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CLINICAL ARTICLE

The Generated Restorative Space Concept: A Digitally Guided Preparation Protocol for Restoring the Vertical Dimension of Occlusion in Patients With Tooth Wear

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ABSTRACT

Objective: Treating patients with worn dentition is complex and requires comprehensive consideration of function, esthetics, and tissue preservation. An important aspect of contemporary dentistry is to be conservative and have proper protocols to plan and treat these situations while protecting the remaining tooth structures. The purpose of this article is to present an organized and conservative digitally aided treatment protocol for patients with worn dentition, which takes into account pre-established parameters that allow increasing the occlusal vertical dimension following the GRS Concept—the Generated restorative space.

Clinical Considerations: This protocol emphasizes the need to assess each clinical scenario and plan prosthetic designs that increase predictability; it also establishes guidelines that promote minimal invasion, proper material selection, and an approach guided by the existing wear pattern, patient-specific factors, and biological preservation.

Clinical Significance: Properly planned treatment and the use of digital technology will enable clinicians to be more conservative and retain the largest amount of the residual tooth structure in wear patients.

Conclusion: Treating patients with generalized worn dentition is a challenging task, and proper treatment planning and execution are needed. Digital assets such as the "cross-sectional view" in CAD software allow the clinician to analyze the generated restorative space, be more conservative, and support the long-term success and predictability of the restorations.

1 | Introduction

Wear and erosion are becoming a common cause for which patients seek treatment in the prosthodontic office [1–6]. Many of these patients have lost occlusal vertical dimension (OVD) and have functional and aesthetic impairments (Figure 1).

The OVD is a complex topic that has been extensively described in the literature [7–11]. There have been many protocols proposed to treat patients with OVD alterations, all of them requiring proper diagnosis and meticulous treatment planning [12–15]. A recent protocol that aimed to clarify and organize worn dentition with other specialties is the LIT Classification [16].

There is evidence that the interocclusal rest position distance is a range and that the stomatognathic system has adaptive capabilities [17]. Thus, increasing the OVD in these patients is an approach to address these clinical scenarios.

The treatment approach for these cases has evolved, shifting from restorations relying on retention and resistance forms to more contemporary approaches that rely on adhesion [18, 19]. A major drawback of full-contour restoration preparation is the significant volumetric reduction of tooth structure required, which leads to up to 70% volumetric removal of the tooth structure to allow for proper material dimensions, path of insertion, and proper seating of the indirect restorations (Figure 2) [20–23].

The evolution of dental materials, technology, and adhesive protocols has led to a paradigm shift in restorative dentistry towards minimally invasive therapy. Adhesive dentistry has become paramount in the biomechanical integration of modern dental materials to minimally prepared teeth [24].

Preparation designs that promote biomechanical optimization and force distribution to increase the longevity of restored dentition have been described [25, 26]. Modern tooth preparations are influenced by the presence, extent, and location of the existing lesion rather than by traditional preparation guidelines [15, 22, 23, 27–29]. Their main characteristic is a non-retentive expulsive geometry, smooth surface, no internal retentive mechanisms, rounded angles, and maximum preservation of the peripheral enamel to ensure proper sealing and margin fit [19]. However, most of these preparation guidelines were designed to receive indirect restorations on single teeth or quadrants opposing a pre-established and stable occlusion, leading to subtractive protocols, where tooth preparation is needed to create space for the restorative material. With the increasing number of patients with generalized wear and the need to re-establish their lost occlusal vertical dimension (OVD), it is crucial to revisit preparation guidelines.

FIGURE 1 | Image illustrating a patient with worn dentition who has lost occlusal vertical dimension.

Treatment planning of indirect bonded restorations in single or multiple teeth, for patients who do not require an OVD increase, offers the advantage of using the opposing dentition as a guideline for future restorations. However, its most significant limitation is that more invasive preparation of the teeth to be restored is required to create space and allow for the dimensional requirements of the restorative material (Figure 3). Tooth preparation must consider structural integrity, presence of fissures, dentin wall thickness, and interaxial dentin support. The biomechanical requirements of materials require the clinician to make decisions on whether to reduce or conserve cusps, bevel marginal ridges, or prepare proximal boxes. More traditional inlays, onlays, and

