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ORIGINAL ARTICLE

Analysis of the implementation of a circuit for intra-operative superposition and comparison of the surgical outcomes using ICBCT in maxillofacial surgery

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Abstract

Purpose This paper describes a novel circuit for intraoperative analysis with ICBCT in maxillofacial surgery. The aim is to establish guidelines, define indications, and conduct an analysis of the implementation of the circuit for intraoperative comparison of surgical outcomes in relation to 3D virtual planning in maxillofacial surgery.

Methods The study included 150 maxillofacial surgical procedures. Intraoperative actions involved fluoroscopy localization, intraoperative CBCT acquisition, segmentation, and superimposition, among other steps. Surgical times due to intraoperative superposition were measured, including time required for ICBCT positioning and acquisition, image segmentation, and comparison of 3D surfaces from the surgical planning.

Results Successful intraoperative comparison was achieved in all 150 cases, enabling surgeons to detect and address modifications before concluding the surgery. Out of the total, 26 patients (17.33%) required intraoperative revisions, with 11 cases (7.33%) needing major surgical revisions. On average, the additional surgical time with this circuit implementation was 10.66 $\pm$ 3.03 min (n $=$ 22).

Conclusion The results of our research demonstrate the potential for performing intraoperative surgical revision, allowing for immediate evaluation, enhancing surgical outcomes, and reducing the need for re-interventions.

Keywords 3D planning · Surgical accuracy · Intra-operative CBCT

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Introduction

Virtual surgical planning is becoming increasingly common in many surgical specialties. Among all specialties, maxillofacial surgery is the one that greatly benefits from 3D technologies [1–3]. Within procedures like orthognathic surgery, the integration of virtual planning has become an essential tool to increase surgical procedures and achieve optimal results [4–6]. This 3D planning involves manipulating DICOM images obtained from a Computerized Tomography (CT). These images undergo processing through specialized softwares, transforming the files into STL format, allowing for the simulation of the surgery in a virtual environment. Additionally, anatomical models or personalized surgical guides of patients are 3D printed in many interventions to guide the surgeon to perform osteotomies or plates, prosthesis or screw positioning. Those allow for more accurate results and safer surgeries [7].

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In addition to virtual surgical planning and 3D printing, in recent years, technology rapidly advanced, introducing new innovative tools that can enhance the precision and efficacy of results in maxillofacial surgeries. Among these innovations, the use of mixed reality approaches [8], intra-operative imaging or surgical navigation [9–13] stand as the most promising ones to increase the precision and safety of surgical procedures. Despite their capabilities, these tools are not without limitations, such as in their ability to continuously monitor and accommodate dynamic movements within the surgical field [14].

Additionally, sometimes it can be challenging to precisely transfer the results that have been previously planned virtually to the operating room, leading to outcomes that may not be entirely reproducible. Consequently, it is necessary to assess the quality and precision of surgical outcomes. The practice of 3D superimposition after orthognathic surgery is being widely used to assess the post-operative outcomes [15].

The novelty of this study lies in the use of superposition intra-operatively, allowing for real-time assessment of surgical improvements before the end of the procedure, to achieve more accurate surgical outcomes and provide the opportunity to make necessary modifications during the same surgical intervention.

Methods

A retrospective collection of all maxillofacial procedures using intra-operative cone beam computed tomography (ICBCT) in a pediatric maxillofacial surgery department from 2020 to 2023 was performed, including a total of 150 patients. The study was approved by local Medical Ethics Committee at Sant Joan de Déu Barcelona Children's Hospital and was conducted in accordance and adapted to principles for medical research as outlined by the Declaration of Helsinki and its later amendments.

All surgeries were performed in an operating room equipped with a low-dose C-arm cone beam computed tomography (CBCT) machine (Fig. 1). An Azurion 7C20 FlexMove (Philips Medical Systems, Best, The Netherlands) was used to obtain a low-dose ICBCT scan during the surgery. The images obtained were used to assess the accuracy of the surgical plan. Surgeons, radiologists, biomedical engineers and image technicians were involved in this process.

Fig. 1 Operating Room equipped with a low-dose C-arm ICBCT machine

Preoperative steps

Prior to surgery, three different steps were needed. First, all maxillofacial interventions included in the study were virtually planned. Each patient underwent a CT scan, conducted at least 15 days prior to surgery, enabling the preoperative virtual planning process. For the image segmentations, IntelliSpace Portal (Philips) was used. For the surgical planning and 3D design, 3-Matic (Materialise, Leuven, Belgium), Timeus (Ortosan Laboratory, Madrid, Spain) and ProPlan CMF (Materialise, Leuven, Belgium) were used.

