Sharma et al. Scr Med. 2024 Mar-Apr;55(2):231-43. DOI:10.5937/scriptamed55-46960
CURRENT TOPIC

Advent of Artificial Intelligence in Orthognathic Surgery: Advancements and Challenges

Anju Sharma,[1] Ginpreet Kaur,[1] Hardeep Singh Tuli,[2] Raunak Singh Chhabra,[3] Rashmi Rana[4]

Abstract

Orthognathic surgery is a procedure used to correct facial deformities and jaw bone misalignment. The use of technology, specifically virtual surgical planning (VSP), has become increasingly prevalent in preoperative planning for orthognathic surgery. High-resolution computed tomography (CT) imaging has enabled computer-aided modelling. Artificial intelligence (AI) implementation has transformed orthognathic surgery methodology. This article highlights the latest market trends and modern-day advancements in the field, including the conventional and surgery first approach for orthognathic surgery. The use of computer-aided surgical simulation (CASS) in VSP for orthognathic surgery was studied. The different software used for orthognathic surgical planning and the detailed protocol followed during the surgery, including the preoperative procedure were discussed along with utilisation of 3-dimension cone-beam computed tomography (3D CBCT) images for surgical planning. The implementation of VSP with CASS had significantly enhanced the accuracy and efficiency of orthognathic surgery for dentofacial deformity correction. The use of technology allowed improved preoperative planning, resulting in better outcomes for patients. The study of different software for orthognathic surgical planning and the protocol followed during surgery has provided valuable insight into the surgery. The continued advancement of technology in orthognathic surgery is promising for the field and for the patients.

Key words: Artificial intelligence; Machine learning; Deep learning; Surgery-first approach; Computer aided design and manufacturing; Surgical system and cone beam computed tomography; Computer aided surgical simulation.

1. Shobhaben Pratapbhai Patel School of Pharmacy and Technology Management, SVKM's NMIMS, Vile Parle, Mumbai, India.
2. Department of Bio-Sciences and Technology, Maharishi Markandeshwar Engineering College, Maharishi Markandeshwar (Deemed to Be University), Mullana-Ambala, Ambala, India.
3. Tech Mahindra, Pune, India.
4. Department of Research, Sir Ganga Ram Hospital, Delhi, India.

Citation:
Sharma A, Kaur G, Tuli HS, Chhabra RS, Rana R. Advent of artificial intelligence in orthognathic surgery: advancements and challenges. Scr Med. 2024 Mar-Apr;55(2):231-43.

Corresponding author:
GINPREET KAUR
E: ginpreet.kaur@nmims.edu

Received: 4 October 2023
Revision received: 23 January 2024
Accepted: 23 January 2024

Introduction

This review highlights the implications of artificial intelligence (AI) techniques integrated with orthognathic surgery. Various software is available for virtual surgical planning and challenges and complications associated with orthognathic surgery.

"AI is a broad transdisciplinary field, it is a branch of science and engineering that deals with machine understanding and is typically referred to as intelligent behaviour, with the creation of artifacts".[1, 2] It is a discipline in computer science that aims to understand and create intelligent entities, which are often manifested as software programs.[3] The use of AI to complete activities that traditionally require human intelligence is transforming numerous industries.[3, 4] Their capacity to identify meaningful associations in data collection can be utilised across diverse clinical scenarios for purposes such as diagnosis, treatment planning and predicting outcomes.[1]

The concept of AI was initially introduced in 1950 when Alan Turing first explained the idea of simulating intelligent behaviour and critical thinking using computer.[5] Early models had several flaws that impeded widespread adoption and medical use.[6] Gunn first researched the use of AI technology in surgery in 1976, when he explored the possibilities of using computer analysis to diagnose sudden abdominal pain. Interest in medical AI has increased during the past two decades.[1]

The virtual and physical domains are where AI is primarily used. The virtual programme uses mathematical techniques to simulate machine learning, commonly referred to as deep learning, which improves learning *via* experience. The three categories of machine learning algorithms include unsupervised (capable of recognising patterns), supervised (employing prior examples for classification and prediction) and reinforcement learning (forming strategies through rewards and penalties within a specific problem domain). It also has electronic medical records that use specific algorithms to find people who have a family history of a hereditary condition or who are at higher risk of developing chronic diseases.[7]

AI can utilise algorithms to "learn" features from a significant amount of healthcare data and use these discovered insights to improve clinical practice. The accuracy of the system can be enhanced by providing it with learning and self-correcting capabilities based on feedback.[1] Its physical application involves physical items, medical equipment and progressively sophisticated robots participating in the provision of treatment (carebots).[7]

With the help of AI, healthcare is undergoing a paradigm shift, owing to the expansion of healthcare data availability and the quick development of analytical tools.[8] According to estimates, AI will have a profound impact on social and economic systems worldwide.[9]

Surgical management with AI

Advances in surgery have altered the treatment of both acute and chronic illnesses, increasing patient survival rates and lengthening patients' lives. Continuous technical innovations in diagnosis, imaging and surgical instrumentation support these advancements.[10] AI for preoperative planning, surgery effectiveness depends on preoperative planning, in which doctors design the surgical operation based on already-existing medical information and imaging. The most popular imaging techniques utilised in clinical settings are X-rays, CT scans, ultrasounds and magnetic resonance imaging (MRIs). Anatomical categorisation, detection, segmentation and registration are common tasks based on medical imaging.[10] AI for intraoperative guidance is used in shape instantiation, tissue tracking, endoscopic navigation and augmented reality.[10] AI for surgical robotics, the goal of AI is to increase the surgical robotic system's ability to recognise complex *in vivo* circumstances, make judgements and complete the necessary tasks more precisely, safely and effectively.[10] Robotically assisted surgery was created to boost surgeon capabilities and to get beyond the drawbacks of existing minimally invasive surgical techniques.[11]

Orthognathic surgical treatment

Surgery requires precise planning to achieve the appropriate stability and harmony.[12] In order to treat obstructive sleep apnoea (OSA), malocclusion and issues with the facial profile, orthognathic surgery is frequently used in craniofacial surgery. The focus of orthognathic surgery is repositioning the maxilla, mandible and chin.[13] It not only enhances fundamental abilities like chewing, speaking and swallowing, but it also forms a component of a comprehensive plan of care for improving quality of life.[14]

Approaches for early orthognathic surgery

Conventional approach

It is known as the orthodontic first approach. Orthognathic surgery traditionally requires significant pre-operative and post-operative orthodontics to achieve significant dentofacial correction.[15] Before undergoing orthognathic surgery, patients receive preoperative orthodontic therapy to reveal the actual skeletal discrepancies and align the maxilla and mandible for a stable surgical occlusion, thereby preventing postoperative occlusal instability. Despite these advantages, preoperative orthodontic treatment comes with notable drawbacks, leading to considerable inconvenience for patients. Dental decompensation involves a gradual decline in the facial cosmetic profile and dental function during the preoperative period. Preoperative orthodontic treatment's biggest weakness is that it takes a long time to complete; depending on how complicated the patient's initial dental condition was, to begin with, it can even take up to 48 months.[13]

Surgery-first approach (SFA)

