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CLINICAL ARTICLE

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Multifunctional anatomical prototypes (MAPs): Treatment of excessive gingival display due to altered passive eruption

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Abstract

Objective: To describe a strategy using digital technologies for improving the diagnosis, treatment planning, and surgical execution of patients with excessive gingival display (EGD) due to altered passive eruption (APE).

Clinical Considerations: An important component for successful patient's management is to fulfill their esthetic expectations whilst delivering predictable and long-term therapeutic outcomes. To achieve this goal in patients with excessive gingival display due to altered passive eruption, it is essential to perform an accurate diagnosis and to communicate to the patient the expected customized results **using digital technologies**. Computer-aided designed and manufactured multifunctional anatomical prototypes (MAPs) may contribute to these purposes. Additionally, they can guide the surgical crown lengthening procedure or serve as a reference during the surgical guide fabrication providing information of the required anatomical landmarks.

Conclusions: This novel strategy protocol for diagnosis, communication, and treatment management of patients with excessive gingival display follows functional and biological principles within the frame of a digital workflow, which improves the diagnostic capabilities, enhances communication, and guides the surgical treatment as shown in the 12 months follow-up of the reported case.

Clinical Significance: Developing a virtual patient by combining multiple digital data sets including cone-beam computed tomography (CBCT), intra-oral scans and digital photography, supports the clinician and the patient to achieve a comprehensive diagnosis and to better communicate the expected results to the patient. Furthermore, this digital treatment exercise based on anatomical and biological principles will facilitate the surgical precision and the achievement of successful outcomes, thus fulfilling the patient needs and expectations.

KEYWORDS
altered passive eruption, artificial intelligence, CBCT, crown lengthening, digital dentistry, excessive gingival display, gummy smile, surgical guide, tooth segmentation

1 | INTRODUCTION

Excessive gingival display (EGD), commonly known as a gummy smile, has been defined as a non-pathological condition in which more than 3 mm of gingival tissue is exposed when smiling, frequently causing esthetic disharmony and patient's concern.[1] The differential diagnosis of this condition is broad since different clinical conditions including vertical maxillary excess (VME), dentoalveolar extrusion, short upper lip length, lip hypermobility, gingival hyperplasia, altered passive eruption (APE), may elicit excessive gingival display.[2]

Altered passive eruption is a condition where the dentoalveolar relationships do not properly achieve the process of passive eruption once the permanent dentition becomes fully functional. In normal developmental conditions, once the teeth intercuspation has been achieved (end of active eruption), the hard and soft tissues recede to allow for proper space for the supracrestal connective tissue attachment (passive eruption). This process of apical tissue migration may take several years, usually resulting in an anatomical crown where a portion (approximately 19%) remains hidden beneath the marginal gingiva.[3] Altered active eruption (AAE) occurs when teeth achieve contact with the opposite occlusal plane prematurely and the osseous crest is on or very close to the cemento-enamel junction.[4] When this active or passive eruption process is altered or retarded, the gingival margin, and sometimes the bone, are located in a more coronal position and manifest as excessive gingival display, frequently leading to esthetic concern due to the presence of short teeth and a gummy smile.[5,6]

The esthetic treatment of APE is usually surgical, through crown lengthening procedures, although the results of these interventions are not highly predictable, with frequent incomplete results or with a high rate of recurrence.[7–10] Moreover, APE may not be the only cause of the gummy smile and its surgical resolution may not fully solve the patient's esthetic concern. In these situations, since these treatments are sought for esthetic reasons, communication with the patient through the use of multifunctional anatomical prototypes (MAPs) is key since patients must be informed on the expected results and actively participate in the decision-making process.[11]

For these reasons, the use of current diagnostic tools should be headed toward a customized treatment plan where the patient can foresee the expected results with one or more treatment procedures. If restorative treatment is required concomitant to crown lengthening procedures, diagnostic wax-ups and try-ins are valuable tools for diagnosis and treatment planning purposes.[12] However, in APE, ancillary restorative treatment (i.e., veneers, crowns) is usually not required unless tooth alignment or incisal edge positions are inadequate. In these patients that crown lengthening procedure will be unable to fully solve the patient's esthetic concern, diagnostic mock-ups can be challenging since they may give the patient unrealistic expectations. The described digital workflow and the use of multifunctional anatomical prototypes (MAPs) may overcome this limitation.