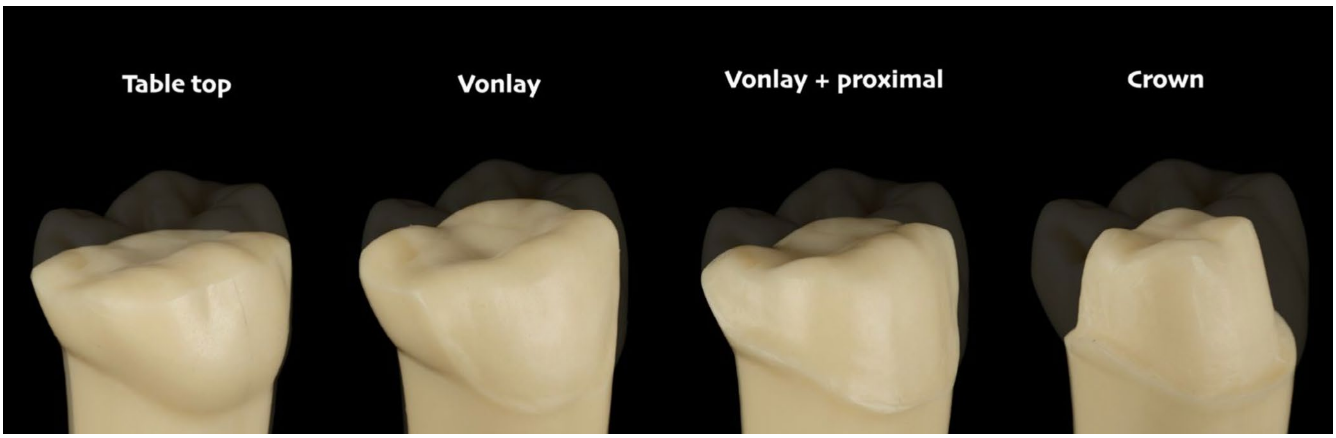


FIGURE 2 | Illustration depicting the volumetric tooth structure reduction with different restorative designs.

FIGURE 3 | Illustration exemplifying the scenario where an indirect adhesive restoration would be prepared on a patient with a established OVD, which would be subtractive in nature.

overlays preparations relied on the design of the preparation as a mechanism for retention. However, retentive designs transfer forces to surrounding walls, which may lead to their fracture if their dimensions are less than 2 mm [15, 19, 23]. Cavitated teeth have alterations in the tension-compression balance, which increase flexure, especially on marginal ridges and functional cusps, leading to cuspal fracture. For this reason, subtractive approaches to achieve cuspal protection have been proposed [30]. However, the evolution of dental materials and dentin-protecting techniqueshas led to a paradigm shift, allowing the reconstruction of deep cavities and reestablishing intercuspal contact with resins whose biomechanical behavior is similar to that of dentin [31].

Modern preparation design is influenced by biological, mechanical, and esthetic principles associated with the type, extension, and location of the lesion, which may be carious in nature or caused by erosion, attrition, or abrasion of the tooth structure (Table 1) [23, 27–29]. The use of bevels has been discussed as an essential component of modern tooth design to increase the bonding surface and create an esthetically pleasing transition between the restoration and the tooth. Bevels also allow proper material thickness in strategic zones such as the buccal aspect of lower premolars and molars, as well as the palatal wall of the same teeth in the maxilla, thereby providing resistance to occlusal forces (Figure 4) [15].

When fully rehabilitating the patient with decreased OVD, the treatment approach differs from that of patients with a pre-established OVD, where the treatment is limited to one or a few teeth. In these patients, the creation of the necessary restorative space is associated with the establishment of a new OVD during treatment planning for the restorative case. In these patients, treatment to replace the missing tooth structure and re-establish the OVD will be additive in nature (Figure 5). Having a controlled increase of the OVD allows the clinician to quantify the generated restorative space (GRS) and relate it to the restorative material of choice, thereby determining the amount and location of the tooth preparation or, in some cases, the lack of need for preparation (Figure 6).

The use of the cross-sectional view tool in the computer-aided design (CAD) software will enable a pre-treatment digital preparation analysis to plan the type and extent of tooth preparations (Figure 7). Once the restorative plan has been intraorally verified by the use of an intraoral mock-up and the preparations have been pre-designed, the plan will be transferred to the patient's mouth through bonded functional esthetic prototypes (BFEP) [32]. This re-establishes the morphology, occlusion, and OVD and serves as preparation guides for the future definitive restorations (Figure 8). However, for the preparations to be controlled and the initial restorative plan to be followed predictably, a proper clinical workflow is required.