Also referred to as the "surgery-first-orthognathic-approach (SFOA)". The term "surgery-first approach" refers to a course of therapy that begins with orthognathic surgery and ends with postoperative orthodontics without first undergoing preoperative orthodontics. SFOA may be enforced using 2 methods: the surgical driven approach and also the orthodontic driven approach. In the first method, surgical correction is used to treat both dental and jaw abnormalities. The latter method involves surgically correcting jaw distortion and using orthodontics to cure dental deformity. The modified-surgery technique is used when preoperative orthodontic therapy lasts for less than six months.[13, 16] The reduced treatment duration has been a key factor in the prevalence of surgery-first orthognathic,[17] another advantage is the improvement in facial profile right away from starting of the treatment, high levels of patient and orthodontist satisfaction are related to better cooperation during postoperative orthodontics and quick patient recovery.[18]

While the orthodontics-first approach suggests that orthodontic therapy begins first, followed by orthognathic surgery, the surgery-first strategy states that orthognathic surgery begins first.[19] Orthodontics alone can address minor dentoskeletal discrepancies, but for more severe and significant disparities, a combination of orthodontic treatment and orthognathic surgery becomes essential for effective and comprehensive management. Orthognathic surgery can be performed as a single-jaw therapy in which just the maxilla or the mandible is operated on, but bimaxillary (or double-jaw) orthognathic surgery must be planned when the diagnostic information and presurgical planning indicate that both jaws need to be osteotomised.[20, 21]

Surgical planning by virtual surgery technology with its opportunities

A method of merging "computer-aided design (CAD)" and "computer-aided manufacture (CAM)" in surgical treatment planning is known as virtual surgery, also referred to as computer-aided surgery. AI empowers surgeons to optimise skeletal alignments, strategize surgeries for both soft and hard tissues and visualise and evaluate three-dimensional (3D) images of soft tissue and skeletal structures. It also allows surgeons to communicate the virtual plan to patients before the procedure.[22] The science of virtual reality involves building an artificial environment to evaluate different body parts' anatomical regions. This can be useful for diagnosis, planning and surgical training.[23]

Virtual surgery typically comprises four stages. Phase 1 is the data collection it includes radiographic examinations and CT scans, as well as clinical examinations with bite registrations and anthropometric measurements. Phase 2 is the planning phase that involves transferring 3D cone beam computed tomography (CBCT) data into specialised planning software. Phase 3 is the surgical phase, it involves translating the digital surgical plan to the patient using stereolithographic models, occlusal splints, cutting guide stents, or intraoperative navigation. Phase 4 the assessment phase, involves employing intraoperative or postoperative CT imaging to assess the precision of virtual surgical plan transfer.[22] By improving the depiction of 3D phenotypic changes, virtual surgical planning has made it easier to make precise diagnoses and thorough treatment plans. Due to these benefits, intraoperative osteotomies and fixation have increased osteotomy accuracy and considerably reduced preoperative surgical planning.[13] CBCT scan is preferred for 3D scan, CBCT is a method for acquiring medical images and a cone-shaped X-ray beam is focused on a two-dimensional (2D) detector. Two CBCT scans were collected using the "i-CATTM equipment, version 17-19 (*Imaging Sciences International*, Hatfield, PA, USA)" one preoperative (taken two months before orthognathic surgery) and one postoperative (taken one month after surgery).[24]

Orthognathic surgery falls under the scope of oral and maxillofacial surgery and orthodontics that tries to correct dentofacial defects by moving the maxillomandibular complex into a more functional, balanced and aesthetically acceptable posture. Because of the procedure's complexity, the accuracy of surgical planning is essential. The adoption of 3D virtual planning techniques and the creation of prototyped splints are made possible by developments in imaging, planning software and prototyping technology. In order to better understand the link between the dental arches and the surrounding bones, virtual surgical planning (VSP) provides new opportunities. When compared to traditional surgical planning, this method offers several benefits, including the ability to visualise deformities and asymmetries that are occasionally missed, the freedom to simulate various surgical procedures to achieve the best possible patient outcomes, the ability to identify potential complications and simplicity in assessing and adjusting the centric relation in the temporomandibular joint.[25] At the end of the 1980s, 3D virtual planning software packages with virtual operating rooms (VOR) were introduced. Significant advancements in these software modules have been made possible by the IT revolution (2000s). The doctor can document, analyse and plan orthognathic surgery using a face skeleton model due to the reconstruction of "digital imaging and communications in medicine (DICOM)" files in a VOR. Dental models and software to analyse the soft tissue surface of the face's soft tissues were also introduced.[26] A pre-intervention survey is performed to evaluate training requirements and a postintervention feedback survey to assess the system's effectiveness, usability and acceptability was utilised to assess the validity of VR surgery.[27] Because of technological advances, particularly 3D printing and VSP, this field has grown and improved significantly. The advancement has significantly enhanced preoperative preparation, leading to a more streamlined journey from pre-surgery to post-surgery. While patients might incur extra expenses, the benefits include reduced operative duration and shorter hospitalisation periods. Future research could concentrate on a cost-benefit analysis to determine whether virtual planning reduces total health-care costs.[7] VSP has proven to be accurate and results in better clinical outcomes as compared to the traditional model surgery.[28] Both the traditional and the new 3D virtual method operate on the same principles. The objective remains to provide the greatest possible outcome for improved patient care.[29]

Implementation of AI software in orthognathic surgical planning

The surgical approach employed and the precision with which the surgical plan is carried out determine how well an orthognathic procedure goes. Two crucial and fast developing topics of study are virtual planning and computer-assisted surgery. Computer-assisted surgery (CAS) is the practise of performing or planning surgery with the aid of cutting-edge technology. The use of software analysis, virtual planning, sophisticated imaging fast prototyping technologies, robotics and image guiding systems are some examples of these techniques.[30] Hirsch first made CAS for mandibular reconstruction available in 2009. Since then, it has become more and more popular. The terms fast prototyping "computer-aided design" and "computer-aided manufacturing" are also used to describe it.[31] For orthognathic (jaw realignment) and temporomandibular joint (TMJ) surgery, facial trauma, implantology (dental implants) and maxillomandibular reconstruction, craniofacial surgery (CMF) and dentistry currently use CAS most frequently.[32] After a model operation is designed, the production of surgical splints on dental casts is the most common method for transferring the desired new relationship of the jaws.[33]

There are a variety of software programmes for CAS and some of them enable internal CAS to be carried out using database images (CBCT, intraoral scans) and with the creation of a surgical splint it is then transferred to the operating room.[34] Few software available for planning of orthognathic surgery are enlisted in Table 1, which include the *Dolphin imaging* (version 11.9, California, USA),[35-37] *Dolphin imaging* (11.95, USA),[38] *Proplan CMF* (Leuven, Belgium),[35, 39-42] *Proplan CMF* (Materialise CMF, USA),[43] *ITK-SNAP* (3.4.0, USA),[44, 45] *Dentofacial Planner Plus* (USA),[36, 37, 46-48] *SurgiCase* (5.0, Belgium),[49] *SurgiCase-CMF PRO 1.2* (USA),[50] *3-matic* (Belgium),[50-52] *3D Slicer* (4.5.0-1, USA),[45, 53, 54] *OrthoGnathicAnalyser (2.0)*,[55, 56] *Maxilim* (Belgium),[39, 55, 57, 58] *IPS CaseDesigner* (2.0.4.2, Germany),[37, 59] *VRMesh* (USA),[59, 60] *NemoFab* (Spain)[61, 62] and *Autodesk MeshMixer* (USA).[35, 61] *Dolphin 3D imaging* software helps to enable CBCT volumes to be oriented and selectively cropped and allows linear measurements of the joint space and volumetric analysis of changes in condylar volume.[63, 64] The "Houston Methodist Research Institute's Surgical Planning Laboratory" has created a computer aided surgical simulation (CASS) protocol tailored specifically for orthognathic surgery. The CASS protocol is discussed below in detail. There is a modified CASS method that uses extraoral photographs in the natural head position (NHP) taken with a camera's built-in gyroscope to achieve the same accuracy as the regular CASS method.[65]

