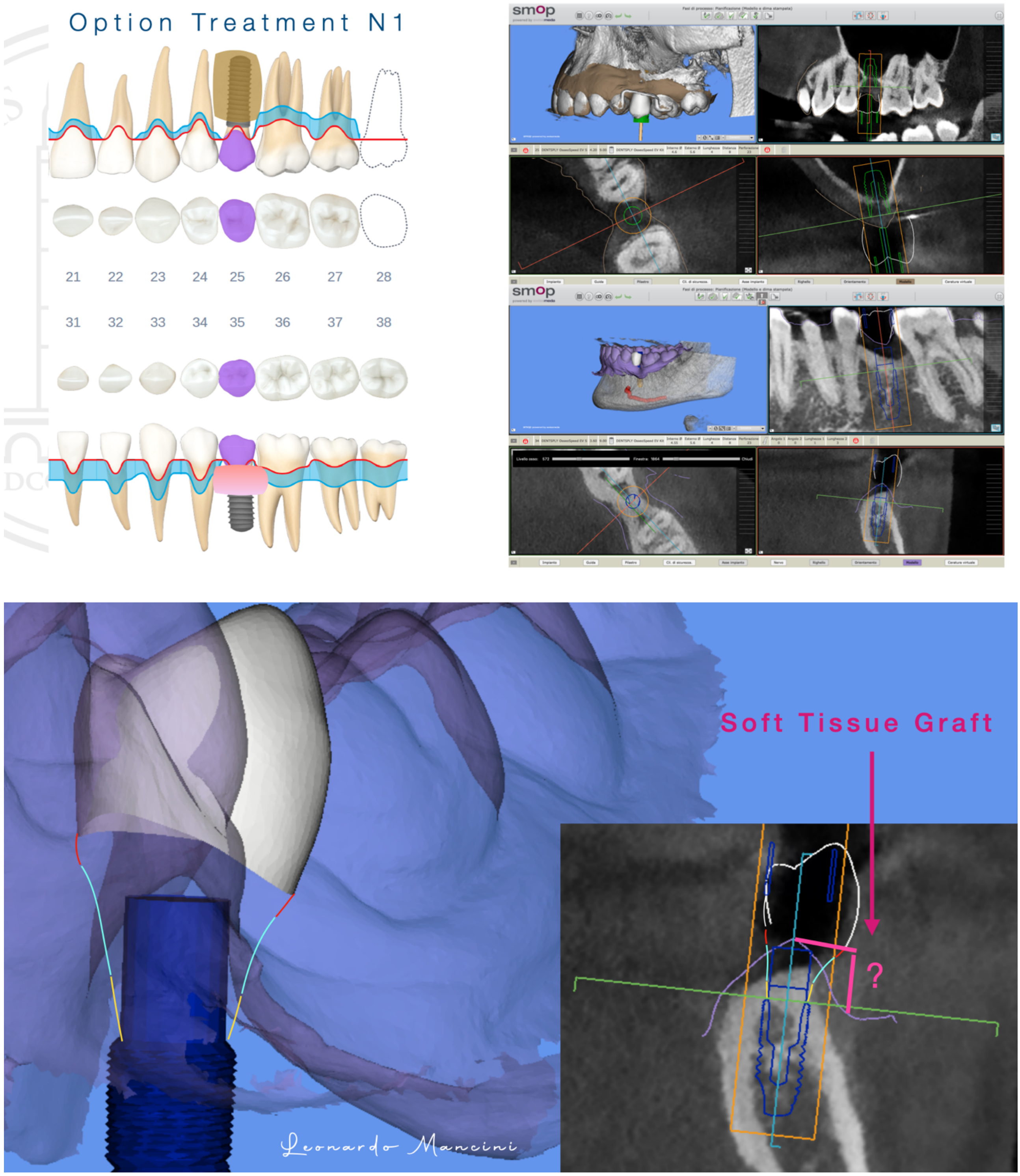

Figure 8. Implant planning involves crucial steps to determine the height of the emergence profile and the implant depth, ensuring proper tissue preservation and support.

Gingival indices

The inquiry into whether dental crowns impact the condition of periodontal tissues has been a subject of extensive examination within dental literature for many years. A specific focus has been directed toward understanding the interplay between periodontal health and the specific contour of dental crowns.

Each type of restorative material employed within the oral cavity, be it metal, ceramic, or acrylic resin, has the potential to attract plaque deposits. The chemical and physical properties inherent to each material result in varying compositions and the retention of plaque. Consequently, the subsequent periodontal reactions differ not only between materials but also among individual patients. Notably, porcelain, due to its chemical composition, is highly biocompatible and exhibits a reduced propensity to accumulate soft debris (19).