Following the surgical planning, the anatomical models (comprising the maxilla, mandible or both, depending on the surgical approach) were printed. These models served multiple purposes: facilitating the adaptation of osteosynthesis material, ensuring the secure placement of surgical guides, and providing a visual reference for delineating precise osteotomy locations.

Finally, prior to the surgery a selection of study points was conducted. These fix points, which will define the superposition between the pre-planning and the intra-operative result, were always defined having as a reference the skull. These study points typically encompass landmarks such as both orbits, the zygomatic arches and nasal bones.

Intra-operative steps

The intra-operative circuit included different steps (Fig. 2):

Fluoroscopy localization This initial step involved calibrating the position of the ICBCT machine by an image technician before the surgery started. Once calibrated, the surgical procedure began.

Intra-operative CBCT acquisition Following the completion of the intervention, an ICBCT acquisition was conducted to assess the achieved outcomes. The C-arm CBCT was positioned taking into account the stretcher position, the anesthesia monitors, lamps and other medical devices such as suction, motor, electric scalpel and piezoelectric scalpel, and then images were acquired.

Importation to PACS Once the ICBCT was acquired, the images were imported into PACS. Simultaneously, a radiological evaluation was conducted by radiologists to verify the position of the screws when necessary.

Segmentation Images were segmented using IntelliSpace Portal (Philips) to obtain the 3D models (in STL format) from