CBCT images were taken prior and post orthognathic surgery for the assessment of mandibular anatomy and position. CBCT images have revolutionised orthodontics by computer-aided surgical simulations and has been adapted for use in orthognathic surgery to make cephalometric analysis, surgical simulation and splint fabrication easier.[64, 66] CBCT scanners produce high-resolu-

Table 1: Software for orthognathic surgery planning

Software	Version	Country	Data	Statistical analysis	Application	Ref.
Proplan CMF	-	Belgium	Each patient had cone-beam CT scanning and using STL format the scanned data is imported into the software.	Paired t-test	Generate 2D or 3D visualisations, preoperative testing, analyse postoperative results and refine surgical plans.	35, 39-43
Dentofacial Planner Plus	-	USA	Compared with CBCT scan of initial one of the patients.	Chi-square test, ANOVA and the Tukey test	Profile analysis, treatment prediction and predict the postsurgical profiles.	36, 37, 46-48
Dolphin Imaging	11.9	USA	It uses an algorithm based on sparse landmarks to predict soft tissue outcomes, offering the flexibility to adjust hard-to-soft tissue ratios to accommodate variations among different patients.	Friedman test	Predict the postsurgical profiles and changes with a primary focus on the 2D midline and upper lip.	35-37
	11.95	USA	Lateral cephalograms, horizontal measurement, vertical measurement and 3 angular measurements of the patients was analysed.	Student's t-test	Assessing skeletal changes post orthognathic surgery.	38
Surgi Case	5	Belgium	CAS was performed on patients with an average age of 35.5 years and CT of the maxillofacial skeleton and lower extremities were performed.	-	Evaluation of orthognathic surgical outcomes and accuracy	49
	CMF PRO 1.2	USA	Preoperative multi-slice imaging data were acquired using a CT unit, stored in DICOM format. It uses a physically based, previously published simulation module.	M, SD, SE, Max, 90th and 95th percentile	Used to calculate postoperative simulation of the soft tissue and helps to simulate any movement.	50
3-matic	-	Belgium	Data is collected through CBCT scan of patients, the software allows for various analyses and simulations on the patient's 3D models.	Student's t-test	This software serves as a preprocessing tool, enabling users to perform tasks such as repairing, preparing geometry, remeshing and making design modifications directly on the mesh data.	50-52
ITK-SNAP	3.4.0	USA	Before the surgical procedure, all the participants underwent preoperative scanning for virtual surgical planning and follow-up scans were performed one week later.	STATA 14.2	This tool is utilised for the segmentation of structures in three-dimensional (3D) and four-dimensional (4D) biomedical images.	44, 45
3D Slicer	4.5.0-1	USA	CBCT scan of patients.	STATA 14.2	The software is designed for visualising, processing, segmenting, registering and analysing medical, biomedical and other 3D images and meshes. Additionally, it facilitates the planning and navigation of image-guided procedures.	45, 53, 54

Ortho Gnathic Analyser	2	-	Using six confirmed cephalometric landmarks, the 3D augmented virtual head model was placed in its anatomically natural position before the surgery.	IBM SPSS software	Analyse and improve 3D planning accuracy in bimaxillary surgery.	55, 56
Maxilim	-	Belgium	CBCT scan of patients.	IBM SPSS software	This tool is employed to create a 3D virtual head model with augmented features.	39, 55, 57, 58
IPS Case Designer	2.0.4.2	Germany	CBCT scan of patients.	t-test	Wizard-based approach for case setup and planning, Real-time soft tissue simulation, 3D Cephalometric analysis.	37, 59
VRMesh	-	USA	The models are scanned using an intraoral scanner and then imported into VRMesh in the stereolithography (.stl) format.	One-sample Student t-test	Used to evaluate the real time quality of the occlusions.	59, 60
NemoFab	-	Spain	CBCT scan of patients.	-	Surgical planning software.	61, 62
Autodesk Mesh-Mixer	-	USA	CBCT scan of patients.	-	Enables the surgeon to precisely analyse and strategize the surgical procedure and is capable of performing Boolean operations.	35, 61

ANOVA: analysis of variance; M: mean; SD: standard deviation, SE: standard error of mean; CBCT: cone beam computed tomography; CAS: computer-assisted surgery; DICOM: digital imaging and communications in medicine; Ref.: reference number;

tion images while using less radiation than spiral CT scanners. In order to assess the complex dentofacial structures, 3D CBCTs are the preferred technique. The limitations of the two-dimensional quantitative and qualitative evaluation of surgical displacements can be overcome by using cone-beam computed tomography and three-dimensional imaging technologies.[67, 68] There are numerous reported uses for CBCT in the fields of orthodontics and maxillofacial surgery, including the identification of impacted teeth and the evaluation of implant sites.[69] Postoperative CBCT imaging was taken within 4 weeks of the surgery.[70]

CASS protocol

Through the use of CASS software, orthognathic surgery's effectiveness and precision in treating dentofacial deformity have been greatly increased.[71] CASS clinical implementation entails the following four steps: 1) gathering preoperative information, 2) data processing, 3) surgical planning and 4) plan execution itself. Typically, a surgeon handles the first and third processes; however, the other two might be delegated to a specialist or an independent service provider.[72]

Preoperative data collection

Preoperative data are acquired in this stage during an hour-long session. Eight steps make up this appointment: (1) taking dental impressions; (2) bite-jig fabrication; a patient-specific bite-jig is created by adapting a stock jig frame to fit the patient's teeth. The number of impressions required for the planning process depends on the type of surgery (Figure 1). Until the fabric is cured, the jig is maintained in place between the patient's teeth. This bite registration should be taken in centric relation (Figure 2). (3) Clinical measures are taken and the measurements required for clinical planning are noted. The following are some examples: (a) "rest-incisal-show" and "smile-dentogingival-show", which are used to determine the maxilla's vertical position; (b) dental midpoint (midline) deviations, which are used to determine the position of the transverse jaw; and (4) clinical photography, in which the patient's face and teeth are captured on camera. Facial images should be shot with the patient in the NHP position and a plumb line in the backdrop so that the proper alignment of the face may be confirmed afterwards. (5) Recording the patient's NHP, which is necessary for the creation of an anatomical reference frame. The goal of these photographs is to confirm that the virtual head model is correctly oriented for planning. A bite-jig is put between the patient's teeth and has a sensor attached to it. It is requested that the patient stand straight and place their head in NHP. Lastly, while in this position, the sensor's pitch, roll and yaw are recorded; (6) confirming that the models and the bite-jig are accurate by testing the fit of the stone dental models on the bite-jig, which is done by a surgeon or an assistant; (7) after obtaining a CT scan, or ideally a CBCT scan, the patient is fastened to the bite-jig, which is then attached to the fiducial registration face-bow. The patient is told to maintain relaxation in his or her facial soft tissues while being scanned.[72]

