

# Zygomaticomaxillary complex fracture repair with intraoperative CBCT imaging. A prospective cohort study

W.M.M.T. van Hout, W.W.B. de Kort, T.C. ten Harkel, E.M. Van Cann\*, A.J.W.P. Rosenberg

Department of Oral and Maxillofacial Surgery, University Medical Center Utrecht, Heidelberglaan 100, 3584 CX Utrecht, PO Box 85500, the Netherlands

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## ABSTRACT

The aim of this study was to evaluate the value of intraoperative conebeam computed tomography (CBCT) imaging in the treatment of zygomaticomaxillary complex (ZMC) fractures.

A prospective single center cohort study was performed. Included were consecutive patients who underwent surgery for a unilateral ZMC fracture. An intraoperative CBCT scan was performed after reduction of the ZMC fracture. Revision reduction was performed of the ZMC and/or orbital floor (OF) on indication. The preoperative and postoperative asymmetry of the outer surface of the ZMC was measured on digital 3D-models of CBCT scans, using a mirroring and surface-based matching technique. The postoperative asymmetry of the ZMC in the study group was compared to the asymmetry of the ZMC in the control group with healthy individuals.

A total of 38 patients with a unilateral ZMC fracture were included. The mean postoperative asymmetry in the study group (1.67 mm, SD 0.89) was less than the mean preoperative asymmetry (2.69 mm, SD 0.95) (paired samples T-test  $p < 0.01$ ) but showed no statistically significant difference with the mean asymmetry in the healthy control group (1.40 mm, SD 0.54) (independent samples T-test  $p = 0.31$ ). Revision reduction of the ZMC and/or OF fracture had been performed in 11 cases after malalignment was noted on the intraoperative CBCT. The indication for intraoperative revision reduction was associated with comminuted ZMC fractures and/or fractures with indication for OF reduction (Pearson Chi Square  $p < 0.01$ ).

Within the limitations of the study, intraoperative CBCT imaging seemed to have a positive influence on ZMC fracture treatment, especially in the case of comminuted ZMC fractures and/or fractures with indication for OF treatment.

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## Introduction

Zygomaticomaxillary complex (ZMC) fractures are common fractures in maxillofacial trauma patients (Boffano et al., 2015; Van Hout et al., 2013). Treatment of ZMC fractures can be challenging, as anatomic reduction must be achieved to accomplish restoration of facial symmetry and aesthetics (Van Hout et al., 2016; Zingg et al., 1992). Facial symmetry is not always reached in one surgical session and can require a secondary surgical intervention. A retrospective cohort study showed that secondary surgical interventions were necessary in 9% of all ZMC fractures and in 21% of the

comminuted ZMC fractures (Van Hout et al., 2016). Intraoperative computed tomography (CT) imaging allows for immediate on-table assessment and revision of ZMC position and orbital floor (OF) treatment in case of malalignment (Olivetto et al., 2020). A treatment algorithm with routine intraoperative CT imaging might reduce the number of secondary surgical interventions (Ellis and Perez, 2014). A literature review showed that intraoperative imaging and early recognition of malposition of the ZMC or OF resulted in revised reduction of the ZMC and/or orbital floor fracture in 22% (Van Hout et al., 2014).

