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British Journal of Oral and Maxillofacial Surgery 64 (2026) 470–477

BRITISH Journal of Oral and Maxillofacial Surgery

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Enriching the virtual twin: clinical benefits of facial scan integration in orthognathic surgery planning

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Received 23 October 2025; revised 8 February 2026; accepted in revised form 7 March 2026
Available online 27 March 2026

Abstract

The aim of this report was to present a reproducible workflow for integrating three-dimensional (3D) facial scans into computed tomography-based virtual surgical planning of orthognathic surgery, thereby enriching the virtual twin with clinically relevant soft-tissue information. This report describes the sequential stages of the workflow: 1) standardised preoperative imaging including computed tomography, intraoral scans (IOS), and three facial scans (rest, smile, lip-retracted); 2) preprocessing of facial scans in 3-Matic to remove dental structures and generate soft-tissue stereolithography (STL) models; 3) virtual twin construction in Materialise Enlight v7.0 by integrating digital imaging and communications in medicine skeletal data, IOS, and surface-based facial models; 4) application of repositioning tools and STL import functions to integrate multiple facial scans; 5) visualisation and analysis of natural head position, digital smile design, and comparison of pre- and postoperative soft-tissue predictions; and 6) finalisation of the case with the generation of intermediate and final splints and export of all planning data. The integration of facial scanning into virtual surgical planning is feasible and may be clinically relevant. While promising, further validation is required to confirm accuracy and reproducibility in routine clinical practice, particularly with respect to natural head position, digital smile design, and soft-tissue prediction. This workflow highlights the potential of recent software advances and facial scanning technologies in orthognathic planning.

Keywords: orthognatic surgery; three-dimensional imaging; virtual imaging; computer-assisted surgery; facial scan; facial analysis

Introduction

Orthognathic surgery refers to surgical procedures aimed at repositioning the jaws. This repositioning seeks to restore a new equilibrium among several functional units of the face, including the jaws, teeth, temporomandibular joints, and soft tissues such as the tongue and lips.[1] Several concepts for attaining facial harmony through orthognathic skeletal adjustments have been put forward, with influential contributions by Arnett et al,[2,3] Reyneke,[4] and Mommaerts.[5]

Prior to any repositioning, a comprehensive facial analysis is mandatory. Over the past decades, this analysis has evolved from two-dimensional (2D) to three-dimensional (3D) imaging. Traditional planar radiographs such as panoramic radiographs and lateral cephalograms have gradually been replaced by cone-beam computed tomography (CBCT) and computed tomography (CT). With the advent of virtual surgical planning (VSP), as described by Swennen et al,[6] the era of manual tracings on acetate has come to an end.[1,7] Conventional facebows have been substituted by the pursuit of the natural head position (NHP) as a more reproducible and clinically relevant reference.[8–10]

Today, VSP relies on the creation of a virtual twin, which is a digital replica of the patient that allows for simulated sur-

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https://doi.org/10.1016/j.bjoms.2026.03.008
0266-4356/

gical movements and prediction of the postoperative outcome. These virtual twins are constructed using both skeletal and soft tissue data derived from digital imaging and communications in medicine (DICOM) files and are now increasingly augmented with intraoral scans (IOS). This results in a composite model, which merges DICOM-based imaging with the high-resolution detail of the dentition from IOS, thereby improving the accuracy of planning.[6,11–14]

More recently, facial scanning technologies, which generate lifelike 3D surface renderings of the patient's face, have been integrated into this workflow. These facial scans produce true-colour, surface-based 3D photographs of the facial soft tissues. Most current systems operate on the principle of optical light reflection.[15–18]

With the development of new software platforms such as Materialise Enlight v7.0, it is now possible to import various stereolithographic (STL) files, including facial scans, into the standard clinical VSP workflow. These innovations allow the virtual twin to be enriched with detailed soft tissue data, enhancing the accuracy of digital smile design, NHP alignment, and prediction of postoperative outcomes.[1,6,19]

The aim of this study is to explore and demonstrate the potential of integrating 3D facial scans into next-generation software platforms for orthognathic surgical planning.