In a study conducted by Vered Y and colleagues in 2011, a comparison was drawn between dental implants and natural teeth situated on the opposite side of the oral cavity. This study scrutinized clinical health indices and microbiological parameters, revealing that plaque accumulation was more pronounced around natural teeth in contrast to dental implants. Furthermore, natural teeth exhibited a tendency toward heightened gingival inflammation and bleeding on probing (BoP) when compared to dental implants (37,38).

Peri-implant mucositis is characterized as a reversible inflammatory process that occurs in the soft tissues surrounding a functional implant, while peri-implantitis is marked by inflammation accompanied by the loss of bone surrounding the implant. It is well-established through both animal experimentation and clinical studies that the formation of subgingival biofilm is a pivotal etiological factor in the initiation of peri-implant inflammation and subsequent loss of marginal bone (39–41).

It has been observed that the inflammatory and immune responses exhibited by the peri-implant mucosa resemble those of the periodontal tissues around natural teeth when confronted with bacteria and pathogens originating from biofilm. This implies that the peri-implant tissue's response to bacterial challenges may follow patterns akin to those seen in periodontal tissues, especially in individuals who are susceptible to these conditions (42). However, it remains uncertain whether individuals susceptible to periodontitis are also predisposed to peri-implantitis. Nevertheless, there is substantial evidence supporting an association between periodontitis and peri-implantitis as indicated in a few reports (Mombelli et al. 1995, Ellegaard et al. 1997, Karoussis et al. 2003) (42).

Inflammation affecting both hard and soft peri-implant tissues, triggered by bacterial biofilms, is now widely acknowledged as one of the foremost challenges in the field of dental implantation, with the highest incidence of implant loss occurring within the initial 12 months (43).

Notably, certain bacteria, including Aggregatibacter actinomycetemcomitans and Porphyromonas gingivalis, have been recurrently isolated from diseased periodontal or peri-implant sites and are recognized as particularly relevant to the development of chronic inflammatory processes in the context of both periodontal and peri-implant health (43).

The pathological processes and the composition of bacteria found at implant sites and around teeth affected by periodontitis have been meticulously documented. This comprehensive description lends support to the notion that cross-contamination from natural dentition to dental implants is a genuine concern, potentially jeopardizing the health of implant sites, particularly in cases where there is no pre-existing inflammation (43).

EVALUATION OF THE PERI-IMPLANT MARGINAL TISSUES

Plaque assessment

Mombelli and colleagues (30) made modifications to the original Plaque Index developed by Silness and Löe (44) to create a tool for assessing biofilm formation in the marginal area surrounding dental implants, known as the modified Plaque Index (mPI).

Lindquist and their team (45) assessed oral hygiene levels using a 3-point scale and found a noteworthy association between oral hygiene practices and the resorption of peri-implant bone over a 6-year observation period. This suggests that maintaining good oral hygiene is vital for the long-term health and stability of dental implants.

Mucosal condition

Peri-implant infections can lead to various symptoms, including swelling and redness of the marginal tissues, bleeding on probing (BOP), the formation of pockets around the implant, and suppuration (30). These are important clinical signs to monitor for in the context of implant health.

To assess and define peri-implant parameters, it is suggested to utilize periodontal indices, such as the Gingival Index System (GI) (46). The GI has been adjusted and tailored for use around dental implants, referred to as mGI (30). Additionally, Apse and colleagues have proposed a simplified version of the Gingival Index (simplified GI) for assessing peri-implant gingival health (47). These indices and systems provide valuable tools for evaluating the condition of tissues around oral implants and monitoring their health.

Peri-Implant Probing

Histologically, the tissue surrounding dental implants, known as peri-implant mucosa, bears similarities to the mucosa around natural teeth. It comprises well-keratinized oral epithelium, sulcular epithelium, and a thin barrier epithelium facing the abutment, which corresponds to the junctional epithelium seen around natural teeth. This abutment-facing epithelium is referred to as the peri-implant junctional epithelium. The height of the peri-implant junctional epithelium is typically around 2 millimeters, with the underlying connective tissue measuring approximately 1.0 to 1.5 millimeters. As a result, the overall biological width, which includes the depth of the sulcus, can often exceed 3 millimeters (48).

The significance of probing, whether around natural teeth or dental implants, has been extensively documented in the dental literature. One notable difference between these two structures is that probing depth at implant sites is generally deeper compared to tooth sites (48). Care must be taken during probing, as slight increases in pressure may sometimes result in injury if the probe goes beyond the peri-implant seal (49). However, it's worth noting that not all researchers agree on the substantial differences in probing depth between implants and natural teeth (50). Nevertheless, there is a general consensus that probing depth tends to be greater in implant sites, and bleeding on probing (BOP) is more sensitive to minor pressure changes at implant sites (49).

