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The Bio-Restorative Concept for Implant-Supported Restorations

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ABSTRACT

Objective: This study aims to present the bio-restorative approach in implant dentistry, which combines biological and restorative concepts through digital planning. This concept combines periodontal, surgical, and prosthetic variables, aiming to reduce patient morbidity while achieving satisfactory esthetic and functional outcomes in implant-supported restorations in the long term.

Overview: Implant dentistry evolved from a primarily surgical to a recent prosthetically driven approach. This evolution was partly due to advancements in bone reconstructive techniques and an increased demand for esthetic outcomes. Recently, digital planning has introduced a new paradigm that allows for the full integration of both approaches. The bio-restorative concept considers functional, esthetic, and biological variables in a virtual planning environment. This is achieved through the simultaneous digital assessment of (A) anatomical site characteristics and (B) implant restorative variables. These variables include digital tooth arrangement, soft–hard tissue conditions, implant variables, supra-platform components, and a surgical plan that respects or modifies peri-implant phenotype.

Conclusions: The bio-restorative concept is intended to improve contemporary implant dentistry by integrating updated biological and prosthetic notions through digital planning. Adopting this paradigm has the potential to redefine the standards in implant dentistry, fostering a holistic and patient-centered approach.

Clinical Considerations: It enhances patient and clinician satisfaction through more efficient and less invasive procedures. Significantly, it improves predictability, leading to successful implant-supported restorations in the long term.

1 | Introduction

Dental implants and their restorative components are integral elements for a unified treatment approach to restore teeth. The success in implant dentistry rests in the long-term outcomes of the implant-prosthetic complex [1]. Similarly, among the different implant treatment modalities, it is paramount that the planning phase should comprehensively evaluate a combination of implant placement and loading protocols [2], ideally prior to tooth extraction.

The treatment concepts in implant dentistry have evolved through a combination of technological advances and scientific evidence. Initially, implants were placed in areas with sufficient bone, the so-called "surgically driven implant placement." However, bone augmentation procedures became more predictable and the

The SQUIRE reporting guidelines has been applied in this manuscript.

importance of an adequate biomechanical relation between abutments and implants was recognized. Thus, the seek to achieve improved esthetic and functional outcomes shifted the surgical protocols toward a "prosthetically driven implant placement." This current concept is based on the 3D implant positioning aligned with the intended restoration, facilitates the prosthetic design, enhances the esthetic outcomes, and reduces potential mechanical complications. However, it may involve additional treatment complexity or interventions due to its inherent need for concomitant regenerative procedures. In the last decade, the incidence of peri-implant diseases has shifted the focus toward achieving peri-implant health, giving more relevance to the peri-implant soft tissues and the implant supra-platform complex [3].

The advent of digital technologies provides a new treatment concept where the most suitable surgical (biological) and prosthetic (restorative) strategies can be pre-assessed in a virtual environment and then combined into a comprehensive approach, the so-called "bio-restorative concept." This concept encompasses digitally assisted elements of diagnosis, treatment planning, and sequencing, thus optimizing the biological and restorative elements of the implant-supported restorations (ISR).

This article introduces the rationale behind utilizing the bio-restorative concept. We provide a checklist that serves as a strategic guideline for the future development of this concept, following evidence-based recommendations and digital technologies.

2 | Key-Element of the Bio-Restorative Concept

The key elements presented in Figure 1 constitute the integral components of the bio-restorative concept. They should be assessed in combination with the most suitable implant placement and loading strategies. These elements aim to respect or reconstruct the peri-implant phenotype through a comprehensive diagnosis and planning that entails the design of the intended restoration, implant design and its 3D position, selecting optimal prosthetic components, and surgical strategy.

2.1 | Digital Tooth Arrangement

Any ISR aims to provide a functional and esthetic outcome that harmonizes with the patient's orofacial structures and occlusion [4, 5]. To achieve this goal, the proposed bio-restorative concept should start with a meticulous diagnosis of the edentulous site to assess the biological and restorative determinants relevant to the successful outcome of the ISR. These determinants include (1) the number and size of teeth missing or to be replaced, (2) incisal edge/central fossa positions, (3) prosthetic volume and configuration, (4) mucosal contours, (5) the need for surgical or prosthetic tissue replacement, (6) extraoral factors (facial analysis), and (7) occlusion. Notably, the ISR should be designed to promote biological integration, conducive to effective oral hygiene procedures, to ensure a long-term prognosis free of biological complications, and achieve good soft tissue esthetics (Figure 2).

To achieve the link between the implant and ISR, digital tools are employed, either with a scanned conventional diagnostic wax-up or with a fully digitized workflow superimposing the radiographic anatomical information (e.g., DICOM files) with the scanned digital images (e.g., PLY or STL files). A diagnostic mock-up may be of added value for full-arch restorations (Figure 3).

2.2 | Assessment of Soft and Hard Tissues

The peri-implant phenotype encompasses the morphological and dimensional characteristics of the tissues surrounding a functional ISR [6].

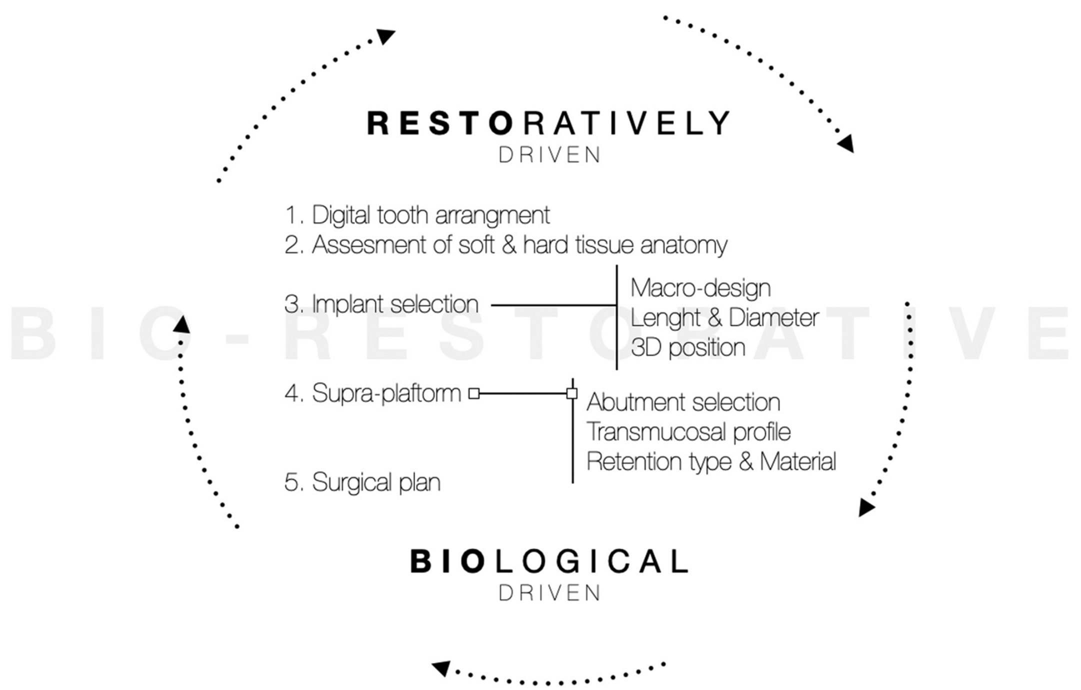

FIGURE 1 | Key-element points of the bio-restorative concept.