Material and methods

Preoperative workup and imaging protocol

Each orthognathic case is subjected to a standardised preoperative diagnostic workup. In our institution, this includes the collection of both 2D and 3D data.[1,6] As part of the 2D documentation, panoramic radiographs, and lateral cephalograms are obtained, complemented by standardised clinical photographs taken under controlled lighting conditions.

A wax bite registration is taken in the retruded occlusal mandibular (ROM) position with the patient in supine position. This wax bite is retained intraorally during the acquisition of the CT scan, which ensures accurate mandibular positioning during imaging.[7,11,12] To guarantee that the resulting dataset is suitable for precise VSP, our centre applies a dedicated CT protocol that adheres to established neuronavigation standards in oral and craniomaxillofacial (OCMF) surgery.

In addition, IOS of the upper and lower dental arches are acquired using a Medit Link 7 scanner. In our workflow, detailed soft tissue morphology is captured, with facial scans obtained using the MetiSmile system (FScan, Shining3D; Facial Analyzer, Shining3D). These scans are performed in a neutral rest position, during a spontaneous full smile, and with a lip retractor in place to fully expose the maxillary anterior teeth. Patients are positioned in NHP, hair is secured away from the face, and extraneous objects such as eyeglasses are removed and hands kept out of the way to minimise artefacts and variability. These facial scans are acquired using a handheld 3D surface scanner (Shining 3D Dental).[15–18]

All image data are processed using Materialise Enlight v7.0 and Materialise Mimics 3-Matic v19.0 (Materialise). The integration of DICOM files, intraoral STL data, and surface-based facial scans into a composite virtual twin is conducted within this digital environment.[19] (Fig. 1).

Initial processing of facial scans

In the first step, the facial scans are processed using 3-Matic (Materialise). Utilising the Trim Tool, all digital information related to the dentition is selectively removed. This results in facial models displaying only the soft tissue structures of the patient, with dental anatomy fully excluded (Fig. 2).

The two processed facial scans, facial scan with lips in resting position excluded—corresponding to the spontaneous smile, and lip-retracted condition—are subsequently exported to a dedicated storage folder. These soft tissue models will later be re-imported into Materialise Enlight v7.0 for integration using the STL import button into the VSP workflow.[15–18]

Virtual twin construction in Materialise Enlight v7.0

Upon initiating a new case in Materialise Enlight v7.0, the patient's DICOM data, acquired with the condyles positioned in the ROM position, are imported into the software environment. Through the predefined segmentation workflow, the cranium, mandible, and facial soft tissues are segmented. Subsequently, the IOS are loaded and mounted (stitched) onto the existing segmented mandible and maxilla. This results in a composite models described by Swennen et al,[7] combining the anatomical accuracy of the DICOM-derived bony structures with the high-resolution detail of the dentition from the IOS data. Along with the segmented soft tissue envelope, these models are saved as reference STL files within the platform.[8–10,20,21]

After this step, the workflow proceeds with several preparatory analyses. Bilateral tracing of the inferior alveolar nerve is performed to safeguard anatomical structures during planning. The NHP is then established directly from the facial scans, providing a reproducible and clinically relevant reference orientation. Finally, a cephalometric analysis is carried out to guide skeletal repositioning. The sequence of these steps may vary depending on the specific surgical protocol being applied (Fig. 3).

Once the preparatory analyses are complete, the osteotomy phase is initiated. Within the virtual environment, all osteotomy surfaces are carefully reviewed and verified before execution. Standard osteotomies are then planned, including a Le Fort I osteotomy, bilateral sagittal split osteotomy, and genioplasty when indicated.[1,22,23] These osteotomies are prepared within the virtual environment to enable precise surgical simulation.