Data processing

The procedure may be carried out by the surgeon, a third-party service provider, or a member of the clinic or institution who is knowledgeable about CASS planning. The procedures for processing data consist of; (1) construction of a virtual model of a composite head - the first stage is to create a model that accurately depicts the teeth, soft tissues and skeleton. The midface model, soft tissue model, mandibular model and fiducial marker model are four distinct and correlated 3D-CT models that are created. (2) Using the fiducial face-bow as a reference, an anatomical reference frame is created for the head model and the NHP of the computer model is created by utilising the recorded roll, pitch and yaw to the face-bow frame. (3) Digitisation of all cephalometric landmarks and completing a cephalometric analysis are regarded to be essential diagnostic procedures for identifying the most effective therapy approach.[5] Any sort of cephalometric analysis can be requested by the surgeon, but he or she should be aware that 3D cephalometry is significantly more complicated than 2D cephalometry. (4) Creating the virtual osteotomies - carry out virtual genioplasty, Le Fort I osteotomies and mandibular ramus osteotomies eg; establishing the final occlusion. (5) The final occlusion that the surgeon chose is etched on the stone dental models. This stone models are initially converted into the final occlusion using the surgeon's generated bite registration. The models are then all simultaneously scanned with either a high-resolution optical surface scanner or a CBCT scanner. After segmenting the scan, a 3D image of the upper and lower teeth in their final occlusion is produced. The "final-occlusal-template," as the produced image is known, is loaded into the planning tool and used as a guide to articulate the jaws in final occlusion. Positioned in line with the upper teeth of the "Le Fort I" segment are the upper teeth of the final occlusal template. After that, the distal mandibular segment is adjusted so that the lower teeth line up with those of the template. The template can be aligned to one jaw, then the other jaw to the template because the template's upper and lower teeth are in final occlusion. This will automatically align both jaws into final occlusion.[72,73]

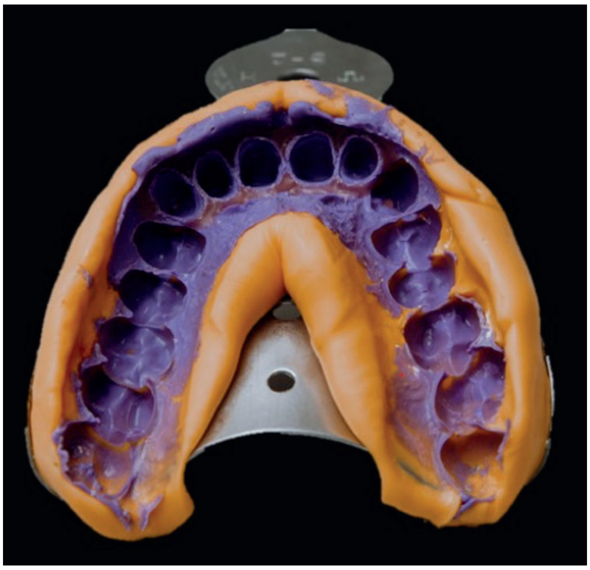

Figure 1: Computer aided surgical simulation (CASS) protocol - bite-jig model

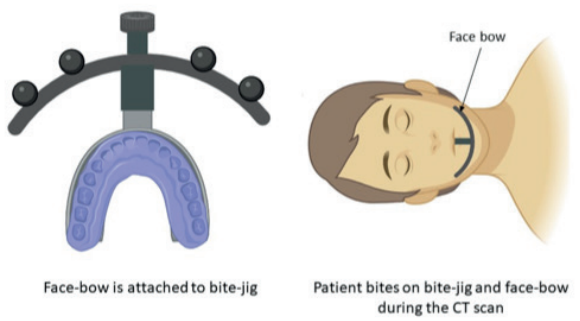

Figure 2: Computer aided surgical simulation (CASS) protocol - patient employing bite-jig

Surgical planning

Using CASS software, this is accomplished on a computer. A surgeon can complete the process alone or with the help of a planning professional familiar with the programme (Figure 3). To make sure that the data processing is accurate, the planning process starts with a checklist. The following items are included on the checklist: (1) Is the anatomical reference frame defined correctly? (2) Have all of the cephalometric landmarks been accurately digitalised? (3) Are all virtual osteotomies correct? (4) Is the final occlusion accurate? Even when mandibular surgery is performed initially, the maxilla should always be the first part of the CASS planning for any double-jaw surgery. This is because the surgeon is more confident where the maxilla should be positioned than the mandible.[72]

The first step in correcting maxillary abnormalities is to verify the alignment of the teeth symmetrically with respect to the midsagittal plane. Three transformations are necessary for symmetric alignment, including normalising transverse position. The maxillary incisal midpoint is transversely translated onto the midsagittal plane, normalising roll. (1) Roll rotation pivots the maxilla around the incisal midpoint, normalising yaw rotation, which pivots the maxilla around the incisal midpoint. (2) Normalisation of vertical position: The maxilla's vertical position is adjusted. The planner adjusts the maxilla forward or downward to place the incisal midpoint optimally in relation to the upper lip stomion. (3) Pitch normalisation - maxillary pitch is adjusted. The planner adjusts the maxilla's pitch by rotating it around the incisal halfway. Maxillary pitch rotation affects the size of the airway, the projection of the anterior nasal spine, the projection of the chin, the inclination of the maxillary central incisors and the inclination of the maxillary occlusal plane. All of these factors must be taken into account when determining the best maxillary pitch for a particular patient. (4) By aligning the maxilla in anteroposterior position, the anteroposterior position is normalised. This correction is performed last since earlier changes could have an impact on how far the maxilla is advanced.[72]

Additionally, it involves aligning the proximal regions of the jaw and correcting mandibular abnormalities, rotation of each proximal segment about the axis of its condyle to align it.[72] Then, chin deformities must be corrected. This assessment is crucial because the movement of the mandibular distal segment changes the position of the chin. Planning progresses to the last phase. In both cases, the planner should execute a genioplasty by changing the chin piece until the outcomes are satisfied, depending on whether the chin is normal or incorrect.[72]

Finally, with the aid of the planner, the residual final symmetry is examined. In improperly symmetric mandibles, symmetry is preserved by putting the distal mandible in final occlusion. The patient's intrinsic mandibular asymmetry could not be fixed even after the distal jaw is brought into final occlusion. Finishing a final symmetry assessment on every patient is crucial since low to moderate degrees of inherent asymmetry could not be obvious to the eye.[72]

Preparation for plan execution

Preparation of the tools required at the time of the surgery for transferring the computerised surgical plan to the patient is the last step of the CASS protocol. Usually, a third-party service provider is hired to handle this. The tables and graphics that show the intended movements, including mapped areas of collision, are created and displayed during surgery to direct the procedure.[72]

The implementation of VSP with CASS has significantly enhanced the accuracy and efficiency of orthognathic surgery for dentofacial deformity correction. The use of technology has allowed for improved preoperative planning, resulting in better outcomes for patients.

