

# Application of three-dimensional technology in orthognathic surgery: a narrative review

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**Abstract.** – With the recent advances in three-dimensional (3D) technology, orthognathic surgery has steadily evolved, gradually performing more sophisticated surgery and expanding its scope of application. The objective of this study is to summarize the current evidence of the application of 3D technology in the field of orthognathic surgery, with the hope of providing helpful information for practitioners who are interested in orthognathic surgery.

Peer-reviewed articles published in English were retrieved from literature through an extensive search performed in PubMed/MEDLINE. The application of 3D technology in orthognathic surgery can be summarized from the aspects of preoperative diagnosis, surgical planning, surgical procedure and postoperative evaluation. There is evidence that supports the use of 3D technology, including cone beam computed tomography (CBCT), 3D imaging devices, 3D printing technology, navigation, computer-aided design and computer-aided manufacturing (CAD/CAM), can help improving orthognathic surgery and achieving promising outcomes.

Even though there may be an added cost, the application of 3D technology has provided decreased operative time and hospital length of stay, which is positive for both practitioners and patients. With precision and minimal invasiveness, 3D technology is considered to be an effective method in exploring more scientific and reasonable programs and procedures of orthognathic surgery.

*Key Words:*

Three-dimensional technology, Orthognathic surgery, Surgical planning, Surgical procedure.

## Introduction

Orthognathic surgery may be described as the surgical procedure which is generally performed in the field of craniofacial surgery to address

maxillary and mandibular deformities from dental malocclusion, problems related to the facial profile as well as to improve the facial appearance<sup>1</sup>. More recently, it has been implemented to correct patients with obstructive sleep apnea (OSA). Orthognathic surgery requires the cooperation of maxillofacial surgeons, orthodontists and prosthodontists from the formulation of surgical planning to the execution of the surgery. Researches<sup>2,3</sup> have demonstrated that orthognathic surgery generated a positive impact on the quality of life of those patients with dentofacial deformities, especially of those patients who missed the main period (deciduous or mixed dentition) in which functional devices were adopted to correct physical anomalies. In addition, orthognathic surgery could be an option for some rare diseases, such as cleidocranial dysplasia and gummy smile (healthy gingival overgrowth) correction<sup>4,5</sup>.

Traditionally, a series of essential parts for preoperative planning are required to ensure the sequence of surgical treatment, including the acquisition of plaster models of the dentition, two-dimensional (2D) radiographs and photos, manual model surgery and the production of acrylic resin wafers<sup>6</sup>. However, this approach has its limitations, as 2D images cannot accurately assess the complexity of 3D soft-tissue facial anatomy<sup>7</sup>. Furthermore, some problems may occur when 2D surgical plans are executed, such as roll and yaw rotation, midline difference and chin inadequacy, especially in a patient with facial asymmetry<sup>8</sup>.

Since the invention of computed tomography (CT) and 3D printing in the last century, the application of 3D technology has been tremendously enhanced. The advent of CBCT did not only modify many of the diagnostic protocols in dentistry, but also lead to the development of orthognathic surgery. The application of CBCT

improves the procedures of orthognathic surgery and enhances analysis of surgical planning<sup>9</sup>. Furthermore, 3D optical devices which provide 3D replication of the facial structure with high accuracy and good safety have gradually been applied, not only for research and educational fields, but also for clinical environment<sup>10,11</sup>. Combined with CBCT, their use has been accepted for planning in orthognathic surgery and demonstrated significant improvements in surgical outcomes. This digital procedure eliminates the use of a face bow transfer and model surgery and improves the accuracy of orthognathic surgery. The fabrication of the guides and jigs to reproduce gaps or spacing also helps the operator to accurately guide the positioning of the bone segments<sup>12</sup>. Moreover, recently developed navigation shows great potential in orthognathic surgery.

The role of an orthognathic surgeon is not limited to performing orthognathic surgery itself, but also encompasses deep involvement throughout the entire process. 3D technology was applied to assist the entire process of orthognathic surgery, including 3D reconstruction, digital diagnosis, surgical planning, surgical simulation, guide plate production and effect evaluation<sup>13</sup>. These processes have made it possible to perform more sophisticated surgery. It is the purpose of the present review to summarize existing evidence of 3D technology used in the field of orthognathic surgery from the aspects of preoperative diagnosis, surgical planning, surgical procedure and postoperative evaluation.