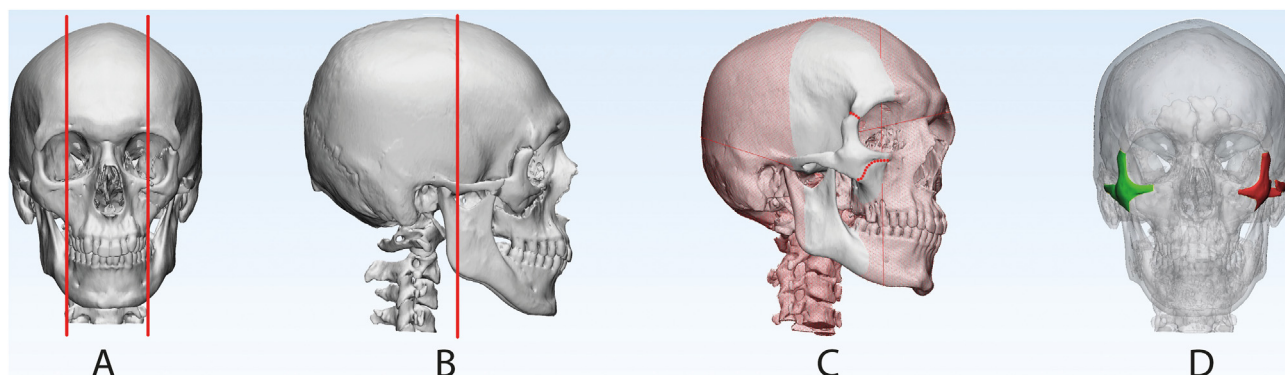
Intraoperative imaging with cone beam computed tomography (CBCT) is part of the treatment algorithm for ZMC fractures that need surgery in the University Medical Center of Utrecht in the Netherlands since 2015. However, intraoperative imaging takes time in the operation room and exposes the patient to radiation.

\* Corresponding author. Department of Oral and Maxillofacial Surgery, University Medical Center Utrecht, PO Box 85500, 3508 GA Utrecht, the Netherlands.

E-mail address: [e.m.vancann@umcutrecht.nl](mailto:e.m.vancann@umcutrecht.nl) (E.M. Van Cann).



**Fig. 1.** The C-arm CBCT scanner in use in the operating room. The C-arm rotates around the patient to obtain the CBCT scan.

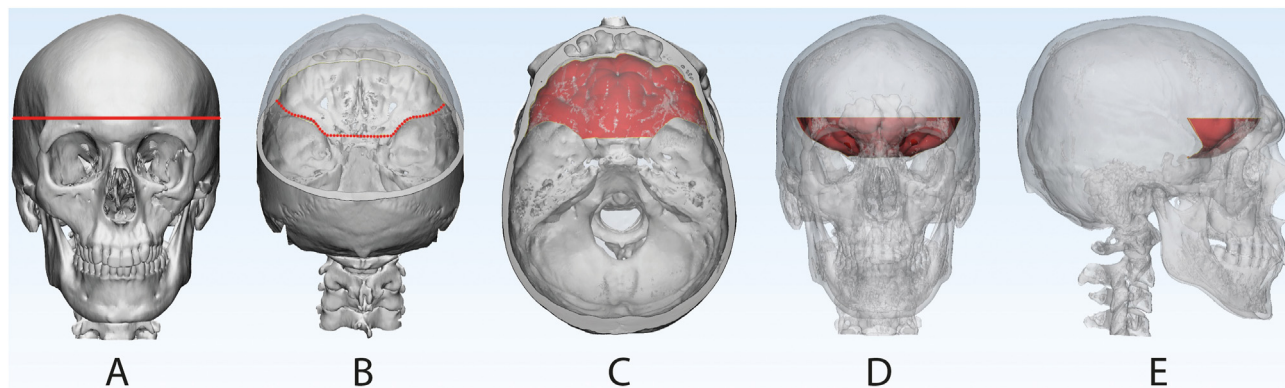


**Fig. 2.** Anatomic landmarks and boundaries used for isolating the zygomaticomaxillary complex (ZMC) surface. A: Orbital midline. B: Articular eminence. C: Frontozygomatic and maxillozygomatic suture. D: The isolated ZMC surface on the healthy (green) and fractured (red) side.

