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3-H in 3-D: Envisaging Beyond the Current Hype, the Hope and Hurdles of Three-Dimensional “Virtual Planning” in Orthognathic Surgery

3-H en 3-D: Contemplando más allá del Entusiasmo actual, la Esperanza y los Obstáculos de la "Planificación Virtual" Tridimensional en Cirugía Ortognática

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SUMMARY: Recent technical and technological advancements in orthognathic surgery concepts, intricate in the diagnosis and treatment planning for corrections of dento-facial deformities, have achieved stable oro-dental functional occlusion and facial esthetic harmony. Undeniably, this can be attributed to the integration of modern, innovative and advanced facial analysis and computer-aided imaging exams into well-orchestrated and executed orthodontic and surgical methods. Three-Dimensional (3-D) virtual planning is a fine example. Today, the acquisition of 3-D images of a patient’s craniofacial complex via cone-beam computed tomography (CBCT), supported by software tools allowing the construction of 3-D dynamic and interactive visual models, eliminates the uncertainty experienced with two-dimensional images. Thereby allowing for a more accurate or predictable treatment plan and efficient surgery, especially for patients with complex dento-facial deformities. This review article aims to describe the current benefits as well as shortcomings of 3-D virtual planning via discussing examples and illustrations from orthognathic procedures, attained from the reported English and Spanish literature during the last 10 years. It is designed to deliver updated and practical guidelines for dental practitioners and specialists (particularly, oral and maxillofacial), as well as researchers involved in 3-D virtual approaches as an alternative to conventional/traditional surgical planning; thereby validating its superiority or benefits in terms of outcome prediction for soft and hard tissues, operational time- and cost-effectiveness; for its integration in day-to-day practise.

KEY WORDS: Cone-beam computed tomography; Cephalometry; Orthognathic surgery; Three-dimensional imaging; Planning.

INTRODUCTION

The American Society of Maxillofacial Surgeons describes dentofacial anomalies as abnormalities in dental and facial growth that affect children and adults with cleft lip/palate and craniofacial macrosomia, as the two most common conditions often encountered at specialized craniofacial centers. Such cases, although not life-threatening, can still affect psycho-social function and overall quality of life (QoL), severely. Indeed, whether the existing facial deformity is congenital or acquired (mainly due to either trauma or post-tumor surgery), the general QoL negative impact to the patient as well as his/her family is significant. Furthermore, proper dento-facial and physical appearance equate happiness and/or success in life; especially during adolescence and early adulthood. Hence, the correction of dentofacial anomalies to restore and/or improve functional (occlusal) as well as aesthetic profiles are critical to our patients, their caregivers, families, friends and acquaintances. The treatment of dentofacial anomalies is expected to result in a radical change for the better, in terms of both masticatory system-related aspects: appearance and functional, typically via orthognathic surgery.

