On the treatment of zygomaticomaxillary complex fractures

INTRAOPERATIVE IMAGING

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On the treatment of zygomaticomaxillary complex fractures
Intraoperative imaging

Over de behandeling van jukbeen fracturen
Peroperatieve beeldvorming
(met een samenvatting in het Nederlands)

Proefschrift

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Contents

Chapter 1

General Introduction

Trauma healthcare in The Netherlands

Every year approximately 80.000 trauma patients are admitted in hospital in The Netherlands for treatment of their injuries. The most frequent cause of trauma is a low-energetic fall (49%), followed by road-traffic accidents (20%). Male-to-female ratio is 1:1, average patient age is 55 years old (SD 30)[1].

Trauma care is provided in 11 specialised regional Level I Trauma Centres and 85 Local Hospitals. Triage of patients is performed at the first instance by the ambulance personnel, based on severity of the injuries. Haemodynamically unstable patients, patients with neurotrauma, multitrauma patients and patients with specific types of injuries are to be transported directly to a Level I Trauma Centre. Other patients can be transported to local hospitals[2].

Figure 1: Map of The Netherlands, Level I Trauma Centres are indicated with a large purple dot, Local Hospitals are indicated with a small blue dot. Figure from National Trauma Registration[1].

The Advanced Trauma Life Support principles are adhered to in the treatment of trauma patients. Patients are assessed and initial resuscitation is performed in a standardised manner, repeated surveys for reassessment are performed[3].

Maxillofacial Trauma in the Netherlands

Maxillofacial trauma is present in 12-13% of trauma patients (21.243 patients in 2017)[1]. The incidence and pattern of maxillofacial trauma has changed over time due to cultural influences (e.g. alcohol consumption, popular attitude towards alcohol in traffic), preventive measures (seatbelt and airbag use in cars and helmet use in mopeds and motorcycles), and technological advances (e.g. electronic bicycles)[4–8].

The Oral and Maxillofacial Surgeon (OMFS) is trained to treat the full scope of maxillofacial injuries, consisting of soft tissue injuries, fractures of the viscerocranium and dental injuries. Therefore the OMFS plays a central role in the treatment of maxillofacial trauma. If necessary the Ophthalmologist, Otorhinolaryngologist or Plastic Surgeon are consulted.

Zygomaticomaxillary complex (ZMC) fractures

The zygoma is a bilateral eminence at the antero-lateral aspect of the face. The zygoma articulates with the frontal bone, greater wing of the sphenoid bone, the zygomatic process of the temporal bone, and the maxilla. The position and form of the zygoma determine cheek projection and facial width. Functionally, the zygoma gives support to the orbital contents as it forms the antero-caudo-lateral part of the orbital floor. Also, it is the site of origin of the masseter muscle[9–11].

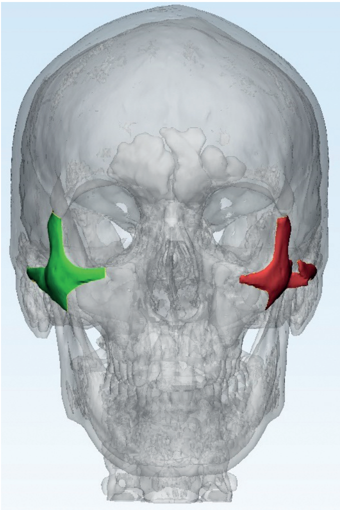

Figure 2: The zygoma. Right side intact (green), left side with ZMC fracture (red).

Fractures of the ZMC are often encountered in maxillofacial trauma patients[4,8,12]. Often the zygomatic bone itself is not fractured, the fractures occur at the sites of connection to the viscerocranium: the lateral orbital rim, zygomatic arch, infraorbital rim, and maxillozygomatic buttress. In comminuted fractures the zygoma itself is fractured as well[9].

Symptoms of ZMC fractures include: epistaxis, sensory loss of the cheek and upper lip (infraorbital nerve), sensory loss of the maxillary gum and teeth (superior alveolar nerves), periorbital swelling and ecchymosis, subconjunctival ecchymosis, flattening of the cheek prominence, trismus, diplopia, ex- or enophthalmos[9,13,14].

Treatment of zygomaticomaxillary complex fractures

In cases with no or minimal dislocation of zygomaticomaxillary complex (ZMC) fractures, no surgical treatment is required. This occurs in 23-52% of the cases[13,15].
In cases with dislocation of the ZMC fracture surgical treatment is indicated to restore form and function. Not all ZMC fractures require internal fixation. None-comminuted ZMC fractures that require no orbital floor treatment, and which are stable after closed reduction can be treated without internal fixation[9,10].

Reduction of the ZMC fracture

Closed reduction of ZMC fracture can be established with the malar hook[16]. The hook is placed behind the ZMC so that the fracture can be reduced. This can be performed transcutaneous via a small stab-incision in the skin of the cheek or via a stab-incision the upper buccal sulcus. A second possibility for closed reduction is via a temporal approach as described by Gillies[17]. Through an incision behind the hairline an elevator is introduced under the superficial temporal fascia and placed under the ZMC, after which the fracture can be reduced.
Open reduction can be performed through an intra-oral upper buccal-sulcus, an upper blepharoplasty or lateral brow incision, and through a coronal approach. Through these approaches both fracture reduction and internal fixation can be performed[18].

Internal fixation of the ZMC

Internal fixation of the ZMC can be performed with miniplates at the lateral orbital rim, the maxilla-zygomatic buttress, the infraorbital rim, and the zygomatic arch (Figure 3)[10,19,20].

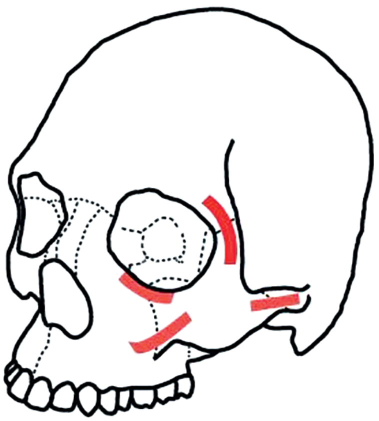

Figure3: Sites used for internal fixation of the ZMC; the lateral orbital rim, zygomatico-alveolar buttress, infraorbital rim, zygomatic arch.

Orbital floor

As the zygoma forms the anterolateral part of the orbital floor, there is almost always an associated orbital floor fracture in case of a ZMC fracture. In case of significant disruption of the orbital floor, exploration and repair of the orbital floor is indicated[14,21]. This is in approximately 12-44% of the cases[10,13].

Repair can be performed by reposition of the fracture or insertion of an implant such as a titanium mesh, polydioxanone sheet, autologous bone transplants, or allogeneic lyophilised cartilage[22,23].

Technological advances in the treatment of ZMC fractures

Recent technological advances in the treatment of maxillofacial fractures include computer-assisted surgical planning[24–26]; intraoperative navigation[27–29]; and intraoperative 3D imaging[30–33].

Computer-assisted surgical planning

In computer-assisted surgical planning, a simulation of the surgery is performed digitally. Mirroring techniques are often appied[24,29]

Templates can be manufactured to be used during the procedure to aid with the place and angle of osteotomies, and the verification of adequate positioning. Also, patient specific osteosynthesis plates and orbital floor implants can be produced[25,34,35].

Computer-assisted surgical planning is performed mainly in orthognathic cases and reconstructive cases. It can also be performed in ZMC fracture repair[24,26].

Intraoperative navigation

Intraoperative navigation allows for the real-time orientation on CT during surgery. For this a wand is used, the location of the tip of the wand is shown on the CT on screens in the operating room.

Intraoperative navigation is often used in conjunction with computer-assisted surgical planning to verify if the planned position of bone fragments or implants has been achieved[27–29,36].

Intraoperative imaging

In intraoperative imaging a mobile CT or CBCT scanner is used, these can be used in any operating room. The CT-scan is performed after treatment of the ZMC-fracture and, if indicated, the orbital floor fracture. In case of insufficient treatment of the ZMC fracture and/or the orbital floor fracture, a direct revision can be performed to improve the treatment result[30,31,33,37].

Intraoperative imaging is more easily applied than computer-assisted surgical planning and intraoperative navigation. No time-delay between patient presentation and treatment is needed for computer-assisted surgical planning and the total extra time-investment is smaller.

Figure 4: Intraoperative navigation in the operating room.

Figure 5: Mobile CBCT scanner in use in the operating room. A sterile cover is placed around the patient to keep the surgical field sterile.

Intraoperative CBCT imaging in other specialties

Intraoperative CBCT imaging is also used in fractures of the extremities[38–44]. Reported rates of direct revisions after intraoperative imaging vary between the different studies. A systematic review on the use of intraoperative 3D imaging in fractures of the upper and lower extremities reports an 11-40% revision rate[44]. Especially in intra-articular fractures 3D imaging can prevent the occurrence of irregularities or steps on the articular surface[38,45].
The reported extra operating time spent for performing the CBCT-scan and evaluation of the images ranges from 5.3 to 10.2 minutes[41,42,46]

Outline Of The Thesis

In **Chapter 2** a descriptive epidemiological study is performed of maxillofacial trauma patients requiring surgical treatment in a level I Trauma Centre in The Netherlands. The goal of this study was to assess the incidence of maxillofacial fractures, determine trends in incidence to aid in capacity planning, and to assess for opportunities for preventive measures.

In **Chapter 3** a retrospective cohort is performed of patients with a ZMC fracture that were treated without intraoperative imaging. The goal of this study was to assess treatment outcome and to identify which ZMC fractures might benefit from the use of additional technical aids to improve treatment outcome.

In **Chapter 4** a literature review is performed of publications on the use of intraoperative imaging in ZMC fracture repair. We aimed to assess the existing literature on intraoperative imaging in ZMC fracture repair. With a focus on the effect it has on restoration of facial symmetry, fracture reduction and the frequency of additional reduction after intraoperative imaging.

In **Chapter 5** a novel method is developed to assess the symmetry of the ZMC. We aimed to develop a method that is suitable to be used to assess the quality of ZMC fracture reduction.

In **Chapter 6** a prospective cohort study is performed on the use of intraoperative CBCT imaging in the treatment of ZMC fractures. We aimed to assess the quality of ZMC fracture reduction with intraoperative imaging; to assess the frequency of direct revisions after intraoperative imaging; to evaluate the effect of direct treatment revisions after intraoperative imaging; and to identify which ZMC fractures are most likely to benefit from intraoperative imaging.

Finally, in **Chapter 7** the findings, implications for clinical care and future perspectives are discussed.

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Chapter 2

An epidemiological study of maxillofacial fractures requiring surgical treatment at a tertiary trauma centre between 2005 and 2010

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Abstract

The epidemiology of maxillofacial fractures shows considerable regional variation as a result of local demographic and socioeconomic factors. We have assessed the epidemiological characteristics of such fractures at our centre in The Netherlands. The medical records of 394 patients who were treated surgically for maxillofacial fractures between 1 January 2005 and 31 December 2010 were analysed retrospectively. The male:female ratio was 3:1. There was a peak incidence in the second and third decades of life among men. The number of injured patients/year remained stable during the selected period. The incidence was highest in the spring and at weekends. Fractures of the mandible and zygoma were the most common. Road traffic accidents were the most common cause of injury (42%) and mainly involved bicycles. A total of 165 (15%) of the patients were intoxicated, and 142 patients (36%) had other serious injuries. Most patients (n = 248, 63%) were treated within a day of presentation. Two hundred and thirty-two patients (59%) spent 4 days or fewer in hospital. The presence of other injuries was associated with a prolonged stay in hospital. Groups at particular risk of maxillofacial fractures are young men and cyclists. The use of helmets by cyclists could achieve a large reduction in injuries to the brain and upper face.

Introduction

There is considerable variation in the epidemiology of maxillofacial fractures. Worldwide, however, they predominantly affect young adult men, and the most common causes are road traffic accidents and interpersonal violence[1–6]. Alcohol is often involved[4].

The goal of maxillofacial surgical treatment is full restoration of function and aesthetics. However, maxillofacial fractures are often accompanied by other serious injuries, such as neurological, orthopaedic, and ophthalmological injuries. These fractures may result in emotional and psychological problems.

Socioeconomic ramifications of maxillofacial trauma are the cost of treatment and admission to hospital, hospital resources, and macroeconomic loss of revenue. For individual patients consequences may comprise functional problems, physical discomfort, aesthetic problems, emotional or psychological distress, an intensive treatment regimen (often in hospital), frequent visits to the outpatient department after discharge, and loss of revenue.

Epidemiological studies of maxillofacial trauma are important to help develop more efficient ways to deliver care, to assess and improve the quality of care, and to advise on tactics for the prevention of injury. We therefore assessed the epidemiological characteristics of maxillofacial fractures treated surgically at our centre.

Patients and methods

Patients were identified using our digital operation registration database. All those included were treated surgically between 1 January 2005 and 31 December 2010 by the Oral and Maxillofacial Surgical Department for a fracture of the mandible, midface, zygoma, orbit, nose, or frontal sinus.

Patients were excluded if they had already been treated in other hospitals for the same fracture, and if they presented with fractures more than 21 days old.

The following data were extracted from the medical records: sex; age; site of the fracture(s); other injuries; cause of the trauma; involvement of alcohol or other substances; date of injury; date of presentation at the hospital; date of operation; method of treatment; and duration of stay in hospital. The data was entered into an electronic database (Excel, Microsoft, 2007).

The type of fracture was documented as mandible, mid-face, nose, orbit, zygoma or frontal sinus, as diagnosed by clinical or radiological examination, or both. Midface fractures were categorised as Le Fort I, II, or III fractures. In the case of a fracture of the zygoma, the accompanying ipsilateral orbital fracture was not documented separately. In the case of a Le Fort II or III fracture the accompanying nasal and orbital fractures were not documented separately.