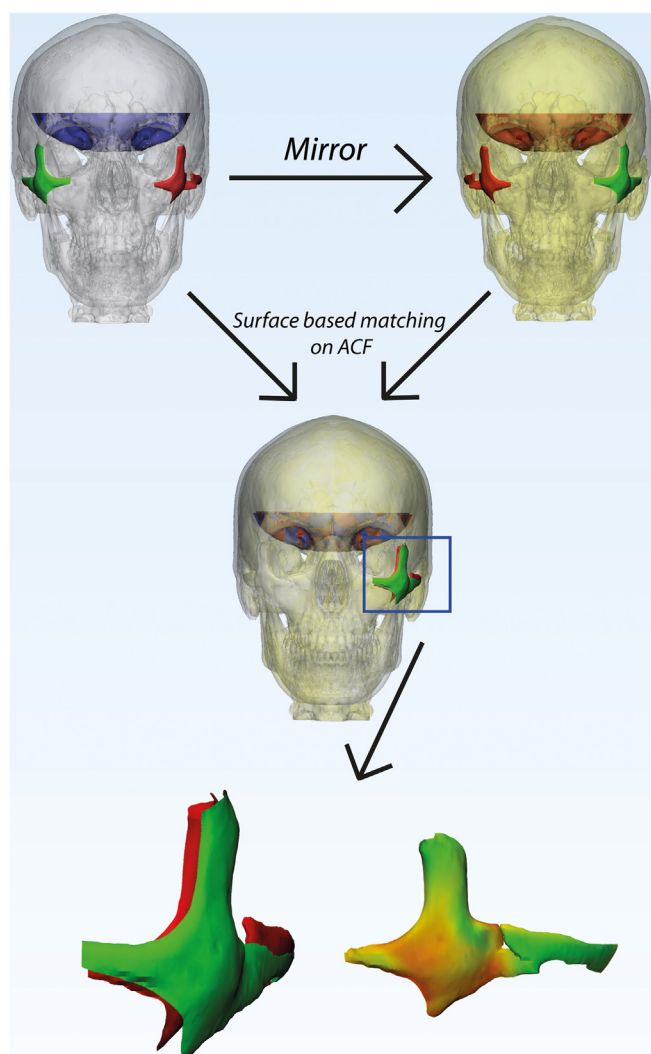
Therefore this study was undertaken to determine in which ZMC fractures intraoperative CBCT imaging is of particular value.

The aim of this study was to assess the added value and effect of intraoperative CBCT imaging on the treatment of ZMC fractures,

and to identify which type of ZMC fractures might benefit from intraoperative CBCT imaging.



**Fig. 3.** Anatomic landmarks and boundaries used for isolating the anterior cranial fossa (ACF) surface. A: Plane 1 cm above the supraorbital rim parallel to the Frankfurt horizontal plane. B: Posterior rim of the anterior cranial fossa. C, D and E: cranial, anterior and lateral view of the isolated ACF.



**Fig. 4.** Method for measuring zygomaticomaxillary complex (ZMC) asymmetry.

## Materials and methods

The approval of this study was waived by the institutional medical ethical commission (reference number WAG/om/15/028782). A prospective single cohort study was designed in accordance with

the STROBE guidelines for reporting observational studies (Von Elm et al., 2008).

### Study population

From September 1, 2015, till October 31, 2017, all consecutive patients aged 18 years and older with a dislocated ZMC fracture eligible for surgical treatment were included. Exclusion criteria were bilateral ZMC fractures, patients with Le Fort II or III fractures, and mentally disabled patients. Formal written consent was obtained from each patient for participation in the study.

### Control group

Fifteen adult trauma patients who had a CT scan that did not show maxillofacial fractures or other forms of acquired or congenital maxillofacial disorders were selected to serve as healthy controls.

### Treatment protocol

Surgical treatment was performed under general anaesthesia. Closed reduction of the ZMC without fixation was performed if there was no indication for exploration of the OF, i.e., no diplopia, OF fracture without dislocation, flat inferior rectus muscle on coronal planes of the preoperative CT scan, or OF defect <50% of the OF.

Open reduction and internal fixation at the lateral orbital rim and/or the zygomatico-alveolar crest was performed in fractures that required OF treatment, comminuted ZMC fractures, and fractures that proved unstable after closed reduction. Further surgical exposure for addition internal fixation of the ZMC was done on indication.