To evaluate the stability of sites or the progression of disease around natural teeth, radiographically determined bone changes and probing depth (PD) changes are commonly employed. These parameters are also applied to dental implants and can offer valuable insights into periodontal stability, although there are still some limitations concerning diagnostic accuracy (51–54).

Recent applications in maintenance protocols include assessing the presence or absence of Bleeding on Probing (BOP), suppuration, and visible plaque at implant sites. These parameters are used to monitor the health of implant sites. However, it's important to note that while Bleeding on Probing (BOP) may provide some information, its predictive value for disease progression may be limited (56).

CAD-CAM

Computer-Aided Design/Computer-Aided Manufacturing (CAD/CAM) technology was initially adopted by the aviation and automotive manufacturing industries in the 1960s before making its way into dentistry roughly a decade later.

The very first CAD/CAM system used in dentistry was the Sopha system, introduced by Francois Duret of France in 1984. This system featured an optical scanner for obtaining a digital impression of a prepared tooth, a computer equipped with the necessary software for planning a restoration, and a numerically controlled milling machine for fabricating the designed restoration (57).

The commercialization of intraoral scanners (IOS) like CEREC allowed for the digitization of dental conditions directly in the patient's mouth (58,59). Since the late 2000s, there has been a significant increase in the availability of commercial IOS with scanners capable of capturing complete dental arches (60).

In a study conducted by R. Nedelcu and colleagues, the accuracy of three intraoral scanners (3M True Definition, CEREC Omnicam, and Trios 3) was evaluated in vivo, and it was concluded that 3M and Trios had high accuracy for full arch scans, making them suitable replacements for conventional impressions for restorations involving up to ten units without extended edentulous spans (61).

In a study by Beatriz et al. in 2016, the accuracy and repeatability of True Definition scanners in full arch implant scans were examined, and the findings indicated that the TrueDef scanner provided measurements within clinically accepted limits (62).

The importance of achieving an ideal emergence angle in dental restorations is widely acknowledged. However, information regarding the acceptable range of emergence angles in restorations remains limited.

The emergence profile of dental restorations plays a crucial role in the clinical outcomes and the development of peri-implant diseases. This is particularly significant in the context of dental implants and their prosthetic restorations. Traditionally, the assessment of these restorations was mainly done through a two-dimensional analysis of periapical X-rays taken at the mesial and distal portions of the implant site. This analysis was used to determine the angle and its impact on the surrounding tissues, particularly the bone.

However, this approach had limitations, as it did not provide reliable data on the buccal aspect of the implant site. The buccal aspect refers to the outer aspect of the restoration, which faces the lips and cheeks, and is a critical area when it comes to soft tissue recession and bone remodeling around dental implants. The lack of comprehensive data on the buccal aspect made it challenging to fully understand and address the impact of restoration design on soft tissue health and bone support.

Recent evidence has highlighted the importance of considering the buccal aspect when evaluating implant restorations. It has become increasingly clear that the emergence profile on the buccal side can significantly influence clinical outcomes and the development of peri-implant diseases. A well-designed emergence profile takes into account factors such as the contour, shape, and position of the restoration to ensure that it promotes healthy soft tissue and bone support.

Understanding the influence of the buccal aspect on peri-implant health has led to improvements in treatment planning and restoration design. Clinicians are now more focused on achieving a harmonious emergence profile that supports esthetics and maintains the health of the surrounding tissues. This may involve customizing the restoration to match the natural contours of the patient's gums and adjacent teeth.

Figure 9. Implant position in relation to the soft tissue contour after individualizing the emergence profile.

In summary, the emergence profile, particularly on the buccal aspect, has gained increasing attention in dental implantology due to its impact on clinical outcomes and peri-implant health (Fig.9) . Clinicians now recognize the need to consider this aspect when planning and designing implant restorations to optimize both esthetics and the long-term health of the implant site.

Introduction to the study

The emergence profile is defined as the transmucosal area between the implant shoulder and the mucosal margin. This transition zone is vital as it provides the support and stability of the peri-implant soft tissues allowing to fabricate natural-looking implant-supported restorations. Recent anecdotal reports highlighted the importance of the transmucosal zone suggesting two functional sections in any implant-supported restoration: the biological contour (BC) and the esthetic contour (EC). (63,64) These sections are described as dynamic areas, which can be identified by observing the profile change in the transmucosal area surrounding the implant-supported crown in a 360° manner.