Information about the method of treatment was gathered from the operating notes, and was categorised as open reduction and internal fixation, intermaxillary fixation, reposition without fixation, or orbital floor repair.
Other injuries were categorised as neurotrauma, spinal trauma, orthopaedic trauma, general surgical trauma, and other trauma. Neurotrauma was defined as cerebral haemorrhage, leak of cerebrospinal fluid, fracture of the cranial base, or other conditions that necessitated neurosurgical intervention such as decompression or placement of an intracranial pressure monitor. Spinal trauma was defined as any type of fracture of the spine. Orthopaedic trauma was defined as any fracture of the upper or lower extremities including pelvis and shoulder. Surgical trauma was defined as any visceral injury, internal haemorrhage, pneumothorax, or fractured rib. Other trauma was defined as any other trauma not coming into those categories, such as ophthalmological injury.
The causes of injury were categorised as road traffic accident, interpersonal violence, sports injury, simple fall (low-energetic), fall from a height, animal-associated, work-related, military, iatrogenic injury, and “other”. In road traffic accidents the vehicle of the injured person was recorded, in sports injuries the sport was recorded, and in animal-associated injuries the animal involved. Only one cause was recorded for each patient. If there was more than one cause, the most appropriate was selected.
No ethics committee approval was needed as this was a retrospective study taken from medical records.
All analyses were made using the Statistical Package for the Social Sciences (SPSS, IBM, Chicago, IL, USA). We used the chi-square test, Student’s two-tailed *t*-test, or the Mann–Whitney U-test, as appropriate. Probabilities of less than 0.05 were accepted as significant.

Results

During the 6-year period 394 patients had had primary surgical treatment for maxillofacial fractures.

Sex and age

There were three times more male than female patients (p = 0.0001; chi-square test), and the male patients were significantly younger than the female patients (p = 0.001; independent samples t-test) (Table 1). There was a distinct rise in incidence among men during the second and third decades.

Distribution over time

The annual incidence of maxillofacial fractures is shown in Table 2, and there were no significant differences over the 6-year period (p = 0.77; chi-square test). The incidence

Table 1: Distribution of age and sex

Patient age	No.	% (total)	No. (m)	No. (f)
0-10	9	2,3	7	2
11-20	81	20,6	61	20
21-30	90	22,8	76	14
31-40	58	14,7	48	10
41-50	52	13,2	40	12
51-60	54	13,7	40	14
61-70	21	5,3	12	9
71-80	15	3,8	7	8
81-90	14	3,6	5	9
Average age	37.6 (SD 19.4 , n=394)		35.5 (SD 17.5, n= 296)	44.1 (SD 23.1, n=98)

Table 2: Distribution of patients with maxillofacial fractures per year.

Year	No.(%)
2005	57 (14)
2006	66 (17)
2007	75 (19)
2008	65 (16)
2009	67 (17)
2010	64 (16)

fluctuated over the months ($p = 0.002$; chi-square test); with higher incidences in April, May, and June ($p = 0.0001$; chi-square test) (Table 3). The incidence varied during the week ($p = 0.006$; chi-square test). Starting on Monday, when relatively few fractures occurred, the incidence increased during the week. At the weekends the incidence was higher than it was on weekdays ($p = 0.001$; chi-square test) (Table 4).

Types of fractures

Fractures of the mandible and zygoma were the most common, and those of the midface, orbit, nose, and frontal sinus less so (Table 5). Seventy patients had Le Fort fractures (18%). Classic bilateral ones affected 32 patients (Le Fort I, $n = 17$, Le Fort II, $n = 8$, and Le Fort III, $n = 7$). The other 38 patients with midface fractures had combined types of Le Fort fractures ($n = 22$) or a unilateral fracture ($n = 16$). Orbital fractures occurred in 63 patients (16%). One third of these ($n = 20$) had isolated orbital blowout fractures.

Table 3: Distribution of patients with maxillofacial fractures per month.

Month	No. (%)
January	30 (8)
February	26 (7)
March	31 (8)
April	41 (10)
May	41 (10)
June	56 (14)
July	26 (7)
August	31 (8)
September	36 (9)
October	21 (5)
November	26 (7)
December	26 (7)

Table 4: Distribution of patients with maxillofacial fractures per day of the week.

Day of the week	No. (%)
Monday	40 (10)
Tuesday	47 (12)
Wednesday	43 (11)
Thursday	59 (15)
Friday	63 (16)
Saturday	71 (18)
Sunday	71 (18)

Table 5: Sites of fractures.

Fracture	No. (%)
Mandible	166 (42)
Zygoma	153 (39)
Midface	70 (18)
Orbit	63 (16)
Frontal sinus	48 (12)
Nose	47 (12)

Cause of fractures

Road traffic accidents were the most common cause of maxillofacial fractures (42%), and the other causes are shown in Table 6. Bicycle accidents were the most common cause of fractures among road traffic accidents (18%), followed by car (13%), moped (6%), motorcycle (3%), and pedestrian incidents (2%). Soccer injuries caused 4% of the fractures, followed by field hockey (2%) and bicycle racing (2%).
All animal-associated incidents that resulted in fractures (2%) were caused by horses. In 9 patients "other" causes were documented: 5 collisions with a heavy object, 1 self-inflicted gunshot, 1 child fell in a playground, 1 patient was injured by a firework, and 1 patient had a jet-ski accident.

Table 6: Aetiology, age, and male-to-female ratio.

Cause	No. (%)	Mean age (SD)	Male-to-female ratio
Road traffic accident	167 (42)	35 (19)	2.5
Interpersonal violence	63 (16)	33 (14)	9.5
Sports injury	46 (12)	32 (16)	8.2
Simple fall (low-energetic)	45 (11)	59 (20)	1.3
Fall from height	38 (10)	41 (21)	2.2
Animal induced	7 (2)	21 (9)	1.3
Work related accident	7 (2)	42 (10)	All male
Military	6 (2)	30 (10)	5.0
Iatrogenic	5 (1)	51 (12)	0.7
Other	9 (2)	30 (17)	All male
Unknown	1 (0.3)	26 (-)	All male
Total	394	38 (19)	3.0

Intoxication

In 57 patients (15%) intoxication was documented in the notes. Alcohol was the most common substance used (n = 52), and combined with cannabis (n = 2) or with cocaine (n = 1). One patient had used cannabis and another patient gamma hydroxybutyrate. Intoxication was not associated with the cause of the maxillofacial fracture, or the presence of other injuries.

Other injuries

A total of 142 patients also had other injuries (36%). Orthopaedic trauma was the most common (n = 86), followed by general surgical trauma (n = 46), spinal trauma (n = 43), neurotrauma (n = 42), and other trauma (n = 7). More than three-quarters of the neurotrauma (n = 32) resulted from road traffic accidents and most were bicycle-related. Of the 70 patients who had a bicycle accident, 13 (19%) also had neurotrauma, compared with 4% of the patients who had a motorcycle or moped incident.

Time to operation

Time from presentation to operation ranged from 0 to 20 days. Most patients (n = 248, 63%), were treated within 1 day of presentation. A large group of patients (n = 119, 30%) was treated within 2 and 5 days of presentation. Other serious injuries that necessitated urgent intervention were the cause of delay in the treatment of the maxillofacial fractures in 65 patients, and excessive facial swelling explained the delay in 8 patients. The delay remained unexplained in the other 46.

Only 25 patients (6%) were treated after more than 5 days, and this delay was explained by other serious injury in 18 patients and operation listed at a later stage in 7 patients. No delay was unexplained.

The 46 patients with unexplained delay in treatment (12% of all patients) were operated on between 2 and 5 days after presentation. In the selected period 2005–2010 the duration of delay remained stable but the number of patients with unexplained delay gradually increased from 2 to 14 patients/year.

Treatment

A total of 293 patients were treated by open reduction and internal fixation with miniplates (74%); 105 with intermaxillary fixation (27%); 80 with closed reduction (for fractures of the zygoma and nose (20%); and 66 with repair of the orbital floor (17%). One patient with a gunshot injury had it debrided, soft tissue repair and, at a later stage, secondary reconstruction of the bony defect with an autologous bone graft. Orbital floor fractures were repaired with polydioxanone (PDS) sheet (n = 28), titanium-mesh (n = 14), titanium mesh with a PDS sheet (n = 7), allogenic lyophilised cartilage (n = 11), allogenic lyophilised cartilage with a PDS sheet (n = 1), autologous calvarial bone (n = 3), hydroxyapatite (n = 1), and in 1 patient the method of treatment was not documented.

Duration of stay in hospital

Duration of stay in hospital ranged from 1 to 127 days. Many patients were admitted for just 1 day and most (59%) were discharged within 4 days. The presence of other injuries was associated with a prolonged stay in hospital (p = 0.0001; Mann–Whitney U-test). When no other injury was present the stay in hospital was about 3 days, but when other injuries were present it was nearer 22 days.

Discussion

Our incidence of maxillofacial fractures peaked in spring and also varied widely during the week, with the most fractures at the weekend. Men in their second and third decades of life (35% of all patients) were particularly at risk. This confirms reports that young men are prone to risk-taking behaviour, resulting in a relatively high incidence of incidents in this group[7]. Road traffic accidents were the most common cause of maxillofacial fractures (42%) and the most common among these involved bicycles (18%). The high rate of maxillofacial fractures among cyclists reflects the vulnerability of cyclists in traffic. In addition to the rate of maxillofacial fractures, these cyclists are also prone to neurotrauma as most of the neuro-trauma in road traffic accidents was bicycle-related. This group in particular may benefit from preventive measures, such as helmets.

Bicycles are a popular means of urban transportation in The Netherlands, but helmets have not been compulsory or customary for bicycle riders. The compulsory use of helmets has been proposed, but is still in dispute. However, helmet laws are thought to discourage cycling, resulting in less cycling and fewer bicycle-related fatalities. Studies in other countries have indicated that wearing a protective helmet directly reduces injuries to the head and brain in cyclists by 63–88% and facial injuries to the upper and middle part of the face by 65%[8].

In our study 19% of the patients involved in a cycling incident had simultaneous neurotrauma compared with 4% of the patients involved in a motorcycle or moped incident. This difference is largely explicable by the compulsory use of helmets by motor and moped riders. We expect that increase in the use of helmets or adopting laws that make helmets compulsory for cyclists will lead to a considerable reduction in cycling-related neurotrauma and facial injuries to the upper and middle part of the face. A reduction in numbers and the severity of neurotrauma and facial trauma would also lead to a considerable reduction in health care costs.

Intoxication was documented in 15% of patients, usually with alcohol (91%). The involvement of substances other than alcohol was probably under-reported as physicians may have been unaware or simply failed to document it in the medical records. Intoxication may not always have been recognised, particularly in severely injured and unresponsive patients, so the rate may be much higher. A prospective study could ensure complete documentation on substance use.

The delay in treatment was unexplained in 46 patients, 12% of all those with maxillofacial fractures. These patients were operated on between 2 and 5 days after presentation (mean 2 days). Shortage of theatre time was the most likely cause, because there were no health-related factors responsible for the delay. Such delay may decrease when theatre time is used more efficiently – for example, by anticipating the increased incidence of these fractures in April, May, and June, and at the weekend.

When interpreting the results of this study, we should take into account that it was done in a tertiary trauma centre where the case-mix usually comprises more severely injured patients than general hospitals with trauma services. Only patients whose fractures had been operated on were included in the study; those treated conservatively were excluded.

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Chapter 3

Surgical treatment of unilateral zygomaticomaxillary complex fractures: A 7-year observational study assessing treatment outcome in 153 cases

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Abstract

This study investigates treatment outcome in zygomaticomaxillary complex (ZMC) fracture repair.

Methods
The medical records and CT-images of patients that received treatment for a unilateral ZMC fracture in 2005-2011 were studied. ZMC fractures were categorised as incomplete (type A), tetrapod (type B) or comminuted (type C). The incidence of sequelae, wound infection and secondary surgical interventions was analysed per fracture category.

Results
A total of 153 patients were treated in the selected period.
Persisting sensory disturbances in the area innervated by the infraorbital nerve were observed in 50 cases (37%), facial asymmetry in 19 cases (14%), enophthalmos in 10 cases (7%) and persisting diplopia in 9 cases (7%). Wound infection occurred in 6 cases (4%). Secondary surgical procedures of the ZMC, orbital floor, and/or extraocular muscles were performed in 14 cases (9%). C-type fractures were associated with more secondary corrections for ZMC malreduction (12%, $p=0.03$), more secondary reconstructions of the orbital floor (10%, $p<0.01$), and more functional corrections of diplopia by extraocular muscle correction (5%, $p=0.02$).

Conclusion
Treatment outcome in C-type ZMC fractures is less favourable than treatment outcome in A-type and B-type fractures. Intraoperative imaging, surgical navigation devices and 3D-planning software may improve treatment outcome in C-type ZMC fractures.

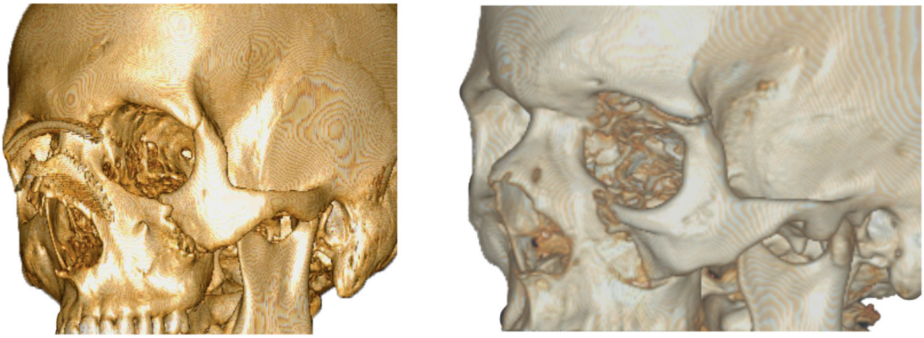
Introduction

Zygomaticomaxillary complex (ZMC) fractures are common injuries in maxillofacial trauma patients [1,2]. ZMC fractures with no or minimal displacement can be treated conservatively. However, for ZMC fractures with dislocation, surgery is indicated [3].
The surgical technique is adapted to the fracture pattern and the patient. Mild cases can be treated in a minimally invasive method, the ZMC is reduced through a small incision and no fixation or 1 miniplate is required. Severe cases need several surgical approaches to both the zygoma and the orbital floor, miniplate fixation at multiple sites and reconstruction of the orbital floor [4].
Recent technological advances such as intraoperative conebeam computed tomography (CT) imaging, surgical navigation devices and 3D-planning software, offer the surgeon additional means to ensure a positive treatment outcome [5–7]. Application of these technological means in every ZMC fracture seems unnecessary, as good results are reported in the majority of patients treated without the use of these technical aids [4,8].
This study was undertaken to investigate in which ZMC fractures treatment yields inadequate results when performed without the use of technological aids. In a retrospective cohort the ZMC fractures were categorised and the occurrence of sequelae, wound infection and secondary surgical procedures of the ZMC, orbital floor and extraocular muscles (functional diplopia correction) was analysed.