The purpose of this article is to propose a clinical protocol for the preparation of posterior teeth in patients with decreased OVD based on a digital analysis from the initial restorative treatment plan. This approach will allow the clinician to have a controlled increase of the OVD following the GRS Concept—Generated restorative space concept, which is based on esthetic, functional, and occlusal parameters, thereby preserving the maximum amount of tooth structure.

2 | Methods

2.1 | The Generated Restorative Space Concept

The Generated Restorative Space concept consists of a series of clinical and laboratory steps which include a comprehensive pre-treatment digital preparation analysis and controlled transfer of the digital design when increasing the OVD from the planning stage to the delivery of final restorations. For ease of comprehension, the protocol will be described in 8 steps (Figure 9).

2.1.1 | Step 1: Data Acquisition

In the first step of the protocol, it is important that the correct data is collected to be able to treatment plan and establish the treatment approach. The first set of data that should be collected is facial photos, which include a closed mouth, rest position, and smile photographs, or facial scanning at rest and smile to start the facially generated treatment plan [33]. Also, an intraoral scan (IOS) of both arches, digital intermaxillary relationship in centric relation, dynamic digital registrations, and a cone beam computed tomography (CBCT) of the patient when necessary are crucial to be able to merge the information in the CAD software.

2.1.2 | Step 2: Software Integration

With the information gathered at the data acquisition stage, the clinician must properly integrate the IOS with the facial photographs at smile, or with the facial scan of the patient smiling, and/or CBCT in CAD software and program the virtual articulator. A proper selection of the digital articulator and condylar element adjustment using averages or dynamic registrations of the patient, and 3D positioning of files in CAD software allow a precise functional design of the case.

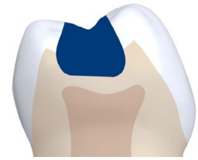
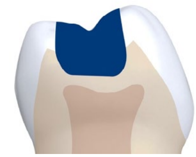
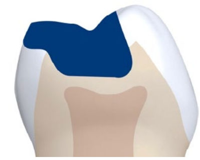
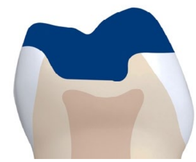
2.1.3 | Step 3: Prosthetic Design

Digital full-mouth designs must be done to promote a functional and esthetic integration of the future restorations following sequenced protocols [34]. During the design process, the new OVD will be determined by opening the arc of closure following esthetic and functional parameters as reference, determined by the clinician and laboratory team. A functional mock-up of this design is then delivered to ensure the digital plan is accurate and approved by the clinician and patient.

2.1.4 | Step 4: Pre-Treatment Digital Preparation Analysis

Once the prosthetic design has been evaluated and accepted, a pre-operative analysis of the restorative space created by the increase in OVD using the Cross-sectional view tool in the CAD software (e.g., Exocad, 3shape) is done to enable the clinician to foresee the preparation design and create a proper GRS for the final restorations. Using the Cross-sectional view tool enables a precise analysis between the remaining tooth structures and the restoration design, thus allowing for organized and controlled

TABLE 1 | Table illustrating different restorative designs for patients with affected posterior dentition, their indications and material selection.

Clinical approach or fabrication method	Restorative design	Preparation approach	Cavity characteristics	Diagram	Suggested material
Direct	—	Reductive approach	Tooth structure loss in occlusal and/or proximal areas with tooth structure loss less than 1/3 the intercuspal distance		Direct composite resin with high filler content
Indirect	Inlay	Reductive approach	Moderate tooth structure loss of more than 1/3 the intercuspal distance which does not affect the cusps and can extend to one inter-proximal area.		– Semi-direct composite resins – Indirect composite resins (CAD/CAM or Printed) – Lithium disilicate (CAD-CAM or Press) – Zirconia
	Onlay	Reductive approach	Moderate tooth structure loss which affects one or more cusps and can extend to one or both inter proximal spaces.		– Semi-direct composite resins – Indirect composite resins (CAD/CAM or Printed) – Lithium disilicate (CAD-CAM or Press) – Zirconia
	Overlay	Reductive approach	Moderate or extensive tooth structure loss which affects all cusps and can extend to one or both inter proximal spaces.		– Indirect composite resins (CAD/CAM or Printed) – Lithium disilicate (CAD-CAM or Press) – Zirconia
	Tabletop/occlusal veneers	Additive approach	Same indications as an overlay but recommended for patients with tooth structure loss due to parafunction or erosion. No preparation done to re-establish the loss tooth structure with the restoration.		– Indirect composite resins (CAD/CAM or Printed) – Lithium disilicate (CAD-CAM or Press) – Zirconia
	Vonlay	Additive approach	Same indications as an overlay, but also involving the facial aspect of the tooth, recommended tor esthetic needs or when there is severe destruction in patients with parafunction.		– Indirect composite resins (CAD/CAM or Printed) – Lithium disilicate (CAD-CAM or Press) – Zirconia