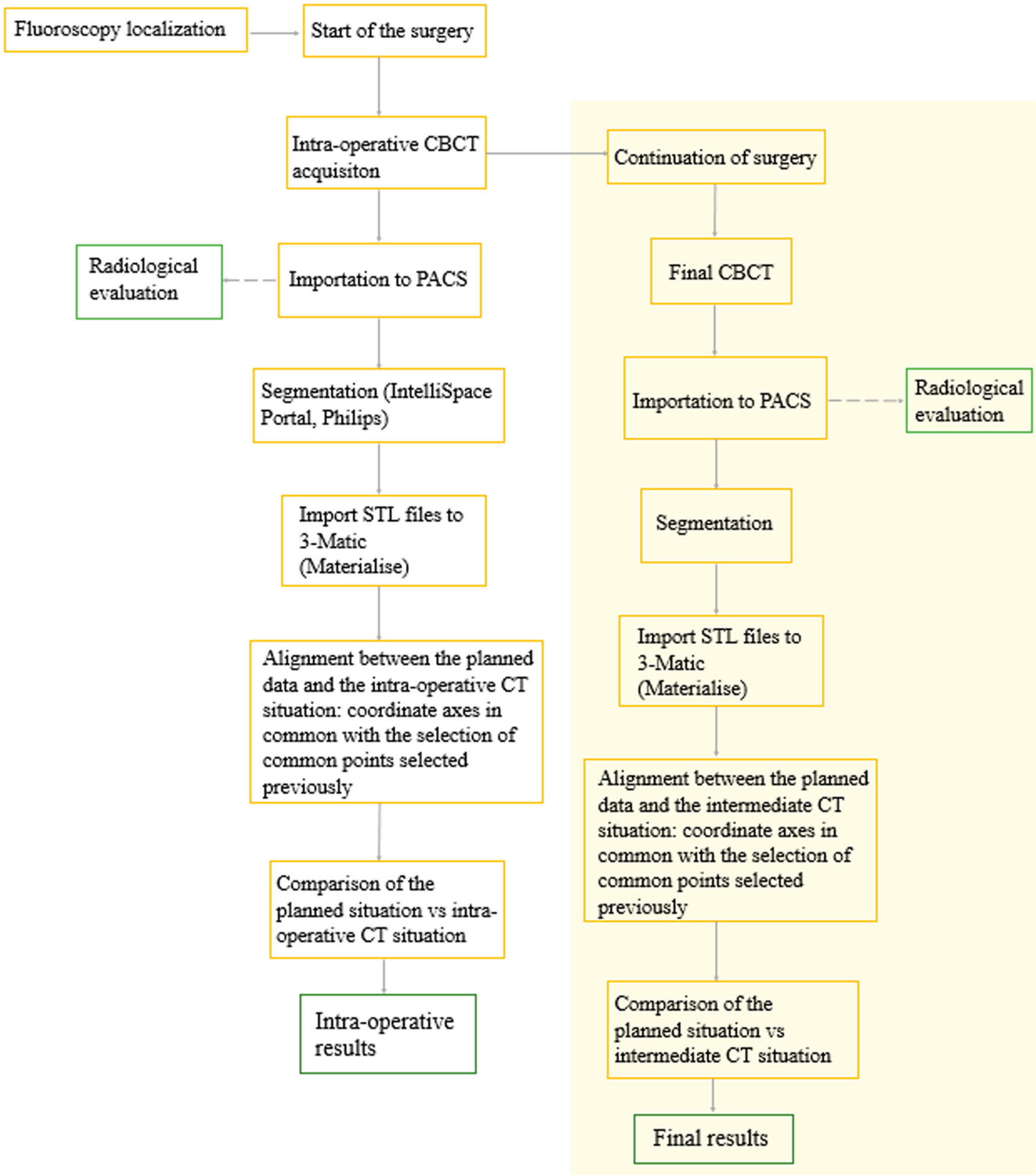

Fig. 2 Intra-operative steps for the comparison of the surgical results using superposition with the previous virtual planning. The steps shadowed in yellow indicate that they were done in complete orthognathic cases (Le Fort I, bilateral BSSO and genioplasty) where there were necessary two CBCT, one intermediate after the reposition of the first maxilla and one at the end of the procedure after bimaxillary surgery and genioplasty

the initial 2D images. Regarding bone segmentation, this was automatically performed.

Import files to 3-Matic The STL files obtained from the segmentation were then imported to 3-Matic (Materialise, Leuven, Belgium) to start the superposition of the models.

Alignment of the 3D virtual models Before the comparison, an alignment between the planned data and the intra-operative results were performed to be superposed; that means that the coordinate axes of both models had to be the same. Alignment was done selecting 3 points in common between the pre-operative 3D model and the intra-operative one using N-points registration. Then, a Global Registration having as a reference the skull was done to minimize the distance between the reconstructions.

Comparison of the superpositions A comparison of the planned situation with the intra-operative situation was

Table 1 Key aspects to compare during the intra-operative superposition in the main interventions

Intervention	Compared aspects
Orthognathic Surgery	Midline, positioning of the condyles, advancement and impaction of the maxilla, occlusion, occlusal plane (canting), positioning of the chin (leveling and advancement)
Maxillary distraction	Osteotomies and positioning of the distractors
Mandibular distraction	Osteotomies and positioning of the distractors
Le Fort III	Osteotomies and positioning of the RED frame distractor
TMJ prosthesis	Positioning of the prosthesis
Mandibular reconstruction	Positioning of the mandible and plates
Condylectomy	Osteotomy and mandibular midline and position

performed using Analysis tools within 3-Matic. Different aspects were compared depending on the intervention. Table 1 shows the aspects compared for the main interventions included in the study.

During the acquisition of ICBCT and intraoperative comparison, in 22 procedures, the total time added to the surgery by this implemented circuit was also measured. Concretely, the analyzed time was:

1. Time needed to prepare, perform and acquire the intra-operative CBCT.
2. Time needed to segment the intra-operative images to obtain the 3D model STL file.
3. Time needed to compare the 3D surfaces of the surgical planning and the surgical result acquired with the intra-operative CBCT.
4. Total time added to the surgery due to the intra-operative superposition.

Evaluation of the results

For each patient, demographic data, surgical procedure type and the need for intra-operative revision based on ICBCT findings was recorded. Surgical revisions were classified into minor and major:

- Minor surgical revision: screw reposition, minor midlines correction (< 2 mm), minor bone remodeling, removing foreign bodies. In these cases, the ICBCT was not repeated.
- Major surgical revision: Surgical correction was performed, followed by a repeat of the ICBCT to verify the outcome. Causes of surgical correction included condylar repositioning, maxillary repositioning, and repositioning of the distractor.

Statistical analysis was carried out using SPSS for Windows (version 15.0.1, SPSS Inc, Chicago, IL). Descriptive statistics were used; numerical data presented as mean SD and categorical variables as frequency (%).

Results

A total of 150 patients were included in the analysis, with a mean patient age of 15.57 years. Among them, there were 88 males and 62 females. In all cases, the entire circuit was fully implemented, allowing surgeons to compare intraoperative results with the desired outcomes planned in the preoperative 3D virtual planning. The majority of patients underwent orthognathic surgery (n = 88). Table 2 displays the revision rates for each procedure.