Crown lengthening surgery for the management of APE is dependent on the existence of supracrestal space for the gingival connective tissue attachment. If there is enough space, the surgical goal is to eliminate the excessive gingival tissue to achieve the ideal esthetic tooth proportions whilst not exposing the root surface and the bone crest to minimize recession and post operative tooth sensitivity. Therefore, an accurate diagnostic requires precise information on the subject's anatomical crown dimensions, the position of the cementoenamel junction (CEJ) and the position of the alveolar bone crest (ABC). However, traditional diagnostic approaches can be clinically invasive, time-consuming, operator-dependent and of varying acuracy.[13]

To overcome these limitations in diagnosis, patient communication, and treatment planning, this manuscript describes a thorough digital strategy based on (1) digital scanning of the anterior maxilla by cone-beam computed tomography (CBCT) and Intraoral scanning (IOs), (2) virtual segmentation of the patient's teeth, and (3) conversion of the digital files into physical 3D printed

FIGURE 1 Extraoral exam, in which the excessive gingival display can be noticed.

FIGURE 2 Facial lower third exam and smile analysis.

multifunctional anatomical prototypes (MAPs) that can be used either for diagnostic purposes as try-in or as a surgical guide.

2 | MATERIAL AND METHODS

A 24-year-old systemically healthy female attended the Postgraduate Periodontal Clinic at the Faculty of Odontology at University Complutense of Madrid seeking advice on the solution to her esthetic complaint based on her excessive gingival display (EGD), what resulted in an unpleasant smile. Her comprehensive diagnosis consisted of taking periodontal records, intraoral and extraoral photographs, videos, intraoral scans (IOs) (Trios, 3shape, Copenhagen, Denmark) and a cone-beam computed tomography (CBCT) with lip retractors[14] to develop a differential diagnosis of her EGD, and thus make an appropriate customized treatment plan.

The resulting diagnosis was an APE combined with vertical maxillary excess and a short upper lip. The proposed treatment consisted of a guided crown lengthening procedure to reduce the EGD and improve teeth display proportion without addressing the muscular or

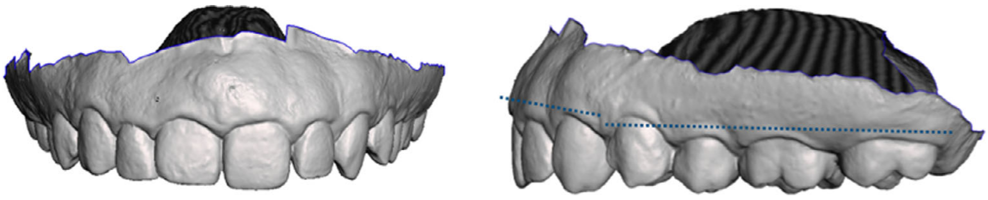

FIGURE 3 Intraoral scan (IOs) of the upper arch. Blue-dotted lines are used to help in the diagnosis process of anterior dentoalveolar extrusion.

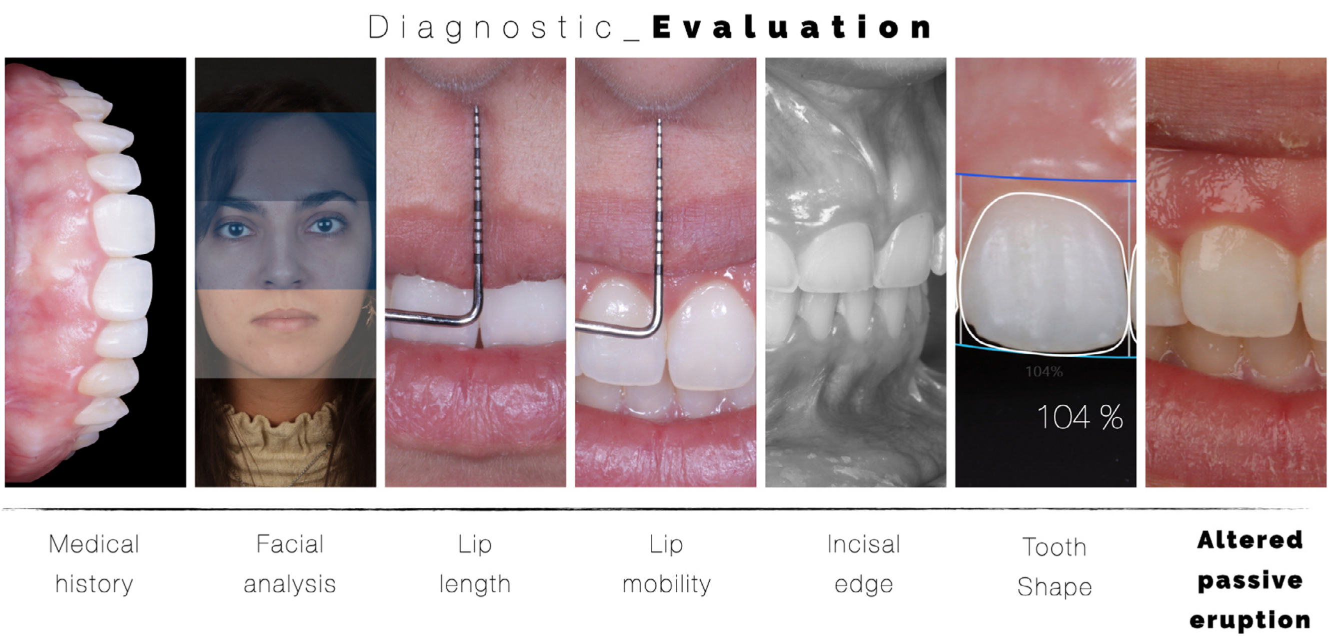

FIGURE 4 Example of the "Diagnostic evaluation sequence".