The biological contour refers to the typical concave shape near the abutment connection, while the esthetic contour represents the convexity extending up to the neck of the implant-supported restoration (Fig. 10A). The handling of these areas during the provisional and definitive restorations is crucial for the stability of the soft tissue,3 the esthetic appearance and peri-implant health over time. (65,66)

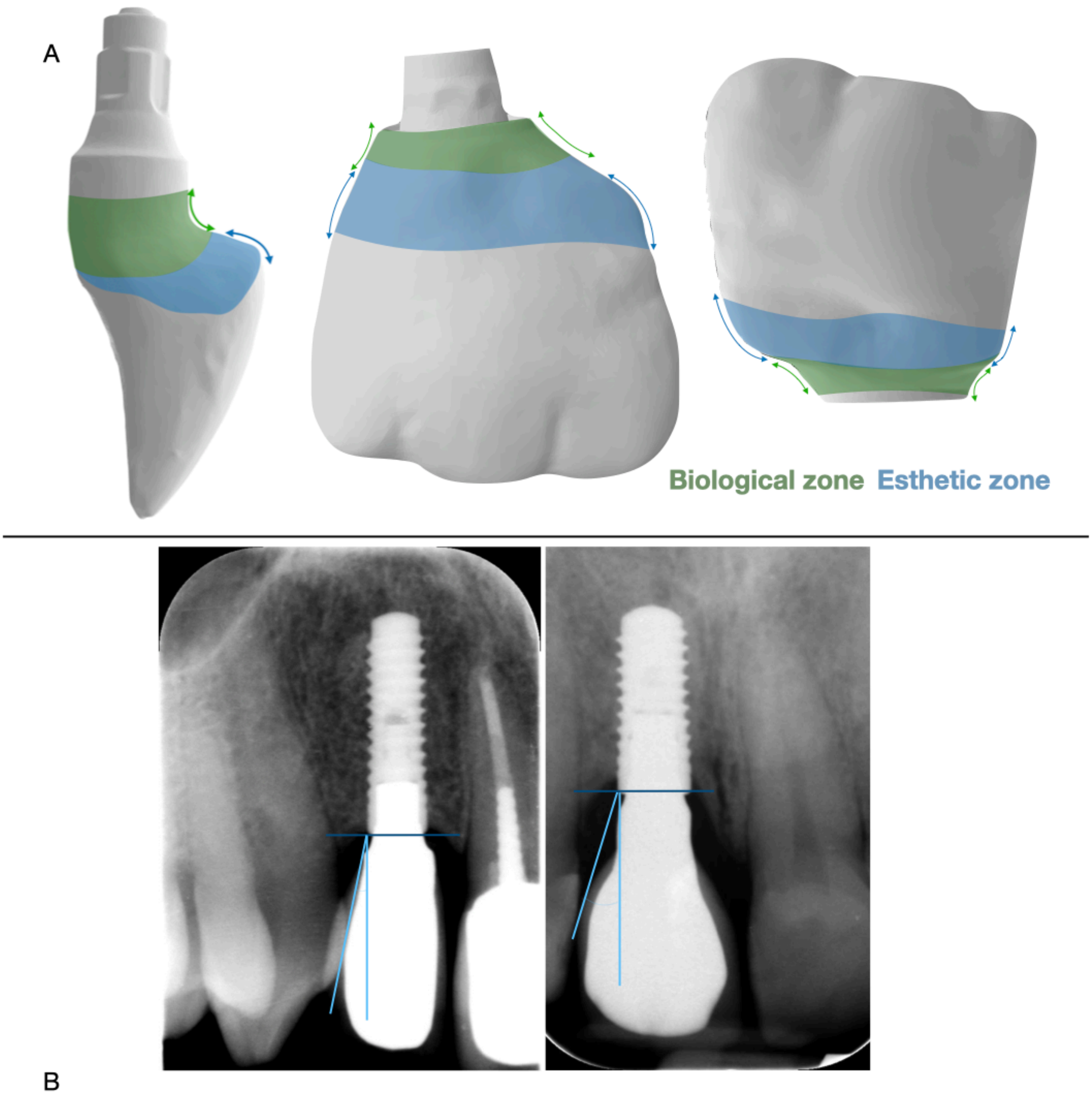

Figure 10. Emergence profile and restorative angle. A, Representative STL images of implant-supported crowns illustrating the biological zone (highlighted in green) and the esthetic zone (highlighted in light blue). B, Representative radiographs showing the calculation of the restorative angle on implant-supported crowns.