A total of 26 patients required intra-operative revision after the scans (17.33%). 11 of the patients (7.33%) required a major surgical revision.

Intra-operative comparative analysis was performed in all 150 cases.

The causes of major surgical revision were: (1) orthognathic surgery: maxillary reposition to midline (3 cases) (Fig. 3), condylar malposition (4 cases); (2) costochondral graft: graft malposition into glenoid fossa (1 case); (3) Le Fort III distraction: bilateral ZMC fracture during osteotomy (1 case), levelling of the distractor (1 case) (Fig. 4); (4) TMJ prosthesis: Prosthesis reposition (1 case).

Regarding the minor revisions, the causes were: (1) orthognathic surgery: minor correction of chin position to midline after genioplasty (7 cases), locating a broken burr or a bracket into the maxillary sinus (2 cases), chin reduction (1 case), reposition of bicortical screw (1 case); (2) condylectomy: minor bone remodeling (2 cases); (3) maxillary distraction: locating a broken burr into the maxillary sinus (1 case); (4) mandibular distraction: change of the vector (1 case). None of the patients required a secondary corrective surgery.

Regarding the supplementary time required to execute the procedure, the results have been measured in 22 intra-operative CBCT acquisitions. Outcomes are shown in Table 3.

On average, an additional 10.66 min were required to perform the intra-operative comparison. In some cases, the preparation and acquisition of the ICBCT took longer (up to 10 min) due to the ICBCT scanner colliding with the operating table, so it was necessary to take more time to set it

Table 2 Results of the revision rates for each procedure included in the study

Procedure	Cases (n)	Total revision rate (%)	Major surgical revision (%)	Minor surgical revision (%)
Orthognathic	88	19.32	7.95	12.50
Iliac crest bone graft	12	0	0	0
Oncological and reconstructive surgery	8	0	0	0
Mandibular distraction	8	12.50	0	12.50
Maxillary distraction	5	20.00	0	20
Le Fort III distraction	5	20.00	20.00	0
TMJ Prosthesis	5	20.00	20.00	0
Costochondral Graft	4	25.00	25.00	0
Orbital fracture	4	0	0	0
Condylectomy	3	66.66	0	66.66
Bone remodeling	3	0	0	0
Fronto-orbital advancement	1	0	0	0
Cranioplasty	1	0	0	0
ZMC fracture	1	0	0	0
TMJ ankylosis	1	0	0	0
Premaxilla osteotomy	1	0	0	0

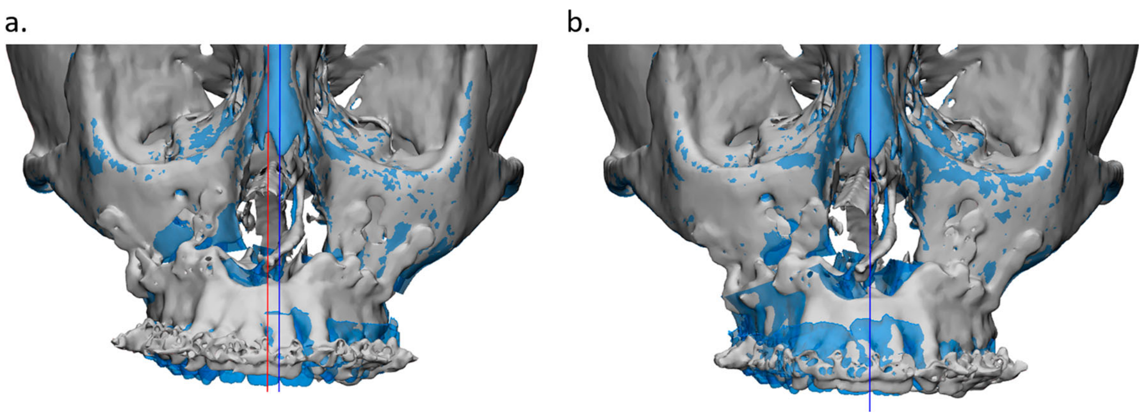

Fig. 3 Intra-operative comparative analysis of an orthognathic surgery case. 3D virtual planned situation (blue) superimposed with the intra-operative result (grey). **a** Intra-operative result of the maxilla after Le Fort I, in which the midline was moved 2.65 mm to right (red line) in comparison with the planned position, **b** result after the revision, in which the maxilla position was corrected to match the 3D virtually planned midline

up. In general, the time needed to segment the images was short because bone was always segmented automatically and the process was fast. Finally, the average duration for performing the intra-operative comparisons was 5.70 min. It is important to note that the time needed to perform the intra-operative comparison varied based on the type of procedure. For instance, orthognathic surgeries involved more factors for comparison compared to condylectomies.