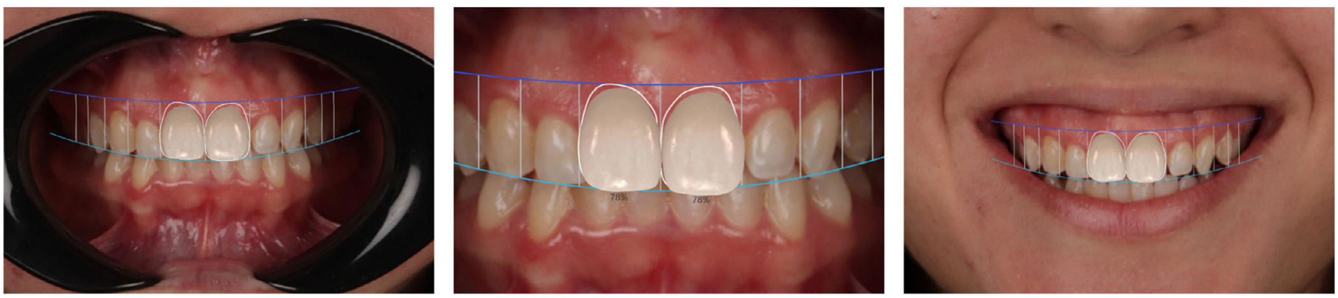

FIGURE 5 Facially-driven smile design comparing ideal central incisors proportions (78%; white line contour) and anatomical size of AI-Patient's segmented teeth.

FIGURE 6 Individualized tooth analysis of the difference between the anatomical crown and the clinical crown within the esthetic region (Teeth ·#15 to #25).

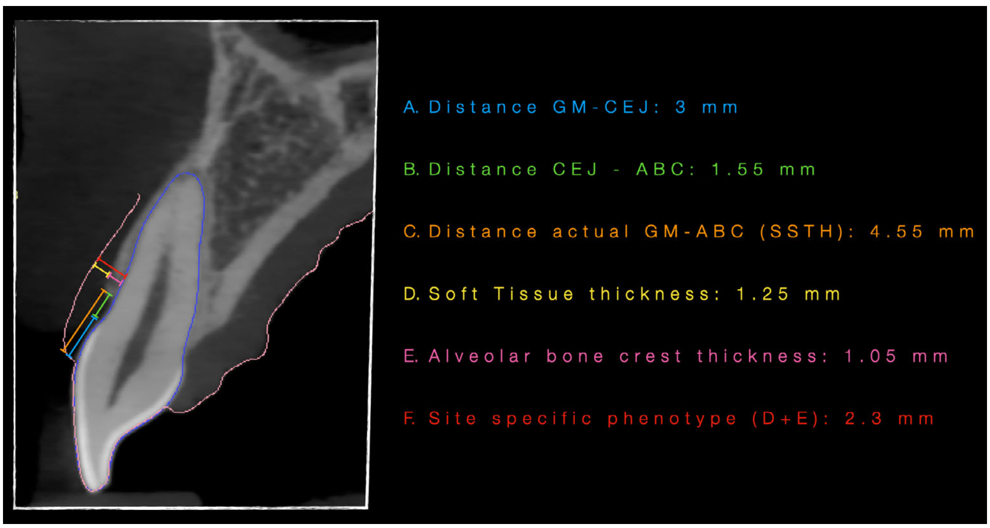

FIGURE 7 Tooth individualized digital analysis and diagnosis based on the superposition of the DICOM and baseline STL files (GM: gingival margin, ABC: alveolar bone crest, CEJ: cementoenamel junction, SSTH: Supracrestal soft tissue height).

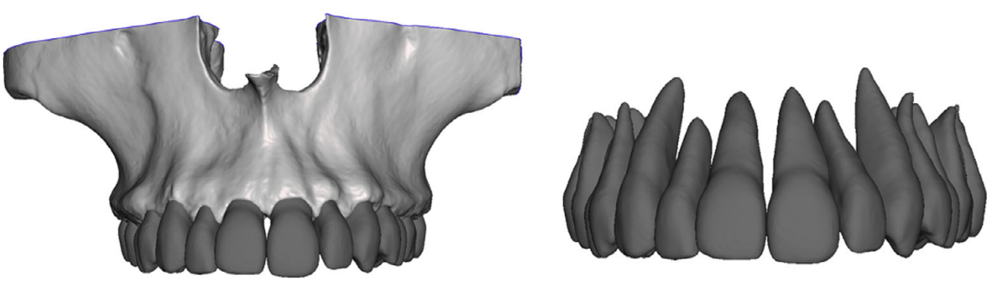

FIGURE 8 Artificial intelligence segmentation of upper maxilla teeth from a DICOM file.