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Such procedures combining orthodontics and surgical interventions of the facial skeleton, change the bony relations of the face (stable jaw-positioning) and improve soft tissues (facial harmony) significantly improving the aesthetics and occlusal relationships of the patient. Hence, such complex procedures require appropriate facial analysis, adequate imaging assessments and the execution of apt surgical techniques. Conventional planning methods in orthognathic surgery habitually depend on two-dimensional (2-D) 'planar' images, including analog/digital photographs and radiographs (mainly, cephalometric and panoramic) to determine craniofacial discrepancies and deformities. While deemed satisfactory, such exams; whether due to difficulties in patient positioning, superposition of anatomical structures and/or challenges related to image resolution and distortion, even with included articulated study casts, provide the surgical team with only limited comprehension of the complex three-dimensional defects and are considered insufficient for adequately planning appropriate corrections with the best possible (and most predictable) clinical outcomes. This is especially true in cases suffering condylar/ temporomandibular joint (TMJ) alterations and/or severe facial asymmetries. Hence, with the introduction of cone-beam computed tomography (CBCT) to our practise, as far back as the 1980's, the acquisition of visual and more accurate three-dimensional (3-D) cross-sectional images of the craniofacial complex became possible, a genuine and powerful paradigm shift revolutionizing the field of cranio-maxillo-facial imaging, diagnosis, treatment planning and surgery. Today, almost every dental discipline (and sub-discipline) benefit from sub-millimetre resolution 3-D imaging, with more and more CBCT devices integrated in our clinics and offices. Undeniably, such computer-aided technologies (design and manufacturing) have enhanced the accuracy of orthodontic surgical planning (including the construction of 3-D surface models and dynamic cephalometry) and simplified surgical techniques (including interactive bone segment cutting, repositioning and reconstruction) for maxillofacial deformities with optimized treatment outcomes. Notably, 3-D -virtual and -printed (via CAD/CAM: Computer-Aided Design and -Manufacturing technologies) surgical splints that can be processed and used during the actual surgery is a reality. Indeed, digital surgical planning allows the surgeon, today, to manipulate and operate digital representations of the skull for a more accurate treatment planning and precise prediction of orthognathic surgery procedure(s), potential difficulties and challenges (and/or obstacles), and outcome (balanced aesthetic and function), thereby assisting in patient selection and procedure matching. Yet, drawbacks and limitations continue to exist. For example, the obtained and/or generated 3-D data need to be adequately and carefully interpreted, and the question of who manipulates or handles the 3-D data set and specific software (technician versus clinician) almost always arises (Swennen *et al*., 2009a; Aboul-Hosn Centenero & Hernández-Alfaro, 2012; Rubio-Palau *et al*., 2012; Stokbro *et al*., 2014; Lin & Lo, 2015). Therefore, the objective of this review article is to describe the advantages and to a greater extent, the limitations of 3-D surgical planning in orthognathic surgery as well as to examine the different evidence-based protocols used, comparing 3-D planning to 2-D conventional planning strategies.

MATERIAL AND METHOD

A structured literature search was performed in multiple web-based engines and bibliographic databases that catalogue published research: Cochrane, EBSCO, Google Scholar, Science Direct and PubMed/MEDLINE (May 2017). The MeSH term used was limited to "orthognathic surgery". The used non-MeSH terms were: "three-dimensional planning" and "virtual planning", with Boolean operators "AND" and "OR" also applied. Further, publication date and language filters were applied to the search. Additionally, a manual search for references, to exploit filtered findings, was conducted. Relevant full-text articles in English and/or Spanish, published between the years of 2005 and 2017 were included here in. Articles related to the advantages, disadvantages, and treatment outcome of orthognathic surgery with involvement of 3-D planning were included, as well as articles comparing 3-D planning with conventional and traditional planning methods. Systematizing our followed process and obtained data were then organized and validated using the Oxford Centre for Evidence-based Medicine – Levels of Evidence (CEBM) criteria and its corresponding grades of recommendation (Howick *et al*., 2011). Notably, the PRISMA statement (Moher *et al*., 2009) for reporting systematic reviews and meta-analyses of studies that evaluate healthcare interventions, the CONSORT statement (Schulz *et al*., 2010) for reporting randomized clinical trials, and the STROBE statement (von Elm *et al*., 2008) for reporting observational studies were also applied. The authors, of whom are qualified and practiced oral and maxillofacial surgeons, do assimilate their expertise in the presented critical analysis.

RESULTS AND DISCUSSION

Our systematized structure literature search identified/filtered 20 articles, categorized as follows: 2 systematic reviews, 1 clinical trial, and 17 observational studies, as is illustrated in Figure 1. Briefly, the follow-up period in the selected studies (and included in this review) ranged from baseline peri-operative intervention up to 6 months post-operatively. 3-D planning timelines ranged from 30 minutes up to 306 minutes. Tissue prediction was less than 2 mm accurate in hard tissues and less than 2.67 mm in soft tissues when comparing pre-operative planning to post-operative results. Interestingly, investigating craniofacial volume, in particular, identified a clear limitation of conventional 2-D planning. Further, all 20 included studies agreed on validating the advantage and benefits of computer-assisted 3-D planning. Yet, as mentioned earlier, disadvantages do exist, and will be discussed, in the following section.

Précis – Facial appearance and topography are clearly three-dimensional, therefore, correction founded principally on two-dimensional photographic- and radiographic-based diagnostic, planning and surgical attempts, are deemed restricted and inadequate. Indeed, the correction of dentofacial anomalies and deformities typically requires the manipulation of teeth and jaws in three dimensions to attain optimal outcomes/results within the joint pre-existing constraints of aesthetics, stability, and occlusal/TMJ function.