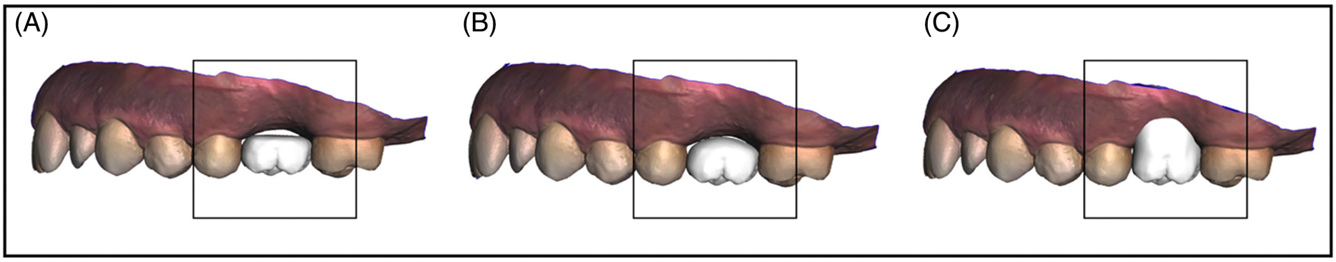

FIGURE 2 | Representation of three different digital tooth arrangement. (A) Diagnose of lack of tissue by recreating the ideal mucosal contours; (B) Bio-restorative design (optimal cervical margin of ISR determined by the natural shape of the missing and adjacent teeth); (C) Ridge-lap design incompatible with a biological integration.

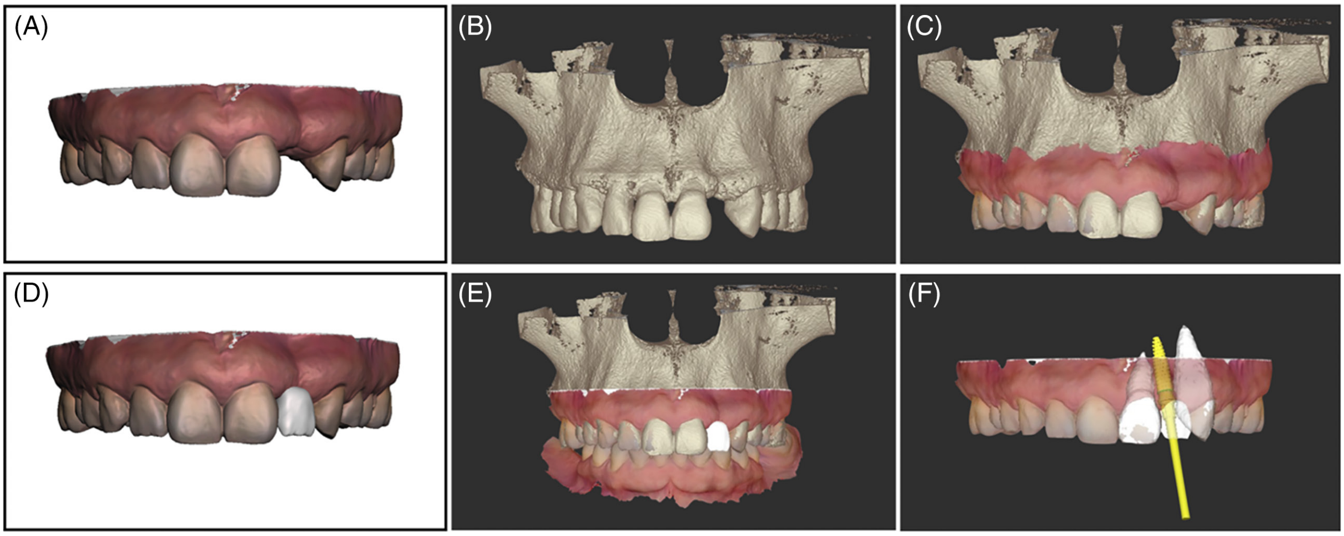

FIGURE 3 | Registration process (superimposition) of digital tooth arrangement for virtual implant planning. (A) Baseline IOs (PLY); (B) Baseline CBCT scan render (DICOM); (C) Registration of A + B; (D) Digital tooth arrangement performed on (A); (E) Registration of D + C to include intended restoration design—note that lower IOs is also registered to assess occlusion; (F) Virtual implant planning based on (E)—note that adjacent teeth segmentation provides additional visual information of adjacent teeth roots position.

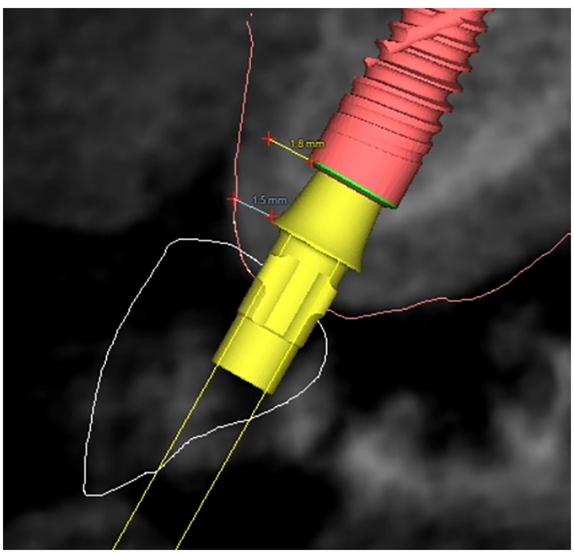

FIGURE 4 | Digital phenotype assessment prior to implant placement. Note how a thick periodontal phenotype is present according to the virtual digital planning.