Recent clinical reports have sought to define an optimal management of the emergence profile based on the prosthetic contour and other factors including implant type, implant depth, implant diameter, soft tissue thickness and type of abutment.(64,67)However, these reports have predominantly relied on qualitative descriptions and have not included any quantitative assessment. Moreover, the concrete description of the zones was not verified 3-dimensionally, which hindered an estimation of the restorative angles associated with different sections, such as the biological contour and esthetic contour.(68)

Typically, the emergence profile has been evaluated 2-dimensionally, using peri-apical x-rays (Fig. 10B). (68-72) Despite its ease and simplicity, this method is limited to assessing the implant-supported crown at mesial or distal sites in a 2-dimensional manner.(69) With the introduction of optical scanners this limitation can be circumvented enabling clinicians and technicians to accurately estimate the restorative angle and the ensuing emergence profile in three dimensions.

The purpose of the present study was, therefore, to describe a novel 3D method to assess the restorative angle and the emergence profile that may serve as a guideline for future clinical trials.

Materials and Methods

A total of thirty implant restorations were extra-orally scanned from two dental laboratories using an intraoral scanner (Prime scan; Dentsply Sirona;), and the STL-generated files were then used for a 2D and 3D analysis.

2D angle analysis

STL files of each restoration were imported into a 3D imaging software (GOM inspect; GOM,) and positioned in such a way to illustrate the crown profile at the mesial and distal sites, mimicking a periapical radiograph. Pictures were taken and imported into an online program (ginifab.com) that allowed the measurement of 2D angles with a digital goniometer. The resulting images were analyzed as previously described 69,72) using the implant/abutment interface and the longitudinal axis of the implants as references. The resulting mesial and distal angles were then calculated (Fig. 11).

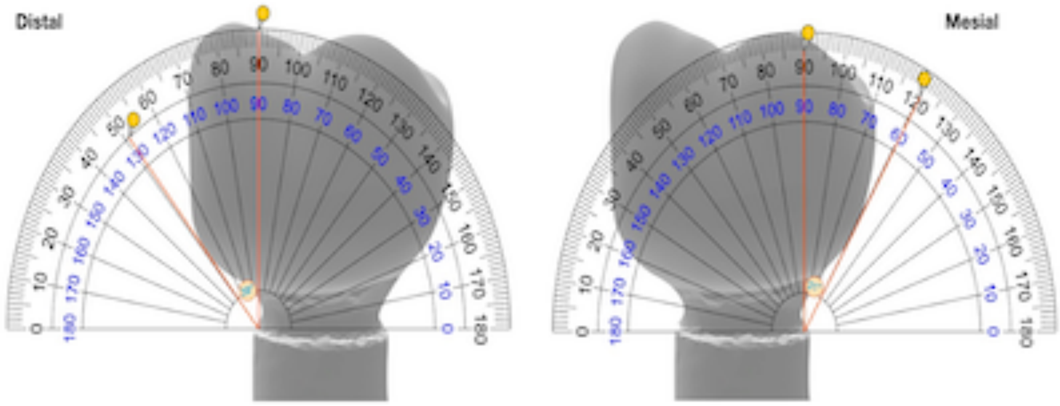

Figure 11. Example of a 2D restorative angle estimation for distal and mesial sites.

3D angle analysis

The emergence profiles were analyzed using a 3D imaging software package (GOM inspect; GOM,). STL files were imported into the 3D software and the abutment base of each crown was outlined with a circular blue zone to generate the crown/abutment interface and to illustrate the transition zones (Fig. 12A). Lines were automatically drawn sagittally and radially from the base of the abutment (Fig. 12B-C). Lastly, using a 3-point estimation method, three automatic points were selected for each line to compute the angle (Fig. 12D). The three points were determined by an algorithm capable of identifying the highest point, the deepest point, and the midpoint along the line used for analysis. This approach allows for the measurement of the angles.

The emergence profile was described by calculating the angles for both the biological and esthetic zone. The procedure was repeated for the buccal, mesial, and distal sites (Fig. 13).