Following this, the final occlusion setup—based on the desired postoperative dental relationship—is imported into the planning system. At this stage, the virtual twin is consid-

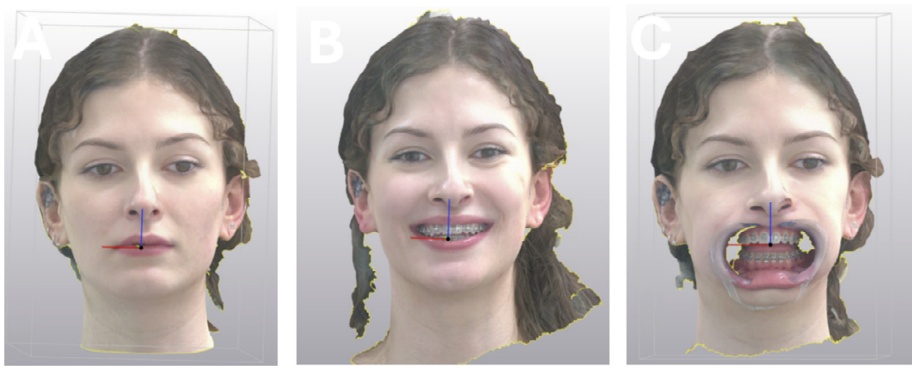

Fig. 1. Print screen of the facial scans in in Materialise 3-Matic v.19.0. (A) Neutral rest position. (B) Smile. (C) Retracted smile.

Fig. 2. Print screen of the facial scan in in Materialise 3-Matic v.19.0. (A) Normal retracted smile. (B) Smile with trim tool in situ. (C) Smile after application of the trim tool without dentition.

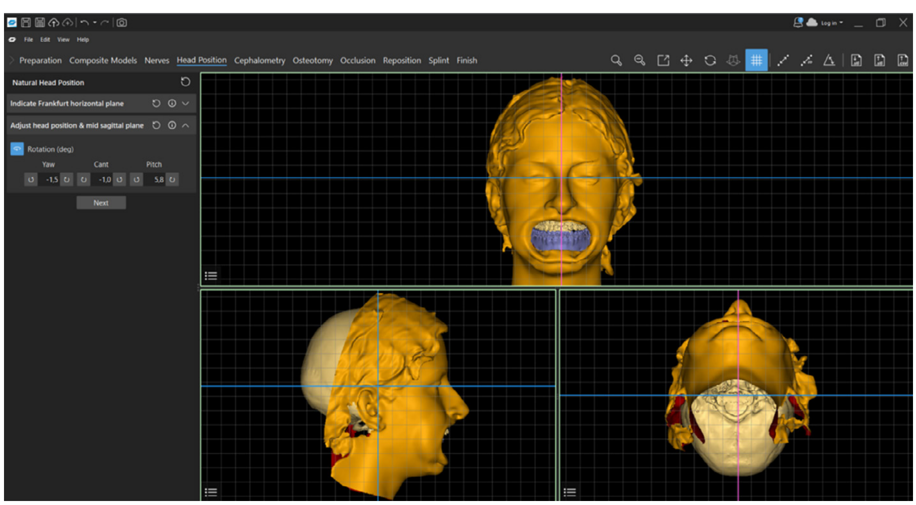

Fig. 3. Establishing natural head position within the virtual surgical planning environment (print screen Materialise Enlight v7.0).

ered nearly complete and ready for final surgical planning and simulation (Fig. 4).