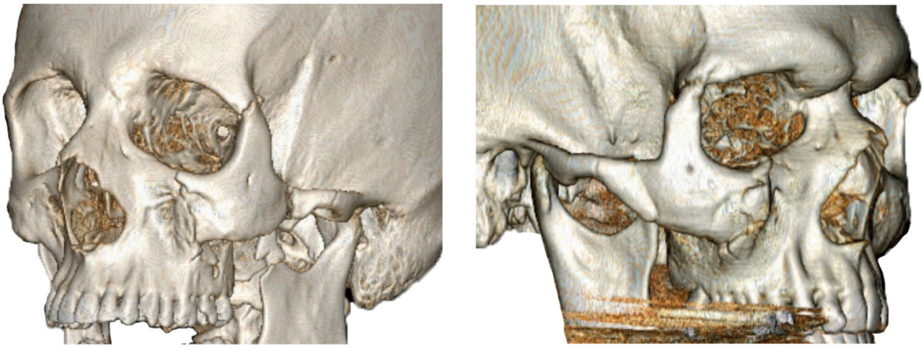
ZMC fracture classification

Several classifications for ZMC fractures have been proposed in the literature. Manson et al. [9], Ellis and Kittidumkerng [4] and Zingg et al. [8] proposed similar classifications for ZMC fractures based on the energy of the injury, the pattern of comminution, the degree of dislocation, and the number of fractured zygomatic pillars.
Based on these classifications , we made the following classification (Figure 1):

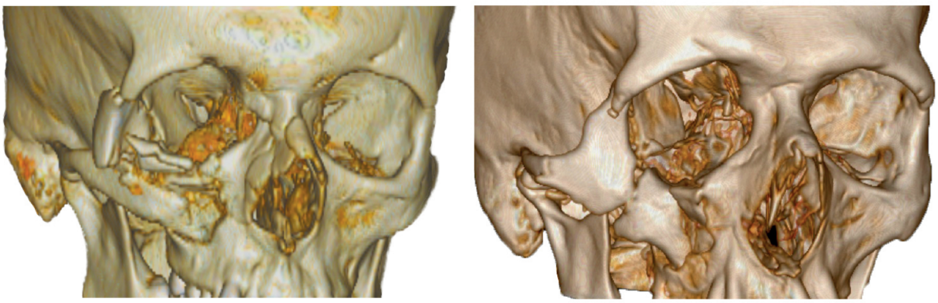
A. Incomplete fractures – low-energy fractures in which at least one pillar of the ZMC remains intact.
B. Tetrapod fractures – all four pillars of the ZMC are fractured.
C. Comminuted fractures – high-energy fractures, the ZMC is divided into 2 or more fragments by additional fractures trough the zygomatic body, lateral orbit or infraorbital rim. If the paranasal part of the infraorbital rim or the triangular process of the frontal bone constitutes a loose fragment, the fracture is also considered comminuted. Fractures with minor fragmentation at a fractured point of articulation and W-type fractures of the zygomatic arch do not qualify as comminuted.



1A: A-type fractures (incomplete)



1B: B type fractures (tetrapod)



1C: C type fractures (comminuted)

Figure 1: Classification of ZMC-fractures.

Materials and methods

A retrospective cohort study was conducted. The study was performed in accordance with the STROBE guidelines for reporting observational studies (Strengthening The Reporting of OBservational Studies in Epidemiology) [10]. The local ethics committee considered the study not subject to consent.

Data collection

Patients who were treated for a ZMC fracture between 2005 and 2011 were identified through the electronic hospital information system. Included were patients who received primary surgical therapy for a unilateral ZMC fracture.

Patient records, operative reports, radiology reports of maxillofacial imaging, and available maxillofacial radiographic images of all patients were studied.

The collected data included: gender, age, aetiology, concomitant other injuries, surgical treatment, sequelae upon follow-up, occurrence of wound infection, and secondary surgical procedures.

Fracture classification

In cases with available adequate CT-scans, CT-images were reviewed and the ZMC fracture was categorised following the classification outlined in the introduction. Two observers (WvH and EVC) assessed the CT-scans and categorised the fractures. The observers were blinded for treatment outcome. Consensus was reached regarding the findings.

Department treatment protocol

Treatment is performed under general anaesthesia. Antibiotic prophylaxis is administered at the induction of general anaesthesia or preoperatively.

In cases with no indication for orbital floor exploration, reduction without fixation is attempted primarily. If unstable, internal fixation is applied at the lateral orbital rim or at the zygomatico-alveolar crest, depending on fracture characteristics and the surgeon’s preference. If indicated more points of internal fixation are applied in a stepwise progressive approach.

Primary orbital floor exploration is performed in case of significant internal orbit disruption.

In cases with indication for orbital floor exploration, open reduction and internal fixation (ORIF) of the ZMC is performed at one or several points, after which the orbital floor is explored and, if necessary, reconstructed.

At the end of the procedure, the forced-duction test is performed to check ocular mobility.

Postoperatively the patient is instructed to avoid pressure on the affected side of the face, and to avoid blowing the nose for 2 to 3 weeks. Postoperative antibiotic prophylaxis is prescribed on indication.

The patient is reviewed 1 week after discharge, several months postoperatively, and further on indication.
No intraoperative imaging, surgical navigation device or 3D-planning software was used in the study period.

Statistical analysis
Statistical analyses of the study results were performed with IBM SPSS Statistics for Windows Version 21.0 (IBM Corp., Armonk, NY, USA). Spearman's rank correlation test was used to determine correlation of treatment outcome and other injuries with the fracture classification. Pearson's chi square test was used to determine if treatment outcome and other injuries were associated with individual fracture categories.
In the discussion section Pearson's chi-square test was used on the results published by Zingg et al. [8], these calculations were made in Microsoft Excel 2010 (Microsoft Corporation, Redmond, WA, USA).
Probabilities of 0.05 and less were accepted as statistically significant.

Results

A total of 153 patients were treated in the selected period. The cause of injury and involvement of intoxication are listed in Table 1.

Table 1: Aetiology and (documented) presence of intoxication

	No. (% of total)	**Intoxication (% of group)**
Traffic accident	73 (47.7%)	15 (20.5%)
Bicycle	34 (22.2%)	7 (20.6%)
Car	15 (9.8%)	0 (0%)
Moped	17 (11.1%)	8 (47.1%)
Motorcycle	4 (2.6%)	0 (0%)
Pedestrian	3 (2.0%)	0 (0%)
Interpersonal violence	21 (13.7%)	4 (19.0%)
Sports injury	18 (11.8%)	0 (0%)
Stumbling	17 (11.1%)	3 (17.6%)
Fall from height	17 (11.1%	5 (29.4%)
Animal-associated	2 (1.3%)	0 (0%)
Other/unknown	5 (3.3%)	0 (0%)

Fracture classification

CT-images on which classification could be performed were present in 126 cases (82%), in 27 cases (18%) no (adequate) CT-images were available.
There were 32 A-type fractures (25%), 52 B-type fractures (41%), and 42 C-type fractures (33%). Patient characteristics per fracture category are listed in Table 2.
Left-right distribution was 87:66.

Table 2: Patient characteristics and presence of other injuries.

	A-type, incomplete fractures (n=32)	B-type, tetrapod fractures (n=52)	C-type, comminuted fractures (n=42)	All patients (n=153)
Patient characteristics				
Mean age	46	40	38	42
Male-to-female ratio	2.2	3.3	2.5	2.7
Most frequent aetiology	Traffic accident	Traffic accident	Traffic accident	Traffic accident
Other maxillofacial fractures* ($p<0.01$)	7 (22%)	15 (29%)	23 (55%)** ($p<0.01$)	48 (31%)
Non-maxillofacial injuries	15 (47%)	20 (38%)	21 (50%)	58 (38%)
Ophthalmic injuries* ($p=0.03$)	3 (9%)** ($p=0.02$)	1 (2%)	0 (0%)	4 (3%)

*: Statistically significant correlation with fracture classification.
**: Statistically significant association with individual fracture category.

Other injuries

Presence of other injuries per fracture category is listed in Table 2.
Concomitant maxillofacial fractures were present in 48 cases (31%). In 34 cases an isolated concomitant fracture of the mandible (n=13), midface (n=15), or frontal bone (n=6) was present. In the other 14 cases the concomitant fractures entailed the mandible and midface (n=7); the midface and frontal bone (n=5); or the mandible, midface and frontal bone (n=2). The presence of concomitant maxillofacial fractures correlated with fracture classification ($p<0.01$) and was associated with C-type fractures ($p<0.01$).
Concomitant non-maxillofacial injuries were present in 58 cases (38%). These included neurotrauma (n=26, 17%), e.g. fractures of the cranial base, intracranial haemorrhage, need for intracranial pressure monitoring; spinal fractures (n=17, 11%); fractures of extremities, including shoulder and pelvis (n=30, 20%); thoraco-abdominal injuries (n=15, 10%); and 1 brachial plexus lesion.

Ophthalmic injuries were present in 4 cases (3%). One patient had a superior orbital fissure syndrome and 3 patients had a traumatic optic nerve neuropathy (TON). The presence of ophthalmic injuries correlated with fracture classification ($p=0.03$) and were associated with A-type fractures ($p=0.02$).

Treatment

The treatment per fracture category is listed in Table 3. Distribution of the sites used for internal fixation is displayed in Figure 2.
Orbital floor treatment was performed more often in C-type fractures (38%, $p<0.01$). The number of sites used for internal fixation was greater in cases in which the orbital floor required treatment.
Surgical antibiotic prophylaxis was administered in 143 cases (93%). No antibiotic prophylaxis was administered in 7 cases (5%), and in 3 cases (2%) the use of perioperative antibiotics could not be determined due to incomplete records. Amoxicillin-clavulanate (n=104, 68%), clindamycin (n=12, 8%), cefazolin (n=11, 7%), cefazolin and metronidazole (n=8, 5%), and other antibiotics or a combination of antibiotics (n=8, 5%) were used.

Table 3: Treatment of zygoma and orbital floor.

	A-type, incomplete fractures (n=32)	**B-type, tetrapod fractures (n=52)**	**C-type, comminuted fractures (n=42)**	**All patients (n=153)**
Treatment of zygoma				
Reduction without fixation	16 (50%)	17 (33%)	3 (7%)	48 (31%)
ORIF	16 (50%)	35 (67%)	39 (93%)	105 (69%)
Treatment of orbital floor				
No OF treatment	27 (84%)	45 (87%)	26 (62%)	123 (80%)
OF exploration without reconstruction	0	1 (2%)	5 (12%)	6 (4%)
OF exploration with reconstruction	5 (16%)	6 (12%)	11 (26%)	24 (16%)
Average no. of fixation sites in cases treated with ORIF				
ORIF without OF treatment	1.3	1.4	1.4	1.4
ORIF with OF treatment	1.5	3	2.6	2.6

OF: orbital floor

Sequelae upon postoperative follow-up

Postoperative follow-up in the outpatient clinic was performed in 134 cases (88%). Follow-up was performed in 24 of the cases with A-type fractures (75%), 47 of the cases with B-type fractures (90%) and 39 of the cases with C-type fractures (93%). Average follow-up was 206 days (SD 230).

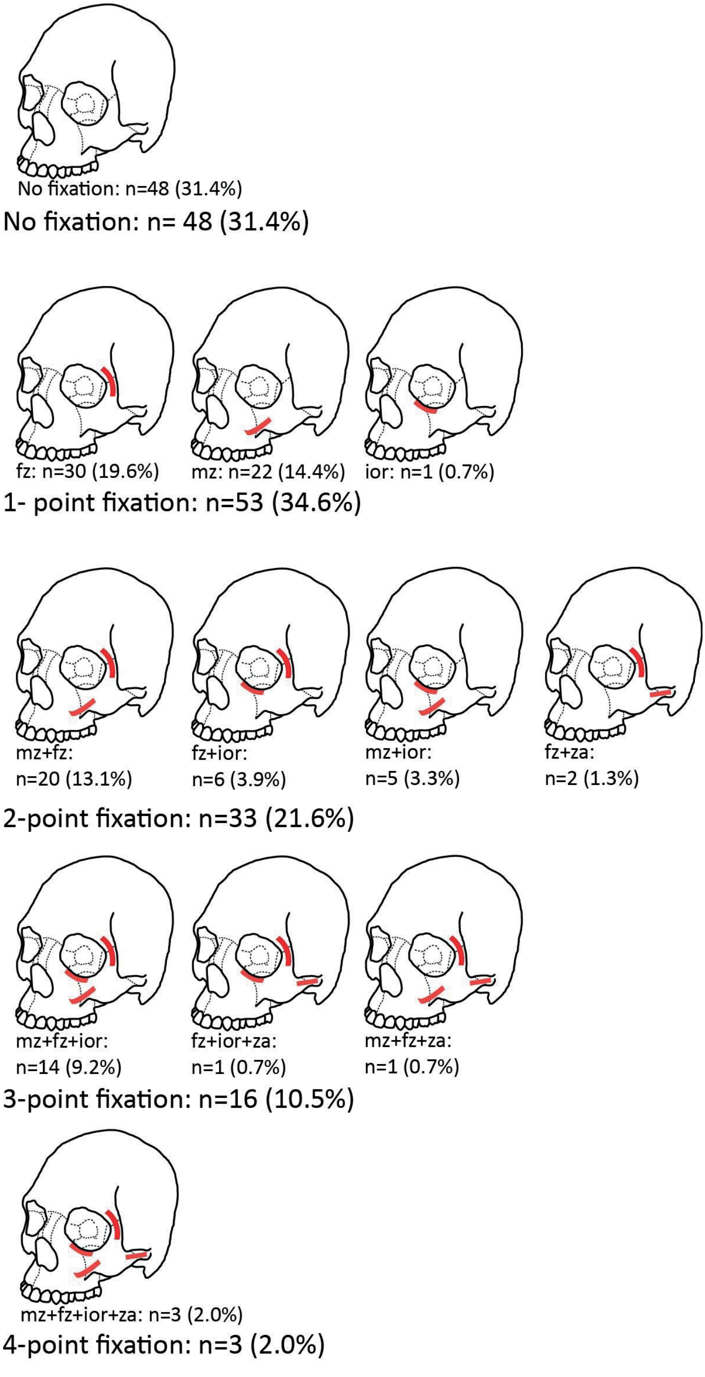


Figure 2: Distribution of sites used for internal fixation of the ZMC.
FZ: frontozygomatic suture; MZ: maxillozygomatic crest; IOR: infraorbital rim; ZA: zygomatic arch

Table 4 shows the occurrence of sequelae per fracture category. A tendency towards increasing incidence of asymmetry (p=0.165), enophthalmos (p=0.245), and diplopia (p=0.06) was observed from category A to C.