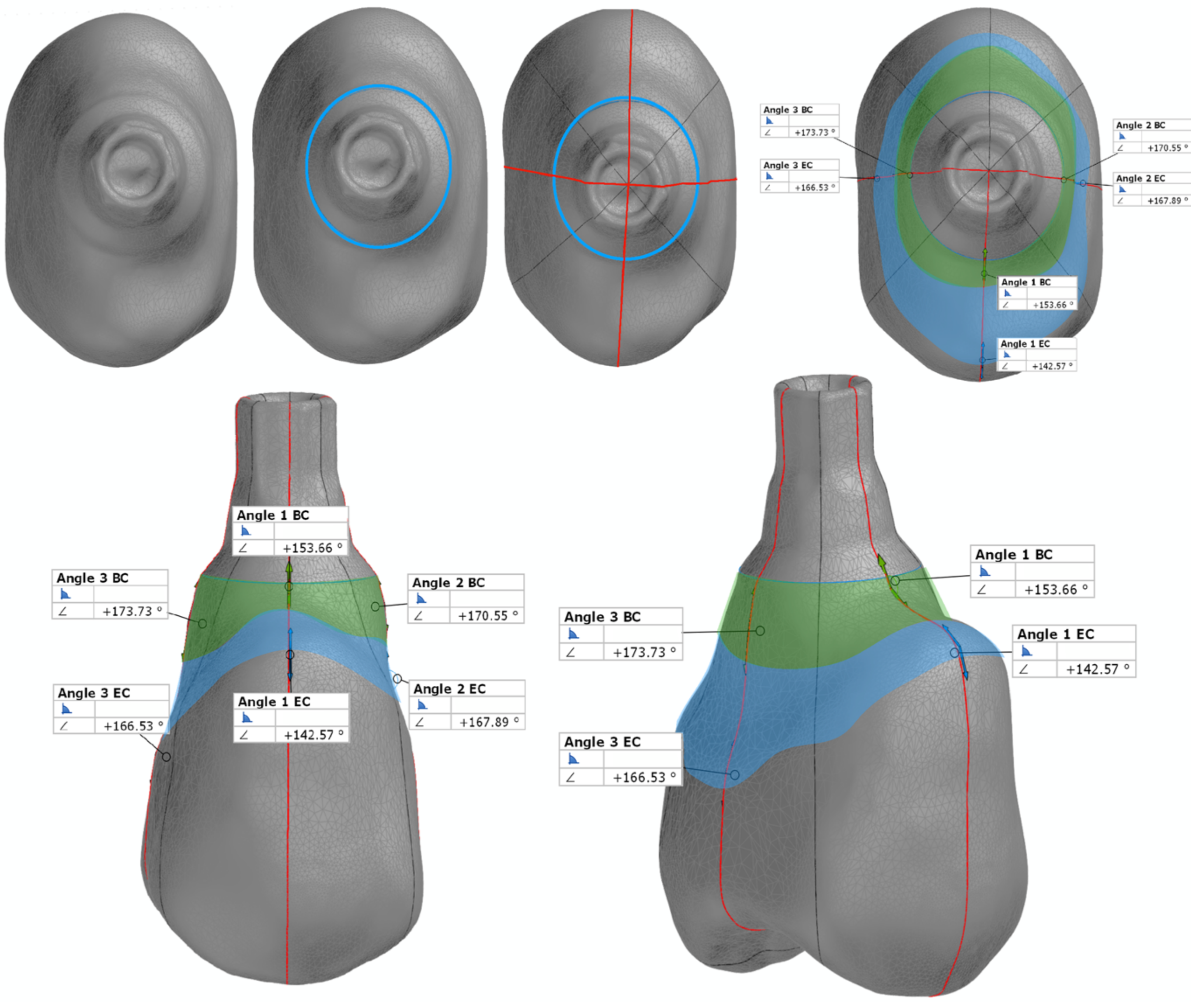

Figure 12. Angle estimation method step by step. A, B, Identification, and delineation of the abutment/crown interface (circular blue line). C, Delineation of the mesial, buccal, and distal lines (in red). D, Angle estimation of the biological and esthetic zone with the automatic three-point detection method (EC). E, F, Frontal and lateral view of the estimated angles.