preparations that can be verified with printed preparation guides at a later stage.

2.1.5 | Step 5: Adhesive Anatomical Restitution

Once the GRS is evaluated from the proposed prosthetic design, a bisacryl mock-up or a bonded functional and esthetic prototype of the ideal restorative design is delivered to the patient and will serve to establish intraoral parameters for tooth preparation and control the functional and esthetic landmarks before the final preparation design [32, 35]. This step will also serve to challenge the new vertical dimension to ensure patient comfort before any irreversible treatment is done. This is a preferred method to challenge the proposed OVD as it allows the patient to test-drive the anatomical form, occlusion, and esthetics of the proposed final restoration design.

2.1.6 | Step 6: Tooth Preparation

Once the patient has test-driven the bonded functional prototype, and both the functional and esthetic parameters have been assessed, the patient is ready for tooth preparation. Tooth preparations must be smooth and convex without sharp angles; it is important that they respect the peripheral enamel to allow for optimized bonding. Preparations should be designed from the ideally positioned full-contour anatomical restitution of the worn teeth through controlled preparation diamond burs. The teeth are prepared through the mock-up or prototype, promoting strategically driven, minimally invasive preparations that will expose peripheral enamel, facilitate a proper path of draw, and allow adequate seating and fit of the ceramic restorations. If a bonded functional prototype is not done, an "Aesthetic Pre-evaluative temporary" (APT) can be used during the preparation design [36].

2.1.7 | Step 7: Preparation Control

The post-preparation verification is done with a printed preparation guide. The use of a digitally created preparation guide enables the clinician to control tooth reduction and obtain a realistic assessment of the preparation, as well as determine the need for retouching based on the dimensions of the preplanned digital design. If additional preparation is required, it should be done before making final scans and proceeding to the design and delivery of the final restorations.

2.1.8 | Step 8: Ceramic Restoration Design and Manufacturing

Ceramic restoration design and manufacturing are done based on the pre-operative plan or modifications made to it during the test-drive stage. It is important that any changes made during the test-drive of the restorations are thoroughly assessed and the modifications are copied to the final restorations to ensure aesthetic and functional success. The delivery of the final restorations is done following proper bonding protocols, which will promote proper seal, longevity, and re-establish the proper OVD.

3 | Discussion

Morphological and biomechanical criteria for minimally invasive posterior indirect restorations have been described in the literature [37–39]. The importance of peripheral enamel, beveling debilitated cusps, rounding internal angles, preventing retentive areas, preserving tooth structure, and promoting the longevity of the restorative treatment has also been described [19, 23, 39]. However, most of the existing literature focuses on the treatment of single teeth or segments with a pre-established occlusion and OVD. These established clinical guidelines, however, have limitations when applied to the treatment of patients with a decreased OVD. In such cases, the clinician does not rely solely on tooth preparations to create a proper restorative space but also on the correct repositioning of the antagonistic arches by increasing the patient's OVD with indirect restorations. For this reason, conventional treatment guidelines may lead to unnecessary over-preparation of teeth when approaching this type of patient. The proposed protocol complements existing guidelines, extending them to address limitations specific to patients with reduced OVD. The loss of OVD as a consequence of generalized wear represents one of the most challenging clinical scenarios in restorative dentistry. Successful therapy in these cases requires a proper diagnosis and a treatment plan that encompasses the functional dynamics and the restorative potential of the case (Figure 10A,B).

