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How useful is intraoperative cone beam computed tomography in maxillofacial surgery? An overview of the current literature

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Abstract. Intraoperative imaging is increasingly used by surgeons and has become an integral part of many surgical procedures. This study was performed to provide an overview of the current literature on the intraoperative use of cone beam computed tomography (CBCT) imaging in maxillofacial surgery. A bibliographic search of PubMed was conducted in March 2020, without time limitation, using ‘‘intraoperative imaging’’ AND ‘‘maxillofacial surgery’’ AND ‘‘cone beam computed tomography’’ as key words. Ninety-one articles were found; after complete reading, 16 articles met the eligibility criteria and were analysed. The results showed that the majority of the indications were related to maxillofacial trauma, particularly zygomaticomaxillary complex fractures. Final verification with intraoperative CBCT before wound closure was the most common use of this device. However, innovative uses of intraoperative CBCT are expanding, such as CBCT coupling with mirror computational planning, and even the combined use of initial intraoperative CBCT acquisition with navigation. Immediate, fast, and easy evaluation of bone repositioning to avoid the need for further surgical revision is the main advantage of this technique. Imaging quality is comparable to that of multi-slice computed tomography, but with lower radiation exposure. Nevertheless, CBCT is still not widely available in maxillofacial centres, probably because of its cost, and perhaps because not everyone is aware of its advantages and versatility, which are reported in this review.

Keywords: cone beam; computed tomography; intraoperative imaging; maxillofacials; urgery; facial skeleton; review.

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The use of intraoperative cone beam computed tomography (CBCT) in maxillofacial surgery has increased greatly since the 2000s[1], but this technology remains unavailable in many hospitals. Due to the complex three-dimensional anatomy (3D) of the facial skeleton, combined with limited surgical access, two-dimensional devices are not ideal for imaging – especially when the orbit is concerned – because of the superimposition of bony structures[1]. Besides, closed treatment is a very common and challenging procedure in maxillofacial surgery, and an adequate and stable reduction is difficult to confirm without a direct view[2].

Intraoperative CBCT has distinct advantages in maxillofacial surgery by generating 3D reconstructions, thereby helping to minimize intra- and postoperative complications[3,4]. Its use has already become widespread in neurosurgery, orthopaedic surgery, and vascular surgery, and CBCT has been shown to have comparable quality to multi-slice computed tomography (MSCT) for high-contrast anatomical structures like bone[1,5]. New applications of intraoperative imaging from CBCT appear promising, such as the association of intraoperative imaging with preoperative data, or combined intraoperative data with computer-assisted surgery[3].

The goal of this study was to evaluate the main current indications for intraoperative CBCT in maxillofacial surgery patients, in particular the advantages and disadvantages when compared to a postoperative MSCT or intraoperative MSCT.

Materials and methods

A bibliographic search of the relevant literature was used to assess the intraoperative use of CBCT in maxillofacial surgery and its benefits. The search was conducted using the electronic database PubMed (National Library of Medicine, NCBI), in order to identify relevant studies published up until March 2020. This current overview of the available literature was performed using the guidelines of the PRISMA statement (Preferred Reporting Items for Systematic Reviews and Meta-Analyses)[6].

A search strategy was developed that combined particular search terms. Term 1 was ‘‘intraoperative imaging’’, term 2 ‘‘maxillofacial surgery’’, and term 3 ‘‘cone beam computed tomography’’. The three terms were joined using the Boolean operator ‘‘AND’’. No date restriction was applied.

All identified studies were loaded into the online Zotero software (Center for History and New Media, George Mason University, Virginia, USA; www.zotero.org) for screening and data extraction. After the removal of duplicates, all titles and abstracts were screened by two reviewers. Next, all full texts of the relevant articles were reviewed by the same reviewers to determine whether they fulfilled the eligibility criteria. The title and abstract screening as well as the full text reviewing were performed independently by the two reviewers. At the end of each stage, disagreements were resolved through discussion and consensus.

Eligibility criteria were set using the PICOS scheme (participants, intervention, comparison, outcome, study design). The inclusion and exclusion criteria are presented in Table 1.