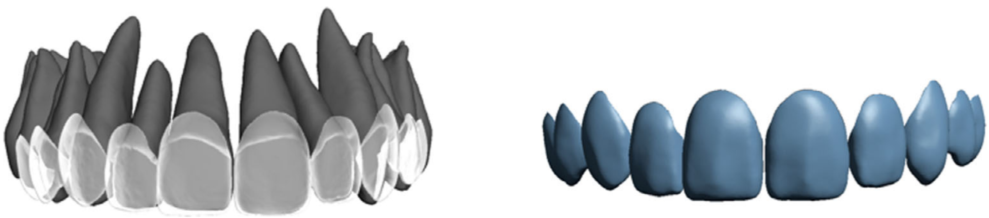

FIGURE 9 Result of MAPs obtained from AI-segmented teeth.

FIGURE 10 3D-printed MAPs.

skeletal component. This treatment plan was presented to the patient, who visualized the anticipated outcomes and accepted the treatment with a thorough understanding of the therapy involved and the expected results. We herein detail the different diagnostic and therapeutic steps taken to treat this patient.

3 | DIAGNOSIS PHASE

A review of the medical records discarded any systemic, developmental, or drug condition related to the EGD. The combined digital, photographic, radiographic and clinical diagnostic evaluation of both the intraoral and extraoral tissues including the combination of *Digital Imaging and Communication in Medicine* (DICOM) files with IOs - *Standard Tessellation Language* (STL) files provided a combined diagnosis of vertical maxillary excess (skeletal component), short and hypermobile upper lip (muscular component), and APE resulting to short clinical crowns (dentoalveolar component). (Figures 1-4).

The clinical crown shape, size, and proportions were analyzed using the photograph planning software (TRIOS Smile Design, 3Shape), revealing abnormal ratios compared to those derived from natural unworn human dentition.[15] The digital smile design according to the esthetic characteristics of her smile was executed by only modifying the crown length.[16] In parallel, STL files corresponding to the patient's segmented teeth were transformed into CAD library teeth (TRIOS Design studio). These files were obtained by segmenting the patient's DICOM file using the artificial intelligence (AI) software (Diagnocat AI system®). Then, by manual alignment, the STLs were superimposed on the facially driven smile design (Figure 5).

When the resulting ideal gingival margin is coronally positioned to the anatomical CEJ, with correct incisal edges and tooth proportions, treatment planning should consist of a crown lengthening procedure without any additional restorative treatment. In other severe EGD cases, the digital diagnosis may result in exposed root surfaces, which warrants the need for additional multidisciplinary treatment, either orthodontic, maxillofacial, or restorative. Furthermore, a comprehensive analysis of other esthetic factors,[16] including occlusion and anterior tooth display at rest position may indicate the need for other restorative treatments, such as the shortening or lengthening of incisal edges.[17]

In this clinical case, maxillary anterior clinical crowns were considered short, however the assessment of the anatomical crown (IA-segmented teeth) had ideal proportions (≈78%).[15] The incisal edges did not contact the lower lip during smile, and there was certain lack of symmetry among the central incisor incisal edges (Figure 5). However, despite informing the patient about this incisal edge discrepancy the patient did not report any concern and therefore, the need for restorative treatment and/or orthodontic therapy was discarded.

4 | PLANNING PHASE

The surgical planning of APE cases requires a comprehensive analysis of the anatomical structures[18] including the supracrestal soft tissue height (SSTH),[19] site phenotype, keratinized tissue height (KT), CEJ, and ABC position.[20,21] These anatomical landmarks are assessed digitally by combining the baseline IOs, the STL file of the AI-segmented teeth (serving as a diagnostic mock-up on patients with APE), and the CBCT DICOM file (Figures 6, 7). Thus, we can plan the site-specific need for either excisional soft tissue resection or the additional need for ostectomy when there is not enough STA dimension, which depending on the patient's phenotype, will dictate the need and quantity of bone removal.[8,9] (Figure 7).

Similarly, the baseline KT width will determine the need for an excisional gingivectomy or an apical reposition flap (ARF).

The diagnosis of this clinical case was an altered passive eruption (APE) type 1B[18] or type 1 with AAE,[4] where the CEJ of the anterior maxillary teeth was apical to the gingival margin (GM) (approximately 3 mm) and the relative distance between the CEJ and the ABC was about 1.5 mm, what resulted in insufficient space for the supracrestal tissue attachment.[6,22–24] Since there was enough keratinized tissue (KT), the treatment plan was a surgical crown lengthening procedure including flap elevation and ostectomy to increase the STA dimension and the transformation of teeth with proportions of 105% to ideal proportions of 78%. (Figures 6, 7).