Before performing irreversible procedures such as tooth preparation, the new vertical dimension must be challenged. This safe practice verifies patient comfort, proper function, and neuromuscular stability. This step could be done with removable appliances such as splints or, as proposed in this protocol, through adhered anatomical restitutions, which involve delivering the ideal prosthetic design in the patient's mouth and adjusting it if needed before preparations are done and final data acquisition or impressions are made. The adhesive anatomical restitution is advantageous over removable appliances to challenge the new vertical dimension as it does not depend on patient compliance; it is more realistic to final treatment thus will allow a better assessment both functionally and aesthetically. It could be modified and adjusted based on patient comfort, and once test-driven, it will give the clinician other critical information for tooth preparation.

The Generated Restorative Space concept proposes a digitally guided strategy to establish the new maxillo-mandibular relation through a controlled increase of the OVD. This approach is aligned with those established by Calamita et al. and Abduo et al., as it allows establishing a restorative design which prioritizes structural preservation and respects the principles of minimal invasion [7, 12].

The use of the "cross-sectional tool view" in CAD software (e.g., Exocad, 3shape) provides a valuable asset that allows clinicians to analyze and compare different areas obtained by merging standard tessellation language (STL) files at various stages of treatment. This allows the clinician to measure the increase in OVD, quantify the restorative space created in each tooth, and perform a pre-treatment digital preparation analysis to assess which areas of the tooth require preparation. Therefore, the dental professional can have an objective visualization of the treatment, which allows for rational and conservative decision-making during therapy and also serves as a great educational tool

FIGURE 4 | Images illustrating preparation design with bevels to receive indirect restorations.

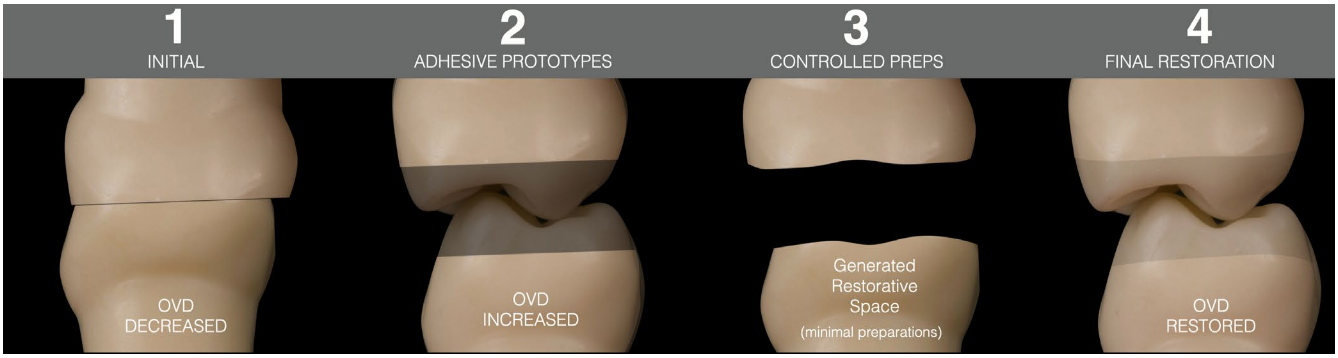


FIGURE 5 | Illustration depicting a situation where there is a reduced OVD. The restorative design is additive in nature.