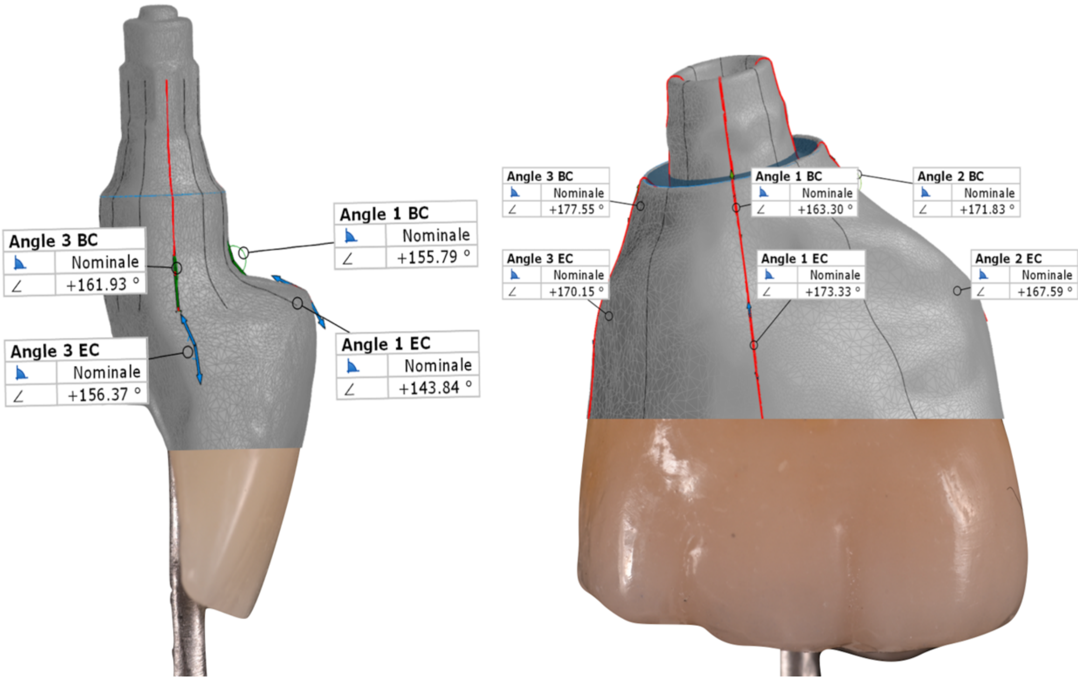

Figure 13. Angle estimation method on two different implant-supported restorations.

Statistical Analysis

A software program (Excel, Microsoft Corporation,) was used to process the data. For the metric variables, mean, standard deviations, median and quartiles were calculated. Due to the exploratory nature of this study, only descriptive statistics were performed using Prism v9 (GraphPad,). The sample size was chosen pragmatically and based on clinical experience and availability. This methodological decision was made to obtain initial but meaningful point estimates and effect sizes for future randomized controlled trials.

Results

A total of 30 implant-supported crowns were used for the analysis posterior Mandible (molars 5 and 5 premolars), 9 in posterior maxilla (5 molars and 4 premolars). 11 anterior restorations only in the maxilla (8 centrals, 2 lateral incisors, and 1 canine. All crowns were mounted onto a ti-base abutment varying in size and diameter according to the specific implant system and design (BL, SLActive, Institut Straumann AG). The reliability of the measurements (2D and 3D) was assessed using the intraclass correlation coefficient (ICC). The ICC for all measurements ranged between 0.77 (95% CI:0.07-0.94) and 0.99 (95% CI:0.97-0.99) indicating a good intra-examiner reliability.

2D angle analysis

The 2D analysis found a mean angle of 29.6±11.3° at mesial sites and of 27.4±9.1° at distal sites for anterior restorations. For posterior restorations the mean angle amounted to 36.2±11.2° at mesial sites and to 39.0±14.2° at distal sites (Fig. 14A).

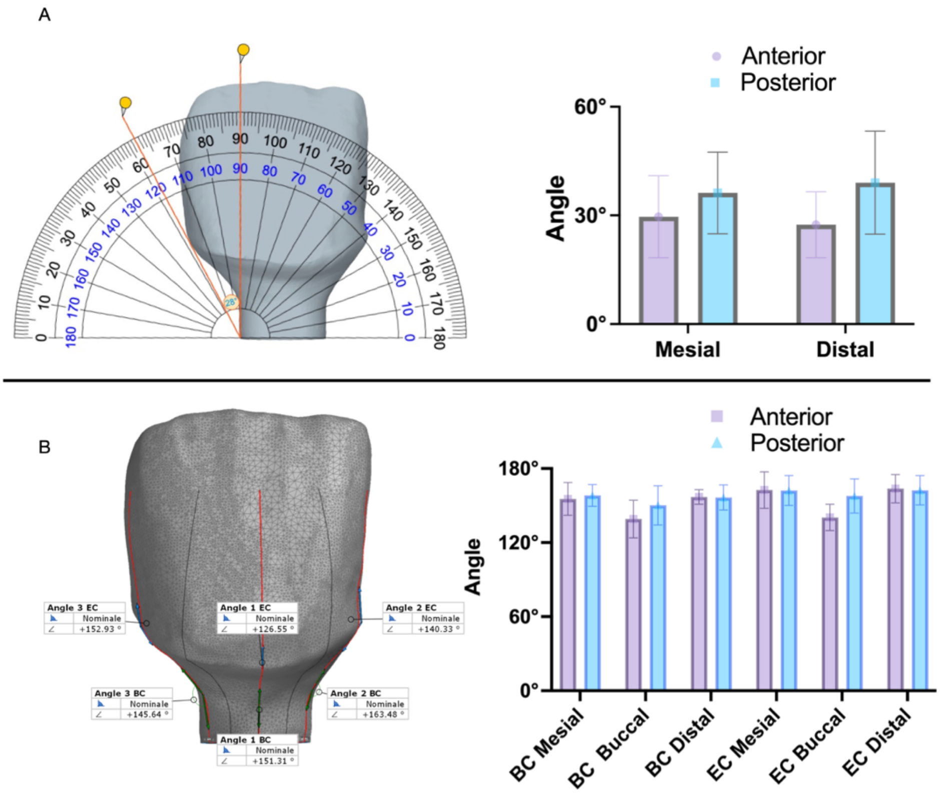

Figure 14. A, Graphic representation of the 2D analysis of the restorative angle, the mean values ± SD of the restorative angle at mesial and distal sites according to location (anterior/posterior). B, Graphic representation of the 3D analysis, the mean values ± SD of the restorative angles at the biologic (BC) and esthetic (EC) zone according to location (anterior/posterior).