Table 4: Sequelae in patients that were followed up.

	A-type, incomplete fractures (n=24)	**B-type, tetrapod fractures (n=47)**	**C-type, comminuted fractures (n=39)**	**All patients (n=134)**
Sequelae upon follow-up				
Asymmetry	2 (8%)	6 (13%)	8 (21%)	19 (14%)
ION dysfunction (persisting at last follow up)	12 (50%)	16 (34%)	12 (31%)	50 (37%)
Enophthalmos	1 (4%)	4 (9%)	5 (13%)	10 (7%)
Diplopia (persisting at last follow up)	0	3 (6%)	5 (13%)	9 (7%)
Facial nerve palsy transient	1 (4%)	0	2 (5%)	3 (2%)
Facial nerve palsy (persisting at last follow up)	0	1 (2%)	1 (3%)	2(1%)
Any	13 (54%)	24 (51%)	24 (62%)	61 (46%)

ION: infraorbital nerve
*: Statistically significant correlation with fracture classification.
**: Statistically significant association with individual fracture category.

Wound infection

Six patients experienced a wound infection (4%). Three patients were treated with systemic antibiotics only, 2 patients were treated surgically under local anaesthesia in the outpatient clinic, 1 patient was treated under general anaesthesia as the infection caused a late bleeding in the maxillary sinus.
Surgical antibiotic prophylaxis was administered at the primary surgical procedure in 5 of the 6 patients that experienced a wound infection, amoxicillin-clavulanate (n=3) and clindamycin (n=2) were used. The infection-rate was higher in patients treated with clindamycin than in patients treated with amoxicillin-clavulanate (p=0.03).
Two 8mg gifts of dexamethasone were administered perioperatively in 2 of the 6 patients that developed a wound infection.
No association existed with an intra-oral surgical approach (p=0.88) and reduction without fixation did not result in less wound infections (p=0.32).
The occurrence of wound infection per fracture category is listed in Table 5. A tendency towards increasing incidence of wound infection was observed from category A to C (p=0.12).

Secondary surgical procedures of ZMC, orbital floor and extraocular muscles
Secondary surgical procedures of the ZMC, orbital floor, and/or extraocular muscles are listed in Table 5.
C-type fractures were associated with correction of ZMC malreduction by re-ORIF or a zygoma-osteotomy (p=0.03), secondary orbital floor reconstruction (p<0.01), and extraocular muscle correction (p=0.04).
Three of the 48 cases treated by reduction without fixation (6%) showed re-dislocation, necessitating ORIF of the ZMC. Re-dislocation did not occur after ORIF.

Table 5: Complications and secondary surgical procedures.

	A-type, incomplete fractures (n=32)	**B-type, tetrapod fractures (n=52)**	**C-type, comminuted fractures (n=42)**	**All patients (n=153)**
Complications				
Wound infection	0	2 (4%)	3 (7%)	6 (4%)
Secondary surgical procedures of ZMC, orbital floor and extraocular muscles				
Correction of ZMC malreduction	2 (6%)	0***(p=0.02)*	5 (12%) ** *(p=0.03)*	7 (5%)
Treatment of ZMC re-dislocation* *(p=0.02)*	3 (9%)** *(p<0.01)*	0	0	3 (2%)
OF revision (after primary reconstruction)	1 (3%)	0	2 (5%)	3 (2%)
OF secondary reconstruction (no primary reconstruction)* *(p=0.01)*	0	0	4 (10%) ** *(p<0.01)*	4 (3%)
Extraocular muscle correction	0	0	2 (5%) ** *(p=0.04)*	2 (1%)
Any	5 (16%)	0 ***(p<0.01)*	9 (21%) ** *(p=0.01)*	14 (9%)

OF: orbital floor
*: Statistically significant correlation with fracture classification.
**: Statistically significant association with individual fracture category.

Sequelae of lower eyelid approaches

Lower eyelid malposition after primary treatment of the ZMC fracture with a lower eyelid approach occurred in 8 out of 37 cases (22%).

In 6 cases (16%) the sequelae were possibly related to the lower eyelid approach. Persisting ectropion occurred in 2 cases (5%), one of which needed secondary correction. Persisting entropion occurred in 2 cases (5%), which were both corrected secondarily. Lateral canthus dystopia occurred in 2 cases (5%), for which in 1 case secondary lateral canthopexy was performed.

One patient (3%) developed a superficial wound infection at the site of a transconjunctival incision with lateral canthotomy. This was one of the patients who later developed entropion requiring secondary correction.

In 2 cases (5%) the lower eyelid sequelae were likely unrelated to the lower eyelid approach. In 1 of these cases the periorbital soft tissues were severely injured, necessitating secondary reconstruction of the nasolacrimal duct system and lateral tarsorrhaphy. In the other case secondary re-fixation of the medial canthal ligament was performed.

Discussion

In our cohort C-type (comminuted) fractures were associated with more secondary corrections for ZMC malreduction (12%, p=0.03), more secondary reconstructions of the orbital floor (10%, p<0.01), and more functional corrections of diplopia by extraocular muscle correction (5%, p=0.02).

C-type fractures also resulted in increased incidence of facial asymmetry (21%), enophthalmos (13%), diplopia (13%), transient facial nerve palsy (5%), persistent facial nerve palsy (3%), and wound infection (7%). However, these associations did not reach statistical significance.

The absence of a statistically significant association of C-type fractures with asymmetry, enophthalmos and diplopia in our cohort might be due to insufficient study power, as other authors published similar findings of increased incidence in comminuted fractures [8,11].

Zingg et al. [8] evaluated 1.025 cases. They found asymmetry occurred in 12% of all cases, and in 16% of the cases with comminuted fractures (p=0.01). Enophthalmos with diplopia occurred in 4% of all cases, and in 9% of the cases with comminuted fractures (p<0.01).

In our cohort, 3 patients with C-type fractures were treated with reduction without fixation by percutaneous traction hook or a Gillies temporal approach. In 2 of these cases a postoperative CT was obtained, both revealed significant asymmetry of the ZMC. One of these patients needed a zygoma-osteotomy and secondary orbital floor reconstruction. Reduction without fixation is not recommended in C-type fractures.

In our cohort 4% of the patients developed a wound infection. This is consistent with incidences of 2-8% reported in the literature [12–14].
Snäll et al. [15] prospectively studied the influence of perioperative glucocorticosteroid treatment on surgical wound healing. Disturbances in surgical wound healing occurred in 24% of the patients treated with dexamethasone, versus 3% in control subjects ($p=0.02$). In our cohort 2 of the 6 patients who experienced a wound infection were treated with dexamethasone perioperatively. Consequently we feel that the use of perioperative glucocorticosteroids for minimizing oedema should not be performed routinely. Glucocorticosteroids should be limited to cases with a strong medical indication.
An association between wound infections and an intraoral surgical approach has been reported [15,16]. No such association was found in our cohort.

In our cohort 37 lower eyelid approaches were performed in 153 patients. Malposition of the lower eyelid due to the approach occurred in 6 cases (16%), in 4 of these cases (11%) secondary correction was performed.
Ridgway et al. [17] performed a meta-analysis of sequelae after lower eyelid approaches for facial fracture repair. In 2,086 patients sequelae occurred in 6.8%, ectropion in 4.7% and entropion in 0.5%. Compared to these numbers, incidence of sequelae of lower eyelid approaches was high in our cohort. However in the meta-analysis the reported rates of ectropion and entropion varied greatly per publication. For instance, in transconjunctival incisions ectropion occurred in 0-22% and in subciliary incisions ectropion occurred in 2-42%.
Similarly in publications focusing on ZMC fracture repair, Ellis and Kittidumkerng [4] report a 20% rate of persisting sequelae after lower eyelid approaches, whereas in Zingg et al. [8] this is 1%.
It seems likely that severity and mechanism of trauma, degree of soft tissue injury, and type and extensiveness of the underlying fracture strongly influence the risk of developing lower eyelid sequelae [18]. Differences in composition of patient groups, study methods, and in outcome definitions may explain the large variation of incidences of sequelae reported in the literature.
Regardless of the exact incidence of sequelae of lower eyelid approaches, the abundance of publications on the subject confirms that postoperative lower eyelid malposition is a risk of lower eyelid approaches that needs to be considered. Consequently we feel lower eyelid approaches in ZMC fracture repair should be limited to cases that require orbital floor reconstruction and cases with severe disruption of the infraorbital rim.

In our cohort 1 patient (0.7%) suffered from superior orbital fissure syndrome and 3 patients (2%) from traumatic optic nerve neuropathy (TON). Reported incidence of superior orbital fissure syndrome in maxillofacial fractures is 0.3-0.8% [19,20]. Reported incidence of TON in patients with maxillofacial fractures is 2-6% [21,22].

Remarkably, all patients with TON in our cohort had incomplete ZMC fractures (p=0.02). A possible explanation is that in incomplete ZMC fractures the orbital compartment is confined due to the intact zygomatic pillars, which allows for an increase in orbital pressure due to haematoma and oedema. Whereas in tetrapod and comminuted fractures a natural and instantaneous decompression of the orbital compartment occurs. In contrast, Al-Qurainy et al. [23] found a higher incidence of TON in comminuted fractures.

Conclusion

Treatment outcome, as measured by sequelae upon postoperative follow-up and secondary surgical procedures, in C-type ZMC fractures is less favourable than treatment outcome in A-type and B-type ZMC fractures.
It is in C-type (comminuted) ZMC fractures that technologies such as intraoperative (conebeam) computed tomography imaging, surgical navigation devices and 3D-planning software are most likely to improve treatment outcome.

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Chapter 4

Intraoperative imaging for the repair of zygomaticomaxillary complex fractures: a comprehensive review of the literature

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Abstract

Background
Intraoperative imaging seems to be the next step to improve surgical outcome in the treatment of zygomaticomaxillary complex (ZMC) fractures. Many publications have appeared on intraoperative imaging for trauma surgery, but in most hospitals intraoperative imaging is not routinely performed for ZMC fracture repair. The goal of this review was to assess the value of intraoperative imaging in ZMC fracture repair.

Methods
The literature was reviewed with focus on the effects of intraoperative imaging on facial symmetry, fracture reduction and the frequency of additional reduction after intraoperative imaging in zygomaticomaxillary complex fractures.

Results
Six publications were found on the frequency of additional reduction after intraoperative imaging in zygomaticomaxillary complex fracture repair. Revision of the reduction of the zygoma was performed in 18% (95%CI 10.5-29.0%), revision of the orbital floor was performed in 9% (95%CI 3.6-17.2%). No publications were found on the effects of intraoperative imaging on facial symmetry or on the accuracy of fracture reduction.

Conclusions
Information obtained from intraoperative imaging often has consequences on the surgical management of ZMC fractures. However, the effect on restoration of facial symmetry and fracture reduction is yet to be established.

Zygomaticomaxillary complex (ZMC) fractures are common fractures in facial trauma[1–3]. Primary surgical treatment is required in case of dislocation of the ZMC to restore facial symmetry; to prevent soft-tissue consequences such as cheek ptosis, epihora and lagophtalmos; to restore mouth-opening in cases of trismus due to coronoid impingement; to restore ocular globe position; and to resolve infraorbital nerve hypesthesia[4].

Anatomical reduction at all points of articulation is the most reliable method to ensure a positive outcome. The fractured points of articulation are usually exposed indirectly as to avoid incisions in the face and to reduce the risk of severing branches of the facial nerve. Indirect approach of the fractures and the associated limited visualization makes the anatomical reduction a challenge.

Intraoperatively the reduction is verified by tactile and auditory feedback (the auditory ‘click’) during manipulation, absence of palpable steps at the points of articulation, direct visualization of the fractures through surgical exposure and clinical assessment of malar projection and facial symmetry. However, posttraumatic swelling, surgically induced swelling and comminution of the fractures can hamper the intraoperative clinical assessment of fracture reduction. Consequently, postoperative radiographic images frequently show suboptimal results[5].

The zygomatic bone, in articulation with the maxilla and the greater wing of the sphenoid, forms the fronto-lateral part of the orbital floor. ZMC fractures are frequently accompanied by a fracture of the maxillary part of the orbital floor. In some cases a fracture of the ethmoid of the medial orbital wall is also involved.

Inferior rectal muscle entrapment, orbital content herniating into the maxillary sinus, early enophtalmos or hypoglobus, and large orbital floor defects that are expected to cause late enophtalmos or hypoglobus are indications for primary orbital floor exploration and repair[6].