It consists of a soft tissue component, entailing keratinized mucosa width (KMW), mucosal thickness (MT), and height of the supracrestal tissues (STH), as well as an osseous component, namely the bone thickness (BT). The relative dimensions of these components may significantly influence the planning (e.g., implant selection, need for tissue augmentation), execution (e.g., implant fixture position, transmucosal components material, and design), and outcome of the ISR (e.g., tissue stability and potential incidence of biological complications).

Presurgical assessment of these soft and hard tissue dimensions can be done by combining digital information from optical surface scans (e.g., PLY or STL files) and 3D radiographic imaging (e.g., DICOM files) (Figure 4). This strategy allows for a virtual—noninvasive—and exact evaluation of the peri-implant phenotype to determine the treatment needs [7–9] (Figure 5).

Recent evidence has emphasized the importance of a minimum dimension of these peri-implant components to achieve predictable outcomes and long-term treatment success (KMW ≥2 mm, MT ≥2 mm, STH ≥3 mm, and PBT ≥2 mm) [10–12]. Contemporary clinical practice [13] prioritizes the peri-implant soft tissue component to achieve successful outcomes [14] of minimal BT or even dehiscence defects [15–17]. However, the presence of an adequate peri-implant phenotype, including minimal BT, may be critical when planning specific implant surgical interventions, such as immediate implants, since they can largely influence the patterns of alveolar bone resorption [18], the translucency of transmucosal components [19], and soft tissue volume stability [19, 20]. Implant planning considerably differs from other implant placement strategies (i.e., early or conventional) and nonesthetic posterior sites.

This thorough assessment, combined with the most suitable implant placement and loading strategies, aims to respect or reconstruct the peri-implant phenotype.

2.3 | Implant Selection

2.3.1 | Macro-Implant Design

The choice for a specific macro-implant design may depend on the clinical situation. Specifically when high-insertion torque and efficient load distributions to the implant restorations are intended. Other factors, such as bone quality and configuration, may influence selecting a specific macro-implant design. For example, "tapered implants" may prevent apical bone fenestration in sites with prominent ridge concavities [21] or increase insertion torque [22].

Although tissue-level implants have demonstrated a lower prevalence of peri-implant diseases [23] and have been reported successfully in the esthetic zone, bone-level implants offer advantages including (1) flexibility of the abutment height and design, (2) greater prosthetic space for the emergence profile manipulation depending on the supra-platform tissue height (STH) and 3D implant position, (3) versatility for supra-platform components replacement (particularly [24] ns with peri-implant soft tissue dehiscence or esthetic concerns).

Yet, the advent of tissue-level implants with a concave or straight polished supra-platform collar may be the appropriate choice when the position of the restorative margin and the 3D implant position have been planned appropriately (Figure 6). When planned and placed adequately, these implants may provide adequate vertical space for the STH (≥3 mm) and the correct emergence profile (Figure 7).

2.3.2 | Length and Diameter

When choosing the most appropriate implant length and diameter, the (#1) anatomical site characteristics (related to (a) phenotype, (b) alveolar ridge height and configuration, and (c) intended restoration cervical margin) and (#2) the volumetric characteristics of the restorative span (associated with the emergence profile) have equal importance.

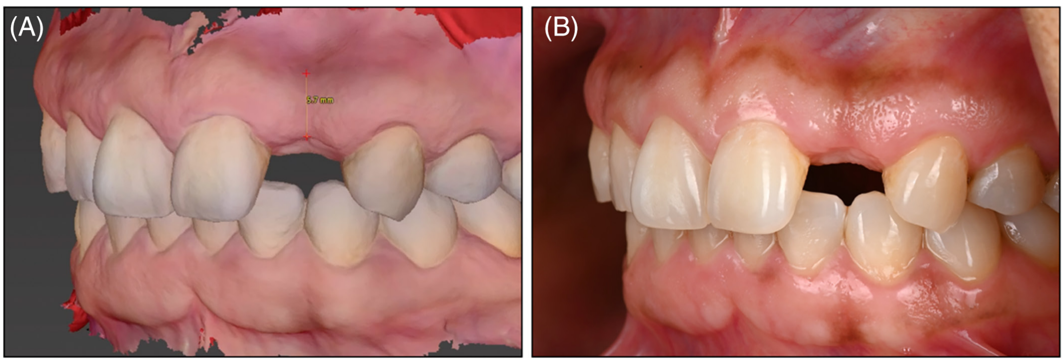

FIGURE 5 | Preoperative soft tissue assessment of the implant site. (A) Digital measurement of KTW on PLY file; (B) Clinical situation.

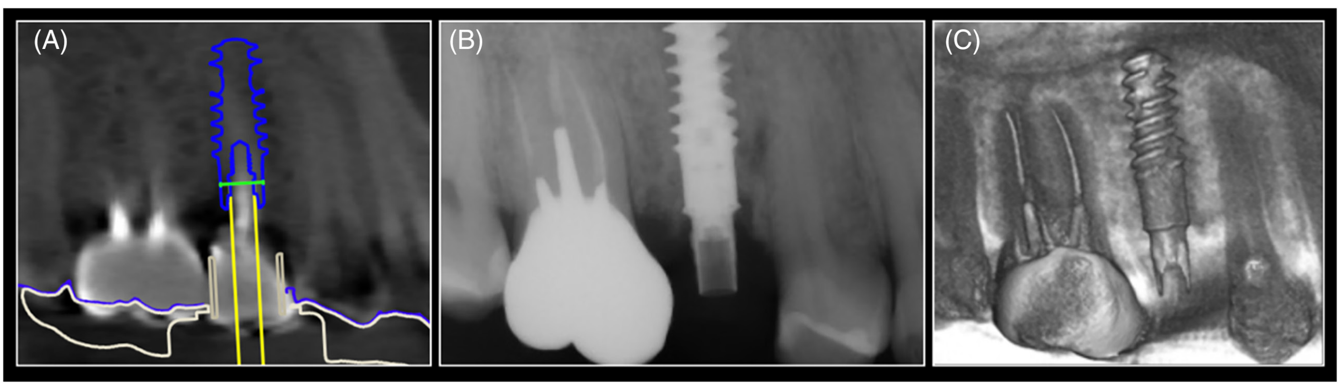

FIGURE 6 | Type 1A implant placement using a straight tissue-level implant to replace an upper second premolar. (A) Virtual planning considering STH and emergence profile; (B) Immediate post-op periapical x-ray; (C) Immediate post-op CBCT reconstruction.