Primary OF exploration was performed for OF defect >50% of the OF, loss of the key-area, significant herniation of orbital contents into the maxillary sinus, inferior rectus muscle impingement, or rounded inferior rectus muscle on coronal planes of the CT scan.

If reduction of the ZMC fracture was expected to realign a significantly disrupted OF fracture, the intraoperative CBCT scan was performed after ZMC fracture reduction to reassess the indication for OF treatment.

After the initial surgical treatment, the intraoperative CBCT scan was recorded (BV Pulsera 12" with 3DRX, Philips Healthcare, Best, the Netherlands) (Fig. 1). Axial, coronal and sagittal slices, and a 3D-reconstruction were visible on the console of the CBCT for assessment of the ZMC and OF by the surgeon.



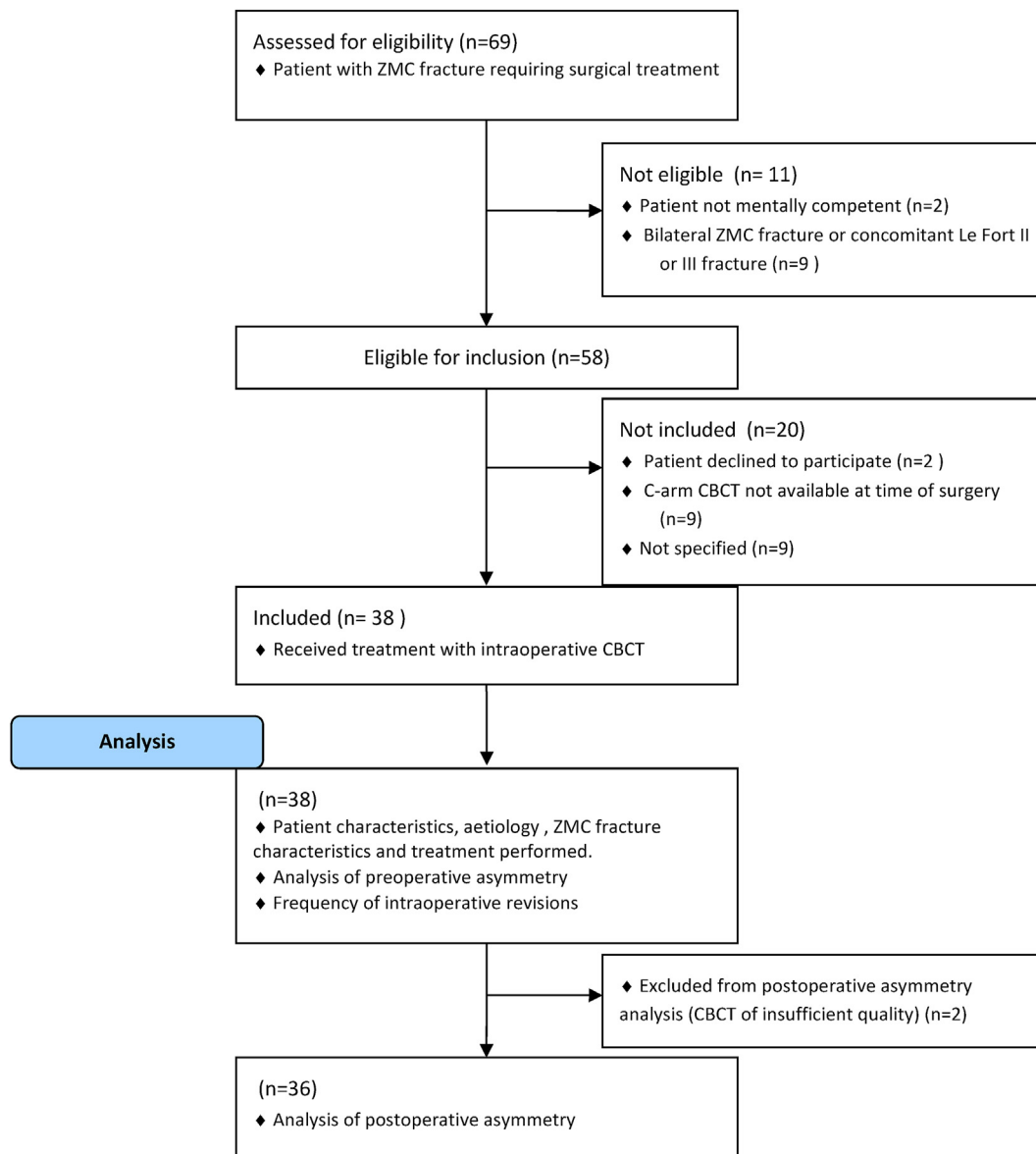


Fig. 5. Study flow chart.

In case of insufficient ZMC fracture reduction after the initial treatment, revision reduction of the ZMC was performed. Criteria for immediate revision were as follows: malalignment of fractured segments, and asymmetry in antero-posterior, medio-lateral or cranio-caudal position of the ZMC compared to the non-fractured side.

In case of insufficient OF treatment after the initial treatment, revision treatment of the OF was performed. Criteria for immediate revision were orbital floor implant not following orbital contour, and orbital floor implant not on the posterior orbital ledge.

After a revision reduction, a second intraoperative CBCT scan was recorded and assessed.

Surgery was performed by one of eight staff surgeons with one of six residents.

#### Analysis of accuracy of ZMC fracture reduction

Accuracy of ZMC fracture reduction was assessed by comparing the postoperative ZMC asymmetry to the preoperative ZMC

asymmetry and to the ZMC asymmetry in the healthy control group.

#### Analysis of ZMC asymmetry

The Digital Imaging and Communications in Medicine (DICOM) files were imported in Mimics Medical (version 20.0; Materialise, Leuven, Belgium). A virtual 3D model was created and transferred into 3-Matic Medical (version 12.0, Materialise, Leuven, Belgium).