Briefly, several 3-D imaging and planning techniques have been introduced to alleviate the shortcomings of conventional 2-D methods via registering and analysing the face in three dimensions and facilitating the reproducible identification of significant landmarks; including: 3-D computerized tomographic scanning, morphanalysis, stereolithography, laser scanning, 3-D ultrasonography, 3-D facial morphometry and 3-D cephalometry, digigraph imaging, contour photography and Moiré topography, to list a few. Yet, although 3-D assisted diagnosis, planning and procedures are now widely available for orthognathic surgery, it remains vastly debatable whether 3-D virtual planning is a better alternative to conventional 2-D planar planning; a concoction of 'hype, hope and hurdles'.

2-D vs 3-D Pre-Operative Diagnostic Planning

Step 1 – Physical Examination: For both methods, in order to adequately achieve a precise diagnosis of the dento-skeletal deformity and create a proper treatment plan, it is still necessary to collect data from different and multiple sources (photographs, cephalograms, dental casts, face-bow, articulators, etc.) in addition to a careful and thorough static (or stationary) physical examination (Swennen *et al*., 2009b). Dynamic evaluation tools and software should soon be available for oro-dental, mandibular and maxilla-facial movements, to control rotation and translation of the cranial complex, minimalizing if not, diminishing errors and inaccuracies of simulations. Until its realization, advances and developments in 3-D imaging technology provide surgeons with additional information that could not be obtained from lateral cephalogram alone, thus improving the quality of pre-operative planning. Indeed, several soft-ware programs are available today offering 3-D planning; thereby allowing a 3-D imagery interaction to simulate the surgery and visualize the prediction of post-operative outcomes in soft and hard tissues. Surgical splints, manufactured using the computer-aided design/computer-aided manufacturing (CAD/CAM) technology, was developed to circumvent errors in the traditional model process that can lead to sub-optimal outcomes.

Step 2 – Imaging: The application of virtual surgical planning has a clear role where soft and hard tissues are necessary components in the completion of the reconstruction. Visual assessment of skeletal discrepancies is based on data obtained from different sources, including clinical examination, as well as photographs, computed tomography (CT) scans and models. Here in, the increased radiation dose associated with virtual surgery is considered as one of the limiting factors in surgical planning. The use of pre-operative as well as post-operative CBCT (effective dose set at 0.05 mSv), or full skull CT (effective dose set at 0.93 mSv) corresponds to an increase in dose compared with using lateral skull radiography (effective dose set at 0.03 mSv) or dental panoramic tomography (effective dose set at

Table I. Results from systematic reviews.

Journal	Authors/ Year	Number of Publications	Objectives	Surgeries	Evidence Level	Recommendation Grade (GoR)
International Journal of Oral & Maxillofacial Surgery	Haas Jr. *et al.*, 2014	9 (137 patients)	To evaluate accuracy and benefits of computer-assisted planning.	Bimaxillary	2a	A
International Journal of Oral & Maxillofacial Surgery.	Stokbro *et al.*/ 2014	7 (149 patients)	To review clinical trials in the literature, which evaluate planning accuracy in 3D planning.	131 Bimaxillary, 10 LeFort I, 7 BSSO, 1 OSAS	2a	A

Table II. Results form clinical trials

Journal	Author/ Year	N	Planning Method/ Software	Image	Dental Arch Imaging	Splint	Surgery	Follow -up	Planning time	Evidence Level	GoR
British Journal of Oral and Maxillofacial Surgery	De Riu/ 2013	20	Computer-assisted planning vs. Conventional planning / Maxilim (Nobel Biocare)	CBCT	Triple scanning with CBCT	CAD/CAM (10) Conventional (10)	Bimaxillary – all cases treated facial asymmetries. Genioplasty (14)	NR	NR	1b	A