Advanced repositioning and STL import functionalities in the clinical workflow

Within the clinical workflow of Materialise Enlight v7.0, a series of advanced functionalities become available during the intermediate 'Reposition' phase. Among the most frequently used are the 'Move,' 'Mirror,' and 'Align' tools, which allow for precise manipulation of individual anatomical segments. These functions significantly increase flexibility in treatment planning and are particularly valuable not only in orthognathic surgery but also in the management of complex craniofacial trauma, where accurate repositioning of skeletal fragments is essential.[15–19]

In addition to these manipulation tools, the software provides an 'STL Import' function that enables the integration of

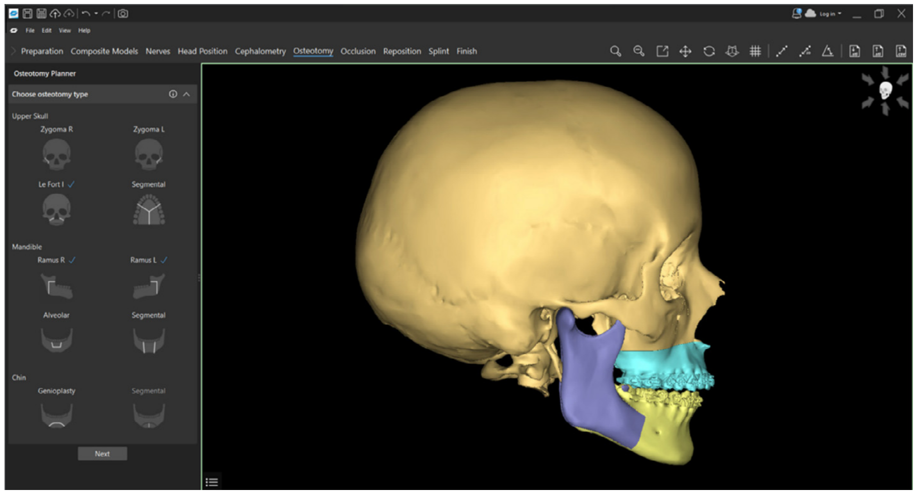

Fig. 4. Print screen of Materialise Enlight v7.0.

supplementary digital models into the virtual twin environment. This feature supports the import of additional IOS, either with or without prosthetic restorations, as well as various facial scans representing the patient in different conditions, including neutral rest position, spontaneous smile, and lip-retracted expression.

Once imported, these facial scans are registered to the CT-derived soft-tissue model within Enlight. Alignment is achieved through a combination of initial positional adjustments and surface-based registration using stable anatomical reference regions such as the forehead, nasal bridge, and zygomatic arches. This process ensures a precise match between the surface-based facial scans and the DICOM-based soft-tissue envelope.[19,24] (Fig. 5).

The integration of these datasets enables the visualisation and analysis of dynamic facial expressions within the same virtual planning environment, as illustrated in Fig. 6.

Enhanced visualisation and analytical value of multiple facial scans in virtual surgical planning

By importing multiple facial scans into Materialise Enlight v7.0, the VSP process gains an additional dimension, offering a novel approach to soft tissue-based analysis. The integration of these scans results in what may be described as a 'soft tissue composite mask', which can be used to extract valuable clinical insights at different stages of the planning workflow.

Natural head position assessment using retracted facial scans

One of the primary advantages is the improved ability to evaluate the NHP. By selecting the lip-retracted facial scan within the head position tab, clinicians obtain an unob-