The data extraction from all studies was performed independently by two reviewers. Forms were developed to facilitate data extraction. For each selected article, the publication date, nationality of the authors, number of patients treated, clinical indication(s), use of combined navigation or preoperative planning, and advantages and drawbacks reported by the authors were underlined. After individual data extraction, the forms were reviewed by the two reviewers and a final form was created.

Results

Of the 91 articles found in PubMed using this search strategy, 25 were selected from their abstracts. Complete reading showed that all of them dealt with the intraoperative use of CBCT in maxillofacial surgery. Seventeen met all of the eligibility criteria to allow quantitative synthesis (Fig. 1)[2,4,5,7–18,22,24]. The oldest article dated back to 2004[7], the most recent was published in 2020[8] The majority were published between 2011 and 2015. These articles came from seven different countries. The most represented countries were Germany and Switzerland, with 82% of the articles.

The reported number of surgically treated patients who benefited from intraoperative CBCT varied from three to 125 per article, with an average of 40 patients. The biggest series included 125 patients and the study concerned major mandibular procedures as an indication for intraoperative CBCT[9]. Overall, the studies included a total of 640 patients. Of the 515 patients with age data available, the average age was 32 years (range 3 months to 91 years); age data were not provided for 125 people.

Clinical indications for intraoperative CBCT were placed into eight categories (Fig. 2). One article reported several indications (three categories)[10]. The main indication was zygomaticomaxillary complex (ZMC) fractures, reported in six articles[5,7,8,10,17,18], followed by mandible surgery, reported in three articles[4,9,11]. Other studies dealt with gunshot wounds[12,13], secondary reconstruction of the ZMC[10,14], isolated zygomatic arch fractures (IZAF)[2,22], displaced naso-orbito-ethmoid (NOE) fractures[11], verification of resection margins in maxillary malignancies[15], and the verification of neurostimulator placement in the sphenopalatine ganglion[16].

Concerning the different modes of use (Fig. 3), 11 articles reported the use of intraoperative CBCT for 3D imaging to evaluate the surgical result, before wound closure and without planning or naviga-

Table 1. Eligibility criteria for the studies. Inclusion and exclusion criteria.

Inclusion criteria	
Participants (P)	Human patients of all ages and any sex
Intervention (I)	Intraoperative CBCT
Comparison (C)	Studies assessing intraoperative use of CBCT in maxillofacial surgery
Outcomes (O)	Indications, advantages and disadvantages of intraoperative CBCT use in maxillofacial surgery
Study design (S)	Prospective and retrospective studies
Exclusion criteria	
Intraoperative MSCT	
Postoperative CBCT	
Preoperative CBCT for navigation without intraoperative CBCT control	
Update or literature review	
Ex vivo research	
Single case report	
Language other than French or English	

CBCT, cone beam computed tomography; MSCT multi-slice computed tomography.