0.03 mSv) in conventional surgical planning for orthognathic surgery (Stokbro *et al*., 2014). Here in, CBCT was used in 11 of the selected; CT was used in 4 studies (Borba *et al*., 2016; Resnick *et al*., 2016; Zhang *et al*., 2016); and both imaging techniques were used in 2 articles. In studies where CBCT imaging was used, the purpose was to create a 3-D model (Hernández-Alfaro & Guijarro-Martínez, 2013; De Riu *et al*., 2014; Swennen, 2014; Nadjmi *et al*., 2014; Liebregts *et al*., 2015a; Van Hemelen *et al*, 2015; Liebregts *et al*., 2015b; Stokbro *et al*., 2016; Wrzosek *et al*., 2016). In these studies, orthognathic surgery planning involved CBCT imaging followed by post-operative CBCT imaging to compare pre-surgical planning with post-operative results. The timing protocol of post-operative CBCT imaging follow-up varied among the studies: from peri-operative imaging up to 6 months post-operatively. In relation to the field of view (FOV), one of the disadvantages of CBCT is that some devices have FOV limitations, which do not permit full imaging of the craniofacial complex. Hence, a 3-D cephalometric analysis cannot be performed. It is worth mentioning that 3-D cephalometric is considered a valuable tool in the diagnosis of skeletal imbalance. Likewise, beneficial in evaluating the growth response to treatment as well as determining and "predicting" long-term stability. Swennen compared 3-D cephalometry with CBCT and CT imaging describing the advantages of the latter, which achieved better image quality in hard and soft tissues and better high-contrast quality. Elimination of super-imposition of anatomical structures permitting 3-D cephalometric analyses with greater accuracy was also mentioned. Stokbro and Hass agree on the use of CBCT over CT. Poor dental image quality in presence of orthodontic brackets was the main disadvantage highlighted (Haas Jr. *et al*., 2014; Stokbro *et al*., 2014). This is perhaps why complementary methods are needed to achieve detailed dental surfaces by means of digital scanning, study cast scans, and the CBCT triple scan procedure proposed prior by Swennen *et al*. (2009b).

In three studies (Aboul-Hosn Centenero & Hernández-Alfaro; Hsu *et al*., 2013; Zinser *et al*., 2013), study casts were scanned to capture a detailed occlusal image of the dentition. Hsu *et al*. scanned study casts using an inter-occlusal jig, which permitted attaining the centric relation and subsequently super-imposing on CT-obtained images, to finally construct or obtain a 3-D model. The authors (Hsu *et al*.) highlighted the importance of achieving a centric relation to further obtain optimal post-operative results.

Interestingly, intra-oral scanning of dentition was performed in one study to accomplish a detailed image of occlusal surfaces. Hernández-Alfaro & Guijarro-Martínez scanned 6 patients using an algorithm integrated on all the CBCT scans. The average intra-oral scanning time was 19 minutes and 45 seconds. The authors supported using this imaging technique for dental arches given there is no need to produce dental impressions, or to obtain study casts. This further simplifies the procedure and reduces the margin of error. Furthermore, this study (Hernández-Alfaro & Guijarro-Martínez) emphasized the noted decrease in the radiation dose received by the patient compared with the aforementioned CBCT triple scan procedure. Indeed, other studies used the CBCT triple scan procedure to obtain a suitable image of the occlusal surfaces of teeth. The aim of the procedure proposed by Swennen *et al*., in 2009 was to achieve a 3-D model suitable for application in orthognathic surgery without the use of study casts and without distorting the facial soft tissues of patients. It was summarized that this outcome can be attained through 3 separate CBCT views. The first view is captured in the natural head position with an inter-occlusal wax bite registration. For the second view, an alginate impression is made using a triple tray and then scanned. Thirdly, the impression on the triple tray is scanned. Finally, all 3 images are incorporated into the accompanying software to generate a combined useful 3-D cranial model (Swennen *et al*., 2009b). This said, in coming years, the field expects an explosion of commercially-available algorithms and softwares for 3-D virtual planning/surgery and true visualization programs, with the desirable validation of craniofacial skeletal components, occlusion and soft tissue outcomes, thereby overcoming many of the limitations of conventional surgical planning, such the lack of prediction of soft-tissues and bone movements three-dimensionally, and the time- and cost-consuming requirement of models and articulators.