The goal of orbital floor repair is restoration of ocular globe position and mobility through restoration of orbital volume and orbital floor continuity. Factors making repair more challenging are large orbital floor defects in which it is difficult to place the orbital floor implant on the posterior ledge and involvement of the medial orbital wall in which it is necessary to insert an obtuse angled implant with careful placement of the medial bulge between the orbital floor and medial orbital wall.

Radiographic imaging is routinely performed postoperatively. However, suboptimal outcomes of the primary intervention rarely lead to a second surgical intervention [7]. This implicitly suggests that suboptimal results are often accepted when further improvement of facial symmetry is weighed against the burden of a second surgical intervention and general anesthesia.

Intraoperative imaging seems to be the next step to improve surgical outcome in ZMC fracture repair. With intraoperative imaging the reduction of the zygoma is assessed immediately, allowing for further reduction in the same session when indicated, thus avoiding the need for a second surgical intervention. C-arm fluoroscopy, ultrasonography, spiral computed tomography (spiral-CT) and cone beam computed tomography (CBCT) are the available imaging modalities. Spiral-CT and CBCT have the additional advantage that the orbital floor and orbital floor repair can be assessed on the acquired images.

Intraoperative C-arm fluoroscopy is available in most hospitals. Fluoroscopy can provide both still shots and real-time imaging during manipulation. On the submentovertex view zygomatic arch contour and malar projection can be assessed. The maxillozygomatic, sphenozygomatic and frontozygomatic articulation may be difficult to assess due to the effects of superimposition. Adequate assessment of the orbital floor is not possible on fluoroscopy.

Intraoperative ultrasonography offers good visualization of the zygomatic arch and possibly the frontozygomatic and infraorbital articulation. The maxillozygomatic and sphenozygomatic articulation are however harder to visualize and malar projection can not be assessed with ultrasonography. Assessment of the orbital floor is possible with ultrasonography, however accuracy is found to be lower than on CT[8,9]. Care should be exerted not to re-dislocate the fracture through local pressure with the transducer, especially in cases in which no internal fixation is applied.

CT has become the standard in preoperative imaging of facial fractures[10]. All points of articulation, zygomatic arch contour, malar projection and the orbital floor can be assessed with CT. Intraoperative spiral-CT with a mobile CT-scanner has been described for the treatment of ZMC fractures[11–14]. Its application is not common due to limited availability and practical limitations such as the weight and size of the equipment.
Cone beam CT (CBCT) is a relatively new imaging modality. A C-arm CBCT scanner provides accurate intraoperative CT images at lower radiation exposure than conventional CT and has approximately the same size and weight as a C-arm fluoroscope[15–18].

The value of intraoperative imaging is measured primarily by observable improved esthetic outcome (i.e. improved restoration of facial symmetry) and secondarily by improved reduction of the zygoma and orbital floor on radiographic imaging. Ideally this should be tested in a randomized controlled trial.

Improved reduction of the zygoma and orbital floor on radiographic imaging can also be assessed longitudinally in a cohort study. The comparison of the intraoperative images before and after additional revisions can be used to assess the consequences of intraoperative imaging on the definitive reduction of the zygoma and/or orbital floor. In combination with calculating the percentage of patients who undergo additional reduction of the zygoma or orbital floor following intraoperative imaging, this would allow for an adequate estimate of the value of intraoperative imaging.

Methods

Using PubMed, MEDLINE-database was searched in December of 2013 for articles focusing on the use of intraoperative imaging for the repair of ZMC fractures.

Articles describing the use of intraoperative spiral-CT, C-arm CBCT, ultrasonography or C-arm fluoroscopy in ZMC fracture repair were included. Articles on isolated zygomatic arch fractures were excluded. The references of the included articles were screened for publications that might have been missed in the initial search.

The flow of information was managed in compliance with the principles of the PRISMA statement[19]. Search results were screened for inclusion on title and abstract. Publications that passed the title and abstract screening, and publications in which the screening was inconclusive were subjected to full-text screening against the in- and exclusion criteria.

Selected for further quantitative analysis were articles that assessed esthetic and/or radiographic outcome of ZMC fracture repair with intraoperative imaging vs. without intraoperative imaging; articles that reported on the frequency of additional reduction of the zygoma or orbital floor during the same procedure following intraoperative imaging; and articles that compared the radiographic images before and after additional reduction following intraoperative imaging. Case reports were excluded from quantitative analysis.

In publications where overlap of data was suspected, the authors were contacted and asked for confirmation.

Ninety-five percent confidence intervals (95%CI) were calculated using the Clopper-Pearson exact method for binomial proportions[20].

Screening and data extraction were performed by WMMTvH.

Results

The search query yielded 153 results on MEDLINE. On title and abstract screening 135 publications did not meet the inclusion criteria, consequently 18 publications were subjected to full-text screening. After full-text screening 13 publications were included, 5 publications were excluded as they focused on isolated zygomatic arch fractures only. Screening of the references of the included publications yielded 2 extra publications that met the selection criteria, bringing the total of included publications to 15. An overlap of data was suspected between 2 publications[13,14]. The authors confirmed overlap of data was indeed present, consequently these 2 publications were considered as a single publication for the quantitative analysis. An overview of the included articles with focus on intraoperative imaging in ZMC fracture repair is presented in Table 1.

Out of the 15 included publications, 6 publications were suitable for quantitative analysis. These 6 studies reported on the frequency of additional reduction of the zygoma and/or orbital floor during the same procedure following intraoperative imaging in ZMC fracture repair.

No comparative studies that assessed esthetic and/or radiographic outcome of ZMC fracture repair with intraoperative imaging vs. without intraoperative imaging were available. No studies were found that compared the intraoperatieve radiographic images obtained after the initial treatment but before revision of the reduction of the zygoma or orbital floor, with radiographic images obtained after the revisions.

Articles on frequency of additional reduction after intraoperative imaging

The study design, the imaging modality used, the treatment before imaging, and the parameters assessed on intraoperatieve imaging varied between the included publications (Table 2).

All publications were cohort or pilot studies. One publication (*Wilde et al.* 2013)[18] specifically mentioned the retrospective nature of the study, the other publications did not mention whether the study was performed in a retrospective or prospective manner.

Three studies used mobile spiral-CT (*Stanley,* 1999; *Hoelze et al.,* 2001, *Hoffmann et al.,* 2002a) [11–13], two used C-arm CBCT (*Heiland et al.,* 2005; *Wilde et al.*, 2013)[16,18], and one study used ultrasonography (*Gülicher et al.,* 2006)[26].

Treatment before imaging consisted of closed reduction of the zygoma, open reduction with internal fixation of the zygoma (ORIF), or ORIF of the zygoma combined with orbital floor exploration and repair.

Table 1: Overview of the articles with focus on the use of intraoperative mobile spiral-CT, C-arm CBCT, ultrasonography or C-arm fluoroscopy for the repair of ZMC fractures.

	Imaging modality	Type of fractures	n=	Scope of research	Results
Wilde et al. 2013[18]	C-arm CBCT	ZMC	21	Assessment of clinical outcome and intraoperative consequences	Good reduction, no re-operations. Postoperative mild facial asymmetry in 4 patients. Intraoperative revision in 4 patients.
Pohlenz et al. 2009[17]	C-arm CBCT	ZMC	9	Analyses quality of images	Quality of images for bony structures nearly equals spiral-CT.
Heiland et al. 2005[16]	C-arm CBCT	ZMC	14	Analyses quality of images and intraoperative consequences	Quality of images good for assessing reduction, screw- and plate placement; good to medium for assessing orbital floor and medial wall; medium for assessing zygomatic symmetry. Revision in 0 patients.
Heiland et al. 2004[15]	C-arm CBCT	ZMC	1	Analyses quality of images	Images usable for assessing operative results.
Hoffmann et al. 2002a[13] / Hoffmann et al. 2002b[14] *	Mobile Spiral-CT	ZMC (3) and solitary zygomatic arch (3)	6	Analysis quality of images and intraoperative consequences	Good image quality for verification of reduction. Revision in 0 patients.
Hoelzle et al. 2001[12]	Mobile Spiral-CT	ZMC (20) and orbital floor (12) fractures	32	Intraoperative consequences	Revision in 3 patients with ZMC fracture. Revision in 1 patient with orbital floor fracture.
Stanley 1999[11]	Mobile Spiral-CT	ZMC	25	Intraoperative consequences	Revision in 7 patients.
Imai et al. 2011[21]	C-arm fluoroscopy	ZMC with displaced arch	38	Assessing reduction quality	Excellent or good reduction in all patients.
Czerwinski et al. 2009[22]	C-arm fluoroscopy	ZMC	1	Finding best view for assessment of reduction	70-90 degrees from coronal plane and 70-90 degrees from sagittal plane are proposed.
Badjate and Cariappa 2005[23]	C-arm fluoroscopy	ZMC	1	Presentation of concept	NA
Kiwanuka et al. 2013[24]	Ultrasonography	ZMC (1) and solitary zygomatic arch (2)	3	Analyses quality of images and realtime assessment of reduction	Accurate visualization of fracture line in zygomatic arch. Adequate reduction in all cases.

Table 1: Continued

	Imaging modality	Type of fractures	n=	Scope of research	Results
Soejima et al. 2009[25]	Ultrasonography	ZMC	23	Assessing reduction quality	Accurate reduction in all patients.
Gülicher et al. 2006[26]	Ultrasonography	ZMC (13) and solitary zygomatic arch (12)	25	Analyses quality of images and intraoperative consequences	Adequate visualization in 24 out of 25 patients. Revision in 7 of 13 patients with ZMC fractures.
Akizuki et al. 1990[27]	Ultrasonography	ZMC (2) and solitary zygomatic arch (1)	3	Presentation of concept	NA

*: These two studies (Hoffmann et al. 2002a13; Hoffmann et al. 2002b14) describe the same group of 6 patients (confirmed by the corresponding author).

Table 2: Description of publications included for quantitative analysis.

	Wilde et al. 2013[18]	Gülicher et al. 2006[26]	Heiland et al. 2005[16]	Hoffmann et al. 2002a**[13]	Hoelze et al. 2001[12]	Stanley 1999[11]
Study design	Retrospective cohort study	Cohort study	Cohort study	Pilot study	Cohort study	Pilot study
Number of patients	21	13*	14	3**	20***	25
Imaging modality used	C-arm CBCT	Ultrasonography	C-arm CBCT	Mobile spiral-CT	Mobile spiral-CT	Mobile spiral-CT
Treatment before imaging	ORIF or closed reduction of ZMC (no orbital floor repair)	ORIF of ZMC (no orbital floor repair)	ORIF of ZMC with orbital floor repair	ORIF of ZMC (no orbital floor repair)	Closed reduction or ORIF of ZMC with orbital floor repair if indicated	ORIF of ZMC, orbital floor repair if indicated
Parameters assessed on images	ZMC position and orbital floor	Zygomatic arch continuity	ZMC position and orbital floor	ZMC position	Orbital floor	ZMC position and orbital floor

* Gülicher et al. also included 12 patients with isolated zygomatic arch fractures; the findings in these patients were omitted as this review focuses on ZMC fractures only.
** Hoffmann et al. also included 3 patients with isolated zygomatic arch fractures; the findings in these patients were omitted as this review focuses on ZMC fractures only.
*** Hoelze et al. also included 12 patients with isolated orbital fractures; the findings in these patients were omitted as this review focuses on ZMC fractures only.

In the studies that used mobile spiral-CT (*Stanley,* 1999; *Hoelze et al.,* 2001, *Hoffmann et al.,* 2002a)[11–13] or C-arm CBCT (*Heiland et al.,* 2005; *Wilde et al.*, 2013)[16,18], the intraoperative images were used for assessment of the reduction of the zygoma and the orbital floor; assessment of the reduction of the zygoma only; or assessment of the orbital floor only. In the study that used ultrasonography (*Gülicher et al.,* 2006)[26], the intraoperative images were used for assessment of the continuity of the zygomatic arch only.

Additional reduction of zygoma

The reduction of the zygoma was assessed intraoperatively in a total of 76 patients in 5 different studies. Two studies used mobile spiral-CT (*Stanley,* 1999; *Hoffmann et al.,* 2002a)[11,13], two used C-arm CBCT (*Heiland et al.,* 2005; *Wilde et al.*, 2013)[16,18], and one study used ultrasonography (*Gülicher et al.,* 2006)[26]. Intraoperative imaging led tot additional reduction of the zygoma in 18% of the cases (95%CI 10.5-29.0%). The revision rate ranged from 0% to 54% (Table 3).

Table 3: Frequency of additional reduction of the zygoma following intraoperative imaging.

	Imaging modality	n=	Surgical approach to zygoma	Additional reduction rate (%)
Wilde et al. 2013[18]	C-arm CBCT	21	ORIF, 1 incision (oral vestibular); or closed reduction without fixation	2 (4.8%)
Gülicher et al. 2006[26]	Ultrasonography	13	ORIF, 2 or 3 incisions (lateral brow, subciliary and/or oral vestibular)	7 (54%)
Heiland et al. 2005[16]	C-arm CBCT	14	ORIF, 2 incisions (infraorbital, oral vestibular)	0 (0%)
Hoffmann et al. 2002a[13]	Spiral-CT	3	ORIF, 3 incisions (subciliary, lateral brow, oral vestibular)	0 (0%)
Stanley 1999[11]	Spiral-CT	25	ORIF, number and site of incisions not specified	5 (20%)
Total		76		14 (18%)

It should be taken into account that Gülicher et al.[26], using ultrasonography, assessed the continuity of the zygomatic arch only, using it as an indicator for zygoma position and projection.

The one study that used ultrasonography (*Gülicher et al.,* 2006)[26] reports a revision rate of 54%. When taking into account the studies that used CT or CBCT only, the average revision rate is 11% (range 0% to 20%; 95%CI 4.6-21.6%).

Extensiveness of the surgical exposition of the zygoma varied between the different studies. *Hoffmann et al.*[13] used 3 incisions, Gülicher et al.[26] used 2 to 3 incisions, Heiland et al.[16] used 2 incisions, and Wilde et al.[18] used 1 incision.