Challenges encountered during surgery

Major challenges faced during orthognathic sur-

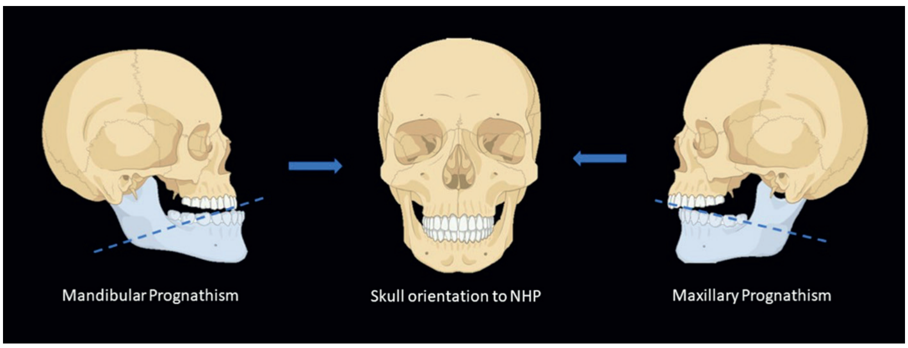

Figure 3: Orthognathic surgery plan using computer aided surgical simulation (CASS)

gery are: (a) Patient age in relation to surgical timing - the skeletal repositioning component of orthognathic therapy is often performed after the majority of face growth has taken place. When a patient is ready for surgery, skilled teams frequently start orthodontic preparation therapy at an age at which they are unlikely to have any considerable remaining growth potential. There is a lack of information regarding the ideal time to do surgery on patients who are still growing and it is unclear how such surgery may affect subsequent growth.[74] The other big challenge is (b) psychosocial evaluation - the patient with underlying psychological and/or psychiatric difficulties is one of the biggest hurdles in orthognathic surgery, especially when such problems are not identified until the postoperative period. To overcome such problem every orthognathic team should ideally have a clinical psychologist or liaison psychiatrist who is knowledgeable in the subject to evaluate patients before treatment and as needed throughout therapy. Pre-treatment body dysmorphic disorder (BDD) screening tools, like the "Body Dysmorphic Disorder Questionnaire (BDDQ)", should be a common procedure.[74] Major disadvantage associated with virtual planning can be such that, the 3D virtual treatment planning viewer format requires a good graphically capable personal computer workstation, which is currently not standard. This issue will soon be resolved by the increasing graphic ability in recent commercially accessible personal computers.[75]

Orthognathic surgery-related complications

Despite the fact that the majority of patients undergo orthognathic surgery for cosmetic reasons, postoperative functional issues are more frequently experienced after cosmetic changes. Patients must therefore carefully consider whether having orthognathic surgery will serve an aesthetic or functional goal. The 3D soft tissue alterations after orthognathic surgery have piqued the curiosity of doctors and patients alike.[76]

Orthognathic surgery can result in a wide range of problems. Intraoperative complications include haemorrhage and bad split/segment fractures. When the "inferior alveolar, superior alveolar, maxillary, retromandibular, facial and sublingual vessels" are injured, it might result in severe bleeding. Bad split/segment fractures, like buccal plate fracture, "distal segment lingual fracture" can occur.[77] As the population ages and medical science and technology advances rapidly, health systems around the world are facing immense pressure to provide high-quality care to patients while demand and costs of health services continue to grow.[78] It has observed that with the use of ultrasonic curettage device there is decrease in intraoperative blood loss and calculated blood loss in orthognathic surgery.

Conclusion

Early orthognathic surgery involves the conventional approach also called as the orthognathic first approach and the surgery first approach. In contrast to the orthodontics-first strategy, which means that the orthodontic treatment comes first, the "surgery-first approach" implies that the orthognathic surgery comes first. Virtual surgery, also known as "computer-aided surgery", is a technique that combines CAD and CAM into surgical treatment planning. Virtual surgery involves 4 phases data collection, planning, surgical and assessment. By improving the depiction of 3D phenotypic changes, virtual surgical planning has made it easier to make precise diagnosis and thorough treatment plans. CBCT images should be taken prior and at the end orthognathic surgery for the assessment of mandibular anatomy and position. In order to assess the complex dentofacial structures, 3D CBCTs are the preferred technique. CASS is clinically implemented in 4 steps: collection of preoperative records, data processing, surgical planning and preparing for plan execution. Basic steps are: first the facial photographs are taken with patient in the NHP, creation of virtual model, 3D cephalometry, correction of maxillary, mandibular and chin deformities and transferring the computerised surgical plan to the patient. Patient age and the psychological and/or psychiatric difficulties can be the challenge for surgery. Other challenge is it requires a personal computer workstation with good graphic ability. Haemorrhage and bad split/segment fractures are the various intraoperative complications associated during surgery. To overcome the challenges of early orthognathic surgery and for effective planning of surgery different software are being employed such as *Proplan CMF, Dolphin Imaging, SurgiCase, 3-matic, ITK-SNAP, OrthoGnathicAnalyser* etc. Use of digital tools will have an immense impact on orthognathic-surgical treatment plans ranging from diagnosis to follow-up treatment. Software has the ability to learn from every real-life case and further improve its performance.

Ethics

This study was a secondary analysis based on the other primary publications and did not directly involve with human participants or experimental animals. Therefore, the ethics approval was not required in this paper.

Acknowledgement

We are thankful to Shobhaben Pratapbhai Patel School of Pharmacy and Technology Management, SVKM's NMIMS for providing the facility.

Conflicts of interest

The authors declare that there is no conflict of interest.

Funding

This research received no specific grant from any funding agency in the public, commercial, or not-for-profit sectors.

Data access

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

Author ORCID numbers

Anju Sharma (AS):
0009-0006-9905-0199
Ginpreet Kaur (GK):
0000-0002-5151-914X
Hardeep Singh Tuli (HST):
0000-0003-1155-0094
Raunak Singh Chhabra (RSC):
0009-0000-9145-3264
Rashmi Rana (RR):
0000-0003-1461-9456

Author contributions

Conceptualisation: AS, GK
Methodology: AS, GK
Investigation: AS, RR, HST, RSC
Writing - original draft: AS, RR, HST, RSC
Writing - review and editing: GK, RSC, HST, RR
Visualisation: AS, GK
Supervision: AS, GK

References

1. Scerri M, Grech V. Artificial intelligence in medicine. Early Hum Dev. 2020 Jun;145:105017. doi: 10.1016/j.earlhumdev.2020.105017.
2. Howard J. Artificial intelligence: Implications for the future of work. Am J Ind Med. 2019 Nov;62(11):917-26. doi: 10.1002/ajim.23037.
3. Yu KH, Beam AL, Kohane IS. Artificial intelligence in healthcare. Nat Biomed Eng. 2018 Oct;2(10):719-31. doi: 10.1038/s41551-018-0305-z.
4. Mohammad-Rahimi H, Nadimi M, Rohban MH, Shamsoddin E, Lee VY, Motamedian SR. Machine learning and orthodontics, current trends and the future opportunities: A scoping review. Am J Orthod Dentofacial Orthop. 2021 Aug;160(2):170-92.e4. doi: 10.1016/j.ajodo.2021.02.013.
5. Kaul V, Enslin S, Gross SA. History of artificial intelligence in medicine. Gastrointest Endosc. 2020 Oct;92(4):807-12. doi: 10.1016/j.gie.2020.06.040.
6. Muthukrishnan N, Maleki F, Ovens K, Reinhold C, Forghani B, Forghani R. Brief history of artificial intelligence. Neuroimaging Clin N Am. 2020 Nov;30(4):393-9. doi: 10.1016/j.nic.2020.07.004.
7. Jandali D, Barrera JE. Recent advances in orthognathic surgery. Curr Opin Otolaryngol Head Neck Surg. 2020 Aug;28(4):246-50. doi: 10.1097/MOO.0000000000000638.
8. Jiang F, Jiang Y, Zhi H, Dong Y, Li H, Ma S, et al. Artificial intelligence in healthcare: past, present and future. Stroke Vasc Neurol. 2017 Jun 21;2(4):230-43. doi: 10.1136/svn-2017-000101.