Step 3 – Surgical Transfer of 3-D Orthognathic Planning. Surgical transfer of orthognathic planning is provided by means of surgical splints. There are intermediate and final acrylic splints, which are fabricated by laboratory technicians, or by the oro-dento maxilla-facial surgeons themselves. With the advent of new technologies, splint manufacturing has been mastered through CAD/CAM techniques, or 3-D impressions; a paradigm computer-assisted shift in diagnosis and pre-operative surgical planning. Another reliable, precise and innovative alternative is intra-operative navigation, which is a definitive tool to determine the final position of bone segments without the need to use splints, or as an additional instrument to guide osteotomies during surgery (Lin & Lo). Zinser *et al*. compared different methods for the transfer of surgical planning, namely: conventional splints, CAD/CAM-manufactured splints, and intra-operative navigation. For the maxilla, CAD/CAM-manufactured splints obtained the greatest accuracy, followed by intra-operative navigation. On the other hand, conventional splints displayed the least accuracy. Nevertheless, none of the methods used in this study attained either adequate accuracy in terms of predicting the final mandibular position of skeletal bases, or the final position of the soft tissues. Only the method using CAD/CAM-manufactured splints could keep both condyles in a centric relation within the TMJ; corresponding to one of the aims of the study. Another aspect worth mentioning in the work of Zinser *et al*. is the average duration of surgery with each of the three different methods. With conventional splints, the average duration of surgery was 4.3 hours. Using CAD/CAM-manufactured splints, average timings increased by 20 minutes, and by 50 minutes when using intra-operative navigation. Regarding CAD/CAM-manufactured splints, the authors pointed out that the increase in surgery time was associated with splints being larger in extent and thus, their fitting proved more cumbersome. In the case of intra-operative navigation, a learning curve associated with the process was identified with an increase in average timing (Zinser *et al*.). Furthermore, Aboul-Hosn Centenero & Hernández-Alfaro used CAD/CAM-manufactured splints to transfer surgical planning at the time of surgery in comparison to conventional splints. It was concluded that a significant difference in terms of manufacturing exists between conventional and CAD/CAM-manufactured splints, where the latter corresponded to a valid and reliable method in the fabrication of splints, which accurately replicated what had been planned via the 3-D software into the surgical scenario. The authors attributed this to an increase in data quality and quantity, which may be combined to achieve only one 3-D model of the patient, thus eliminating multiple sources of information as is the case of 2-D planning. Future advancement in computers and imaging will compliment the surgeon with 3-D imagination and better splints than conventional occlusal splints for a more precise transfer of the 3-D orthognathic planning.

Step 4 – Movement Response and Prediction of Soft and Hard Tissues. Given that the orthognathic-driven improvement of facial aesthetics focuses on patients themselves, hence, prediction of soft tissue response to hard tissue movement becomes essential for planning; a difficult challenge indeed. This is especially true when using conventional planning methods whereby the Visual Treatment Objective (VTO) is based upon cephalometric tracings. Such, does not permit an accurate prediction, particularly at the soft tissue level. Most of the studies analysed in this review compared surgical planning with post-operative results following orthognathic surgery to validate 3-D planning with respect to tissue response and movement prediction. Two main methods to compare what has been planned with post-operative results arise: (1) the difference between surfaces; and (2) the difference between points of reference. True post-operative results are systematically underestimated when using the difference between surfaces. Moreover, should the osteotomy at the time of surgery be different to what was initially planned, the results will be further altered, despite the bone segment ending up in the correct position. A more reliable result is obtained using points of reference. However, this is based on the manual positioning of these points of reference to be evaluated later. There is general consensus in the literature that a difference of less than 2 mm between planning and post-operative results is acceptable given that those 2 mm are not clinically significant in the analysis of lateral skull radiographs. In both systematic reviews (Stokbro *et al*., 2014; Hass *et al*., 2014), the authors agreed with all the differences in measurements between the planning stage and post-operative results in the studies included, which did not allow for meta-analysis due to their heterogeneity. Clinical trials were recommended using 3-D points of reference to attain homogeneity of results and hence be able to make comparisons between the different studies. Indeed, Haas Jr. *et al*. in their systematic review, dissected 9 studies, which evaluated accuracy in terms of soft tissue prediction using computer-assisted planning. It was concluded that computer-assisted 3-D planning is an accurate method for predicting maxillary and mandibular position, however soft tissue prediction was inaccurate. Stokbro *et al*. (2014) analysed 12 articles regarding soft tissue prediction in their systematic review. 3-D planning is advantageous in analysing hard and soft tissues, as a whole. Visualising the soft tissues allows clinicians to better inform patients and discuss their needs in order to achieve a soft tissue simulation based on their requirements, yet, due to lack of accuracy, conflicts arise through enriching expectations amongst patients.Utility, applications and practicality continue to be explored as new technologies become available and as experience with the current technologies (and combinations) increases.