### Search Criteria

This is a narrative review of published studies. An extensive search was performed in PubMed/MEDLINE using orthognathic surgery as a search term. Taking into account technological progress and recent reports, focus was placed on the last 20 years, and articles published from May 20, 2002, to May 20, 2022, were considered. The search returned 8,133 articles. Peer-reviewed articles published in English language were selected, but no restrictions in terms of article type and geography were applied. Articles which were relevant to the application of 3D technology in orthognathic surgery were retrieved. To complement this review, the electronic search was supplemented with a manual search of the references of these articles. Screening of articles extracted from electronic databases was done by

reading titles and abstracts. The full text of those considered likely to be relevant were retrieved. A systematic review methodology dictated by the Preferred Reporting Items for Systematic Reviews and Meta-analyses (PRISMA) guidelines was not strictly adhered in this study as this is a narrative review.

### Digital Diagnosis

There is evidence that supports the fact that the application of 3D technology can improve orthognathic surgery from the aspects of digital diagnosis, surgical planning, surgical procedure and postoperative evaluation. With the advantages of decreased operative time, high precision and minimal invasiveness, 3D technology can help achieving promising outcomes. On the contrary, there is also evidence that the use of 3D technology may result an added cost in clinical practice.

An early and accurate digital diagnosis supported by clinical and radiological examinations, such as CBCT, is essential<sup>14</sup>. The acquisition and processing of data is critical before the digital diagnosis, which is of great importance to the subsequent processes. After collecting basic information of patients and completing the clinical examination, data acquisition starts with CBCT, which has become the most reliable tool due to its availability, lower X-ray dose and excellent bone resolution<sup>15</sup>. Meanwhile, an intraoral scanner (IOS) can be used to obtain digital dentition since its accuracy has been verified<sup>16</sup>. For surface imaging, 3D optical devices have demonstrated excellent accuracy and reliability for facial soft-tissue measurement in orthognathic surgery<sup>17</sup>. These devices can obtain 3D face model with real skin texture and color in open data format through non-contact measurement in a short period, which could be a more suitable option for quantification of volume and contour of facial soft-tissue measurement. Moreover, recently developed RGB-D camera can collect accurate static and dynamic 3D facial scans with low cost and high measurement accuracy<sup>18</sup>. After importing and registering the obtained data using various software programs, a 3D virtual patient is constructed with the combination of bone anatomy represented by CBCT, the STL model of the intraoral tissues measured by IOS and 3D face model with real skin texture obtained by 3D optical device<sup>19</sup>.

The construction of 3D virtual patient plays a

key role in the diagnosis of orthognathic surgery, which offers a thorough in-depth 3D virtual inspection to plan the orthognathic surgery. The combination of clinical examination and 3D virtual patient provides an unprecedented potential toward the diagnosis in clinical environment. Moreover, studies<sup>20</sup> have demonstrated the consistent efficacy of 3D virtual patient in a variety of educational fields, including clinical training in healthcare professions. Incorporating CBCT slices, the 3D virtual patient allows 2D inspection of the patient's anatomy in three standard planes to comprehensively measure clinical information, and a number of relevant clinical information regarding the patient can be gleaned.

Two visualization techniques are most widely used in clinical practice: (1) volume rendering is appropriate for the 3D visualization of tooth roots and volume quantification of airway; (2) surface rendering illustrates the hard and soft tissues, which offers great potential to implement the related data in the 3D virtual viewer and allows thorough in-depth 3D cephalometric analysis of facial tissues and teeth. Using these techniques, two innovative virtual approaches were developed for digital diagnosis. The first approach was the triple CBCT scan protocol, which allows one to augment the 3D virtual model to be appropriate for surgical planning without the use of markers and plaster dental models<sup>21,22</sup>. By calculating the cephalograms from CBCT and linking hard and soft-tissue surface rendered representations together, the second approach bridged conventional cephalometry with 3D cephalometry of the facial soft-tissue mask and underlying bone and teeth with a common 3D cephalometric reference frame<sup>23,24</sup>. The static diagnosis of the patient is one of the disadvantages of these approaches. However, the virtual dynamic diagnosis method has been proposed and is considered to be integrated in the future.

### Surgical Planning

Model surgery was previously performed with a radiocephalometric analysis of the facial profile and malocclusion before surgery. With the help of 3D technology using CAD software, the method of model surgery has moved from conventional planning to virtual planning. The accuracy of surgical planning has improved significantly by creating a 3D virtual patient, which has created a paradigm shift in orthognathic surgery. Through