3D angle analysis

The angle estimates at the different regions interest are presented in Table 1. The 3D analysis detected two angles per site, one for the esthetic zone and one for biological zone. In addition, the 3D method allowed the analysis of the buccal aspect. In anterior restorations, the mean angle of the esthetic zone amounted to 162±14° at mesial sites, to 140±10° at buccal sites and to 163± 11° at distal sites. The corresponding angles at the biological zones, amounted to 155±13° at mesial sites, 139±15° at buccal sites and 157±5° at distal sites. In posterior restorations, the mean angle of the esthetic zone amounted to 162±12° at mesial sites, to 157±13 at buccal sites and to 162±11 at distal sites. The corresponding angles at the biological zone, amounted to 158±8 at mesial sites, 150±15° at buccal sites and 156±10 at distal sites.

	Mesial	Buccal	Distal
Anterior			
Esthetic (°)	162±14 [166 (140;179)]	140±10 [134 (133;149)]	163±11 [165 (152;175)]
Biological (°)	155±13 [156 (142;166)]	139±15 [142 (138;148)]	157±5 [156 (150;163)]
Posterior			
Esthetic (°)	162±12 [165 (154;168)]	157±13 [158 (153;169)]	162±11 [164 (154;171)]
Biological (°)	158±8 [158 (152;166)]	150±15 [154 (145;158)]	156±10 [156 (151;163)]

Table 1. Summary of angle estimates at the different sites (mesial, buccal and distal) according to the region of interest (esthetic or biologic zone) and location (anterior or posterior).

Note: Data presented as mean±SD [median (Q1, Q3)].

Discussion

The present study intruduced a novel 3D method technique to calculate the emergence profile and restorative angles of single implant-supported crowns. This new method overcomes the limitation of the traditional 2D approach, which only allows measurements of restorative angles at mesial and distal sites.(69-72) This is of vital importance as recent evidence indicates that the emergence profile and the ensuing restorative angles are significantly associated with the stability of midfacial mucosal margin,3 and marginal bone levels.(69,71,73) The present report showed that in general the restorative angles for mesial and distal sites were similar regardless of jaw location (anterior vs. posterior) (Maxilla vs Mandible). This similarity may be attributed to the implant placement within the bony envelope, resulting in minimal interproximal tissue discrepancies such as marginal bone height. Notwithstanding, the restorative angle between anterior and posterior restorations did differ, most likely due to the implant diameter used. The implant diameter for anterior restorations is closer to the natural tooth root than in the posterior restorations, resulting in a smoother transition from the implant platform to the restorative angle.

Interestingly, the esthetic and biological contours on buccal sites tended to be lower at anterior restorations, leading to a more pronounced concave shape. A recent RCT found that a concave shape is better for midfacial mucosa stability than a convex shape as it lessens pressure on soft tissues leaving room for tissue in-growth (65) and thus reducing the risk of developing midfacial mucosal recessions.(65)

Despite the numerous attempts to establish an appropriate emergence profile, most available clinical studies lack of quantitative analysis or rely on radiographs (2D analysis).(74) This is probably the cause for the current absence of evidence-based prosthetic guidelines for implant-supported restorations. This novel method can potentially improve communication between clinicians and dental technicians, which may pave the way for the introduction of prosthetic guidelines for implant-supported restorations. In addition, from research perspective, this tool may predict the impact of the emergence profile on clinical outcomes including mid-facial tissue changes and marginal bone loss.

The present technical report has some limitations. This is an in vitro study with a limited sample size, therefore, the clinical implications of the findings and their association with actual clinical outcomes are yet to be fully understood and explored. Moreover, this study did not assess confounding variables that naturally impact the form and shape of the restorations, such as the horizontal and vertical position of the implant.

Conclusion

Within the limitations of the present study, the 3D analysis seems to be a reliable and applicable method for the quantitative evaluation of the emergence profile in daily practice. Future randomized clinical trials are needed to assess whether a 3D analysis with the ensuing emergence profile serves as a predictor for clinical outcomes.

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