The outer surfaces of the fractured ZMC, intact contralateral ZMC and the anterior cranial fossa (ACF) were selected in a standardized manner (Figs. 2 and 3). Then the entire 3D model, including both ZMC and the ACF surfaces, was duplicated in mirror-image.

The mirror-image 3D model was superimposed with the original 3D model, by aligning the mirror-image ACF surface with the original ACF surface. First, the mirrored ACF was matched with the original ACF by indicating 5 points on both objects. Then surface based matching was performed to find the best fit between the two surfaces, using an iterative closest point algorithm.

**Table 1**  
Patient characteristics, aetiology, ZMC fracture characteristics and treatment performed.

	All patients (n = 38)
<i>Patient characteristics</i>	
Mean age	43
Male-to-female ratio	25:13
Other maxillofacial fractures	8
Dental injuries	3
Ophthalmic injuries	1
Other injuries (non-maxillofacial)	14
<i>Aetiology</i>	
Traffic accident	18
Interpersonal violence	7
Sports accident	3
Fall from height	3
Work-related accident	3
Stumbling	2
Animal related accident	2
<i>ZMC fracture characteristics</i>	
Left-right distribution	24:14
Comminuted ZMC fracture	7
Non-comminuted ZMC fracture	31
Primary indication for OF treatment	6
<i>Treatment performed</i>	
Closed reduction, no OF treatment	15
ORIF, no OF treatment	19
ORIF, with OF treatment	4

ORIF: Open reduction and internal fixation.

During the alignment of the mirrored ACF with the original ACF, the 3D spatial relation between the mirrored ACF and the rest of the mirror-image 3D model (including the mirror-image of the intact contralateral ZMC-surface) was preserved. As a consequence, the mirror-image of the intact contralateral ZMC was positioned at the site of the fractured ZMC, in the symmetrical position (Fig. 4).

The surface distance analysis between the original fractured ZMC surface and the mirror-image of the intact contralateral ZMC surface was then carried out. The shortest distance in millimeters was calculated from 2.67 points/mm<sup>2</sup> on the fractured ZMC, to the surface of the intact contralateral mirrored ZMC. The mean surface distance (MSD) between these surfaces served as a measure for ZMC asymmetry.