Timing for 3-D Virtual Treatment Planning in the Daily Orthognathic Clinical Routine – Current traditional and/or conventional clinical orthognathic surgery planning is associated with elevated costs in terms of time as well human resources. A great deal of time must be invested in performing every stage of planning; including: alginate impression recordings, pouring and casting impressions, mounting of study casts on an articulator, cephalometric tracings, modelling surgeries, and fabrication of intermediate and final acrylic resin splints. As a result, for simpler, faster or more cost-effective ways in obtaining patient data, computer-assisted 3-D planning allowed to diminish the timings.

Table III. Results form observational studies.

Journal	Author /Year	N	Planning Method/ Software	Image	Dental Arch Imaging	Splint	Surgery	Follow-up	Planning Time	Level of Evidence	GoR
Annals of Maxillofacial Surgery	Nadjmi/ 2014	20	3D planning/ Maxilim (Nobel Biocare)	CBCT	NR	CAD/CAM	Bimaxillary(16) BSSO (4) Genioplasty(6)	4 months	NR	4	C
Journal of Oral and Maxillofacial Surgery	Liebregts/ 2015	100	3D planning/ Maxilim (Medicim NV)	CBCT	NR	NR	BSSO(100)	6 months	NR	4	C
Journal of Cranio-Maxillo-Facial Surgery	Van Hemelen/ 2015	66	2D planning (35) vs 3D (31) / Maxilim (Medicim NV)	CBCT	Triple scanning with CBCT	CAD/CAM	Bimaxillary (46) BSSO (17) Le Fort I (3) Genioplasty (28)	4 months 6 months	2D 20 min. 3D 38 min.	2b	B
Journal of Cranio-Maxillo-Facial Surgery	Liebregts/ 2015	60	3D planning/ Maxilim de Medicim NV	CBCT	NR	CAD/CAM	Bimaxillary (60)	1 week	NR	4	C
Int Journal of Oral and Maxillofacial Surgery	Stokbro/ 2015	30	3D planning/ Dolphin (USA)	CBCT	NR	CAD/CAM	Bimaxillary(30) Segmentation (13) Genioplasty (5)	43 days	NR	2b	B
Journal of Oral and Maxillofacial Surgery	Borba/ 2016	50	3D planning/ Dolphin (USA)	CT	NR	NR	Bimaxillary (50)	NR	NR	2b	B
Journal of Oral and Maxillofacial Surgery	Resnick/ 2016	43	2D vs. 3D planning/ Dolphin (USA)	CT	NR	3 D printing	Bimaxillary (19) Asymmetry (17) Segmentation (7)	NR	2D: 524-544 min. 3D: 188-288 min.	2b	B
Int Journal of Oral and Maxillofacial Surgery	Wrzosek/ 2016	41	2D vs 3D planning/ Materialise (USA)	CBCT	NR	3 D printing	Bimaxillary (20) Asymmetry (21)	1 month	2D: 447 min. 3D: 306 min.	4	C
Oral Surgery Oral Medicine Oral Pathology and Oral Radiology	Zhang/ 2016	30	3D planning/ Dolphin (USA)	CT	Intraoral scanning	3 D printing with bone guide	Bimaxillary (30) Genioplasty (17)		NR	4	C