Additionally, in orthognathic surgery, it was necessary to perform two ICBCT scans: one during the intermediate phase (typically after bilateral BSSO if the mandible-first protocol was followed) and another final ICBCT when aligning the maxilla and chin. Consequently, in orthognathic surgery, the overall time added to the procedure was doubled—approximately 10 min for verifying the mandible's position and an additional 10 min for confirming the final positioning of the maxilla and chin.

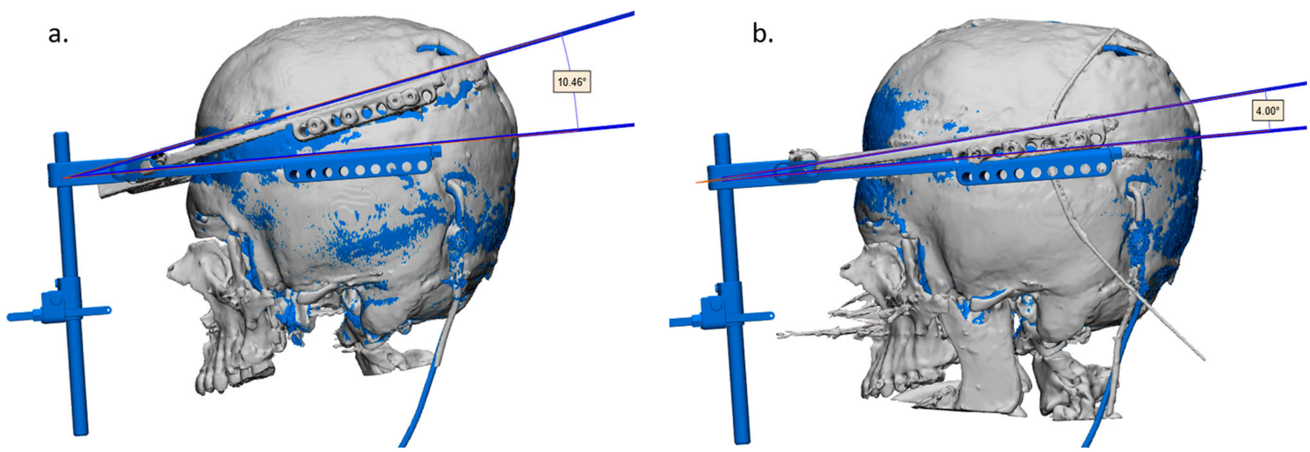

Fig. 4 Intra-operative comparative analysis of the positioning of the RED frame in a case of Le Fort III distraction. 3D virtually planned situation (blue) was superimposed with the intra-operative outcome (grey). **a** Intra-operative result showing a deviation of 10.46° in the position of the distractor in comparison with the 3D virtually planned position, **b** result after the revision, in which the position of the distractor had been corrected to be positioned more accurately to the 3D virtual planned position

Table 3 Results of the time added to the surgery analyzed in 22 cases

	Time of preparation and acquisition of ICBCT (min)	Time needed to segment images (min)	Time needed to perform the intra-operative comparison (min)	Total time added to the surgery (min)
Mean	3.55	1.41	5.70	10.66
SD	2.14	0.39	1.90	3.03
Max	10.00	2.16	8.07	18.50
Min	1.63	0.83	2.15	6.80

Discussion

No guidelines exist in the literature regarding the indications for using intraoperative imaging in the maxillofacial region [16]. However, the main indication for ICBCT reported in the literature was facial trauma surgery [17]. The primary indication for ICBCT in this study was orthognathic surgery, which has not been previously described in the literature. The explanation is that the study was conducted in a pediatric hospital, where the incidence of facial trauma surgery was low. In contrast, the vast majority of patients had underlying cleft lip and palate and other craniofacial syndromes, and therefore underwent orthognathic, craniofacial and reconstructive surgery.