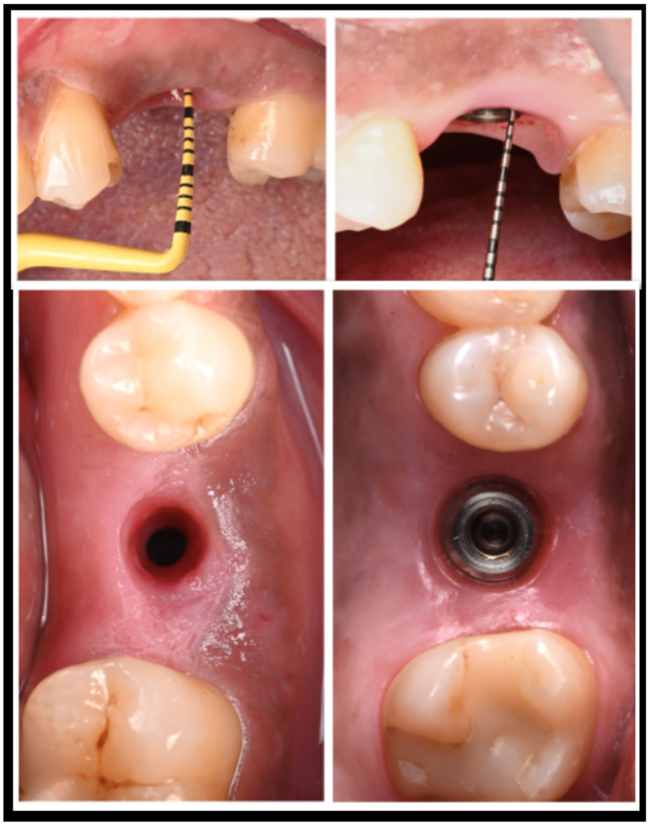

FIGURE 7 | STH respected in a bone-level (BL) implant (left) and tissue-level (TL) implant (right). Note that probing from the mucosal margin to the implant platform indicates 3 mm in the BL implant, whereas only 1 mm is in the TL implant since 2 mm of the STH is already established around the polish collar.

In large restorative sites (i.e., canines, wide premolars, molars), regular-body implants may provide biological advantages in maintaining the peri-implant phenotype compared to wide-body implants. Therefore, wide implants are recommended only where restoratively indicated (e.g., long cantilevers, patients with bruxism) and adequate anatomical receptor site characteristic described above (#1) are present [25].

The implant fixture should be planned with the intended cervical margin position of the ISR so that the emergence profile ensures esthetic and biological integration (phenotype requirements) [26] (Figure 8).

Short implants (i.e., ≤6 mm) and narrow diameter implants (≤3.5 mm) (NDIs) [27] are a predictable options to replace missing teeth in deficient anatomical sites, with the purpose of reducing patient morbidity (i.e., avoiding sinus floor elevation, ridge augmentation) or preventing sensitive structures damage (i.e., inferior alveolar nerve). In fact, NDIs have demonstrated similar survival rates to regular diameter implants [23], including single ISR [28]. In situations with limited mesiodistal space adjacent to neighboring teeth (i.e., implant platform-tooth distance <1.5 mm), using NDIs in combination with nonmatching connections may contribute to preserving interproximal bone peaks and papillae [14, 24]. Also, when placing immediate implants, NDIs may contribute to maintain the integrity of the labial bone by increasing the facial jumping distance [21, 29, 30] and hence, reducing the risk for peri-implant soft tissue dehiscence [31, 32] or buccal concavities [33].

Short implants should be carefully considered to balance the slightly higher reported failure rates against the additional morbidity and risks of alveolar ridge augmentation, which would be required to provide regular-length implants where anatomical constraints are present [34, 35].

2.3.3 | 3D Implant Position

With the use of current digital workflow, the ideal 3D implant position can be planned based on the intended buccal mucosal margin position and the following factors:

a. When planning for the apico–coronal (depth) implant position, the following formula (Figure 9) is proposed to provide enough vertical space for an adequate STH, accounting both (A) transitional zone where the abutment (transmucosal component) will dictate mainly the biological response [36] and (B) the prosthetic area of interest [37, 38] which influences the configuration and angle of the emergence profile [39].

Buccal mucosal margin of intended restoration
+ running space (B) + height of the transmucosal component (A)
= Vertical implant platform position.

b. Mesiodistally, the implant platform should be planned and centered in relation to the intended ISR, aiming for a symmetric emergence profile [38] with adequate access to oral hygiene. When using nonmatching connection implants, a minimum 1.5 mm distance to the adjacent teeth and 3 mm inter-implant distance is recommended to maintain peri-implant tissue health stability [5, 14, 24, 40]

c. The appropriate orofacial and axial position of the implant should aim for the emergence of the prosthetic screw at the central fossa (premolars and molars) to mitigate the vulnerability of active cusps during chewing due to the screw access hole [41]. In incisor teeth, an implant body positioned 1 mm palatal to the intended incisal edge is recommended so the buccal jumping gap can be managed [42, 43]. Axial body inclination should be compatible with an appropriate emergence profile [44].

   Conducting a comprehensive assessment during virtual planning is imperative to ensure the abutment configuration and the ISR material align with the intended outcome. In cases where compatibility is not guaranteed, considerations may include reducing the implant diameter, utilizing angled screw channel abutments, use of customized abutments, reevaluating retention strategies, and revisiting material alternatives.