*Rate of immediate revision reductions and rate of secondary surgical interventions*

Immediate revision of ZMC position, OF treatment, and “other revision” were registered directly after the surgery.

The medical records of the included patients were reviewed 2 years after the closure of inclusion. Secondary surgical interventions such as revision reduction of ZMC or OF in a separate surgery, secondary orbital floor reconstructions, zygomatic osteotomies, soft-tissue corrections, extraocular muscle corrections and other types of secondary surgical interventions relating to the ZMC fracture were screened for, and recorded and analyzed if they had occurred.

*Statistical analysis*

Statistical analysis was performed with IBM SPSS Statistics for Windows Version 25.0.0.2 (IBM Corp., Armonk, NY, USA). Probabilities of 0.05 and less were accepted as statistically significant.

The Pearson  $\chi^2$  test was used to determine the association of revision reductions with fracture categories.

The data on asymmetry of the ZMC was unsigned and therefore skewed. The skewness was corrected for by log-transformation. An independent-samples T-test was performed to test for differences in mean logMSD between groups. A paired-samples T-test was performed to test for differences in mean logMSD before and after intervention in the same group.

**Results**

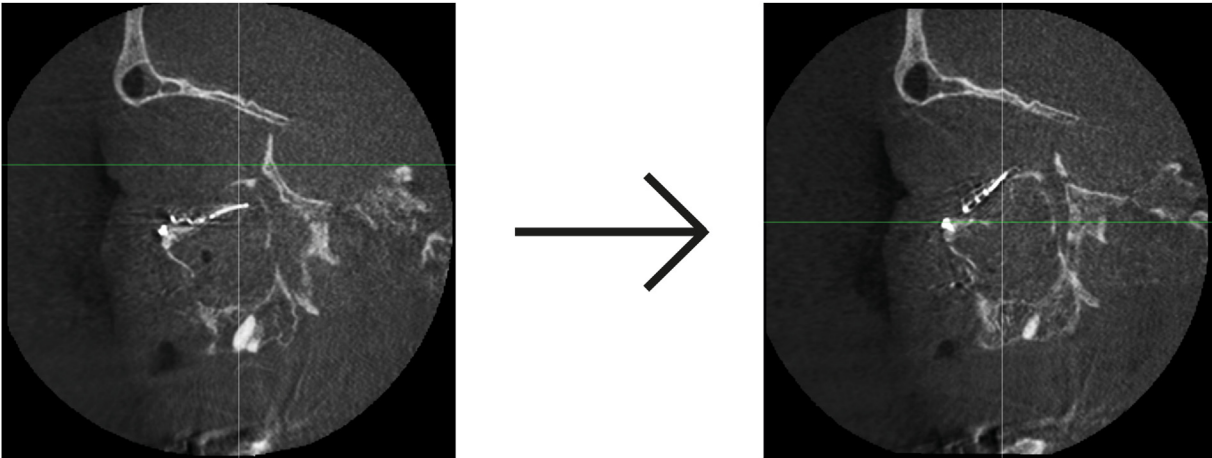
A total of 38 patients were included in the study. The study flow chart describing patient inclusion is provided in Fig. 5.