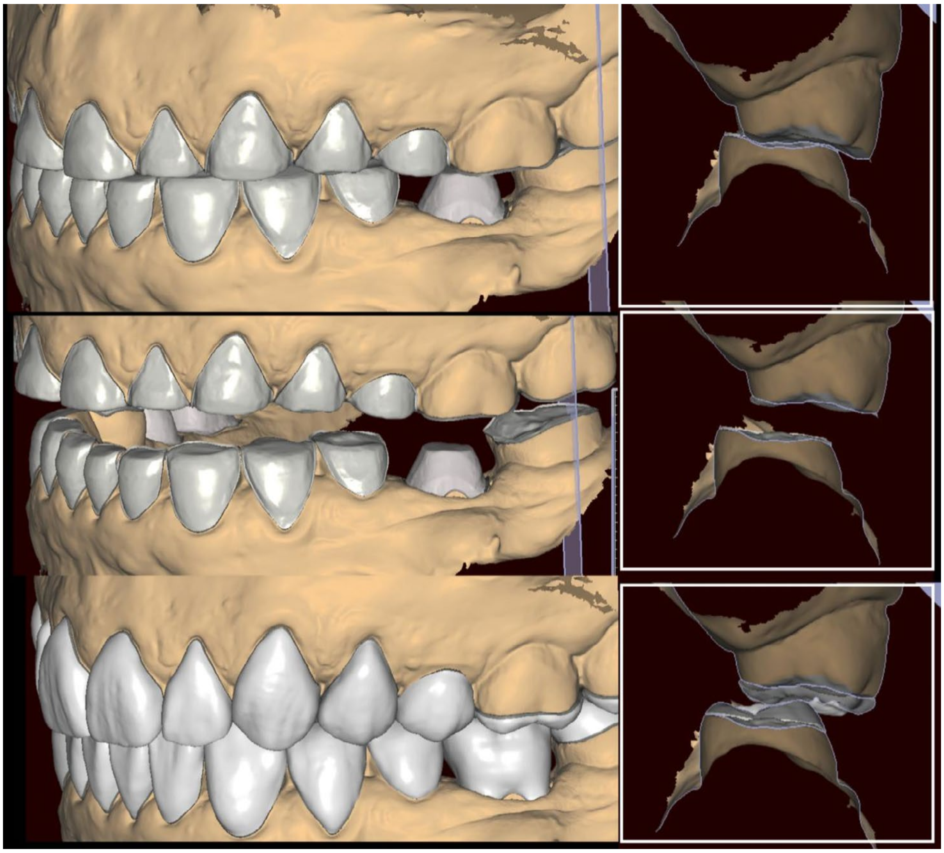


FIGURE 6 | Digital images of the preoperative digital analysis which illustrate the GRS in a patient with wear and decreased OVD.

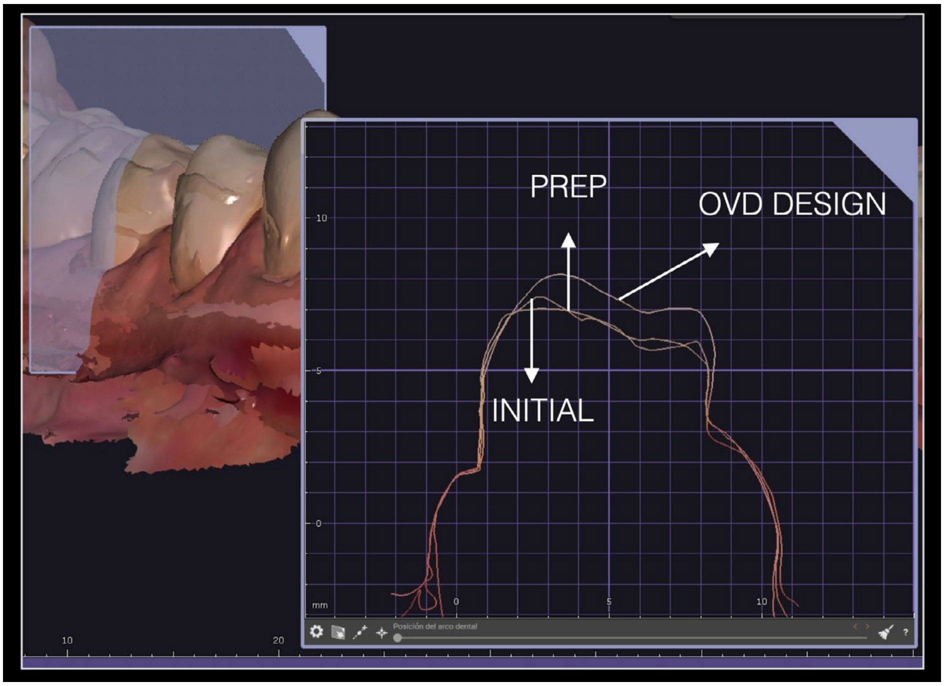


FIGURE 7 | Cross Sectional view of a tooth with wear which will be restored. Analyzing this in a CAD software (Exocad GmbH) allows the clinician to be more conservative and have control of the preparation design.