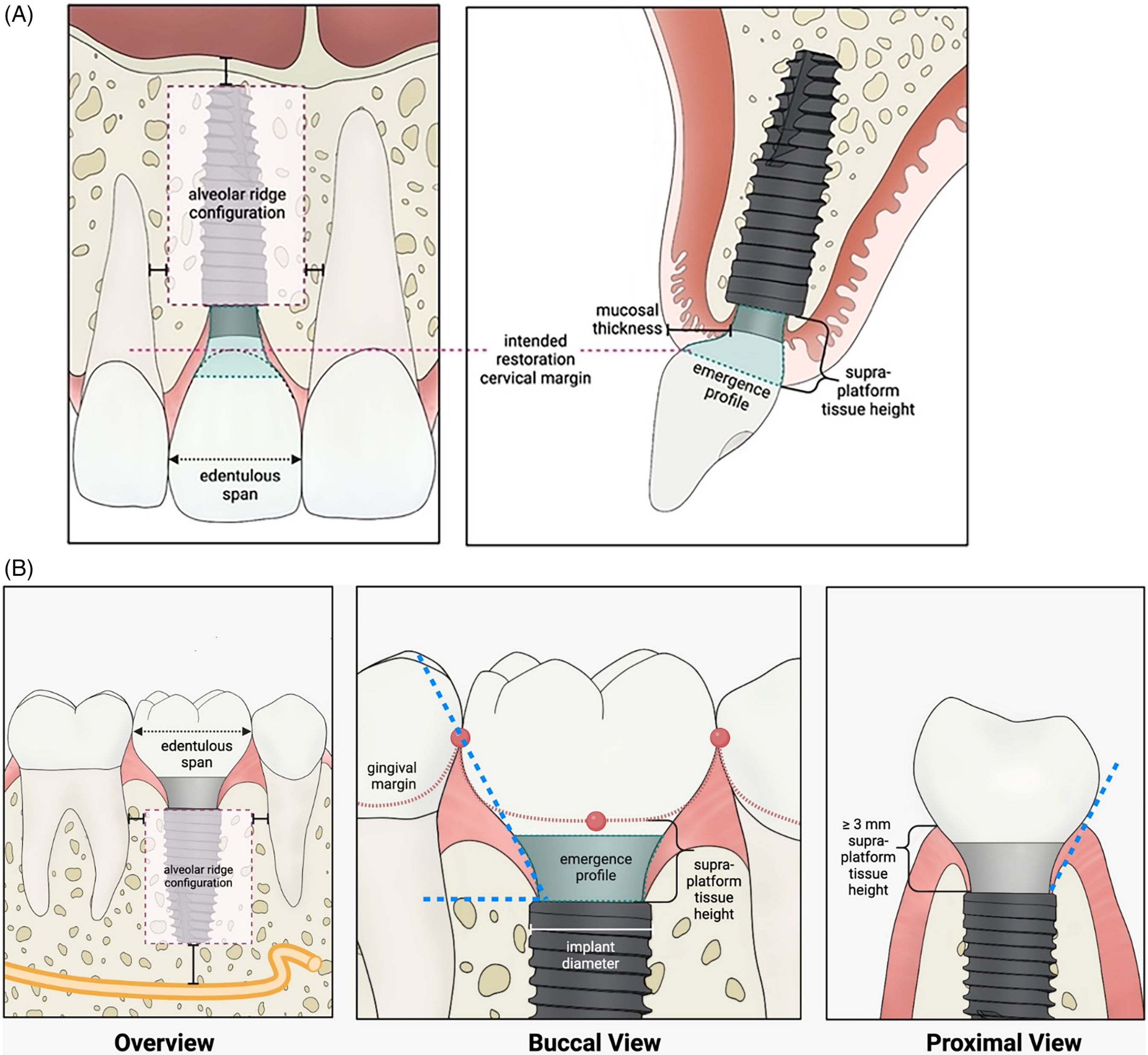

FIGURE 8 | (A) Selection of implant diameter during virtual implant planning. Note that both (#1) "anatomical site characteristics" and (#2) "restorative site characteristics" play an equal role during implant planning. (B) Large restorative space where regular-body implant is selected to preserve the phenotypic characteristics of the site and prevent potential peri-implant complications due to a correct 3D position that allows an adequate emergence profile and supracrestal tissue height (supra-platform configuration).

2.4 | Supra-Platform Components

2.4.1 | Abutment Selection

Once the 3D implant position is determined, it must continue to be refined during planning. This refinement is necessary because factors beyond the future buccal mucosal margin of the ISR, such as the abutment height and design, influence it. The selection of an appropriate abutment is critical in the long-term esthetic, biological, and functional ISR outcomes. Hence, planning should be made before the implant is placed [12, 45, 46]. Considering (a) the intended 3D implant positioning, (b) the intended ISR material and retention modality, (c) the foreseen restorative space and abutment retentive phase, (d) the intended emergence profile and (e) the cement-line between the abutment platform and the ISR (Figure 10).

When using healing abutments, their configuration should correspond with the future temporary and definitive abutments, providing similar benefits to TL implants. This practice aims to prevent any disruption in the configuration of peri-implant tissues during the healing process [47], avoiding bone remodeling by the sequential exchange of abutments [48]. Alternatively, if an implant system does not permit such correspondence, the placement of the definitive abutment at the time of surgery, "one abutment one time" [49], should be considered (Figure 11).

The abutment's design should allow a minimum of 1.5 mm of supra-platform space and a narrow, straight/concave design to allow tight connective tissue apposition and seal, thus reducing excessive bone remodeling [50–52]. When the implant is placed deep subcrestal, it is recommended to reduce its diameter and increase its height to minimize saucerization and to move the cementation line away from the bone crest [50].

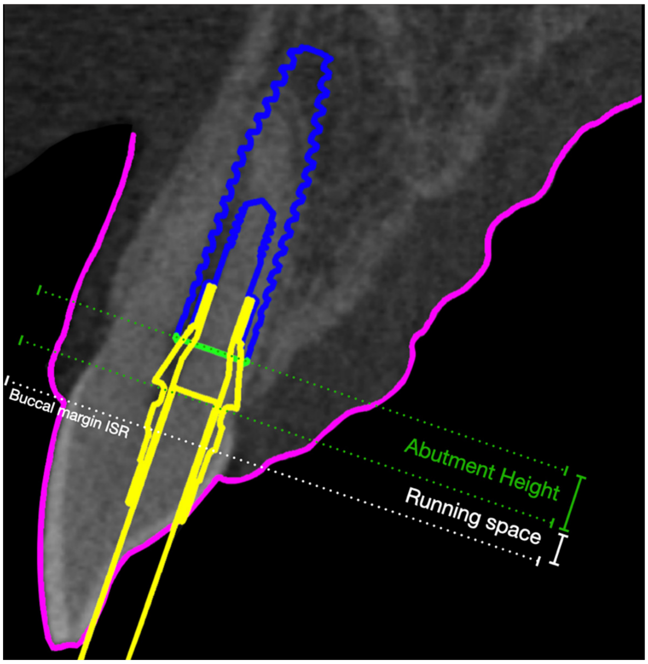

FIGURE 9 | Virtual planning of the vertical implant position of an immediate implant placement.

2.4.2 | Emergence Profile

An adequate transmucosal profile is critical for achieving esthetic outcomes and facilitates optimal oral hygiene. Recent advancements in digital technologies have facilitated the planning of this profile by using customized healing abutments [51], immediate provisional ISR [42, 52], or soft tissue conditioning during provisional restorations [37, 38].

Consequently, immediate provisional ISR can be fully designed and fabricated based on the planned 3D implant position prior to implant placement [53]. Also, soft tissue conditioning is facilitated by designing and fabricating sequential provisional ISRs to achieve the predefined emergence profile [54].