*Patient and fracture characteristics*

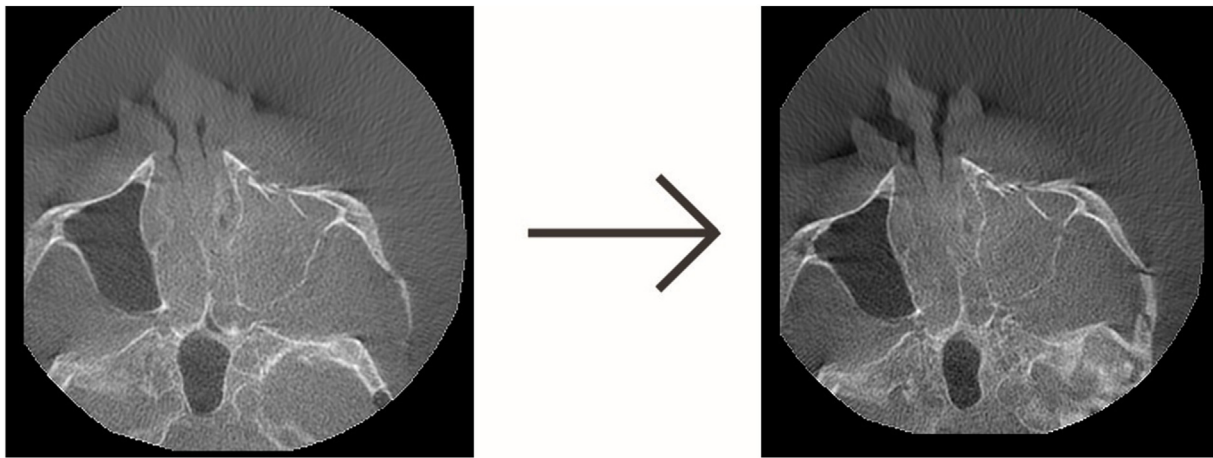
The pertinent patient characteristics, aetiology, ZMC fracture classification and treatment are provided in Table 1.

*Characteristics of the healthy control group*

The mean age of the healthy control group was 26.6 years, (range 21–40 years), with a male to female ratio of 8:7.



**Fig. 6.** Example of a case in which the orbital floor (OF) treatment was revised. The orbital floor implant was repositioned on the posterior orbital ledge.



**Fig. 7.** Example of a case in which the zygomaticomaxillary complex (ZMC) reduction was revised. Symmetry of the antero-posterior position of the ZMC and the alignment of the fracture segments at the zygomatic arch were improved.

#### Accuracy of ZMC fracture reduction

ZMC asymmetry in the healthy control group was 1.40 mm (SD 0.54). Preoperative ZMC asymmetry was 2.69 mm (SD 0.95). Postoperative ZMC asymmetry was 1.67 mm (SD 0.89).

ZMC fracture reduction significantly decreased the asymmetry (2.69 mm vs 1.67 mm; paired-samples T-test  $p < 0.01$ ). Postoperative asymmetry was comparable to the asymmetry in healthy controls (1.67 mm vs 1.40 mm; independent samples T-test  $p = 0.31$ ).

#### Treatment revisions after intraoperative CBCT imaging

The intraoperative CBCT was followed by revision reduction in 11 cases: revisions of ZMC ( $n = 6$ ), revisions of ( $n = 2$ ), revisions of ZMC and OF ( $n = 2$ ), and one removal of a dislodged piece of bone from the orbital cavity. An example of a case in which the OF treatment was revised is provided in Fig. 6, and an example of a case in which the ZMC reduction was revised is provided in Fig. 7.

Of the 4 cases in which a revision of the OF was performed, 2 cases required repositioning of the titanium mesh orbital floor implant. In the other 2 cases, the reduction of the ZMC had realigned the previously disrupted OF, thus obviating OF exploration.

Comminuted ZMC fractures and/or involved OF were associated with revision reduction after intraoperative CBCT (Pearson  $\chi^2 p < 0.01$ ). Of the 9 comminuted ZMC fractures and/or involved OF, 8 needed revision reduction, whereas of the 29 cases without comminution and no involved OF for OF treatment, only 3 needed revision reduction.

This single parameter (comminution of the ZMC and/or indication for OF treatment) showed a sensitivity and specificity of 73% and 96%, with a positive predictive value of 89% and negative predictive value of 90% for the occurrence of treatment revisions after intraoperative CBCT imaging.

#### Rate of secondary surgical interventions

Of the 38 patients, 37 patients had been followed-up, with a mean follow-up of 109 days (SD 15). Two cases needed secondary (separate) surgical intervention: one extraocular muscle correction to correct persisting diplopia and one traumatic scleral rupture needed evisceration of the eye. No secondary surgical interventions for malalignment of the ZMC or OF had been performed.