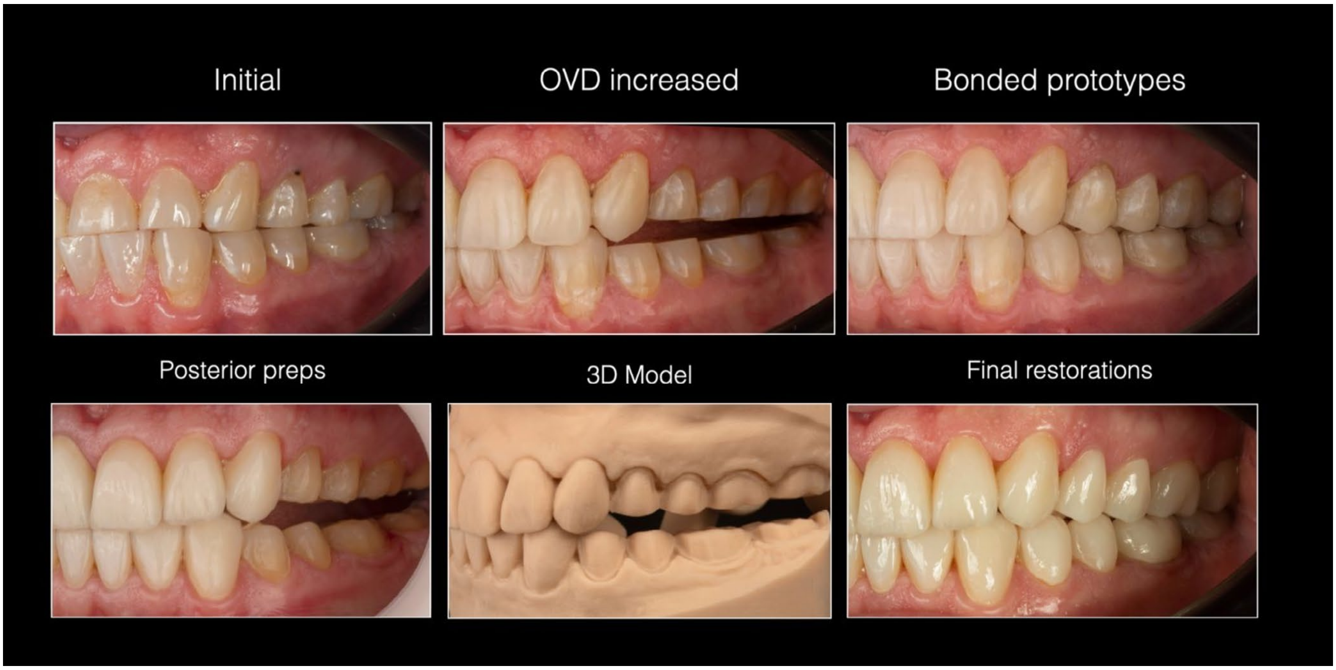


FIGURE 8 | Clinical illustration of the steps to restore a patient with the worn dentition.

with the patient. A digital preoperative analysis with "the cross-sectional tool" is significantly advantageous over a conventional wax-up, as it allows for a precise quantification of the material needed to restore the case in specific areas of the tooth, which would be difficult to quantify with conventional wax-ups.

The importance of understanding the biomechanical and adhesive behavior of indirect restorations in posterior teeth has been described [40, 41]. The proper establishment of the restorative space, as described in the present protocol, allows for ultra-thin restorations such as occlusal veneers, which will have good clinical behavior and reduce unnecessary tooth reduction. These benefits are supported by long-term studies in the literature showing survival rates of up to 12 years [42]. It also facilitates standardizing the diagnostic sequence and promotes interdisciplinary communication, which is crucial in complex