9. Uribe FA, Farrell B. Surgery-first approach in the orthognathic patient. Oral Maxillofac Surg Clin North Am. 2020 Feb;32(1):89-103. doi: 10.1016/j.coms.2019.08.009.
10. Zhou XY, Guo Y, Shen M, Yang GZ. Application of artificial intelligence in surgery. Front Med. 2020 Aug;14(4):417-30. doi: 10.1007/s11684-020-0770-0.
11. Hamet P, Tremblay J. Artificial intelligence in medicine. Metabolism. 2017 Apr;69S:S36-S40. doi: 10.1016/j.metabol.2017.01.011.
12. Haas OL Jr, Becker OE, de Oliveira RB. Computer-aided planning in orthognathic surgery-systematic review. Int J Oral Maxillofac Surg. 2014 Nov 25:S0901-5027(14)00430-5. doi: 10.1016/j.ijom.2014.10.025.
13. Seo HJ, Choi YK. Current trends in orthognathic surgery. Arch Craniofac Surg. 2021 Dec;22(6):287-95. doi: 10.7181/acfs.2021.00598.
14. Van Hemelen G, Van Genechten M, Renier L, Desmedt M, Verbruggen E, Nadjmi N. Three-dimensional virtual planning in orthognathic surgery enhances the accuracy of soft tissue prediction. J Craniomaxillofac Surg. 2015 Jul;43(6):918-25. doi: 10.1016/j.jcms.2015.04.006.
15. Naran S, Steinbacher DM, Taylor JA. Current concepts in orthognathic surgery. Plast Reconstr Surg. 2018 Jun;141(6):925e-36e. doi: 10.1097/PRS.0000000000004438.
16. Ahmadvand A, Alavi S, Mehraban SH. An overview of surgery-first orthognathic approach: History, indications and limitations, protocols, and dentoskeletal stability. Dent Res J (Isfahan). 2021 Jun 22;18:47. PMID: 34429867.
17. Sharma VK, Yadav K, Tandon P. An overview of surgery-first approach: Recent advances in orthognathic surgery. J Orthod Sci. 2015 Jan-Mar;4(1):9-12. doi: 10.4103/2278-0203.149609.
18. Peiró-Guijarro MA, Guijarro-Martínez R, Hernández-Alfaro F. Surgery first in orthognathic surgery: A systematic review of the literature. Am J Orthod Dentofacial Orthop. 2016 Apr;149(4):448-62. doi: 10.1016/j.ajodo.2015.09.022.
19. Liou EJ, Chen PH, Wang YC, Yu CC, Huang CS, Chen YR. Surgery-first accelerated orthognathic surgery: orthodontic guidelines and setup for model surgery. J Oral Maxillofac Surg. 2011 Mar;69(3):771-80. doi: 10.1016/j.joms.2010.11.011.
20. Borba AM, Borges AH, Cé PS, Venturi BA, Naclério-Homem MG, Miloro M. Mandible-first sequence in bimaxillary orthognathic surgery: a systematic review. Int J Oral Maxillofac Surg. 2016 Apr;45(4):472-5. doi: 10.1016/j.ijom.2015.10.008.
21. Bouletreau P, Makaremi M, Ibrahim B, Louvrier A, Sigaux N. Artificial intelligence: applications in orthognathic surgery. J Stomatol Oral Maxillofac Surg. 2019 Sep;120(4):347-54. doi: 10.1016/j.jormas.2019.06.001.
22. Gelesko S, Markiewicz MR, Weimer K, Bell RB. Computer-aided orthognathic surgery. Atlas Oral Maxillofac Surg Clin North Am. 2012 Mar;20(1):107-18. doi: 10.1016/j.cxom.2012.01.002.
23. Ayoub A, Pulijala Y. The application of virtual reality and augmented reality in Oral & Maxillofacial Surgery. BMC Oral Health. 2019 Nov 8;19(1):238. doi: 10.1186/s12903-019-0937-8.
24. Vale F, Scherzberg J, Cavaleiro J, Sanz D, Caramelo F, Maló L, et al. 3D virtual planning in orthognathic surgery and CAD/CAM surgical splints generation in one patient with craniofacial microsomia: a case report. Dental Press J Orthod. 2016 Jan-Feb;21(1):89-100. doi: 10.1590/2177-6709.21.1.089-100.oar.
25. Otranto de Britto Teixeira A, Almeida MAO, Almeida RCDC, Maués CP, Pimentel T, Ribeiro DPB, et al. Three-dimensional accuracy of virtual planning in orthognathic surgery. Am J Orthod Dentofacial Orthop. 2020 Nov;158(5):674-83. doi: 10.1016/j.ajodo.2019.09.023.
26. Plooij JM, Maal TJ, Haers P, Borstlap WA, Kuijpers-Jagtman AM, Bergé SJ. Digital three-dimensional image fusion processes for planning and evaluating orthodontics and orthognathic surgery. A systematic review. Int J Oral Maxillofac Surg. 2011 Apr;40(4):341-52. doi: 10.1016/j.ijom.2010.10.013.
27. Pulijala Y, Ma M, Pears M, Peebles D, Ayoub A. An innovative virtual reality training tool for orthognathic surgery. Int J Oral Maxillofac Surg. 2018 Sep;47(9):1199-205. doi: 10.1016/j.ijom.2018.01.005.
28. Farrell BB, Franco PB, Tucker MR. Virtual surgical planning in orthognathic surgery. Oral Maxillofac Surg Clin North Am. 2014 Nov;26(4):459-73. doi: 10.1016/j.coms.2014.08.011.
29. Quevedo LA, Ruiz JV, Quevedo CA. Using a clinical protocol for orthognathic surgery and assessing a 3-dimensional virtual approach: current therapy. J Oral Maxillofac Surg. 2011 Mar;69(3):623-37. doi: 10.1016/j.joms.2010.11.009.
30. Stokbro K, Aagaard E, Torkov P, Bell RB, Thygesen T. Virtual planning in orthognathic surgery. Int J Oral Maxillofac Surg. 2014 Aug;43(8):957-65. doi: 10.1016/j.ijom.2014.03.011.
31. van Baar GJC, Forouzanfar T, Liberton NPTJ, Winters HAH, Leusink FKJ. Accuracy of computer-assisted surgery in mandibular reconstruction: A systematic review. Oral Oncol. 2018 Sep;84:52-60. doi: 10.1016/j.oraloncology.2018.07.004.
32. Landaeta-Quinones CG, Hernandez N, Zarroug NK. Computer-assisted surgery: applications in dentistry and oral and maxillofacial surgery. Dent Clin North Am. 2018 Jul;62(3):403-20. doi: 10.1016/j.cden.2018.03.009.
33. Zizelmann C, Hammer B, Gellrich NC, Schwestka-Polly R, Rana M, Bucher P. An evaluation of face-bow transfer for the planning of orthognathic surgery. J Oral Maxillofac Surg. 2012 Aug;70(8):1944-50. doi: 10.1016/j.joms.2011.08.025.
34. Elnagar MH, Aronovich S, Kusnoto B. Digital workflow for combined orthodontics and orthognathic surgery. Oral Maxillofac Surg Clin North Am. 2020 Feb;32(1):1-14. doi: 10.1016/j.coms.2019.08.004.
35. Knoops PGM, Borghi A, Breakey RWF, Ong J, Jeelani NUO, Bruun R, et al. Three-dimensional soft tissue prediction in orthognathic surgery: a clinical comparison of Dolphin, ProPlan CMF, and probabilistic finite element modelling. Int J Oral Maxillofac Surg. 2019 Apr;48(4):511-8. doi: 10.1016/j.ijom.2018.10.008.
36. Soheilifar S, Soheilifar S, Afrasiabi Z, Soheilifar S, Tapak L, Naghdi N. Prediction accuracy of Dolphin software for soft-tissue profile in Class I patients undergoing fixed orthodontic treatment. J World Fed Orthod. 2022 Feb;11(1):29-35. doi: 10.1016/j.ejwf.2021.10.001.
37. Piombino P, Abbate V, Sani L, Troise S, Committeri U, Carraturo E, et al. Virtual surgical planning in orthognathic surgery: two software platforms compared. Appl Sci. 2022 Sep 19;12(18):9364. doi: 10.3390/app12189364.
38. Thet PH, Kaboosaya B. Reproducibility of computerized cephalometric analysis software compared with conventional manual tracing for analyzing skeletal