In the present study, the total revision rate was 17.33%, including minor adjustments and refinements. The major revision rate was 7.33%, indicating patients which would have needed secondary surgery. Compared to other studies, this rate was relatively low, likely attributed to the comprehensive protocol employed here, which incorporates 3D virtual surgical planning, 3D model printing, and CAD/CAM customized implants. For instance, Alasraj et al. reported a revision rate of 50% in a retrospective study involving 22 patients with facial fractures [18]. Similarly, other authors described a retrospective study of 71 patients with ZMC fractures, reporting a revision rate of 23.9% [19].

Beyond facial trauma surgery, other indications for ICBCT are described in the literature [17]. Although the use of ICBCT in orthognathic surgery has been limited to date, some publications have reported its usefulness. For instance, Seeberger et al. evaluated the positioning of the proximal condylar segment with high oblique sagittal split osteotomy using ICBCT in 22 patients [11]. In another study, ICBCT was utilized to ensure screw penetration and depth, thereby avoiding injury to the inferior alveolar nerve during bilateral sagittal split osteotomy [20]. However, the authors have developed and implemented an extensive checklist protocol for evaluating ICBCT in maxillomandibular surgery. This protocol helps properly evaluate intraoperative results while reducing the time required for ICBCT assessment.

In the oncological field, ICBCT is utilized for achieving surgical margins accuracy [21] and for reconstruction with custom-made implants. Additionally, it can be valuable in detecting foreign bodies, as reported in patients with gunshot injuries [22]. Similarly, as in our sample, the use of ICBCT in bone remodeling is described [23].

However, to the best of our knowledge, there are no studies describing the use of ICBCT in facial bone distraction. The authors have employed it in several facial osteogenic distraction surgeries to intraoperatively assess osteotomies, screw positions, and distraction vectors. Likewise, there is a lack of literature regarding other indications of ICBCT, such as reconstruction of the temporomandibular joint with prosthesis and iliac crest bone grafts, among others. Nevertheless, the authors believe that ICBCT with superimposed preoperative data is valuable in the aforementioned surgeries for verifying surgical accuracy.

On the one hand, ICBCT presents two main concerns: radiation exposure and additional operative time. Firstly, the radiation dosage for a maxillofacial beam CT scan is approximately 2–5 mSv, while for a CBCT scan, it is around 0.35 mSv [24]. In this study, a low-dose protocol was used, with doses of 0.56 mSv for each CBCT. Additionally, patients who did not undergo an intraoperative CBCT underwent a postoperative CBCT scan for control purposes, with a radiation dose of 1.31 mSv.

Secondly, our results indicate that the ICBCT acquisition time averaged 3.55 ± 2.14 min, with the total added time of implementing the circuit being 10.66 ± 3.03 min. This represents a relatively insignificant amount of extra time. However, it was not possible to measure the time required for the superimposition comparison in all cases included in the study. Other authors using intraoperative CBCT reported scan times of 14.5 ± 4.9 min [25] and 18.9 ± 4.6 min [18].

In summary, based on this study and the reviewed literature, the main advantages of ICBCT include detecting and addressing issues during surgery, thus reducing the need for additional corrective surgeries. It may also potentially reduce the need for extensive surgical approaches due to intraoperative verification of surgical results. Additionally, it provides high-quality bone imaging comparable to conventional CT, with minimal metal artifacts. Moreover, it offers low radiation exposure, and when preoperative data are superimposed, minor adjustments can be made, achieving a higher level of accuracy. On the other hand, the main disadvantages of ICBCT are limitations in soft tissue imaging. Despite low radiation exposure, it is not entirely harmless and may slightly increase operative time. Furthermore, its elevated costs make it challenging to implement the device in many hospitals.

The present study has some limitations that should be considered. Firstly, its single-center design and the varying levels of surgeon experience are factors that may influence the outcomes. The differences in experience among surgeons could introduce bias and potentially affect the reported revision rates in the study. Additionally, including a larger sample size in the analysis of the total time added to the surgery could provide a more accurate representation of the additional time.

Future work will focus on assessing the accuracy of surgical results intraoperatively in orthognathic surgery using patient-specific plates compared to standard plates. This will enable the evaluation of the precision of the results and the utility of the circuit.

Conclusion

The findings from our study highlight the potential for intraoperative revision, enabling immediate assessment and reducing the need for secondary corrective procedures. Our integrated workflow, as demonstrated in this study, has the capacity to improve surgical outcomes and minimize unfavorable results. By addressing errors in real-time, our approach offers a viable solution to reduce the necessity for reinterventions in cases where the surgical outcome deviates from pre-surgical virtual planning.