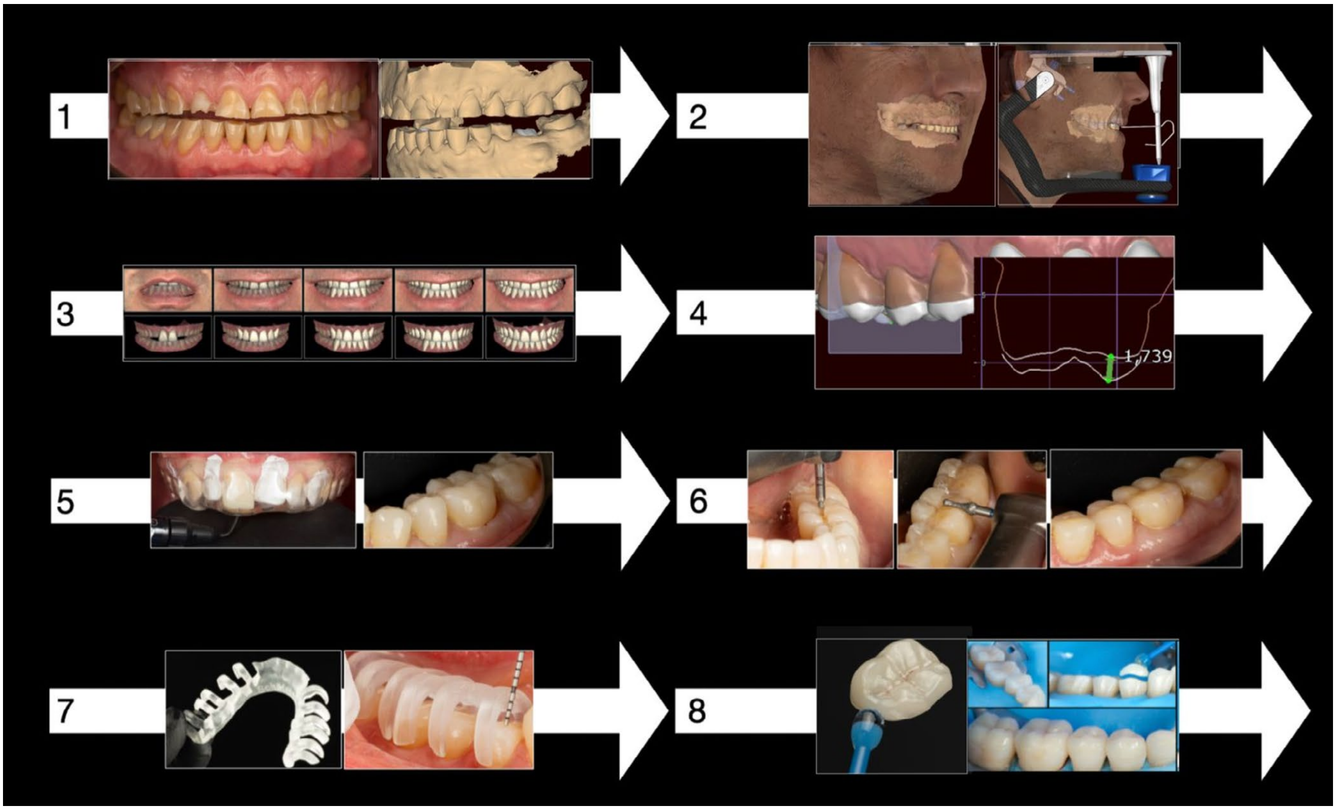


FIGURE 9 | Workflow illustrating the steps in the generated restorative space concept.

FIGURE 10 | (A) Pre therapy photo of a patient with worn dentition with functional and esthetic limitations. (B) Post-therapy photo of a patient with worn dentition where both function and esthetics have been re-established.

rehabilitation [38]. The workflow is based on the morphology-driven approach as described by Veneziani [19].

The limitations of the proposed protocol include the need for advanced clinical training, technological equipment, and the need to surpass the learning curve associated with interpreting data obtained from the digital planning. However, it is a clinically applicable and scientifically based approach to managing cases with decreased OVD, and its implementation, guided by biology, adhesion, and digital planning, will allow for sound treatments that are functional, minimally invasive, and predictable, thus increasing success when treating these complex cases.

4 | Conclusion

Prosthetic rehabilitation of patients with generalized worn dentition poses a challenge for clinicians, which goes beyond the complexity of the restorative technique itself. These cases require extensive treatment planning and an understanding of the specific scenario; thus, the prosthetic design in these cases must consider morphology, function, esthetics, and biology. A proper analysis of the required restorative space must be done to allow for minimally invasive preparations and respect the inherent mechanical requirements of the restorative material of choice. Also, the use of technological tools like the "cross-sectional view" allows the clinician to analyze the GRS and facilitates improved preservation of natural tooth structure and supports the long-term success and predictability of the restorations.

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Conflicts of Interest

The authors declare no conflicts of interest.

Data Availability Statement

Data sharing not applicable to this article as no datasets were generated or analysed during the current study.

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