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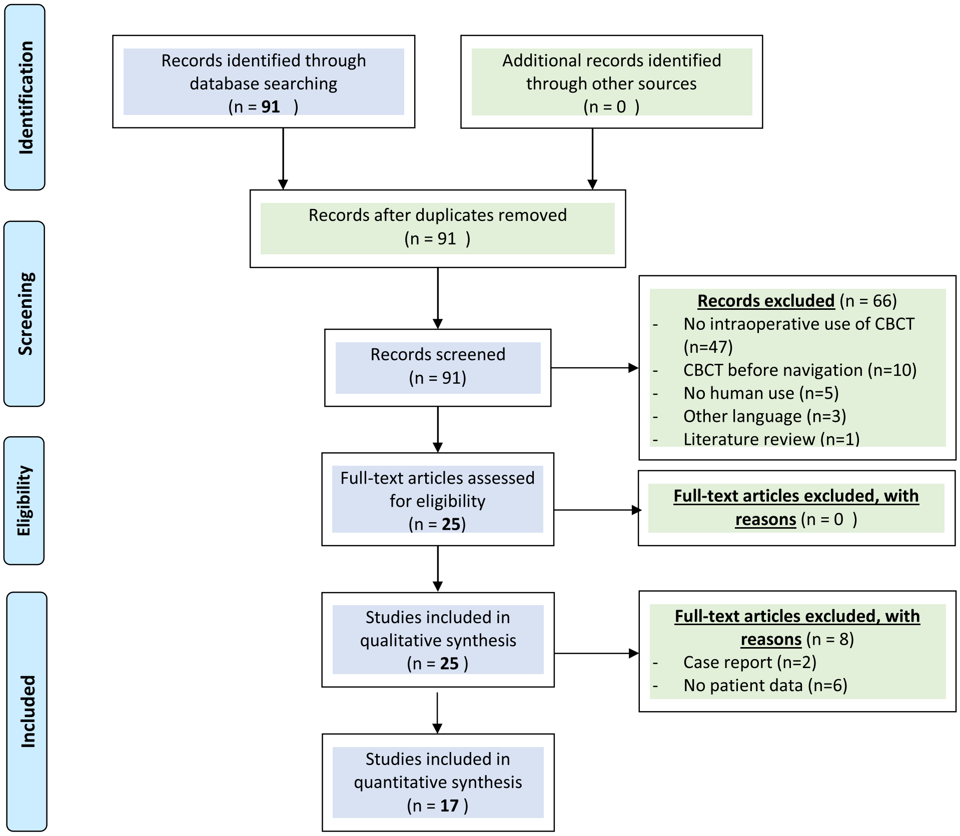

Fig. 1. Flow chart: overview of the selection process according to the PRISMA guidelines.

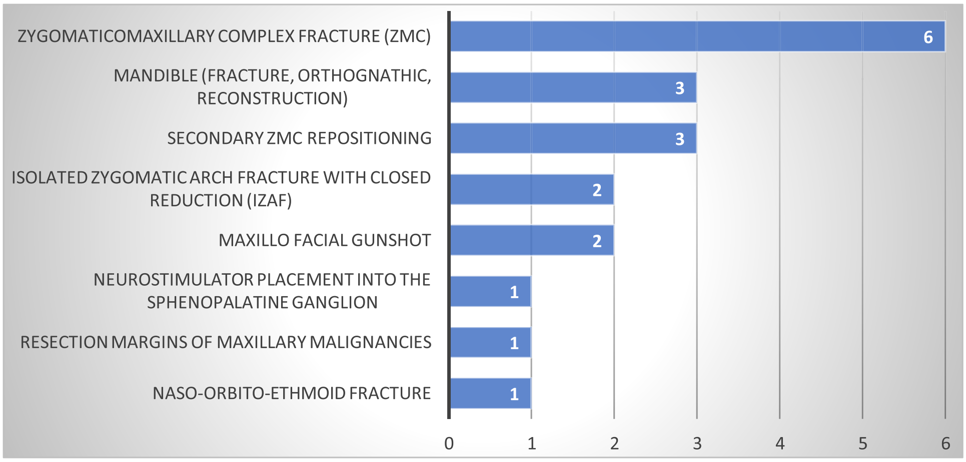

Fig. 2. Number of articles according to the clinical indication for intraoperative CBCT in maxillofacial surgery.

tion[2,4,5,7,8,9,11,14,16,18,22], two articles reported its use as an initial registration tool for navigation[12,13], two articles as a means of verification after use for surgical planning[15,17], one article as a means of verification after use for navigation[12], and one article as a means of verification in surgical planning and navigation[10].