Author contributions Conceptualization: Núria Adell-Gómez and Andrés García-Piñeiro. Methodology: Núria Adell-Gómez, Marta Gómez-Chiari, Josep Rubio-Palau, Arnau Valls-Esteve and Adaia Valls-Ontañón. Formal analysis and investigation: All authors. Writing—original draft preparation: Núria Adell-Gómez and Andrés García-Piñeiro. Writing—review and editing: Adaia Valls-Ontañón, Lucas Krauel, Arnau Valls-Esteve and Josep Rubio-Palau Supervision: Josep Rubio-Palau.

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Declarations

Conflict of interest Authors declare no conflict of interest.

Ethical approval This study was approved by the Ethics Committee and conducted in compliance with the Helsinki Declaration (Fortaleza, Brazil, October 2013). The informed consent was requested when necessary.

References

1. Rubio-Palau J, Prieto-Gundin A, Cazalla A, Serrano M, Garcia G, Parri F, Rivera A (2016) Three-dimensional planning in craniomaxillofacial surgery. Ann Maxillofac Surg. https://doi.org/10.4103/2231-0746.200322
2. Vercruysse H, Rubio-Palau J, van de Casteele E, Nadjmi N, de Praeter M, Dunaway D (2021) Virtual planning in Le Fort III distraction osteogenesis: a case series. J Cranio-Maxillofac Surg 49(5):341–346. https://doi.org/10.1016/j.jcms.2021.01.011
3. Lee Y-C, Kim S-G (2023) Redefining precision and efficiency in orthognathic surgery through virtual surgical planning and 3D printing: a narrative review. Maxillofac Plast Reconstr Surg 45:42. https://doi.org/10.1186/s40902-023-00409-2