FIGURE 11 Multifunctional anatomical prototype (MAPs) try-in (Lower third and smile analysis).

FIGURE 12 MAPs try-in (Intraoral exam). The difference between the first and second quadrants can be appreciated, obtaining an increment ≈ 3 mm of the clinical crown.

5 | PATIENT COMMUNICATION PHASE

Once we got this ideal treatment, it was presented to the patient as a mock-up, so she could visualize the expected outcomes. This communication step is particularly important in patients where the EGD has a multifactorial etiology, since focusing only on one etiological factor may lead to undesired esthetic results.

With this purpose, we fabricated 3D-printed multifunctional anatomical prototypes (MAPs) based on the patient's tooth proportion and shape as a diagnostic mock-up to anticipate the expected results after the crown lengthening procedure. This step allowed us to show the patient the proposed outcomes of this surgical therapy directly and thus explain the limits of the surgical procedure to reduce the EGD.

Based on the DICOM data obtained from the CBCT, each tooth from the esthetic region (#1.5 to 2.5) was virtually segmented and transformed into individual STL files with the required information regarding shape, proportions, and CEJ location (Figure 8). Then, AI-segmented teeth were introduced into a computer-aided design software to attain individualized prototypes by superimposition with the baseline intraoral scan files of the patient (Figure 9). Eventually, these prototypes were printed with restorative resin (Formlabs, Sommerville, USA) using an additive stereolithography (SLA) printer (Form 3B+, Formlabs, Sommerville, USA) and then tested on the patient with the prototype leaning upon the gingiva as a diagnostic mock-up (Figure 10 and Figure 11).

Extraoral and intraoral photographs and videos, with the patient using the prototypes were taken and used for the patient communication and self-evaluation (Figure 11). The patient could then assess the result of increasing up to 3 mm in the clinical crowns on the central incisors (Figure 12). This digital workflow allowed the patient to have a realistic pre-visualization of the outcome, since the prototypes were consistent with her underlying teeth, and she accepted the proposed surgical procedure without any additional treatment. However, there are situations when the ideal teeth are different from the patient's anatomical proportions, and these customized prototypes, based on these ideal proportions will present the patient the need for ancillary treatments.

6 | TREATMENT PHASE

Once the patient accepted the proposed treatment outcome visualized with MAPs, the crown-lengthening surgery was carried out.

Within this surgical procedure, MAPs were used as a reference to perform the surgery precisely. For this purpose, MAPs can be used as a surgical guide or serve as a reference to create an additional surgical guide by means of CAD software that follows the precise shape of the planned and tested prototypes (Figure 13). This surgical guide was used not only to guide the excisional gingivectomy (first landmark) but also to perform the osseous surgery after raising full-thickness flaps (second landmark), thus re-establishing the new ABC position and creating adequate space for STA in each tooth (Figure 13).

The excisional gingivectomy was performed with a diode laser following the surgical guide and the position of the new gingival margin was achieved, a full-thickness flap was elevated to expose the CEJ and the ABC. Ostectomy was performed with round and end-cutting burs to create sufficient space for the supracrestal tissue attachment. Minor osteoplasty was done to improve flap adaptation with diamond round burs and the flap was then repositioned and sutured using vertical mattress sutures with palatal knots. The GM in the immediate post-op achieved the foreseen position of the MAPs with a mean gain of 3 mm of the clinical crown without exposing the CEJ (Figure 14).

7 | DISCUSSION

EGD correction and treatment of patients with APE can be challenging since achieving predictable outcomes to satisfy the patient's

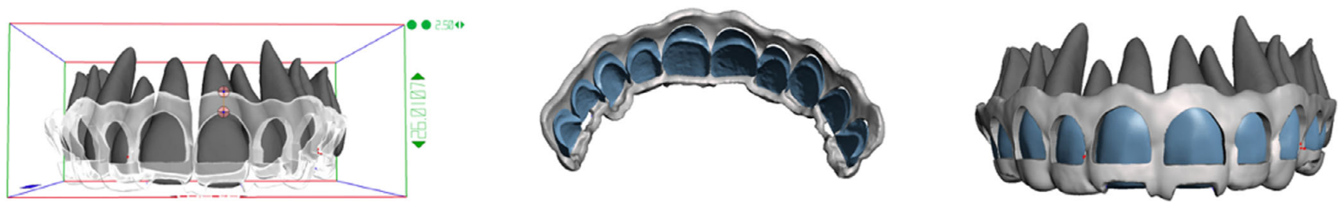

FIGURE 13 Digital planning and design of the surgical guide, following the outline of MAPs already approved by the patient.