Additional reduction of orbital floor

The orbital floor was assessed intraoperatively in 80 patients in 4 different studies. Two studies used mobile spiral-CT (*Stanley,* 1999; *Hoelze et al.,* 2001)[11,12] and two used C-arm CBCT (*Heiland et al.,* 2005; *Wilde et al.*, 2013)[16,18]. Intraoperative imaging led to additional revisions in 9% of the cases (95%CI 3.6-17.2%). The revision rate ranged from 0% to 15% (Table 4).

Treatment approach of the orbital floor prior to imaging and consequently the purpose of the intraoperative imaging varied between the different studies. Heiland et al.[16] explored the orbital floor prior to imaging in all cases, and used the images to assess the reconstructed orbital floor and to judge whether revision was indicated. Hoelze et al.[12] explored the orbital floor prior to imaging on indication, and used the images to assess the need for exploration in the unexplored orbits and to assess the need for revision in the repaired orbits. Stanley et al.[11] explored the orbital floor prior to imaging on indication, and used the images to assess the repaired orbital floor and to judge

Table 4: Frequency of revision of orbital floor following intraoperative imaging.

	Imaging modality	n=	Approach to orbital floor prior to imaging	Purpose of intraoperative imaging	Revision rate (%)
Wilde et al. 2013[18]	C-arm CBCT	21	No exploration	Assess indication for exploration in unexplored orbits	2 (9.5%)
Heiland et al. 2005[16]	C-arm CBCT	14	Exploration and repair in all cases	Assess need for revision of repair in explored orbits	0 (0%)
Hoelze et al. 2001[12]	Mobile Spiral-CT	20	Exploration and repair if indicated	Assess need for revision of repair in explored orbits, and indication for exploration in unexplored orbits	3 (15%)
Stanley 1999[11]	Mobile Spiral-CT	25	Exploration and repair if indicated	Assess need for revision of repair in explored orbits	2 (8%)
Total		80			7 (9%)

whether revision was indicated. Wilde et al.[18] did not explore the orbital floor prior to imaging and used the imaging to aid in the decision whether the orbital floor should be explored.

Discussion

Intraoperative imaging led to additional reduction of the zygoma and/or orbital floor during the same procedure in 22% of the patients with ZMC fractures (95%CI 14.1-31.5%). The input given by the images was thus considered relevant by the surgeons and often influenced the surgical treatment.

Revision of the reduction of the zygoma was performed in 18%. A wide range of revision rates is observed (0% - 54 %), this is possibly in part explained by a difference in extensiveness of the initial treatment. Heiland et al.[16] and Hoffmann et al.[13] report a 0% revision rate using a relatively aggressive surgical approach through 2 and 3 incisions respectively. Wilde et al.[18], using a more conservative approach through a single oral vestibular incision or closed reduction, report a 10% revision rate. This theory is in part contradicted by the results of Gülicher et al.[26], who report a high revision rate despite a surgical approach through 2 to 3 incisions. Gülicher et al.[26] however use a different method of intraoperative imaging (ultrasonography of the zygomatic arch), thus caution should be exerted when comparing the results with those achieved after intraoperative spiral-CT or CBCT.

Revision of the orbital floor was performed in 9%. Assessment of the orbital floor was performed in studies using spiral-CT or CBCT only. Treatment approach to the orbital floor and purpose of the intraoperative imaging with regards to the orbital floor varied between the studies. Either assessment of the indication for exploration of the orbital floor after initial reduction of the zygoma without orbital floor repair, or assessment of the orbital floor repair after initial reduction of the zygoma with orbital floor repair, were performed.

A combined approach, as performed by Hoelzle et al.[12], seems most appropriate. In those cases where the indication for orbital floor exploration exists preoperatively, the repair can be evaluated after reduction of the zygoma and subsequent reconstruction of the orbital floor. In those cases where no indication for orbital floor exploration exists preoperatively, the orbital floor can be reassessed after the reduction of the zygoma. Reduction of the zygoma may enlarge the associated orbital floor defect[28,29], thus in cases in which no indication for orbital floor exploration exists preoperatively, orbital floor exploration might be indicated after reduction of the zygoma.

At our center, the C-arm CBCT is used intraoperatively regularly in the treatment of maxillofacial fractures. It is found very useful, especially in case of multiple and/or comminuted fractures. In the treatment of ZMC fractures, the authors specifically value the possibility to assess non-exposed buttresses, the orbital floor and orbital implant position. Visualization of the non-exposed buttresses may facilitate less invasive surgery through fewer incisions because it allows for non-invasive visualization of the fracture reduction; this effect is also described by Stanley et al.[11] and Wilde et al.[18].

In our experience intraoperative imaging rarely increases patient exposure to ionizing radiation as the intraoperative imaging obviates postoperative imaging. Consequently, only in the cases in which the imaging has therapeutic consequences patient radiation exposure is increased by repeated intraoperative scanning.

Justification for the use of intraoperative imaging should ideally be based on scientific evidence of superior treatment results. The Level of Evidence[30] for the use of intraoperative imaging is still slim. The main concern is that the available evidence is indirect. Although it seems established that intraoperative imaging leads to direct revisions of the zygoma and orbital floor, the positive consequences of these revisions is merely implied and yet to be proven. There is no evidence that additional reduction following intraoperative imaging correlates with improved restoration of facial symmetry or improved fracture reduction. The effect of intraoperative imaging on restoration of facial symmetry and fracture reduction in ZMC fracture repair has, to our knowledge, not been assessed comparatively or longitudinally in any paper.

The lack of comparative studies is likely explained by the high number of patients needed to attain the appropriate study power. As intraoperative imaging has a consequence on the therapy provided in only a part of the cases, study- and control-group size would have to be substantial to provide significant evidence.

Chen et al.[31] comparatively assessed the effect of intraoperative fluoroscopy on restoration of facial symmetry and fracture reduction in zygomatic arch fracture repair. Photographs and CT-scans after zygomatic arch fracture repair with vs. without intraoperative imaging with C-arm fluoroscopy were rated on facial symmetry and fracture reduction respectively. The results on fracture reduction and facial symmetry were both in favor of intraoperative imaging, however there is no mention of assessor blinding for the use of intraoperative imaging in the evaluation of either. Especially assessing facial symmetry on photographs is qualitative and subjective and should be performed blinded.

Of course the use of intraoperative imaging for ZMC fracture repair should also be put in an economic context. Hardware purchase and maintenance and a prolonged operating time add to the treatment cost. This should be weighed against the cost reduction achieved by the prevention of revision surgery in inadequately treated cases, and the potential cost reduction achieved by omitting postoperative imaging.

Conclusion

Intraoperative imaging for zygomatic fracture repair is found to be useful as it motivated the surgeon to change the reduction of the zygoma and/or orbital floor in 22% of the patients. The clinical relevance of these immediate revisions is yet to be established.

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Chapter 5

A novel method for quantitative 3-dimensional analysis of zygomaticomaxillary complex symmetry

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Article submitted

Abstract

Objective

To develop a reliable and accurate method to quantify the symmetry of the zygomaticomaxillary complex (ZMC).

Methods

Virtual 3D-models where created from 53 computed-tomography scans; 15 'healthy' subjects without maxillofacial disorders, and 38 patients with a ZMC fracture requiring surgical treatment.

Asymmetry of the ZMC was measured using a mirroring and surface-based matching technique that uses the anterior cranial fossa to determine the symmetrical position of the ZMC. The mean surface distance (MSD) between the ZMC-surface and the symmetrical position is calculated, this is a measure for ZMC asymmetry.

Reliability of the method was tested in the 15 healthy cases. Inter- and intra-observer variabilities were assessed. Accuracy was assessed by comparing ZMC asymmetry between the healthy cases and the ZMC fracture cases, and by assessing correlation of ZMC fracture severity with ZMC asymmetry.

Results

The average MSD of the 15 healthy cases was 1.40mm±0.54. The average MSD of the 38 ZMC fracture cases was 2.69mm±0.95, significantly higher ($p<0.01$). ZMC asymmetry correlated with fracture severity ($p=0.01$).

Intra-rater ICC was 0.97 with an intra-rater variability of 0.09mm± 0.11. Inter-rater ICC was 0.95 with an inter-rater variability of 0.12mm±0.13.

Conclusion

The method is reliable and accurate for quantitative 3D-analysis of ZMC-symmetry. It takes into account both the asymmetry caused by the shape of the ZMC as well as asymmetry caused by the position of the ZMC.

Clinical relevance

This method can aid in the evaluation of disorders of the ZMC, and the planning and postoperative evaluation of surgical procedures of the ZMC.

Introduction

The zygomaticomaxillary complex (ZMC) is a bilateral symmetrical eminence at the antero-lateral aspect of the face. Distortion of ZMC form and position is often encountered in ZMC fractures, which are common fractures in maxillofacial injuries[1–3]. Asymmetry of the ZMC may also be present in congenital syndromes such as craniofacial microsomia, Crouzon syndrome and Treacher Collins syndrome[4,5].

Visualization of the osseous ZMC is best attained with Computed Tomography (CT)[6,7]. ZMC fractures are examined on CT-images to determine the indication for surgical treatment and to evaluate treatment results postoperatively. In the clinical setting, the assessment of ZMC asymmetry on axial, coronal and sagittal CT slices and a 3D reconstruction is usually qualitative.

Several methods have been developed for the quantitative assessment of the ZMC symmetry on CT[8–12]. These methods are either linear distance or angle measurements within CT-slices or coordinates-based methods in which a 3D reference frame is constructed of the CT-data. A disadvantage of these methods is that the asymmetry of only specific landmarks is quantified, whereas the CT provides data on the entire ZMC. Most of the data is thus left unused. Moreover, imprecision is introduced by the placement of landmarks[13]. Analysis of the entire ZMC surface is a superior method for measuring ZMC symmetry, as it uses all available data on the ZMC in the CT-scan, which increases the accuracy of the method.

Three studies that describe methods to quantify the asymmetry of the entire ZMC surface have been published[14–16]. In these studies, the mirrored contralateral ZMC-surface is placed at the symmetrical position and used to determine the level of asymmetry of the non-mirrored ZMC. ZMC asymmetry is quantified by measuring the shortest distance between the surface of the original and mirrored ZMC at a multitude of points throughout the surface of the ZMC. The mean surface distance of all these points is used as a measure for ZMC asymmetry. A disadvantage of the methods described in these studies, is that areas adjacent to the ZMC or the ZMC-surface itself are used as reference-area to determine the symmetrical position of the mirrored ZMC. In this way the asymmetry of the ZMC itself is quantified, without considering the position of the ZMC within the viscerocranium. Moreover, in ZMC fractures these reference areas are often fractured and displaced, which would hamper the analysis. The aim of this study is to develop a reliable and accurate method of quantifying ZMC symmetry, taking into account both the asymmetry of the shape of the ZMC and the asymmetry of the position of the ZMC within the viscerocranium.

Materials and methods

A cross-sectional anthropometric study was performed. The local ethics committee exempted this study from formal ethical review (reference number WAG/mb/19/012910).

Data selection

This study contained two groups of patients, 15 subjects without maxillofacial disorders (hereafter called 'healthy cases'), and 38 patients with a ZMC fracture requiring surgical treatment (hereafter called 'ZMC fracture cases').
For the healthy cases, CT scans of the facial bones of 15 adult trauma patients were randomly selected. Inclusion criteria were: absence of fractures to the head and neck area, age >18 years, CT scan performed with a maximum slice thickness of 1.0mm and slice increment of 1.0mm. Exclusion criteria were: presence of maxillofacial fractures, congenital or acquired disorders causing maxillofacial asymmetry.
For the ZMC fracture cases, the preoperative CT-scan of patients that were included in a prospective cohort study were used. Inclusion criteria for the fracture group were: age > 18 years, unilateral ZMC fracture that requires surgical treatment. Exclusion criteria were: bilateral ZMC fractures, Le Fort II or III midfacial fractures and mentally incompetent patients.

Analysis of ZMC symmetry

The digital imaging and communications in medicine (DICOM) files of the CT scans were imported in Mimics Medical (version 20.0; Materialise, Leuven, Belgium). From each CT scan a virtual 3D model was created which was exported in 3-Matic Medical (version 12.0, Materialise, Leuven, Belgium).
The outer surface of the left and right ZMC and the surface of the Anterior Cranial Fossa (ACF) were selected in a standardized manner. The boundaries for defining the ZMC surface were the article tubercle of the temporal bone dorsally, the orbital midline medially, the frontozygomatic suture cranially and the maxillozygomatic suture caudally (Figure 1). The boundaries for defining the ACF surface were the dividing line between the ACF and the middle cranial fossa dorsally and a plane 1cm above the superior orbital rim parallel to the Frankfurt Horizontal plane cranially (Figure 2).
The created 3D model with the isolated ZMC-surfaces and ACF-surface is shown in Figure 3A. Subsequently, a mirrored duplicate of the entire 3D-model, including the ACF and ZMC surfaces was created (Figure 3B).
The mirrored 3D-model is then superimpositioned with the original 3D-model, using the ACF-surface as reference area (Figure 3C). First, the mirrored ACF was matched roughly with the original ACF on 5 manually placed corresponding points on both objects. Then, the mirrored ACF-surface was matched to the best fit with the original ACF-surface by surface-based matching with an iterative closest point algorithm. A

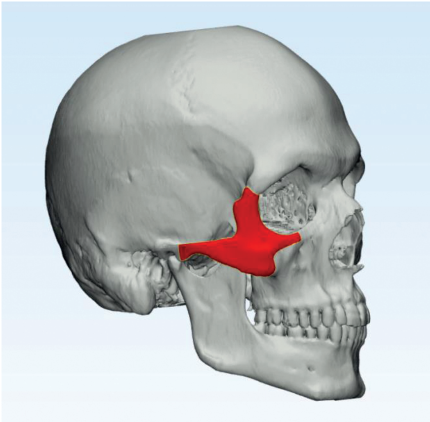

Figure 1: Boundaries used for isolating the ZMC surface.
- Dorsal boundary: articular tubercle of the temporal bone.
- Medial boundary: orbital midline.
- Cranial boundary: frontozygomatic suture.
- Medio-caudal boundary: zygomaticomaxillary suture.