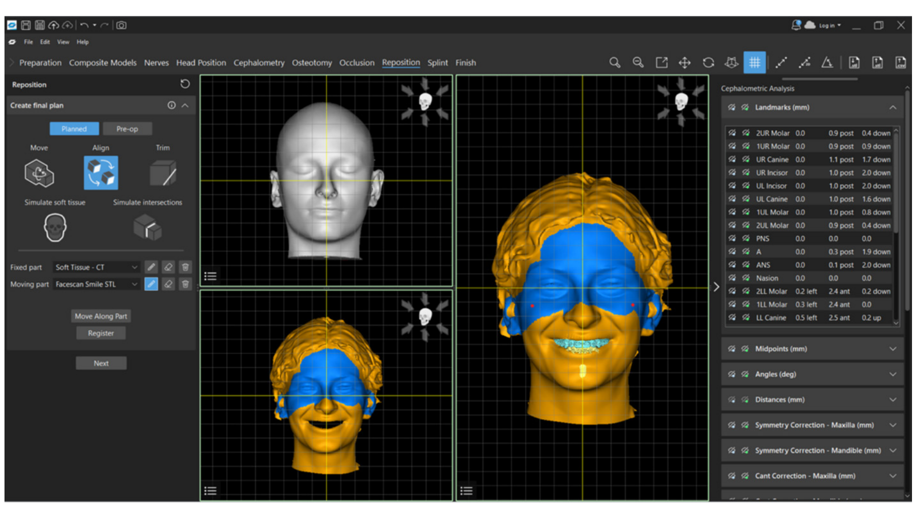

Fig. 5. Alignment of an imported facial surface scan to the CT-derived soft-tissue model within Materialise Enlight v7.0. Alignment is performed using surface-based registration over stable anatomical regions (forehead, nasal bridge, and zygomatic arches), ensuring accurate correspondence between the DICOM-based and surface-based facial models before further virtual planning.

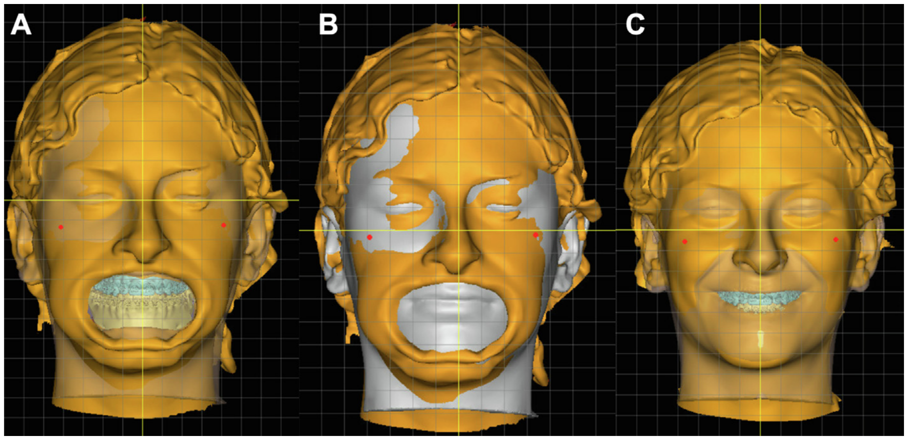

Fig. 6. Face scans imported in Materialise Enlight v7.0. A. Facial scan with retractor. This enables a reliable assessment of maxillary roll, referenced not to the infraorbital line but, more precisely, to the soft-tissue bipupillary line. B. This view provides an overall visualisation of the soft-tissue mask from the DICOM dataset relative to the soft-tissue facial scans. C. Using the smiling facial scan, we can accurately assess the virtual incisor display ('tooth show') and correlate it with the clinical findings.

structed view of the maxillary dental archin direct relation to the interpupillary line. This provides a more intuitive assessment of midline alignment and maxillary cant.[22,25,26]

Traditionally, NHP and maxillary orientation have relied on skeletal landmarks and planes, such as the Camper's plane or the infraorbital line. However, these references are not without limitations and often exhibit a degree of arbitrariness. The use of facial scans introduces a more naturalistic reference framework, although further research is required to determine its superiority or reproducibility. This ongoing debate underscores the distinction between clinical protocol and artistic surgical judgment, emphasising the nuanced nature of orthognathic treatment planning.[20,21]

Digital smile design integration

A second benefit of incorporating facial scans, particularly the smiling facial scan, is the potential for digital smile design (DSD). This tool allows for the evaluation and fine-tuning of incisor display, anterior intrusion/extrusion, and maxillary cant. Unlike conventional methods, which rely on skeletal planes, the cant can now be adjusted relative to the interpupillary line, yielding a more aesthetically driven result. This approach significantly improves patient communication, providing a clear visual representation of the proposed changes.[22,24–26]

Preoperative and postoperative soft tissue comparison

A third and highly impactful feature, newly introduced in Enlight v7.0 (and previously unavailable in version 6.0), is the ability to compare preoperative and predicted postoperative soft tissue outcomes. This visualisation not only supports surgical decision-making but also improves patient understanding and acceptance by clearly demonstrating the expected aesthetic changes.[27,28] (Fig. 7).