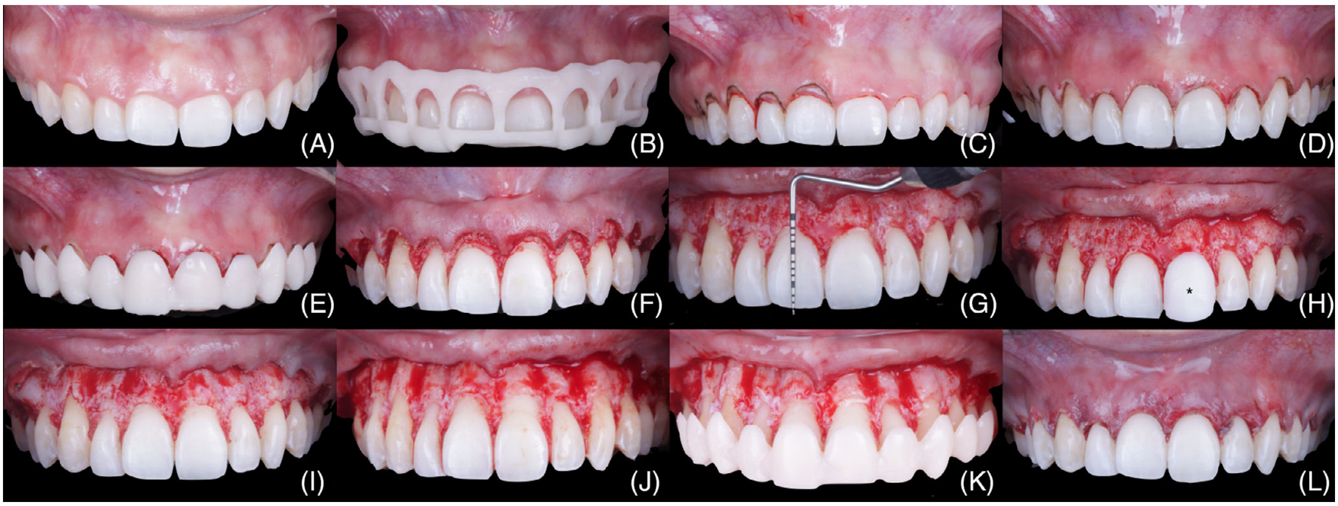

FIGURE 14 Complete surgical sequence (A: baseline situation, B: surgical guide try-in, C: Gingivectomy evaluation of first quadrant, D: Complete gingivectomy, E: accuracy evaluation of gingivectomy with splinted-MAPs, F: full thickness flap elevation, G: Intrasurgical evaluation of splinted-MAPs and distance from planned CEJ to ABC, H: individual MAP on tooth ·#21, I: pre osseous surgery, J: post-osseous surgery, K: evaluation of osseous surgery with splinted MAPs, L: flap suturing with palatal vertical mattress sutures).

FIGURE 15 1, 2, and 4-week follow-up clinical pictures showing uneventful and favorable healing.

esthetic expectations require a precise diagnosis and accurate treatment planning to fulfill both biological requirements and satisfactory esthetic results.

The presented clinical technique article illustrates an innovative diagnostic and treatment approach using the proposed multifunctional anatomic prototypes (MAPs) that provide: (1) A minimally invasive diagnostic and planning method with improved accuracy and reduced patient chair time. (2) An enhanced patient communication using image reconstructions and 3D-printed anatomical prototypes based on the foreseen ideal results with the proposed treatment plan. (3) A guided surgical procedure following the landmarks outlined in the proposed treatment plan. (Figure 16).

The introduction of CBCT and Intraoral Scanning (IOs) in dentistry has facilitated precise diagnosis and treatment planning in APE cases, since the digital DICOM files clearly outline the hard tissues (tooth and osseous anatomical landmarks) and the STL files capture the position of the soft tissues.[25] Using appropriate software to superimpose both files (DICOM and STLs), we can create an integrated virtual ecosystem where the exact positions of the ABC, CEJ, GM and their respective relationships can be identified and evaluated in each tooth.

In crown lengthening procedures, the diagnostic phase to determine STA height has been traditionally performed through bone sounding, which is a clinically invasive procedure requiring local anesthesia. Moreover, its reliability may be limited in cases of thin buccal bone plates or bone dehiscence. In these scenarios, the surgical treatment plan may represent a clinical challenge, more dependent on the operator's experience than on an accurate diagnosis.