4. Schneider D, Kämmerer PW, Hennig M, Schön G, Thiem DGE, Bschorer R (2019) Customized virtual surgicalplanning in bimaxillaryorthognathicsurgery: a prospectiverandomized trial. Clin Oral Investig 23(7):3115–3122. https://doi.org/10.1007/s00784-018-2732-3
5. Velarde K, Cafino R, Isla A, Ty K, Palmer X-L, Potter L, Nadorra L, Pueblos L, Clark L (2023) Virtual surgical planning in craniomaxillofacial surgery: a structured review. Comput Assist Surgery 28(1):2271160. https://doi.org/10.1080/24699322.2023.2271160
6. Bhuskute KP, Jadhav V, Sharma M, Reche A (2023) Three-dimensional computer-aided design System used in orthodontics and orthognathic surgery for diagnosis and treatment planning—a narrative review. J Clin Diagn Res. https://doi.org/10.7860/JCDR/2023/64570.18710
7. Alhabshi M, Aldhohayan H, BaEissa O, Al Shehri M, Alotaibi N, Almubarak S, Al Ahmari A, Khan H, Alowaimer H (2023) Role of three-dimensional printing in treatment planning for orthognathic suergey: a systematic review. Cureus 15(10):e47979. https://doi.org/10.7759/cureus.47979
8. Brunzini A, Mazzoli A, Pagnoni M, Mandolini M (2023) An innovative mixed reality approach for maxillofacial osteotomies and repositioning. Virtual Real. https://doi.org/10.1007/s10055-023-00867-z
9. Amundson M, Newman M, Cheng A, Khatib B, Cuddy K, Patel A (2020) Three dimensional computer-assisted surgical planning, manufacturing, intraoperative navigation, and computed tomography in maxillofacial trauma. In: Atlas of the oral and maxillofacial surgery clinics of North America, vol 28. W.B. Saunders, Philadelphia, pp 119–127. https://doi.org/10.1016/j.cxom.2020.05.006
10. Wilde F, Schramm A (2014) Intraoperative imaging in orbital and midface reconstruction. Facial Plast Surg 30(5):545–553. https://doi.org/10.1055/s0034-1393700
11. Seeberger R, Thiele OC, Mertens C, Hoffmann J, Engel M (2013) Proximal segment positioning with high oblique sagittal split osteotomy: indications and limits of intraoperative mobile cone-beam computerized tomography. Oral Surg Oral Med Oral Pathol Oral Radiol 115(6):731–736. https://doi.org/10.1016/j.oooo.2012.10.016
12. Alkhayattm NM, Alzahrani HH, Ahmed S, Alotaibi BM, AlsaggafAlamuaysh RMAM, Alomair AA (2023) Computer-assisted navigation in oral and maxillofacial surgery: a systematic review. Saudi Dent J. https://doi.org/10.1016/j.sdentj.2023.12.002
13. Lutz J-C, Hostettler A, Agnus V, Nicolau S, George D, Soler L, Rémond Y (2018) A new software suite in orthognathic surgery: patient specific modeling simualtion and navigation. Surg Innov. https://doi.org/10.1177/1553350618803233
14. Anand M, Panwar S (2021) Role of navigation in oral and maxillofacial surgery: a surgeon's perspectives. Clin Cosmet Investig Dent. https://doi.org/10.2147/CCIDE.S299249
15. Oliveira Andriola F, Haas Junior O, Guijarro-Martínez R, Hernández-Alfaro F, Belle de Oliveira R, Miranda Pagnoncelli R, Swennen G (2022) Computed tomography imaging superimposition protocols to assess outcomes in orthognatic surgery: a systematic review with comprehensive recommendations. Dentomaxillofac Radiol 51:20210340
16. Strong EB, Tollefson TT (2013) Intraoperative use of CT imaging. In: Otolaryngologic clinics of North America, vol 46, Issue 5, pp 719–732. https://doi.org/10.1016/j.otc.2013.07.003
17. Assouline SL, Meyer C, Weber E, Chatelain B, Barrabe A, Sigaux N, Louvrier A (2021) How useful is intraoperative cone beam computed tomography in maxillofacial surgery? An overview of the current literature. In: International journal of oral and maxillofacial surgery, vol 50. Churchill Livingstone, London, pp 198–204. https://doi.org/10.1016/j.ijom.2020.05.006
18. Alasraj A, Alasseri N, Al-Moraissi E (2021) Does intraoperative computed tomography scanning in maxillofacial trauma surgery affect the revision rate? J Oral Maxillofac Surg 79(2):412–419. https://doi.org/10.1016/j.joms.2020.09.025
19. Cuddy K, Dierks EJ, Cheng A, Patel A, Amundson M, Bell RB (2021) Management of zygomaticomaxillary complex fractures utilizing intraoperative 3-dimensional imaging: The ZYGOMAS protocol. J Oral Maxillofac Surg 79(1):177–182. https://doi.org/10.1016/j.joms.2020.08.028
20. Agbaje JO, Salem AS, Lambrichts I, Daems L, Legrand P, Politis C (2016) Intraoperative computed tomography in bilateral sagittal split osteotomy. J Maxillofac Oral Surg 15(4):461–468. https://doi.org/10.1007/s12663-015-0868-0
21. Ivashchenko O, Pouw B, de Witt JK, Koudounarakis E, Nijkamp J, van Veen RLP, Ruers TJM, Karakullukcu BM (2019) Intraoperative verification of resection margins of maxillary malignancies by cone-beam computed tomography. Br J Oral Maxillofac Surg 57(2):174–181. https://doi.org/10.1016/j.bjoms.2019.01.007
22. Gröbe A, Weber C, Schmelzle R, Heiland M, Klatt J, Pohlenz P (2009) The use of navigation (BrainLAB Vector vision2) and intraoperative 3D imaging System (Siemens Arcadis Orbic 3D) in the treatment of gunshot wounds of the maxillofacial region. Oral Maxillofac Surg 13(3):153–158. https://doi.org/10.1007/s10006-009-0166-4
23. Goguet Q, Lee SH, Longis J, Corre P, Bertin H (2019) Intraoperative imaging and navigation with mobile cone-beam CT in maxillofacial surgery. Oral Maxillofac Surg 23(4):487–491. https://doi.org/10.1007/s10006-019-00765-2
24. King E, Daly MJ, Chan H, Bachar G, Dixon BJ, Siewerdsen JH, Irish JC (2013) Intraoperative cone-beam CT for head and neck surgery: feasibility of clinical implementation using a prototype mobile C-arm. Head Neck 35(7):959–967. https://doi.org/10.1002/hed.23060
25. Shaye DA, Tollefson TT, Strong EB (2015) Use of intraoperative computed tomography for maxillofacial reconstructive surgery. JAMA Fac Plast Surg 17(2):113–119. https://doi.org/10.1001/jamafacial.2014.1343