stability after orthognathic surgery. J Maxillofac Oral Surg. 2023 Dec;22(4):833-40. doi: 10.1007/s12663-023-02071-7.
39. Lee KJC, Tan SL, Low HYA, Chen LJ, Yong CW, Chew MT. Accuracy of 3-dimensional soft tissue prediction for orthognathic surgery in a Chinese population. J Stomatol Oral Maxillofac Surg. 2022 Oct;123(5):551-5. doi: 10.1016/j.jormas.2021.08.001.
40. Wu Y, Chen JM, Xie FP, Liu HH, Niu G, Lin LS. Simulation of postoperative occlusion and direction in autotransplantation of teeth: application of computer-aided design and digital surgical templates. Br J Oral Maxillofac Surg. 2019 Sep;57(7):638-43. doi: 10.1016/j.bjoms.2019.05.011.
41. Lu C, Xie Q, He D, Yang C. Stability of orthognathic surgery in the treatment of condylar osteochondroma combined with jaw deformity by CT measurements. J Oral Maxillofac Surg. 2020 Aug;78(8):1417.e1-1417.e14. doi: 10.1016/j.joms.2020.03.025.
42. Chen K, Zhang Z, Jiang J, Wang J, Wang J, Sun Y, et al.. Prediction of condylar movement envelope surface based on facial morphology. Heliyon. 2023 Jul 7;9(7):e17769. doi: 10.1016/j.heliyon.2023.e17769.
43. Zavattero E, Romano M, Gerbino G, Rossi DS, Giannì AB, Ramieri G, et al. evaluation of the accuracy of virtual planning in orthognathic surgery: a morphometric study. J Craniofac Surg. 2019 Jun;30(4):1214-20. doi: 10.1097/SCS.0000000000005355.
44. Tran Duy TD, Jinnavanich S, Chen MC, Ko EW, Chen YR, Huang CS. Are signs of degenerative joint disease associated with chin deviation? J Oral Maxillofac Surg. 2020 Aug;78(8):1403-14. doi: 10.1016/j.joms.2020.03.019.
45. Stokbro K, Thygesen T. A 3-dimensional approach for analysis in orthognathic surgery-using free software for voxel-based alignment and semiautomatic measurement. J Oral Maxillofac Surg. 2018 Jun;76(6):1316-26. doi: 10.1016/j.joms.2017.11.010.
46. Magro-Filho O, Magro-Ernica N, Queiroz TP, Aranega AM, Garcia IR Jr. Comparative study of 2 software programs for predicting profile changes in Class III patients having double-jaw orthognathic surgery. Am J Orthod Dentofacial Orthop. 2010 Apr;137(4):452.e1-5; discussion 452-3. doi: 10.1016/j.ajodo.2009.02.027.
47. Gimenez CM, Bertoz FA, Gabrielli MA, Magro Filho O, Garcia I, Pereira Filho VA. Cephalometric evaluation of the predictability of bimaxillary surgical-orthodontic treatment outcomes in long face pattern patients: a retrospective study. Dental Press J Orthod. 2013 Sep-Oct;18(5):53-8. doi: 10.1590/s2176-94512013000500010.
48. Xiao Z, Chen G, Zhao Y, Wang Y, Gu Y. Perceptual difference of smile aesthetics between 2-dimensional photographs and 3-dimensional dentofacial images: a cross-sectional study. BMC Oral Health. 2023 Feb 16;23(1):104. doi: 10.1186/s12903-023-02798-2.
49. Zhang L, Liu Z, Li B, Yu H, Shen SG, Wang X. Evaluation of computer-assisted mandibular reconstruction with vascularized fibular flap compared to conventional surgery. Oral Surg Oral Med Oral Pathol Oral Radiol. 2016 Feb;121(2):139-48. doi: 10.1016/j.oooo.2015.10.005.
50. Marchetti C, Bianchi A, Muyldermans L, Di Martino M, Lancellotti L, Sarti A. Validation of new soft tissue software in orthognathic surgery planning. Int J Oral Maxillofac Surg. 2011 Jan;40(1):26-32. doi: 10.1016/j.ijom.2010.09.004.
51. Karsli N, Yurdakul Z, Gonca M, Çava K. Does the traditional or digital dental model measurement method affect the results?: A validation study. EADS. 2023;50(2):87-94. doi: 10.52037/eads.2023.0021
52. Sürer E, Ünal M, Gül Aygün EB, Ucar Y. Evaluating the conversion degree of interim restorative materials produced by different 3-dimensional printer technologies. J Prosthet Dent. 2023 Oct;130(4):654.e1-e6. doi: 10.1016/j.prosdent.2023.07.001.
53. Trang NT, Ashikaga Y, Matsushita K, Ohiro Y. Investigating the relationship between the remodeling of TMJ bony structures and condylar rest position following orthognathic surgery in class II and class III skeletal malocclusions. J Oral Maxillofac Surg Med Pathol. 2023 Jul 1;35(4):308–16. doi: 10.1016/j.ajoms.2022.12.003
54. Shujaat S, da Costa Senior O, Shaheen E, Politis C, Jacobs R. Visual and haptic perceptibility of 3D printed skeletal models in orthognathic surgery. J Dent. 2021 Jun;109:103660. doi: 10.1016/j.jdent.2021.103660.
55. Baan F, Liebregts J, Xi T, Schreurs R, de Koning M, Bergé S, et al. A new 3D tool for assessing the accuracy of bimaxillary surgery: the OrthoGnathicAnalyser. PLoS One. 2016 Feb 22;11(2):e0149625. doi: 10.1371/journal.pone.0149625.
56. Baan F, Sabelis JF, Schreurs R, van de Steeg G, Xi T, van Riet TCT, et al. Validation of the OrthoGnathicAnalyser 2.0-3D accuracy assessment tool for bimaxillary surgery and genioplasty. PLoS One. 2021 Jan 26;16(1):e0246196. doi: 10.1371/journal.pone.0246196.
57. van Luijn R, Baan F, Shaheen E, Bergé S, Politis C, Maal T, et al. Three-dimensional analysis of condylar remodeling and skeletal relapse following LeFort-I osteotomy: A one-year follow-up bicenter study. J Craniomaxillofac Surg. 2022 Jan;50(1):40-5. doi: 10.1016/j.jcms.2021.09.021.
58. Rozeboom AVJ, Schreurs R, Helmer LML, Dubois L, Lobbezoo F, de Lange J. Volumetric outcomes of treatment for unilateral condylar fractures: A pilot study. Adv Oral Maxillofac Surg. 2023 Mar;9:100399. doi: 10.1016/j.adoms.2023.100399.
59. Almadi D, Benington P, Ju X, Ayoub A. Reproducibility and reliability of digital occlusal planning for orthognathic surgery. Int J Oral Maxillofac Surg. 2023 Oct;52(10):1074-80. doi: 10.1016/j.ijom.2023.03.001.
60. Lin CY, Hsung TC, Khambay B. Reducing cone beam CT scan height as a method of radiation reduction for photorealistic three-dimensional orthognathic planning. J Craniomaxillofac Surg. 2015 Jul;43(6):907-12. doi: 10.1016/j.jcms.2015.04.002.
61. Onică N, Onică CA, Tatarciuc M, Baciu ER, Vlasie GL, Ciofu M, et al. Managing predicted post-orthognathic surgical defects using combined digital software: a case report. Healthcare (Basel). 2023 Apr 25;11(9):1219. doi: 10.3390/healthcare11091219.
62. Yılmaz ZÇ, Özel A, Sağlam R, Uçkan S. Comparison of scleral show alterations following Le Fort I osteotomy with either maxillary impaction or lengthening. J Craniomaxillofac Surg. 2021 May;49(5):347-51. doi: 10.1016/j.jcms.2021.01.031.
63. da Silva RJ, Valadares Souza CV, Souza GA, Ambrosano GMB, Freitas DQ, Sant'Ana E, et al. Changes in condylar volume and joint spaces after orthognathic surgery. Int J Oral Maxillofac Surg. 2018 Apr;47(4):511-7. doi: 10.1016/j.ijom.2017.10.012.
64. Tabchi Y, Zaoui F, Bahoum A. Accuracy of hard and soft tissue prediction using three-dimensional simulation software in bimaxillary osteotomies: A systematic review. Int Orthod. 2023 Dec;21(4):100802. doi: 10.1016/j.ortho.2023.100802.
65. Ferraz FWDS, Iwaki-Filho L, Souza-Pinto GN, Iwaki LCV, Li AT, Cardoso MA. A comparative study of the accuracy between two computer-aided surgical simu-