No need for a secondary surgical procedure was reported by the authors who used intraoperative CBCT verification before wound closure, except in one indication: the implantation of a neurostimulator in the sphenopalatine ganglion for patients with drug-refractory cluster headaches. Indeed, all of the intraoperative CBCT scans suggested correct positioning of the stimulator, but immediate postoperative CBCT verification imaging with a higher impedance revealed misplacement in four patients (16.6%). Seven articles with large series reported 11.8% to 29.6% (15.6% average) unsatisfactory bone repositioning or unexpected compli-

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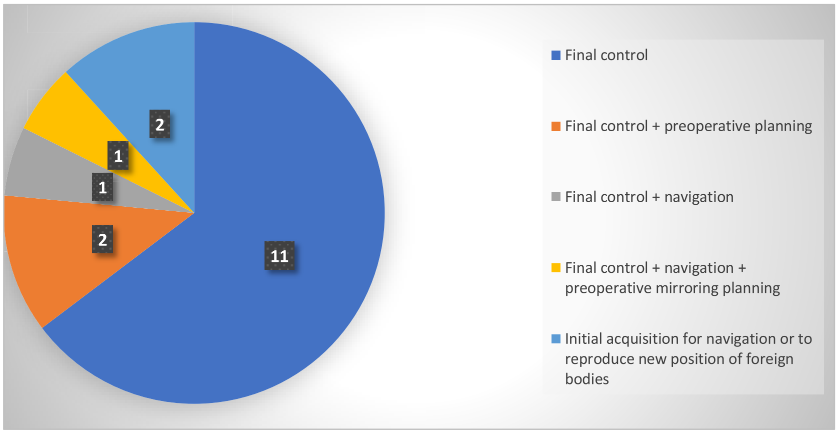

Fig. 3. Number of articles according to the different uses of intraoperative CBCT.

cations detected with intraoperative CBCT, corresponding to 28 patients out of 180, who needed an immediate correction during the same surgical procedure. These cases concerned intraoperative CBCT without navigational assistance for ZMC fractures[5,8,18], IZAF(2,22)[2], surgical management of condylar fractures[4], and orthognathic surgery[11] (Fig. 4). In the two gunshot facial trauma series, initial intraoperative CBCT indicated the new positions of displaced projectiles and helped the surgeons to remove foreign bodies without complications in all cases. Final verification before closure confirmed the absence of foreign bodies.

Three studies assessed the quality of intraoperative CBCT datasets as suitable for the visualization of the facial bones after the reduction of fractures, eliminating the need for additional radiographic verification after surgery[1,10,18].

The main advantages reported by the teams using intraoperative CBCT were (1) immediate and rapid evaluation of the adequacy of bone repositioning; (2) avoidance of further surgical revisions, which entail additional costs and increased morbidity; (3) ease of handling; (4) elimination of the need for radiographic technicians; (5) radiation dose reduction of 50% compared with MSCT; (6) elimination of radiographic verification after surgery; (7) lower level of metal artefacts; (8) quality comparable to MSCT for the facial skeleton; (9) average examination time faster than intraoperative MSCT (10 minutes vs 30 minutes); and (10) lower costs than with mobile MSCT.

The main drawbacks were (1) limitations for soft tissue imaging: visualization but no assessment possible; (2) lower resolution in comparison with fixed CBCT; (3) restricted field of view; (4) increased operative time; (5) radiation exposure; (6) cost: extra time in the operating room, extra exposure to anaesthesia, and the cost of the device and its maintenance; and (7) interpretation difficulties of thin osseous structures.

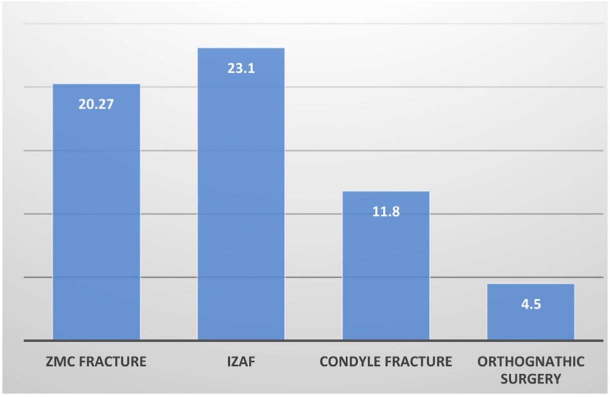

Fig. 4. Percentage of patients undergoing immediate surgical correction after intraoperative CBCT, according to the clinical indication. (ZMC, zygomaticomaxillary complex; IZAF, isolated zygomatic arch fracture.)