CAD/CAM technology can also be helpful in the planning stage to design and fabricate customized healing abutments for socket-sealing procedures [51]. These digital approaches aid in soft tissue conditioning, significantly reducing chair time and minimizing patient morbidity associated with the final restoration delivery.

Lastly, software integration (e.g., Synergy) facilitates modifying the virtual 3D implant position while adjusting the transmucosal profile of the intended ISR. This integrated approach allows for achieving an appropriate emergence profile and thus preventing the "compensatory restorative over-contouring" that is commonly attributed to the insufficient vertical distance between the implant platform and the restoration's mucosal margin [26] (Figure 12).

2.4.3 | Retentive and Restorative Material

The selection of appropriate restorative materials is an essential element in the clinical success since the most frequent complications are mechanical [55].

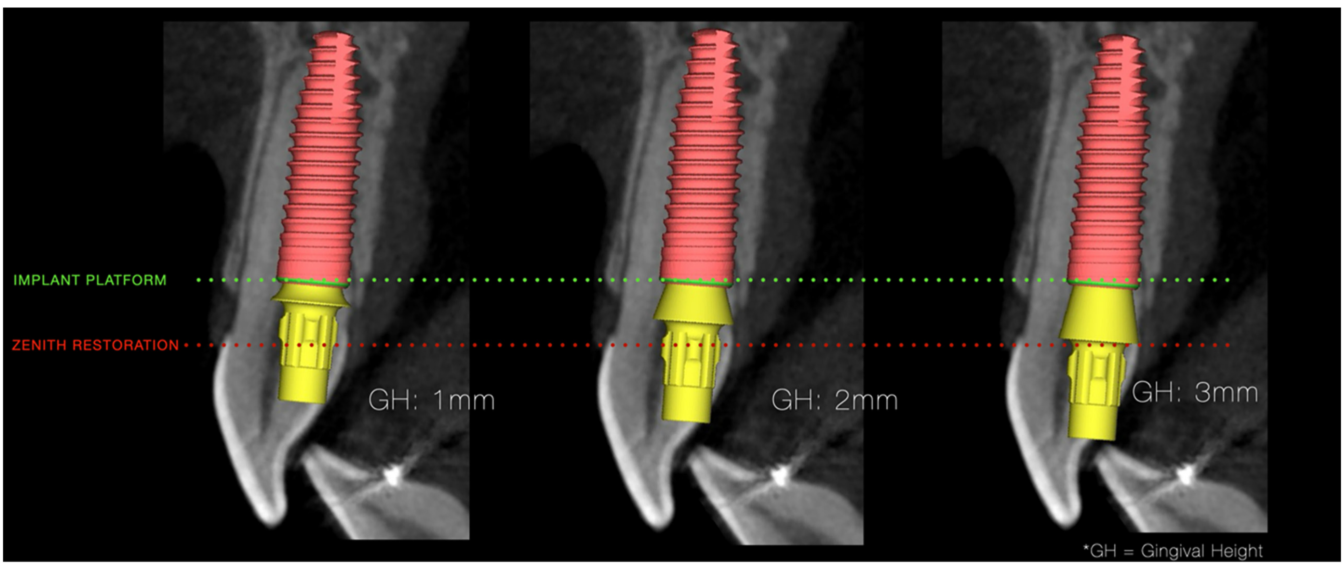

FIGURE 10 | Digital treatment planning allows for a virtual simulation of the implant design and position and the integration of different abutment alternatives: (1) short ti-bases (<1.5 mm) with cementation line close to the bone and potential risk for bone remodeling.; (2) Balanced abutment height compatible with adequate STH and emergence profile; (3) Abutment height with reduced space for the running space. These designs are recommended only if soft tissue conditioning is not required.

Material selection and retention type is determined by (1) the size and configuration of the tooth/ISR, (2) esthetic demand, (3) intended abutment, and (4) the 3D implant position (mainly orofacial position and angulation).

A compromise in restorative space and thickness of materials can lead to an increased risk of mechanical complications, while the increased material thickness can result in over-contoured emergence profiles and compromised esthetic restorations (Figure 13). Accordingly, the 3D implant position and the configuration of the retentive part of the abutment in relation to the digital tooth arrangement should be assessed during the planning phase.

In some cases where there are limitations in prosthetic volume and thickness, ceramic abutments have shown advantages to meet esthetic requirements [56].

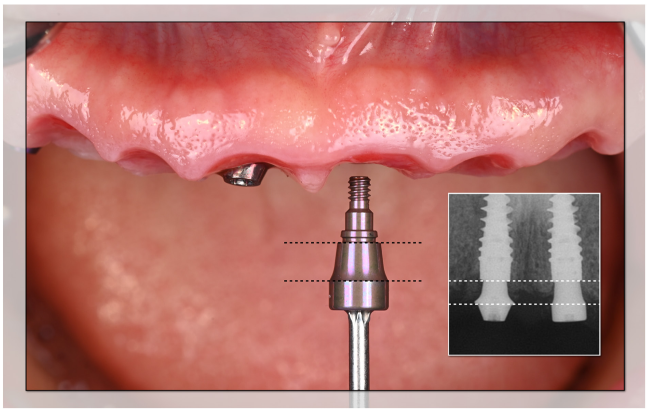

FIGURE 11 | Healing abutment (#2.1) and definitive abutment (#1.1) with consistent transmucosal configurations. Note that the configuration of 1.5 mm of both abutments is narrow and concave, and the prosthetic platform is located above the crestal bone level.

During the virtual planning, a diagnostic evaluation is initially conducted with a predetermined prosthetic design, restorative material desired, and retention mechanism to assess the feasibility of the preferred treatment plan. However, if it is determined that the preferred plan cannot be successfully implemented a subsequent diagnostic exercise is performed to determine the patient's suitability for an alternative treatment modality. These instances involve an exploration of various options and considerations of alternative approaches that may better align with the patient's specific requirements, such as prosthetic tissue replacement to minimize patient morbidity.

Providing an adequate implant position for a direct screw-retained prosthesis often requires ancillary regenerative procedures, such as bone grafting or soft tissue augmentation. In these situations, cement-retained restorations, or screw-retained restorations with angled screw channels abutments may be a viable option to reduce surgical complexity and patient morbidity (Figure 14). However, this approach should be limited to slight facial angulation of the implant without increasing the risk of biological, mechanical, or esthetic complications [57, 58].