#### Discussion

Intraoperative CBCT imaging seems to be of value for the treatment of ZMC fractures: revision reduction was indicated by intraoperative CBCT imaging in 11 of the 38 ZMC fractures, and a statistically significant reduction of the asymmetry of 1.02 mm was achieved by using intraoperative CBCT imaging (paired-samples T-test  $p < 0.01$ ).

In the study population, comminuted ZMC fractures and/or fractures with indication for OF reduction were strongly associated with the need for revision reduction (Pearson  $\chi^2 p < 0.01$ ). The positive predictive value (89%) and the negative predictive value (90%) of this single parameter (comminuted ZMC fractures and/or indication for OF reduction) for revision reduction after intraoperative CBCT imaging are both high. Therefore, comminuted ZMC fractures and/or indication for OF reduction are therefore indications to use intraoperative CBCT imaging. This finding is in accordance with the study performed by Cuddy et al. (2018).

In a previously published study on ZMC fractures treated without intraoperative CBCT imaging, 9% of the patients required secondary surgical interventions to correct ZMC and/or OF malalignment (Van Hout et al., 2016), whereas in the present study on ZMC fractures treated with intraoperative CBCT imaging, 0% of the patients required a secondary surgical intervention (Pearson  $\chi^2 p = 0.06$ ).

The mobile CBCT scanner proved easy to use. Recording of the intraoperative CBCT scan and the evaluation of the images took 15–20 min, if the scanner had been put in the right position parallel to the patient with the software running prior to the start of surgery. This is slightly longer than the reported extra operating time needed for performing and evaluating an intraoperative CBCT scan in surgery of the lower extremity (Geerling et al., 2009; Richter and Zech, 2009).

Exposure to radiation should be kept as low as reasonably achievable. The treatment algorithm included intraoperative CBCT imaging for all displaced ZMC fractures. Radiation exposure was not increased in case the intraoperative CBCT scan confirmed adequate alignment of the fracture, as the intraoperative CBCT imaging was performed in lieu of postoperative CT imaging. Radiation exposure was increased in case malalignment on the intraoperative CBCT was followed by revision reduction, necessitating a second intraoperative CBCT for the evaluation of the revision reduction. The small increase in radiation exposure outweighs the alternative of secondary surgical interventions.

The present study has some limitations. The best method to evaluate ZMC fracture reduction would be to compare the position of the ZMC after fracture reduction to the position of the intact ZMC prior to the fracture. However, in the present study there were no CT scans available from the intact ZMC of the trauma patients prior to the fracture. So, instead of an image of the intact ZMC prior to the fracture, a mirror-image was created of the contralateral intact ZMC.

The present study uses a mirroring- and surface-based matching technique for measuring ZMC symmetry. An advantage of this method is that there is no need to define a symmetry plane. The method has similarities with the methods used by Ho et al., 2016, 2017 and Gibelli et al. (2018), but differs with regard to the reference area for the surface based matching. In present study, the ACF is the reference area. As a consequence, variation in both position and form of the ZMC is reflected in the asymmetry measurements. Not only the shape of the ZMC but also the position of the ZMC within the viscerocranium can be distorted in ZMC fractures, and both are important factors for cheek projection and facial appearance.

A methodological limitation of this study is the design. To compare the outcome of a group treated with intraoperative imaging and a group without intraoperative imaging, a randomized controlled trial would have given the highest level-of-evidence. A randomized controlled trial was not an option, however, as intraoperative imaging was already part of the department treatment algorithm for all displaced ZMC fractures since 2015. Therefore a prospective cohort study was performed.

A final limitation is the relatively small study population; as a consequence, the conclusions of this study were formulated cautiously.

## Conclusion

Within the limitations of the study, we conclude that intraoperative CBCT imaging seems to have a positive influence on ZMC fracture treatment, especially in the case of comminuted ZMC fractures and/or fractures with indication for OF treatment. The use of intraoperative CBCT imaging can be considered for comminuted ZMC fractures and ZMC fractures with indication for OF treatment.

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