Discussion

Intraoperative CBCT was used in two-thirds of the cases to verify the surgical site before wound closure in maxillofacial surgery. The main indications for this single intraoperative CBCT use were predominantly facial traumas, and the first and most studied fracture was the ZMC fracture (Fig. 2).

The ZMC fracture is a very common fracture in maxillofacial surgery, but aesthetics and anatomical requirements prevent direct visualization and make it difficult to confirm that an adequate reduction and osteosynthesis have been achieved[2,3]. Intraoperative 3D CBCT has been shown to significantly reduce the need for reoperation, especially in patients suffering from comminution of the bony buttresses[17]. Comminution is significantly associated with the need for intraoperative revision[8,17], and swelling or distorted anatomical landmarks constitute a risk of ZMC fracture and/or NOE fracture malpositioning, with the need for challenging revisional procedures if intraoperative CBCT is not performed. In addition, this intraoperative procedure prevents unnecessary orbital reconstruction after ZMC reduction, and conversely shows if orbital reconstruction is necessary after ZMC reconstruction[1,17]. Intraoperative CBCT makes it possible to perfectly visualize the positioning of the orbital reconstruction plate. Additional approaches can also be avoided in many cases. After the failure of conventional techniques, secondary ZMC repositioning with intraoperative CBCT has been shown to be successful, with no patients needing additional procedures[14].

Concerning mandible procedures, surgery for condylar fractures entails a limited surgical approach and therefore a restricted view, while requiring precise reduction to allow optimal occlusion and temporomandibular joint (TMJ) function. Intraoperative CBCT allows the location of fixation screws to be visualized, thereby avoiding damage to the inferior alveolar nerve and misplacement in the TMJ[4]. Two studies used intraoperative CBCT to check the lingual cortical bones and screw positions in body and angle fracture cases[8,9]. Intraoperative CBCT was used to verify mandibular reconstruction in one series[9].

In orthognathic surgery, new positioning of the proximal segment after high oblique sagittal split osteotomy (HSSO) was found to lead to a change in the

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position of the condyle[11]. This change was measured by Seeberger et al. in a prospective study[11], and whatever the type of mandibular movement, there was an increase of 0.31 mm in the intercondylar distance in all patients, and a slight opening rotation of less than 1° after HSSO osteosynthesis. In one case with maxillary impaction, revision was required because of a lateral shifting of the condyles. It is known that if the intercondylar distance increase exceeds 1 mm, the impact on the TMJ is significant. Therefore, intraoperative CBCT could be useful in difficult maxillomandibular surgery cases, including maxillary cranial impaction.

Non-comminuted IZAF were studied in a prospective randomized trial, which showed no significant difference between the group with intraoperative imaging and the group without this imaging concerning the need for a second surgery[2].

Therefore, the main indications for intraoperative 3D CBCT as a final control are displaced and especially comminuted ZMC fractures, pan-facial fractures with loss of clinical anatomical landmarks, and maxillary impaction associated with HSSO in orthognathic surgery.

Several case reports have dealt with intraoperative CBCT in maxillofacial surgery. One of these studied a sinus floor augmentation procedure to verify the integrity of the sinus membrane and sufficient volume for later implant insertion[19]. The use of intraoperative CBCT combined with navigation and preoperative planning has also been described in the bone resection of facial fibrous dysplasia and TMJ ankylosis[20].

New applications combining intraoperative CBCT and new technologies in maxillofacial surgery are already being used. Mirroring computational planning can be used in complex ZMC fractures in order to reduce both the malpositioning and orbital volume divergence that may occur, which may result in asymmetry, mouth-opening disorders, eyeball malpositioning, and diplopia. Mirroring is built preoperatively from the non- affected zygoma and orbit, to define the ideal postoperative positioning of the affected side. So, the superimposition of 3D CBCT data over the preoperative data allows optimal repositioning to be determined. Mirroring enables more precise reduction and orbital floor restoration, because a discrepancy exceeding 2 mm is considered to be clinically relevant and requires immediate revisional surgery[10,17].