better visualization of 3D anatomical structure, virtual surgical planning (VSP) in orthognathic surgery facilitates diagnosis, treatment planning, and evaluation of treatment outcomes<sup>25</sup>. VSP has resulted in decreased planning time, shorter operative time and increased accuracy of osteotomies and fixation<sup>26,27</sup>. In addition, advancements in imaging system have allowed for CAD modeling that includes planning of osteotomies, production of cutting guides to improve the accuracy osteotomy, and production of intermediate and final splints. Furthermore, over the past 10 years, the development of 3D printed models and patient-specific guides has improved surgical planning as well as the transfer of the surgical plan into the operating room for a better surgical result<sup>28</sup>. By examining the conformity of the VSP to the postoperative result, Wilson et al<sup>29</sup> reported there was a high degree of conformity comparing the orthognathic VSP to the actual postoperative result. Additionally, another potential advantage for VSP was the high accuracy of soft tissue simulation with facial contouring. Mazzoni et al<sup>30</sup> tested the use of CAD/CAM cutting guides and customized titanium plates for upper maxilla repositioning and concluded that it could be a promising method for the accurate reproduction of preoperative virtual planning without the use of surgical splints. The combination of orthognathic surgery and other surgeries was also expanded with the development of 3D technology. Dentofacial deformities, such as maxillary deficit, can cause TMJ instability and treatment of deformities should be started together with TMJ, thus having more significant improvement<sup>31</sup>. Using 3D technology to plan orthognathic surgery combined with simultaneous custom TMJ replacement, Movahed et al<sup>32</sup> decreased the preoperative workup time and increased the accuracy of model surgery.

Studies<sup>33,34</sup> have compared VSP with conventional ones and demonstrated acceptable accuracy in all bony segments. Zinser et al<sup>33</sup> compared the versatility and precision of CAD/CAM surgical splints, intraoperative navigation, and classic intermaxillary occlusal splints for surgical transfer of VSP. The results indicated it could be an alternate approach to the use of classic intermaxillary occlusal splints. Ritto et al<sup>34</sup> compared VSP with conventional articulator model surgery, and determined VSP is an accurate method for positioning the maxilla. The decreased planning time is another advancement proposed in the literature. Steinhuber et al<sup>35</sup> compared the working

time between the VSP and conventional ones: the results showed that the mean time to plan single jaw surgery and double jaw surgery with the use of VSP decreased from 145 to 109 min and from 224 to 149 min, respectively. Currently, a certain number of surgeons still uses conventional surgical planning methods, such as clinical examination, face-bow transfer and plaster model surgery. Despite its many advantages, VSP is time-consuming for the preparation and requires expensive devices. However, it is likely that the shortcomings of VSP will be overcome in the near future to bring great benefits in orthognathic surgery.

### Surgical Procedure

Over the past 10 years, the development of 3D printed models and patient-specific guides have simplified surgical procedure, as well as improved the accuracy<sup>36</sup>. The classical production of an occlusal splint requires the combination of plaster models, face-bow and articulator. With 3D technology, occlusal splint can be generated by using CAD/CAM technique to facilitate orthognathic surgery. The use of CAD/CAM occlusal splint can be an alternative with high accuracy, reliability and consistency, as well as improved quantitative control and efficiency<sup>36</sup>. Furthermore, digital occlusal splint overcomes the potential defects from the conventional method, including the non-controllable errors, inter-laboratory difference and time-consuming problem. Lauren and McIntyre<sup>37</sup> described CAD and production of occlusal splints and concluded that digital splints reduced the average time needed for placement because intraoral equilibration was minimized. Shqaidef et al<sup>38</sup> assessed the accuracy of rapid prototyping of virtual occlusal wafers derived from laser scanned dental models using CAD/CAM software. The absolute mean error was  $0.94 \pm 0.09$  mm, but it ranged from 0.04 mm to 1.73 mm, which required further study to assess the difference. Shaheen et al<sup>39</sup> validated the accuracy of 3D printing of final digital occlusal splints based on 3D planning of orthognathic surgery. The mean absolute distance error was 0.4 mm with a standard deviation of 0.17 mm, which can be accepted clinically.

To ensure osteotomy placed exactly as in the digital planning, osteotomy guides are necessary, and the repositioning guides can exactly place the bone segment in the desired position. Kraei-

ma et al<sup>40</sup> assessed the outcome of patients who had been treated with patient-specific CAD/CAM osteotomy guides as part of a bimaxillary osteotomy. The results showed that the method enabled accurate placement of the maxilla, independent of the condyle or mandible, without the need for extraoral reference points. Li et al<sup>41</sup> illustrated the feasibility and validity of a new CAD/CAM template to guide the osteotomy and the repositioning. The results demonstrated clinically acceptable precision of the template for the position of the maxilla ( $<1.0$  mm), which may be a useful alternative to the intermediate splint technique. Lee et al<sup>42</sup> introduced a keyhole system to simultaneously reposition the maxilla and mandible without an intermediate occlusal splint. By using bone-supported guides and computer designed titanium miniplates, Brunso et al<sup>43</sup> concluded that the virtual orthognathic positioning system was safe and well tolerated, which provided position control with considerable surgical accuracy and simplified the surgery.