2.5 | Surgical Planning

Digital surgical planning is an essential step in the bio-restorative concept. The amount of information that can be handled in a virtual scenario allows for planning the surgical approach, from incision design to soft tissue augmentation.

The choice between flap or flapless surgery when placing dental implants should be based on careful presurgical planning, favoring flapless implant placement when (1) there is an adequate amount of keratinized mucosa and (2) in sites with anatomical characteristics able to compensate for any potential deviations of the drilling process and implant placement. Flapless approach

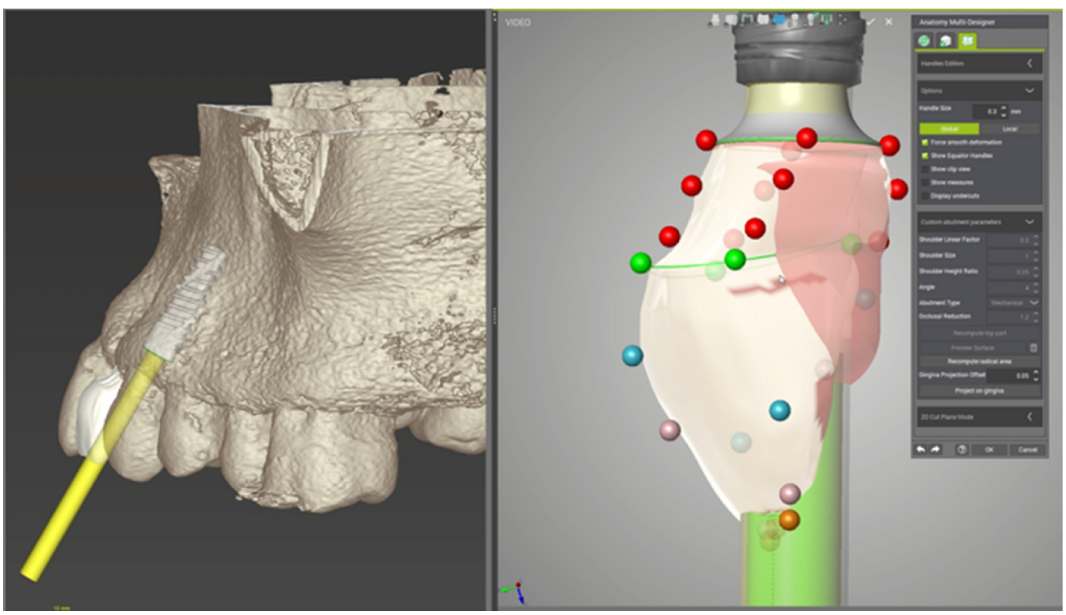

FIGURE 12 | "Software integration." Left-Implant planning software (CodiagnostiX) connected to CAD software (CARES) through Synergy. In Type 1A cases, if the buccal mucosal margin of the future restoration is planned to be slightly modified, this reference (buccal "critical" profile) may be predefined to guide the peri-implant soft tissue healing.

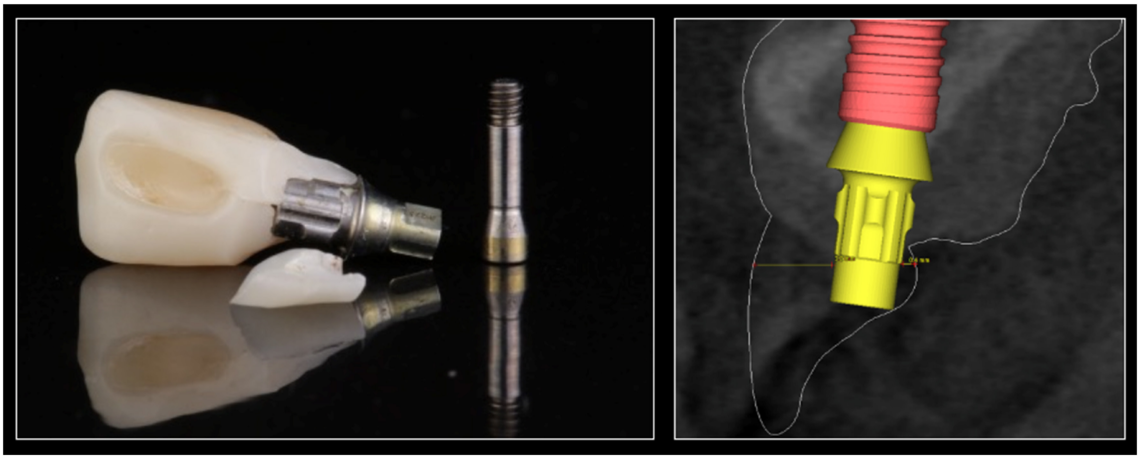

FIGURE 13 | Mechanical complication due to insufficient space between the abutment's retentive part and the intended restoration's palatal outline. Note that the selection of restorative materials and supra-platform components during the implant planning may permit the avoidance of these complications.

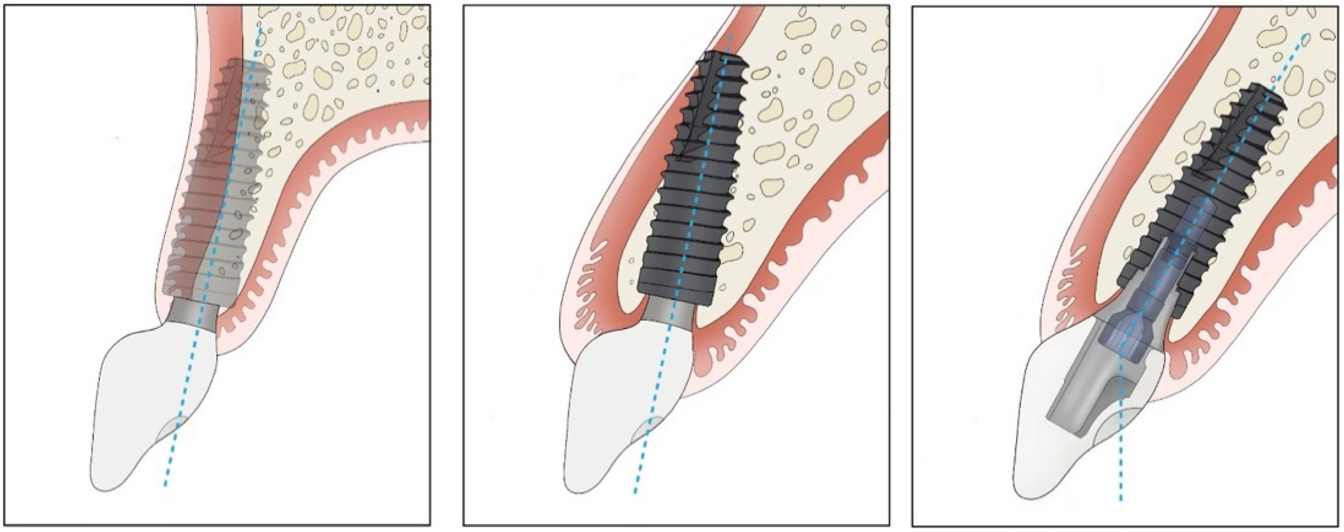

FIGURE 14 | Same clinical scenario, different treatment plans. Angled screw channel abutment may avoid cement-retained ISR in some cases where implant axis angulations must be compensated. Also, they can be chosen during the virtual planning phase to prevent ridge augmentation procedures, reduce morbidity, and contribute to a minimally invasive bio-restorative approach.