lation methods in virtual surgical planning. J Craniomaxillofac Surg. 2021 Feb;49(2):84-92. doi: 10.1016/j.jcms.2020.12.002.

66. Alkhayer A, Piffkó J, Lippold C, Segatto E. Accuracy of virtual planning in orthognathic surgery: a systematic review. Head Face Med. 2020 Dec 4;16(1):34. doi: 10.1186/s13005-020-00250-2.
67. Cevidanes LH, Bailey LJ, Tucker GR Jr, Styner MA, Mol A, Phillips CL, et al. Superimposition of 3D cone-beam CT models of orthognathic surgery patients. Dentomaxillofac Radiol. 2005 Nov;34(6):369-75. doi: 10.1259/dmfr/17102411.
68. Motta ATS da, Carvalho F de AR, Oliveira AEF, Cevidanes LHS, Almeida MA de O. [Superposição automatizada de modelos tomográficos tridimensionais em cirurgia ortognática]. Dental Press J Orthod. 2010 Apr;15(2):39–41. Portuguese.
69. Popat H, Richmond S, Drage NA. New developments in: three-dimensional planning for orthognathic surgery. J Orthod. 2010 Mar;37(1):62-71. doi: 10.1179/14653121042885.
70. Wong A, Goonewardene MS, Allan BP, Mian AS, Rea A. Accuracy of maxillary repositioning surgery using CAD/CAM customized surgical guides and fixation plates. Int J Oral Maxillofac Surg. 2021 Apr;50(4):494-500. doi: 10.1016/j.ijom.2020.08.009.
71. Ruggiero F, Borghi A, Bevini M, Badiali G, Lunari O, Dunaway D, et al. Soft tissue prediction in orthognathic surgery: Improving accuracy by means of anatomical details. PLoS One. 2023 Nov 27;18(11):e0294640. doi: 10.1371/journal.pone.0294640.
72. Xia JJ, Gateno J, Teichgraeber JF, Yuan P, Chen KC, Li J, et al. Algorithm for planning a double-jaw orthognathic surgery using a computer-aided surgical simulation (CASS) protocol. Part 1: planning sequence. Int J Oral Maxillofac Surg. 2015 Dec;44(12):1431-40. doi: 10.1016/j.ijom.2015.06.006.
73. Xia JJ, Gateno J, Teichgraeber JF, Yuan P, Li J, Chen KC, et al. Algorithm for planning a double-jaw orthognathic surgery using a computer-aided surgical simulation (CASS) protocol. Part 2: three-dimensional cephalometry. Int J Oral Maxillofac Surg. 2015 Dec;44(12):1441-50. doi: 10.1016/j.ijom.2015.06.007.
74. Naini FB, Gill DS. Challenges and opportunities facing contemporary orthognathic surgery. J Orthod. 2019 Jun;46(1_suppl):71-6. doi: 10.1177/1465312519840044.
75. Swennen GR, Mollemans W, Schutyser F. Three-dimensional treatment planning of orthognathic surgery in the era of virtual imaging. J Oral Maxillofac Surg. 2009 Oct;67(10):2080-92. doi: 10.1016/j.joms.2009.06.007.
76. Kau CH, Cronin A, Durning P, Zhurov AI, Sandham A, Richmond S. A new method for the 3D measurement of postoperative swelling following orthognathic surgery. Orthod Craniofac Res. 2006 Feb;9(1):31-7. doi: 10.1111/j.1601-6343.2006.00341.
77. Kim YK. Complications associated with orthognathic surgery. J Korean Assoc Oral Maxillofac Surg. 2017 Feb;43(1):3-15. doi: 10.5125/jkaoms.2017.43.1.3.
78. Kakarala K, Shnayder Y, Tsue TT, Girod DA. Mandibular reconstruction. Oral Oncol. 2018 Feb;77:111-7. doi: 10.1016/j.oraloncology.2017.12.020.