The 3D printing fixation plate is another area of 3D technology used in orthognathic surgery. Using 3D technology, a study conducted by Huang et al<sup>44</sup> developed a fixation plate that can provide precise positioning and fixation for the Le Fort I osteotomy. The use of patient-specific titanium implants for maxilla segment repositioning and fixation without surgical splints are reported in the literature<sup>45</sup>. Suojanen et al<sup>45</sup> reported individual implants based on the anatomical structures, which can provide exact positioning and stability of the repositioned maxilla.

The applications of navigation can optimize the functional and esthetic outcomes in patients with dentofacial deformities by identifying pertinent anatomic structures, transferring the surgical plan to the patient, and verifying the surgical results. Furthermore, navigation can define and localize operative anatomy, to localize implant position, and to orient the surgical wound during the surgical procedure. One of the critical factors that affects the development of orthognathic surgery is the consideration of pertinent anatomy, which is often hidden during surgical procedure. The narrow surgical field often makes it difficult to view the operative site directly. Surgical navigation gives real-time visualization on the positions of the instruments in relation to critical structures and enables surgeons to precisely carry out surgical planning without injuring pertinent anatomy<sup>46</sup>. With navigation, the exact position of the tip of any surgical instrument can

be accurately evaluated at all times during the surgery procedure<sup>47</sup>. During the osteotomy, navigation can localize the anatomy and identify the depth and extension. For intraoral vertical ramus and subcondylar osteotomies, the introduction of the endoscope to provide complete visualization of the osteotomy site may overcome the traditional limitations through direct visualization<sup>48</sup>.

### Postoperative Evaluation

The postoperative evaluation after the orthognathic surgery is critical to ensure the therapeutic effect. The technique of voxel-based rigid registration and superimposition on a 3D cephalometric reference system demonstrated unprecedented potential for postoperative evaluation of surgical outcomes in orthognathic surgery<sup>49</sup>. The evaluation of surgical outcomes using CBCT imaging can be divided into 3 stages. On the first stage at 3 to 6 weeks after the surgery, CBCT is performed to assess the accuracy of the transfer of repositioning the bony segments. In addition, when orthodontic brackets are removed about 6 months to 1 year after the surgery, CBCT is performed to assess the simulation of facial soft-tissue morphology. Finally, the long-term treatment outcome is evaluated using CBCT after 2 years of the surgery.

Quantitative studies<sup>50,51</sup> have been conducted by different research groups worldwide to evaluate postoperative results after the orthognathic surgery. Zavattoni et al<sup>50</sup> assessed the postoperative results of orthognathic surgery by superimposing the postoperative CT scan onto the virtual plan and reported an overall high degree of accuracy. Li et al<sup>51</sup> conducted craniofacial spiral CT to evaluate postoperative effect of orthognathic surgery assisted by 3D technology and validate the surgical design protocol. The images were imported into software with the digital model designed before the surgery, and differences of landmarks were compared. The results indicating the orthognathic surgery with the aid of navigation met the clinical needs.

Superimposition on some stable maxillary structures, such as the anterior surface and tip of the zygomatic process, can be used to evaluate treatment changes of orthognathic surgery. The advent of CBCT allowed the observation of skeletal and dental changes that could not be attempted with standard 2D radiographs<sup>52</sup>. 3D registrations offer advantages over 2D including

volume/regions of interest for registration rather points or lines, lack of distortion of bilateral structures, and head positioning errors. A study conducted by Cevidanes et al<sup>53</sup> determined the reproducibility of 3D superimposition to evaluate overall facial changes, which provided a valid and reproducible 3D assessment of growing patients. Ruellas et al<sup>54</sup> built 3D models using CBCT before treatment and after treatment for 16 growing subjects; the results showed adequate intraobserver and interobserver reproducibility values.

### Conclusions

Orthognathic surgery plays a key role in the craniofacial field to correct both functional and aesthetic problems. First introduced in the 19<sup>th</sup> century, the field of orthognathic surgery has grown and improved significantly over the last few decades because of the application of 3D technology. Increasing interest has been focused on the application of 3D technology in orthognathic surgery since there is a general trend towards a CBCT supported 3D diagnostic and planning ecosystem, which has tremendously improved diagnosis and created a more efficient process from preoperative planning to postoperative evaluation. Although there may be an added cost to the patient, it has provided decreased operative time and hospital length of stay. With precision and minimal invasiveness, 3D technology is considered to be an effective method in exploring more scientific and reasonable programs and procedures of orthognathic surgery.

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#### Conflict of Interest

The Authors declare that they have no conflict of interests.

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#### Authors' Contribution

Rongkai Cao completed the conception of the review and wrote the original draft. Lishan Li collected and interpreted the data from literature. Yujie Cao revised the manuscript. All authors gave their approval to submit.

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