Similar efficacy in mean clinical crown lengthening has been demonstrated using a conventional technique (i.e. bone sounding + free hand surgery) than a guided dual technique (i.e. digital planning + surgical guides).[26,27] However, root exposure or soft tissue rebound are some potential complications consequent of planning the new gingival margin position due to (1) CBCT measurements in the axial view plane which are later individually transferred into a CAD software[28] or (2) facially driven esthetic diagnostic wax-ups which do not follow biological concepts.[26] The proposed novel approach, where AI-segmented teeth are employed, adds value to previously proposed digital workflows potentially solving this problem. It includes the exact position and shapes of the underlying teeth directly into the CAD software to plan the case accordingly to anatomical landmarks. In this way, inaccuracies originated in manually transferring CBCT measurement into the clinical environment are eliminated and the planning is also considerably less time-consuming and biologically oriented.

Furthermore, a detailed assessment of site-specific phenotype characteristics using the virtual planning software may contribute to long-term gingival margin stability due to an individualized ostectomy. All of the above, together with a simultaneous reduction on patient's

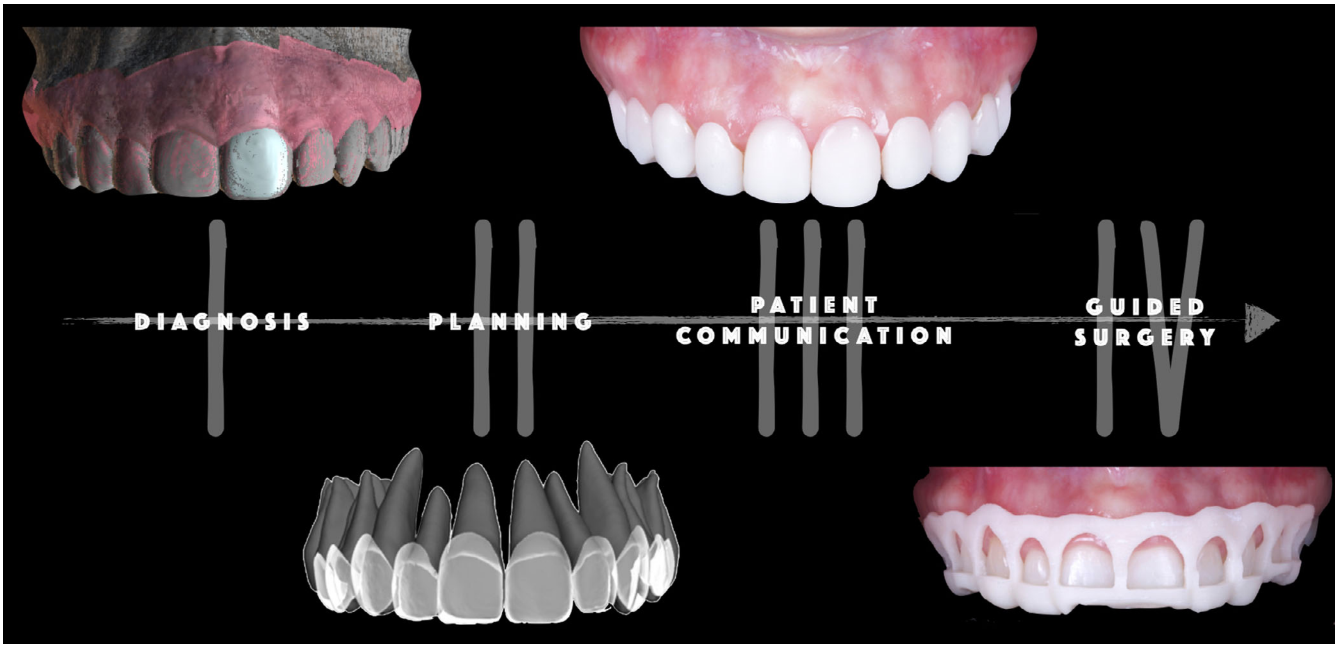

FIGURE 16 Treatment timeline: (A) digital diagnosis, (B) planning phase based on AI-segmented teeth and registration with IOs, (C) patient communication employing MAPs, (D) guided surgery with an additional surgical guide based on MAPs (MAPs can also be used as a surgical guide themself).