Concerning the combined use of intraoperative CBCT and navigation, the main indication is maxillofacial surgery for gunshot wounds. CBCT can be used at the beginning and/or at the end of the surgical procedure for conventional verification. Navigation surgery can be performed from the initial intraoperative CBCT datasets, in order to reproduce the new position of projectiles that are displaced intraoperatively in specific localizations, such as the maxillary sinus, temporal region, and orbit. Some circumstances indicate the need for navigation: the failure of previous attempts to remove a projectile or foreign body, the presence of multiple foreign bodies, and the presence of at-risk structures close to the foreign body or in the path of surgical access to the foreign body. In all cases reviewed in this study, foreign bodies were found and removed uneventfully, with minimally invasive surgery[12],[13].

Based on this overview of the current literature, we can assess the advantages and disadvantages of intraoperative CBCT compared with postoperative or intraoperative MSCT. Concerning the medical aspects, the primary benefit of this procedure is that it enables the surgeon to react immediately in the operating room when intraoperative images show inadequate fracture reduction or improper placement of implant material. A shaded surface display and also multiplanar reconstructions can be generated intraoperatively with the use of the software described earlier as being of value for the evaluation of midfacial fractures. Most of the authors mentioned a decrease in morbidity for these patients. So every procedure can be completed as minimally invasively as possible with minimized visible scarring, and the risk of damage to the surrounding anatomical structures is also reduced[10,18].

Concerning the technical aspects, C-arm CBCT was considered easy to use by all of the authors, and the device requires less space than mobile MSCT. Additional time was reported for the sterile coverage of the patient and the set-up of the C-arm CBCT in the room, as well as for reading the images, which takes an average of 15 minutes, ranging from 8 to 30 minutes per case, depending on the experience of the surgeon and the operating room staff [14].

Regarding the quality of the images, it has been proven that intraoperative 3D imaging with a 3D C-arm CBCT system can image high-contrast structures such as bone with quality comparable to that of MSCT, even in close proximity to implant material[1,10,18]. Furthermore, the low level of metal artefacts with CBCT improves the quality of image assessment and enables the surgeon to localize metallic foreign bodies[1],[7],[9],[12],[18].

Finally and of importance, radiation exposure is a key criterion when considering the choice of imaging procedures, particularly in the paediatric population. As reported in the literature, intraoperative CBCT requires a radiation exposure of an equivalent average dose of approximately 25 mSv for a low-dose protocol, which is similar to four conventional X-rays. A low-dose protocol was used by all of the authors quoted in this overview. This represents a radiation dose reduction of 50% compared to MSCT[1],[7],[10],[18],[21]. As the difference between conventional X-rays and intraoperative CBCT is low, there is no extra exposure for patients who undergo intraoperative CBCT, because they do not need additional postoperative MSCT or conventional radiography[18].

As well as medical aspects, economic aspects must also be taken into consideration. When no second or third approach is required, the time from incision to suture can be reduced substantially, the implant cost can be decreased, and the operating room costs too. Furthermore, mobile CBCT is less expensive than mobile MSCT, and the presence of radiology staff is not mandatory during the examination.

Concerning the drawbacks, the soft tissues are visualized, but information about the quality of the soft tissue cannot be obtained. This implies the need for MSCT before surgery in the case of neurological or other injuries. Image quality and resolution also differ according to the type of device: images from mobile CBCT show lower resolution and a smaller volume compared to fixed systems. Unsatisfactory results in regards to the use of intraoperative CBCT to verify neurostimulator placement in the sphenopalatine ganglion could probably be explained by this insufficient soft tissue resolution and the higher quality obtained with a fixed CBCT for postoperative verification[16]. Only two authors considered that thin osseous bone structures are more difficult to interpret on mobile CBCT compared to stable CBCT or mobile MSCT[16,18].

One of the biggest challenges to the improvement of the efficiency of mobile CBCT is increasing the field of view. Indeed, current 3D C-arm CBCT can achieve 3D image volumes of approximately 12 cm × 12 cm × 12 cm, which means that it is difficult to cover the complete facial skeleton in one rotation. However, none of the authors had to perform additional dataset acquisitions to analyse the area of interest. Some authors regard this limited image volume as a disadvantage in the reconstruction of the facial skeleton, as it hinders or prevents

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Table 2. Isocentre depending on the anatomical region studied, to help laser light positioning before intraoperative CBCT acquisition.