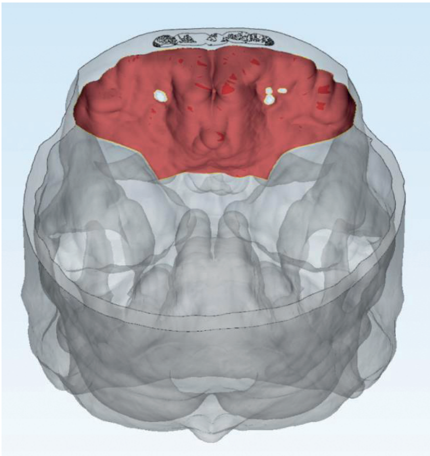

Figure 2: Boundaries used for isolating the ACF surface.
- Cranial boundary: plane 1cm above the superior orbital rim, parallel to the Frankfurt Horizontal plane.
- Dorsal boundary: dividing line between the anterior and the middle cranial fossa.

distance threshold of 5.0mm and 100 iterations were used for the surface-based matching; the matching process was repeated until a constant average surface distance was obtained.

During this alignment, the 3-dimensional spatial relation between the mirrored 3D-model (including the mirrored ZMC surfaces) and the mirrored ACF was preserved. Consequently, the mirrored ZMC-surfaces made the same movement as the mirrored ACF, and are thus projected over the non-mirrored ZMC-surfaces in the symmetrical position (Figure 3D).

After alignment a surface distance analysis was carried out between the outer surfaces of the left-side ZMC and the mirrored right-side ZMC in the healthy cases (Figure 3E). The surface distance analysis calculated the shortest distance from an average of 2.67 points per mm2 on the left-side ZMC to the surface of the mirrored right-side ZMC. The outcome measures for ZMC symmetry was defined as the mean surface distance (MSD) in millimeters. In the ZMC-fracture cases a surface distance analysis was carried out between the outer surfaces of the fractured ZMC and the mirrored contralateral ZMC.

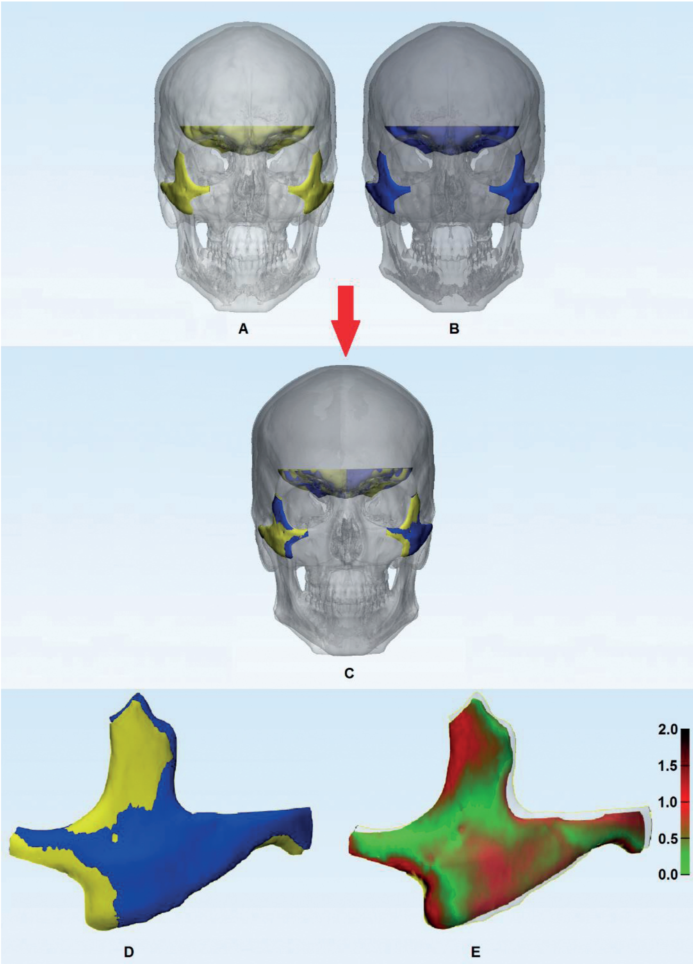

Figure 3: Overview of the method for measuring ZMC asymmetry.
A: Original 3D-model of the CT with the isolated ZMC and ACF surfaces.
B: Mirrored 3D-model of the CT with the isolated ZMC and ACF surfaces.
C: Mirrored 3D model (blue) superimpositioned on original 3D model (yellow) by surface-based matching of the mirrored ACF of the blue model with the non-mirrored ACF-surface of the yellow model.
D: Right-side mirrored ZMC-surface (blue) projected over the left-side original ZMC-surface (yellow) in the symmetrical position.
E: Surface distance analysis of the right-side mirrored ZMC-surface projected over the left-side original ZMC-surface, with distance map in millimeters.

In the healthy cases, an additional surface distance analysis was performed to calculate the MSD between the ACF and the mirrored ACF, to evaluate the symmetry of the reference area.
In the healthy group, the 15 datasets were independently analyzed by two authors (WdK and WvH), one author (WdK) analyzed all datasets twice. In the ZMC fracture group, the 38 datasets were analyzed by one author (WdK). Both authors were trained to use Mimics and 3-Matic software.

ZMC fracture classification

The ZMC fracture classification that was used is based on the classification of Zingg et al.[17], it is described more extensively in a previous publication[18]. Incomplete ZMC fractures (A-type), complete ZMC fractures (B-type), and comminuted ZMC fractures (C-type) are distinguished. Fracture severity increases from A-type, to B-type, to C-type. The ZMC fractures were classified by the treating Oral and Maxillofacial Surgeon.

Statistical analysis

To assess reproducibility two-way mixed intraclass correlation coefficients (ICC) were calculated of the 15 healthy cases to quantify inter- and intra-observer agreement. An ICC above 0.9 was considered excellent[19].
The data on ZMC asymmetry in the healthy cases did not adhere to the normal-distribution as it was skewed. After log-transformation the data was normally distributed. Consequently several options exist for comparing ZMC asymmetry between the ZMC fracture cases and the healthy cases: a parametric test of the original data (independent samples T-test), a non-parametric test of the original data (Mann whitney U-test), or a parametric test of the log-transformed data (independent samples T-test). All these options gave the identical outcome.
Spearman rank correlation was used to determine the correlation between the ZMC fracture classification and ZMC asymmetry.
Statistical analysis was performed with SPSS Statistics (IBM Corp. Released 2017. IBM SPSS Statistics for Windows, Version 25.0. Armonk, NY: IBM Corp).

Table 1: Patient characteristics.

Healthy cases (n=15)		
Mean age		27
Male : female		8 : 7
ZMC-fracture cases (n=38)		
Mean age		43
Male : female		25 : 13
Fracture characteristics	Left : Right	24 : 14
	A-type	14 (37%)
	B-type	17 (45%)
	C-type	7 (18%)

Results

In total 53 patients were included in this study, the patient characteristics are displayed in Table 1.

ZMC symmetry

In the healthy cases, ZMC asymmetry expressed in MSD was 1.40mm (SD 0.54) on average.
In the ZMC fracture cases, MSD was 2.69mm (SD 0.95) on average. In A-type fractures average MSD was 2.37mm (SD1.00), in B-type fractures average MSD was 2.69mm (SD0.88), and in C-type fractures average MSD was 3.33mm (SD 0.79).

Reliability

In healthy cases analysis of ZMC asymmetry was performed 3 times (Table 2). The intra-rater ICC was 0.97 with an intra-rater variability of 0.09mm ± 0.11mm (95% CI 0.03–0.15). The inter-rater ICC was 0.95 with an inter-rater variability of 0.12mm ± 0.13mm (95% CI 0.04–0.19).

Accuracy

ZMC asymmetry was higher in the ZMC fracture cases than in the healthy cases (MSD 1.40mm vs 2.69mm; $p<0.01$).
In the ZMC fracture cases, ZMC asymmetry correlated with the classification for ZMC fracture severity, increasing asymmetry was observed from A-type, to B-type, to C-type ZMC fractures ($p=0.01$).

Symmetry of the reference area

The ACF asymmetry expressed in MSD was 0.70mm (SD 0.12) on average.

Table 2: MSD in millimeters between the left-side ZMC and the mirrored right-side ZMC in the healthy cases.

Case	Observer 1-1	Observer 1-2	Observer 2	Average MSD
1	1.47	1.41	1.35	1.41
2	0.80	0.82	0.73	0.78
3	0.97	0.98	1.15	1.04
4	1.23	1.28	1.41	1.31
5	1.25	1.24	1.22	1.23
6	0.80	0.91	0.76	0.82
7	1.67	1.66	1.65	1.66
8	1.82	1.91	1.85	1.86
9	1.31	1.13	1.11	1.19
10	1.22	1.29	1.26	1.26
11	2.98	2.56	2.46	2.67
12	0.91	0.93	0.95	0.93
13	2.32	2.43	2.41	2.39
14	1.09	1.15	1.06	1.10
15	1.40	1.27	1.26	1.31
All				1.40

Discussion

Analysis of ZMC symmetry in the 15 CT-scans of the healthy cases showed a mean ZMC asymmetry of 1.40mm MSD. The intra-rater ICC was 0.97 with an intra-rater variability of 0.09mm ± 0.11mm (95% CI 0.03–0.15). The inter-rater ICC was 0.95 with an inter-rater variability of 0.12mm ± 0.13mm (95% CI 0.04–0.19).The calculated inter- and intra-observer ICC were >0.9, which indicates that the method is highly reproducible and thus reliable.

The accuracy of our method is more challenging to assess, as no gold standard exists for measuring ZMC symmetry. We decided to determine if the outcome of the method correlated with the clinical perception, by comparing ZMC asymmetry in ZMC fracture cases that required surgical treatment (and thus deemed displaced by the clinician) with ZMC asymmetry in healthy cases. A statistically significant difference was observed (MSD 1.40mm vs 2.69mm; $p<0.01$). Additionally, we assessed whether the outcome of the method correlated with a classification for ZMC fracture severity. Increasing asymmetry was observed from A-type (2.37mm), to B-type (2.69mm), to C-type (3.33mm) ZMC fractures ($p=0.01$). These findings indicate that the method is accurate. There are three previous studies which assessed ZMC symmetry of the entire ZMC surface, in these studies an MSD ranging between 0.84 mm – 0.9 mm was found[14–16]. At 1.40mm MSD our study measured a higher value for ZMC asymmetry. However, these three studies used methods in which the reference for placing the mirrored contralateral ZMC in the symmetrical position is the ZMC itself or a reference-area directly adjacent to the ZMC. Consequently, although these three studies are excellent in measuring the asymmetry of the ZMC itself, the asymmetry of the position of the ZMC within the viscerocranium is not taken into account. This might explain the lower MSD reported in these studies[14–16].

In our study the ACF is used as reference-area for placing the mirrored contralateral ZMC in the symmetrical position. The ACF surface is selected so that a part of the object surface is perpendicular to all three axes. This helps in the reliable superimposition of the mirrored ACF with the original ACF with surface-based matching, as a deviation in any direction would cause an increase in surface distance. Additionally, Nada et al.[20] reported that superimpositioning of 3D models derived from (CB)CT on the ACF is accurate and reproducible.

As previously addressed, by using the ACF as the reference area, the asymmetry of the position of the ZMC within the viscerocranium is reflected in the value for ZMC asymmetry. This is a key aspect to take into account, as the combination of the form of the ZMC with the position of the ZMC defines cheek projection and is therefore an important factor for facial appearance.

In addition, in case of a ZMC fracture, the reference areas described in Ho et al. 2016[14], Ho et al. 2017[15] and Gibelli et al. 2018[16] are distorted by the fracture, which is likely to influence the reliability of the method. This is less likely with the ACF as reference area as it is farther away from the ZMC. In the 38 patients with a ZMC fracture used in this study, the ACF was intact in all cases. In addition, the ACF surface is larger and therefore the surface-based matching is likely to be less sensitive to minor distortions within the surface in case it has been affected by the trauma.

Asymmetry of the ACF was assessed in the 15 cases without congenital or acquired asymmetry to evaluate the symmetry of the reference area, the MSD between the original and mirrored ACF was 0.70mm. This is less than 50% of the asymmetry of the ZMC.

Based on the arguments provided above and the excellent symmetry of the ACF we regard the ACF suitable to be used as reference area for measuring ZMC asymmetry.

The biggest limitation in our study is the way in which the surface distance is measured: from every point on the left-side ZMC the shortest distance to the surface of the mirrored right-side ZMC is calculated. In the ideal method, every point on the surface of the ZMC would be indexed with its corresponding point on the surface of the mirrored ZMC. The average distance between all corresponding points would better reflect the true ZMC asymmetry. The current method results in an underestimation of ZMC asymmetry as the distance from a point on the ZMC to the corresponding point on the mirrored ZMC surface is often larger than the distance to the closest point on the mirrored ZMC surface.

To the best of our knowledge, all studies on this subject have been performed with this limitation as the described ideal method does not yet exist.

A second limitation of our method is that it is less suitable in cases with asymmetry at the level of the anterior cranial fossa. This might be the case in certain congenital craniofacial disorders.

Conclusion

The proposed method is reliable and accurate for quantitative 3D-analysis of ZMC-symmetry. It takes into account both the asymmetry caused by the shape of the ZMC itself as well as asymmetry caused by the position of the ZMC within the viscerocranium.