3-D procedural timings were recorded as follows: 35 minutes on average for 3-D planning, 80 minutes on average for designing the repositioning and osteotomy guides (in order to eliminate the intermediate splint), and 30 minutes on average for producing the final splint. This adds up to an average of 145 minutes for an overall planning time, quite similar to that for surgeons performing the procedure for the first time. Others recorded 3-D planning timings, in 135 minutes, as follows: 30 minutes for scanning of the bite registration, 60 minutes for virtual model surgery, and 45 minutes for CBCT capture and for intermediate splint design. Splint printing with a 3-D printer was identified to take 2 hours, so printing can be done on the same day. This proposed planning method reduces planning time significantly when compared with a conventional planning method. Furthermore, Swennen evaluated the time needed for 3-D orthognathic surgery planning at a clinic with high volumes of patients. The authors designed a 3-D planning protocol suggesting efficiency and time-/cost-efficacy. Planning was therefore standardised achieving excellent results whereby bi-lateral osteotomy planning time averaged 29 minutes and 19 seconds; and planning time for triple surgery (bilateral sagittal split osteotomy, Le Fort I, and genioplasty) averaged 41 minutes and 1 second. The method was recommended as it can be integrated efficiently into the daily practise of the maxillofacial surgeon (Swennen). Van Hemelen *et al*. recorded both, 2-D and 3-D planning timings. Unlike other studies, lower planning timings were registered using a conventional method, averaging 20 minutes, when compared to the 38 minutes required for 3-D planning. The authors attributed that this was partly due to the time required for producing the virtual model using the software as well as to the incremental learning curve. However, it is noteworthy that data compilation was not taken into account, which would completely alter the recorded planning timings. In a final example, Resnick *et al*. compared conventional and computer-assisted planning in terms of planning time and economic cost. Significant differences were noted, favouring the computer-assisted approach, with decreases in time and costs. The authors estimated an approximate cost between 2,700 and 2,883 USD for computer-assisted planning, and between 3,380 and 3,537 USD for conventional planning. Computer-assisted planning consumed 188-288 minutes in this study, and 524-544 minutes for conventional planning. Costs were calculated taking into account the average salary of maxillofacial surgeons in the US; with the increase in the cost of conventional planning was due to the direct supervision of the surgeon at every stage of planning (Resnick *et al*.). How figures would differ from other indications for virtual surgical planning remains open.

Advances in computer-aided 3-D design, planning and manufacturing technologies revealed, with great hype and hope, the benefits of and increasing utility and applications for precise virtual surgical planning in orthognathic surgery, especially when compared to conventional 2-D methods and tools. This narrative literature review identifies increased interest, use and integration of 3-D virtual methods, tools and approaches for the treatment of patients' oro-dental and maxillofacial deformities, in every day practice. To date, costs, time and learning curves are amongst the main limitations and/or hurdles facing such technologies. More simple methods and approaches are expected in the very near future, especially with evidence obtained from high-quality multi-centered clinical double-blind randomised controlled trials. A working clinical protocol allowing the surgical team to obtain homogenous results and predictable outcomes is desirable.

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RESUMEN: Los recientes avances técnicos y tecnológicos en los conceptos de la cirugía ortognática, involucrados en la planificación del diagnóstico y tratamiento para la corrección de deformidades dento-faciales han sido notablemente considerables en lograr una oclusión oro-dental funcional y una estética facial armónica. Innegablemente, esto se puede atribuir a la integración de análisis faciales avanzados, modernos e innovadores y exámenes de imágenes asistidos por computadora a métodos ortodonticos y quirúrgicos bien orquestados y ejecutados. La planificación virtual tri-dimensional (3-D) es un buen ejemplo. Hoy, la adquisición de imágenes 3-D del complejo cranio-facial de pacientes vía tomografía computarizada cone beam (TCCB), apoyada por herramientas computacionales, permite la construcción de modelos visuales 3-D dinámicos e interactivos, eliminando la incertidumbre experimentada con las imágenes bi-dimensionales. Permitiendo, de este modo, un plan de tratamiento más preciso o predecible y una cirugía más eficaz, especialmente para pacientes con deformaciones dento-faciales complejas. Este artículo de revisión tiene como objetivo el describir los actuales beneficios, así como las limitaciones de la planificación virtual a través de la discusión de ejemplos de procedimientos ortognáticos, obtenidos de la literatura reportada en inglés y español durante los últimos 10 años. Fue diseñado para entregar una actualización resumida y una guía práctica para los practicantes y especialistas interesados (particularmente, oro y maxilofaciales), explícitamente, así como a los investigadores involucrados en aproximaciones 3-D como una alternativa a la planificación quirúrgica convencional/tradicional; validando así su superioridad o beneficios en términos de predicción de resultados para tejidos blandos y duros, efectividad en tiempo operacional y costos; para su integración en la práctica cotidiana.

PALABRASA CLAVE: Tomografía computarizada cone-beam; Cefalometría; Cirugía ortognátiva; Imágenes tridimesionales; Planificación.

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