Anatomical region studied	Isocentre
IZAF	45° angle with regard to the zygomatic arch on the fracture side
Condyle	1 cm before the tragus of the ear on the trauma side
ZMC	Level of the sinus floor, paranasal to the side of the fracture or median in cases of bilateral fractures
Full mandible	Anterior nasal spine
Mandible angle	Near tooth 17 or 27
Orthognathic maxillomandibular	Just caudal to the posterior border of the hard palate

IZAF, isolated zygomatic arch fracture; ZMC, zygomaticomaxillary complex.

comparisons between the affected and unaffected sides, such as in IZAF and orbital wall or ZMC fractures[18,19]. In contrast, other authors think that this is only partially true because today suitable software allows the dataset generated intraoperatively by the 3D C-arm device to be easily merged with the preoperative diagnostic CT dataset. Accordingly, the affected and unaffected sides can be compared completely[1,6,10,17]. The field of view is becoming larger with the new generation of mobile CBCT scanners, and imaging of the entire skull can be provided in one rotation if the flat panel sensor width is at least 25 cm. However, the possibility of adjusting the field of view to individual requirements is desirable, as this could further reduce the patients' exposure to radiation. Meanwhile, the region of interest to be imaged should be positioned with a laser light at the isocentre. The isocentre is different according to the localization of the region of interest, and this was described by each author to help centring (Table 2).

Radiation exposure from intraoperative CBCT is low, but still remains a problem. The surgeon must perform a risk–benefit analysis and attempt to limit the intraoperative scanning of adult patients with complex reconstructive needs related to trauma or tumour extirpation. The paediatric population has to be spared from radiation as much as possible. Another dilemma faced is if the initial repair is judged inadequate after a first intraoperative CBCT. Once the reduction is revised, the surgeon must decide whether to perform a second CBCT to verify the reduction or avoid this and assume that the reduction is adequate[21]. Some authors repeated the procedure up to four times, but on average 1.3 operative CBCT scans were performed in each patient, and the number of CBCT scans was significantly correlated with the complexity of the trauma[8,22]. When further revision is needed with additional CBCT, the extra anaesthesia, radiation exposure, and operating time will increase morbidity and the cost of the procedure. So it can become prohibitive if multiple datasets are needed for a given procedure[14]. Unfortunately, the cost of the mobile CBCT device remains an obstacle and this might explain why, in spite of promising results, intraoperative CBCT in maxillofacial surgery has not gained broad acceptance to date. However, a mobile CBCT for maxillofacial surgery use can be shared with several surgical teams, such as orthopaedic surgeons and neurosurgeons, thus improving the return on the investment.

In conclusion, intraoperative CBCT is relatively new but is playing an increasingly important role in computer-assisted surgery of the facial skeleton. The main indication is maxillofacial trauma, with a success rate of close to 100% achieved in the first operation, reducing the need for a second intervention and thus decreasing morbidity. Many authors now consider that postoperative MSCT or CBCT imaging with 3D volume rendering should be mandatory for midfacial fractures with orbital wall involvement. The results suggest that if intraoperative CBCT is available, additional postoperative imaging is not necessary. Intraoperative CBCT has many advantages, but cost concerns, additional anaesthesia, and radiation exposure should limit its use to patients with distorted anatomical landmarks, pan-facial fractures, and those undergoing revisional repairs. The combination of intraoperative CBCT with mirroring and navigation is opening up new avenues in intraoperative imaging for major and complex maxillofacial surgery procedures. Its use improves the quality of care and might reduce long-term costs. We recommend that surgeons consider the use of intraoperative CBCT imaging in maxillofacial reconstructive surgery, particularly in complex cases.

Patient consent

Exemption: systematic review.

Funding

None.

Ethical approval

Exemption: systematic review.

Competing interests

None.

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