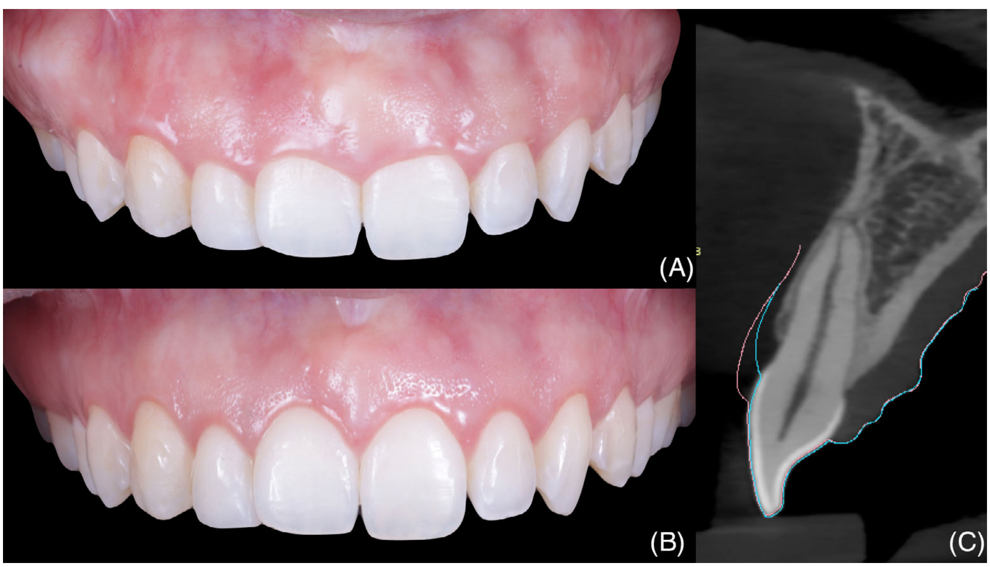

FIGURE 17 Baseline situation (A) vs. 12 months follow-up results (B) shows the stability of the obtained results, in which the desired tooth proportions have been obtained, and the GM has remained in its planned position, which can be confirmed by registering both STL, baseline (pink outline) and 12 months follow up (blue outline) STL, with the DICOM file (C).

FIGURE 18 MAP repositioned on #21 after 12 months follow-up to demonstrate stable and accurate outcomes according to the planned gingival margin position. (Note: incisal edge of #21 was initially longer than #11).

chair time for both diagnosis and surgery, can result in a more favorable patient experience.

Multifunctional anatomical prototypes (MAPs) can also become an excellent communication tool since the main indication of the treatment is an esthetic improvement. By allowing the patient to visualize the ideal esthetic result, we can discuss with the patient the needed treatment plan to achieve this proposed outcome. This is illustrated in the presented clinical case where the patient was diagnosed with an excessive gingival display with simultaneous etiologies (skeletal, muscular, and dentoalveolar). Despite several treatment options to treat this condition were proposed to the patient, she accepted a minimally invasive approach to solve her APE after evaluating the expected result with MAPs and being satisfied with the proposed outcomes. Additionally, through this result visualization, we usually positively impact the patient's psychology by gaining self-confidence and a proactive attitude toward the proposed treatment stages and postoperative care. However, a limitation must be acknowledged since these 3D-printed snap-on prototypes will have a certain thickness that will slightly increase the buco-lingual contours when placed over the teeth. As 3D printing technology improves its accuracy, thinner prototypes will allow the creation of a more realistic representation of the underlying teeth.

Lastly, MAPs can be used as a reference to design a surgical guide or they can be used themselves as a guide, enabling an easier and more precise surgical procedure that delimitates the excision of excessive gingiva (gingivectomy). Using MAPs as a surgical guide is especially useful in the papillary region, where traditional surgical guides do not allow access due to its design. MAPs can also be used as an ostectomy reference when the full-thickness flap is elevated if STA dimension needs to be enlarged. Crown-lengthening surgical guides are designed based on the preoperative baseline IOS which usually do not adapt precisely to the bone surface once the flap is elevated. To solve this problem, the use of a second surgical guide for ostectomy purposes has been described.[29] However, MAPs are settled accurately over the teeth (Figure 14H), facilitating CEJ identification during surgery and serving as a reference to perform the required ostectomy without needing a secondary guide. Since the diode laser facilitates intraoperative visualization due to better bleeding control, it was employed to demonstrate an accurate CEJ identification after performing the gingivectomy following MAPs or the surgical guide (Figure 14B-E).

Although the planning stages to produce the MAPs require additional professional time, this clearly compensates with a shorter and more accurate surgical intervention and consequently with reduced

FIGURE 19 Extraoral exam, 1 year. The excessive gingival display has been reduced according to the planning and the patient is satisfied with the outcomes communicated before the surgery.

patient chair time. This workflow may contribute to achieve an accurate postoperative positioning of the gingival margin (Figure 15), but its long-term stability of the treatment outcomes will depend on other factors, such as operator skills, patient's phenotype, errors and inaccuracies during MAPs design or 3D printing, healing patterns and tissue contraction,[7–10] mainly when the surgery is carried out in one single stage[30] (Figure 16). However, the proposed digital workflow provides strategic information on the anatomy landmarks that will guide the different surgical techniques available for crown lengthening in APE cases[14,31] with accurate results demonstrated at 12 months (Figures 17-19).

8 | CONCLUSIONS

The proposed digital workflow based on the use of multifunctional anatomic prototypes represents an improvement to facilitate a differential diagnosis of excessive gingival display cases, for designing and communicating the ideal treatment plan, and for guiding the required surgical procedure according to individualized diagnosis and foreseen treatment outcomes.

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DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available on request from the corresponding author. The data are not publicly available due to privacy or ethical restrictions.

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