together with computer-assisted surgery or dynamic system may simplify the procedure, optimize wound healing, and reduce patient's morbidity [59, 60].

Digital planning should also facilitate the identification of tissue deficiencies, particularly buccal concavities or horizontal defects. Buccal deficiencies can lead to (1) esthetic concerns due to changes in light reflection in the anterior area and (2) the presence of an ISR with a "buccal cantilever," leading to food impaction and increasing the risk of peri-implant diseases.

The decision on addressing buccal concavities should be made during the virtual planning phase, to plan incisions and flap accordingly. If insufficient peri-implant BT or bone grafts are planned for other purposes (e.g., filling a buccal gap), bone augmentation procedures are recommended. In cases where PBT is adequate, options such as soft tissue grafting (connective tissue graft), connective tissue substitutes, or dedicated perio-prosthetic flaps (Figure 15) design should be considered.

3 | Discussion

The bio-restorative approach requires a comprehensive understanding of implant dentistry's biological, restorative, and surgical principles. Digital technologies have significantly facilitated the integration of these disciplines within a unified virtual scenario. Consequently, the diagnostic, planning, and surgical execution have become more predictable. To translate the virtual planning clinically [61], static computer-aided implant surgery (sCAIS) [62], dynamic computer-aided implant surgery (dCAIS) [63], and robotic surgery [64] are recommended. They can assist in achieving higher implant survival compared to freehand procedures [65].

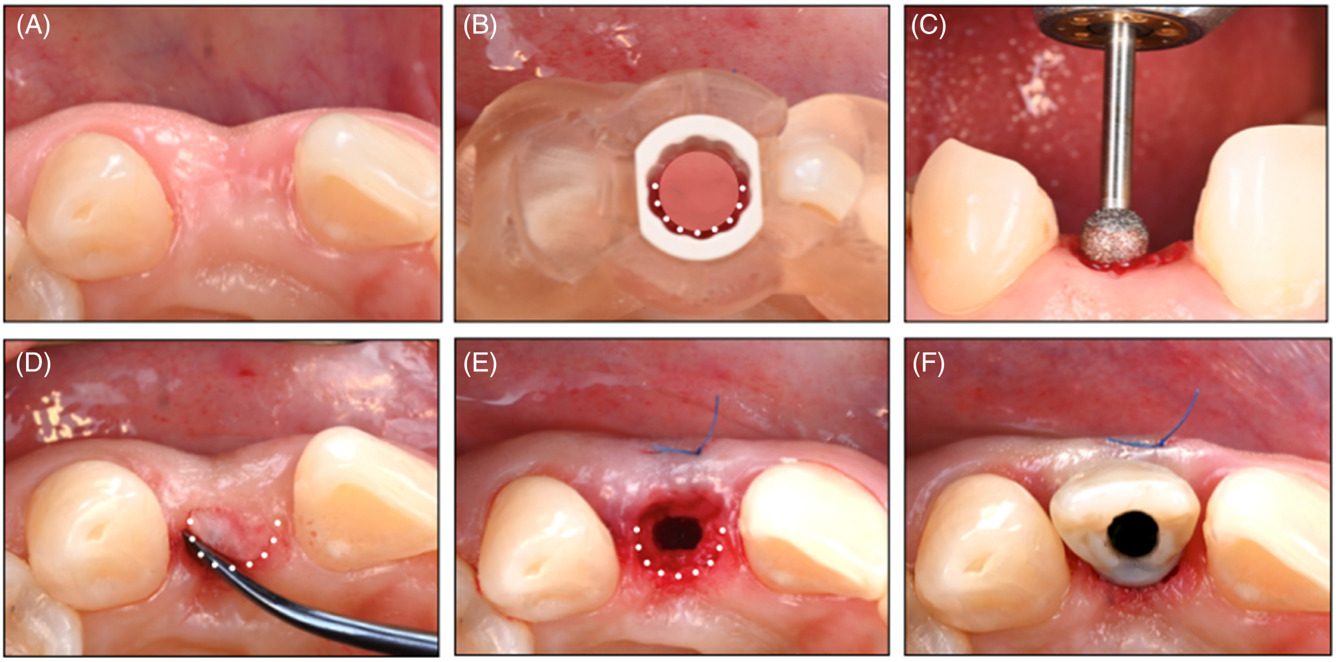

FIGURE 15 | Example of a perio-prosthetic flap. (A) Buccal soft tissue deficiency at implant site; (B) Representation of incision outline using the surgical guide; (C) De-epithelization of outlined implant site; (D) Flap (connective tissue) elevation; (E) Buccal suture of pedicle flap; (F) Flap buccally displaced with immediate temporary implant-supported restoration.

Failure to adequately consider these principles can increase the risk of poor esthetics, biomechanical problems (i.e., fracture, screw loosening, etc.), and biological outcomes, thus compromising the long-term success of the ISR and adjacent teeth (i.e., proximal caries, attachment loss, etc.) as previously evidenced [66, 67].

This study, however, has important limitations due to its nature as a position paper and its reduced length. Although most key factors are mentioned, not all are developed in detail. For example, macro-implant design is vaguely reduced to comparing tissue and bone-level implants, and different restorative materials are not mentioned. However, a more detailed explanation of each specific factor will address this issue in the near future.

4 | Conclusion

The bio-restorative concept presented in this article embodies a comprehensive approach to contemporary implant dentistry, supported by the current scientific literature and implemented through available digital technologies.

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Conflicts of Interest

The authors declare no conflicts of interest.

Data Availability Statement

The data that support the findings of this study are available from the corresponding author upon reasonable request.

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Supporting Information

Additional supporting information can be found online in the Supporting Information section.