Finalisation and export of surgical planning data

Once the definitive surgical plan has been finalised, both intermediate and final surgical splints can be generated directly within the software environment. The creation of these splints marks the conclusion of the digital planning workflow and indicates that the case is ready for surgical execution.

At this stage, all relevant planning data can be exported in standardised formats. This export typically includes STL files of the segmented skeletal structures, the generated splints, and the corresponding soft-tissue models. In addition, the software (Materialise, Enlight v7.0) automatically produces a PowerPoint report that provides a structured summary of each step of the planning process and its outcomes. The export further contains the set of cephalometric landmarks and the established NHP, ensuring that all critical reference information is preserved for clinical application.

The availability of these outputs enables seamless communication between the surgical team, the dental laboratory, and the patient. Furthermore, the exported material functions not only as a practical guide during surgery but also as a permanent record that can be used for academic reporting and clinical documentation.[1,22,23]

Discussion

The advent of VSP and the creation of the virtual twin have significantly transformed the approach to orthognathic surgery. One of the most impactful changes is observed in the frontal assessment of facial structures. In particular, the evaluation of maxillary cant has become substantially more intuitive and reliable compared to traditional model surgery using plaster casts. Historically, cant assessment was performed using facebow registrations and clinical measurements, often with limited reproducibility and high operator dependency.[1,22,23]

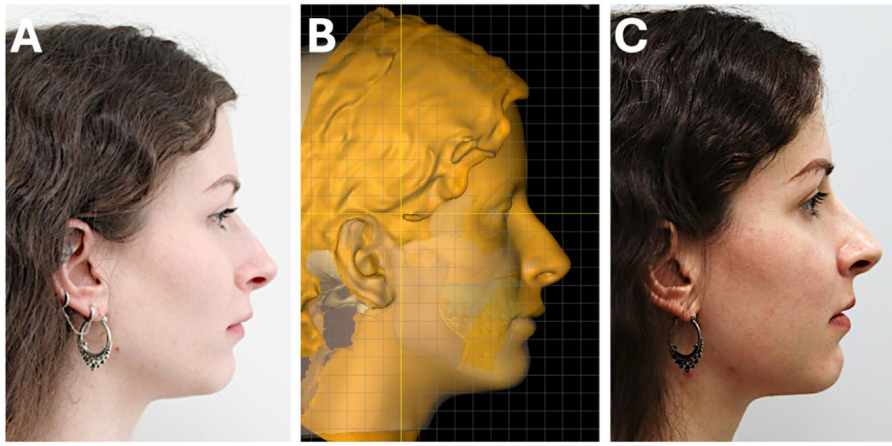

Fig. 7. Clinical pictures in the sagittal view. (A) Preoperative. (B) Virtual surgical planning. Transparent facial outline is the post-operative prediction. (C) Postoperative result 6 months after LeFort I osteotomy and BSSO advancement.

Despite these advances, a major limitation in current VSP workflows is that cranial orientation is still largely based on skeletal reference points, such as the Frankfort horizontal plane (defined by bilateral porion and the left infraorbital rim) or the infraorbital line in the frontal view.[20,21] While these provide standardised geometric anchors, they lack clinical relevance in terms of facial aesthetics. In removable prosthodontics, for example, the Camper's plane, which is defined by the soft tissue tragus and ala of the nose, is commonly used for functional and aesthetic tooth positioning.[29] However, transferring this clinically intuitive reference to a digital environment remains challenging.

A more streamlined and reproducible workflow could likely have been achieved by performing the facial scan trimming directly in 3-matic rather than within Enlight. Adopting an analogue trimming approach—first defining the trim based on dentition and head orientation, and subsequently aligning all three facial scans (rest, smile, and retracted)—would have provided greater control over the spatial relationship between the facial surface and dentition. This sequential alignment would ensure that each facial scan remains accurately registered to the underlying anatomy, thereby minimising manual adjustments and improving consistency throughout the virtual planning process.

A similar challenge exists in the evaluation of the facial midline. Importantly, midline assessment is always performed relative to soft-tissue reference points such as the glabella, nasion, philtrum, and pogonion, rather than purely skeletal landmarks. Discrepancies between dental, skeletal, and soft-tissue midlines are common and strongly influence the aesthetic perception of symmetry. The integration of facial scans within VSP therefore provides a unique opportunity to directly visualise these relationships, allowing maxillary and mandibular repositioning not only with respect to skeletal planes but also to the patient's facial soft-tissue axis. This soft-tissue-guided approach may improve the clinical relevance of midline corrections and improve patient communication regarding expected aesthetic outcomes.[22,24,30,31]

One potential solution to this limitation lies in the use of facial scans acquired in different orientations and expressions. As demonstrated in our workflow, a lip-retracted face scan with open eyes allows for direct visualisation of the maxilla in relation to the interpupillary line, offering a more clinically driven assessment of maxillary cant. Similarly, the smiling facial scan enables DSD, where parameters such as anterior intrusion/extrusion, incisal show, and cant can be adjusted based on facial soft tissue dynamics rather than skeletal planes alone.[22,24–26] Nevertheless, as shown in Fig. 1B, the smiling facial scan may be compromised if the patient does not produce a full, natural smile. In such cases, essential aesthetic parameters such as incisal display and gingival exposure may be underestimated. This underscores that clinical examination and conventional measurements remain indispensable to complement digital workflows. Additional factors further support this argument: the dynamic and voluntary nature of smiling introduces variability between sessions, lip strain can distort incisal show, and soft-tissue tension may conceal subtle asymmetries. Taken together, these aspects highlight the continuing need for careful clinical validation when integrating smile-based face scans into VSP.

Beyond these expression-related challenges, further limitations must be acknowledged. At present, the accuracy and reproducibility of soft tissue registration between facial scans and DICOM-derived STL data are not fully validated. While the forehead appears to be relatively stable, discrepancies around the periorbital region have been observed across different scan acquisitions.[15–18] There is an evident need for standardised scanning protocols, including patient preparation (such as securing hair, lowering hands during retracted scan acquisition) to reduce variability.[24,32]

Nonetheless, the import and integration of facial scans hold substantial clinical potential. Ambiguities surrounding the orientation of maxillary cant and the midline position may be mitigated and patient communication becomes significantly more visual and comprehensible. The authors hypothesise that the future of VSP will increasingly incorporate facial soft tissue analysis as a core component, further enriching the virtual twin toward a more comprehensive and lifelike model. Future iterations may include dynamic motion capture, condylar articulation, and expression-based simulation.[27,28]

From a technical standpoint, current VSP engines remain optimised for speed and computational performance and are primarily limited to STL-based representations. The adoption of full-colour 3D mesh formats such as Polygon File Format (.PLY) or Object File (.OBJ) could further enhance realism and visual feedback, improving both surgical planning and patient education.

Significant research is still required to evaluate the accuracy, precision, and reproducibility of facial scanning technologies. This includes both validation of the scanning devices themselves and their integration with bone-based VSP workflows. Additionally, studies comparing NHP determination across different clinicians and methods are urgently needed.

Conclusion

With this novel workflow, we aim to demonstrate the clinical potential of recent software updates and the incorporation of facial scanning technologies in orthognathic planning. Further research is necessary to assess their accuracy, standardisation, and long-term impact on treatment outcomes, particularly regarding natural head position, digital smile design, and soft-tissue prediction.

Ethics statement/confirmation of patient permission

Ethics approval no. Patient permission obtained.

Conflict of interest

We have no conflicts of interest.

Funding

None.

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