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Chapter 6

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

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Abstract

An intraoperative conebeam computed tomography (CBCT) allows for immediate on-table assessment and revision of zygomaticomaxillary complex (ZMC) position and orbital floor (OF) treatment. This could potentially improve surgical outcome and prevent reoperations.
The aim of this prospective cohort study was to assess the accuracy of ZMC fracture reduction with intraoperative CBCT; to determine the rate of direct revisions after intraoperative imaging; to evaluate the effect of direct treatment revisions after intraoperative imaging; and to identify which ZMC fractures benefit most from intraoperative CBCT imaging.
Accuracy of ZMC fracture reduction was analysed by 3D-measurements of ZMC symmetry. ZMC fractures were categorised in three groups (incomplete, complete, comminuted), associations with treatment revisions were assessed.
Included were 38 patients with a unilateral ZMC fracture. In the study population average preoperative asymmetry was 2.69 mm(SD 0.95), and postoperative asymmetry was 1.67mm(SD 0.89). This improvement was statistically significant (paired samples T-test $p<0.01$). Postoperative asymmetry was comparable to the asymmetry in the healthy population (independent samples T-test $p=0.31$).
Intraoperative CBCT was followed by a treatment revision in 11 cases (29%), this was associated with ZMC fractures with comminution and/or OF involvement (89%; Pearson Chi Square $p<0.01$).
We recommend the use of intraoperative CBCT for ZMC fractures with comminution and/or OF involvement.

Introduction

Zygomaticomaxillary complex (ZMC) fractures are common in maxillofacial trauma patients[1,2]. Treatment of ZMC fractures can be challenging as anatomic reduction must be achieved to accomplish restoration of facial symmetry and aesthetics [3–5]. A retrospective cohort study in our hospital showed that after the intial repair, secondary surgical interventions are performed in 9% of ZMC fractures and in 21% of comminuted ZMC fractures[5]. An intraoperative conebeam computed tomography (CBCT) allows for immediate on-table assessment and revision of ZMC position and orbital floor (OF) treatment. This could potentially improve surgical outcome and prevent reoperations. A review showed that intraoperative imaging in ZMC fracture repair results in a 22% revision rate by the early recognition of inadequate initial treatment of the ZMC or OF on the intraoperative images[6]. Intraoperative imaging with CBCT was added in 2015 to our treatment protocol for ZMC fractures. This prospective study was performed to evaluate the effect of the incorporation of intraoperative CBCT imaging in the treatment protocol for ZMC fractures in our hospital. We aimed to assess quality of ZMC fracture reduction, to determine the rate of treatment revisions following intraoperative CBCT, to evaluate the effect of direct treatment revisions after intraoperative imaging, and to identify which ZMC fractures benefit most from intraoperative CBCT imaging.

Material and methods

A prospective cohort study was performed in accordance with the STROBE guidelines for reporting observational studies[7].

Patient selection

Patients aged 18 years and older that were to be treated surgically for a ZMC fracture between September 1st 2015 and October 31st 2017 at the department of Oral Maxillofacial Surgery in the University Medical Center Utrecht were eligible for participation in the study. Excluded were patients with bilateral ZMC fractures, patients with a Le Fort II or III fracture, and mentally incompetent patients. All patients meeting the selection criteria in the selected period were to be included in the study. Formal written consent was obtained from each patient for participation in the study.

Treatment protocol

Surgical treatment is performed under general anaesthesia. In cases without indication for exploration of the OF, closed reduction without fixation is attempted primarily. Unstable fractures are subsequently treated by open reduction and internal fixation at the lateral orbital rim or at the zygomatico-alveolar crest. If indicated further surgical exposure and more points of internal fixation are applied.

Primary OF exploration is performed in case of significant disruption or the OF; i.e. a large OF defect (>50%), loss of the key-area, significant herniation of orbital contents into the maxillary sinus, or decreased ocular motility due to inferior rectus muscle impingement.

Figure 1: Intraoperative imaging with C-arm CBCT.

After the initial treatment a CBCT scan is performed (BV Pulsera 12” with 3DRX, Philips Healthcare, Best, The Netherlands; Figure 1). Axial, coronal and sagittal slices, and a 3D-reconstruction can be viewed on the console of the CBCT to assess the position of

the ZMC and the OF. Insufficient ZMC fracture reduction and/or OF treatment is followed by immediate revision. After the revision, a new intraoperative CBCT-scan is performed to assess the revised treatment result.
If reduction of the ZMC fracture is expected to realign a significantly disrupted OF fracture, the intraoperative CBCT scan is performed after ZMC fracture reduction to confirm realignment of the OF. If the OF has realigned, no exploration of the OF is performed. In case significant disruption of the OF persists, then OF exploration and repair is performed, followed by a new intraoperative CBCT-scan to assess the OF treatment.
Treatment is performed by a staff surgeon with a resident, 8 staff surgeons were involved in the treatment of the patients in this study.

ZMC fracture classification
Figure 2 shows the ZMC fracture classification. The classification is described more extensively in a previous publication[5].

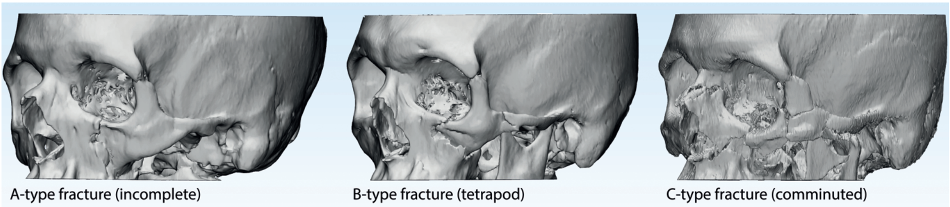

Figure 2: ZMC fracture classification.

Analaysis of accuracy of ZMC fracture reduction
Accuracy of ZMC fracture reduction was assessed by measuring ZMC asymmetry on the preoperative CT (before treatment) and on the intraoperative CBCT performed after (final) fracture reduction.
The CT-scans of 15 healthy adult patients were analysed to serve as healthy controls. These were randomly selected CT-scans of adult patients without maxillofacial fractures, or other forms of acquired or congenital maxillofacial disorders.

Analysis of preoperative ZMC asymmetry
The Digital Imaging and Communications in Medicine (DICOM) files of the preoperative CT-scan 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).

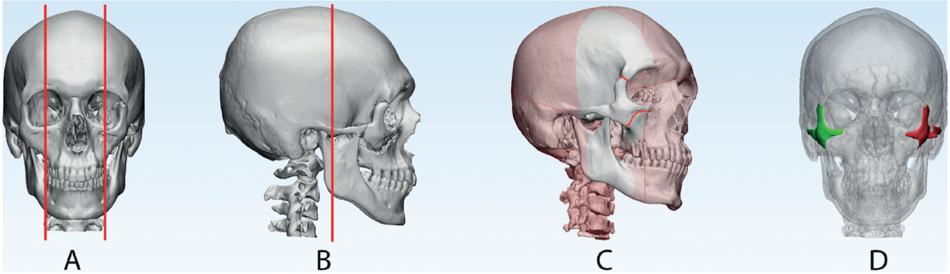

Figure 3: Anatomic landmarks and boundaries used for isolating the ZMC surface.
A: Orbital midline. B: Articular eminence. C: Frontozygomatic and maxillozygomatic suture. D: The isolated ZMC surface on the healthy (green) and fractured (red) side.

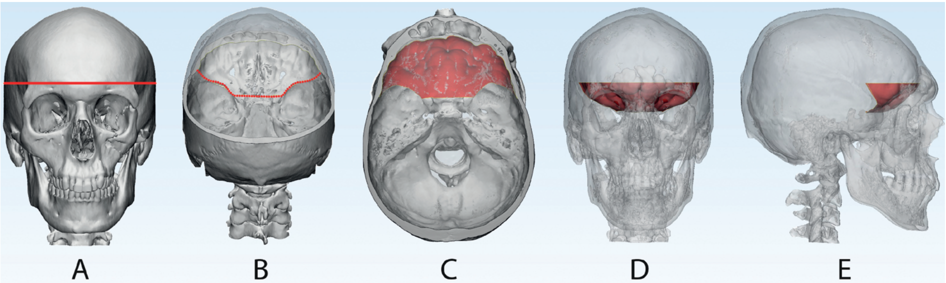

Figure 4: Anatomic landmarks and boundaries used for isolating the ACF surface. A: Plane 1cm above the supraorbital rim parallel to the Frankfurt horizontal plane. B: Posterior rim of the anterior cranial fossa. C, D and E: cranial, anterior and lateral view of the isolated ACF.

The outer surfaces of the fractured ZMC, the healthy (intact contralateral) ZMC and the Anterior Cranial Fossa (ACF) were selected in a standardized manner (Figure 3 and 4). Then the entire 3D model, including both ZMC and the ACF surfaces, was duplicated in mirror-image.

Subsequently the mirror-image 3D model was superimpositioned with the original 3D model, by aligning the mirror-image ACF surface with the original ACF surface. First, the mirrored ACF was matched roughly 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. 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 (inclucing the mirror-image healthy ZMC-surface) was preserved. Consequently the mirror-image healthy ZMC was projected over the fractured ZMC, in the symmetrical position.
A surface distance analysis between the original fractured ZMC-surface and the mirror-image healthy ZMC surface was then carried out. The shortest distance in millimeters

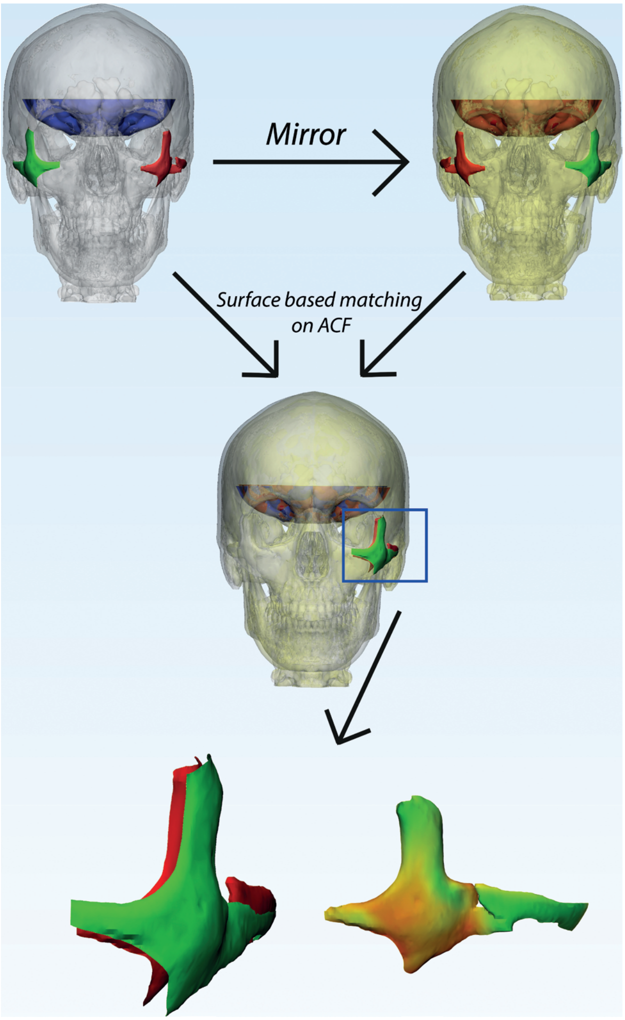

Figure 5: Method for measuring ZMC asymmetry.

was calculated from 2.67 points per mm2 on the fractured ZMC, to the surface of the healthy mirrored ZMC. The mean surface distance (MSD) between these surfaces served as a measure for ZMC asymmetry. A schematic display of this method is shown in Figure 5.

The precision of this method was analysed in a separate study, which showed excellent inter-observer (0.09 +/- 0.11mm) and intra-observer (0.12 +/- 0.13mm) reproducibility[8]. The same method was applied on the CT-scans of the healthy control group.

Analysis of postoperative ZMC asymmetry

The DICOM files of the intraoperative CBCT capturing the final fracture reduction were imported in Mimics Medical (version 20.0; Materialise, Leuven, Belgium). A virtual 3D model was created which was transferred into the 3-Matic Medical (version 12.0, Materialise, Leuven, Belgium) file containing the previously analysed 3D model of the preoperative CT. The 3D-model of the preoperative CT was reduced in size so as not to contain the affected ZMC or the mandible as this could negatively influence the alignment of the intraoperative 3D-model with the preoperative 3D-model. The intraoperative 3D-model was aligned to the best fit with the reduced preoperative 3D-model by surface based matching (using the iterative closest point algorithm).

The outer surface of the repositioned ZMC (on the 3D model of the intraoperative CBCT) was isolated in the same method as used in the preoperative CT.

A surface distance analysis was carried out between the outer surfaces of the repositioned ZMC (of the intraoperative CBCT) and the healthy mirrored ZMC (of the preoperative CT). The MSD between these surfaces served as a measure for postoperative ZMC asymmetry.

Rate of immediate treatment revisions

Immediate treatment revisions were recorded by the maxillofacial surgeon. These revisions were categorized into revision of ZMC position, revision of OF treatment, or 'other'.

Analysis of CBCT images for relevance of intraoperative revisions

In cases in which the intraoperative CBCT was followed by immediate revision of ZMC reduction or of the OF treatment, a second intraoperative CBCT was performed according to the treatment protocol. These two intraoperative CBCT scans were compared to evaluate the alteration in treatment.

Revision of ZMC position

In cases in which ZMC position had been altered, the effect on ZMC symmetry was measured. Asymmetry was quantified on the CBCT-scan after the initial reduction (prior to the revision) and on the CBCT-scan after revision of reduction. The difference in asymmetry between these 2 CBCT-scans was the result achieved by revision of ZMC position.

Revision of OF treatment

In cases in which the OF reconstruction had been altered, the effect on orbital volume was measured.

Orbital volumes were measured in Horos software (version 3.3.5, Horos Project, Annapolis, MD, USA), applying the method of Shyu et al.[9].

Rate of secondary surgical interventions

Two years after closure of inclusion, the medical records were reviewed for secondary surgical interventions.

Statistical analysis

Statistical analyses were 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.

Spearman's rank correlation test was used to determine the correlation of asymmetry values and rate of immediate revisions with the fracture classification. Pearson's chi square test was used to determine the association of immediate revisions with individual fracture categories.

The data on asymmetry of the ZMC is 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. An ANOVA was performed to assess if there was difference in mean logMSD between the fracture categories.

Results

Thirty-eight patients were included in the study. A flow chart is provided in Figure 6.

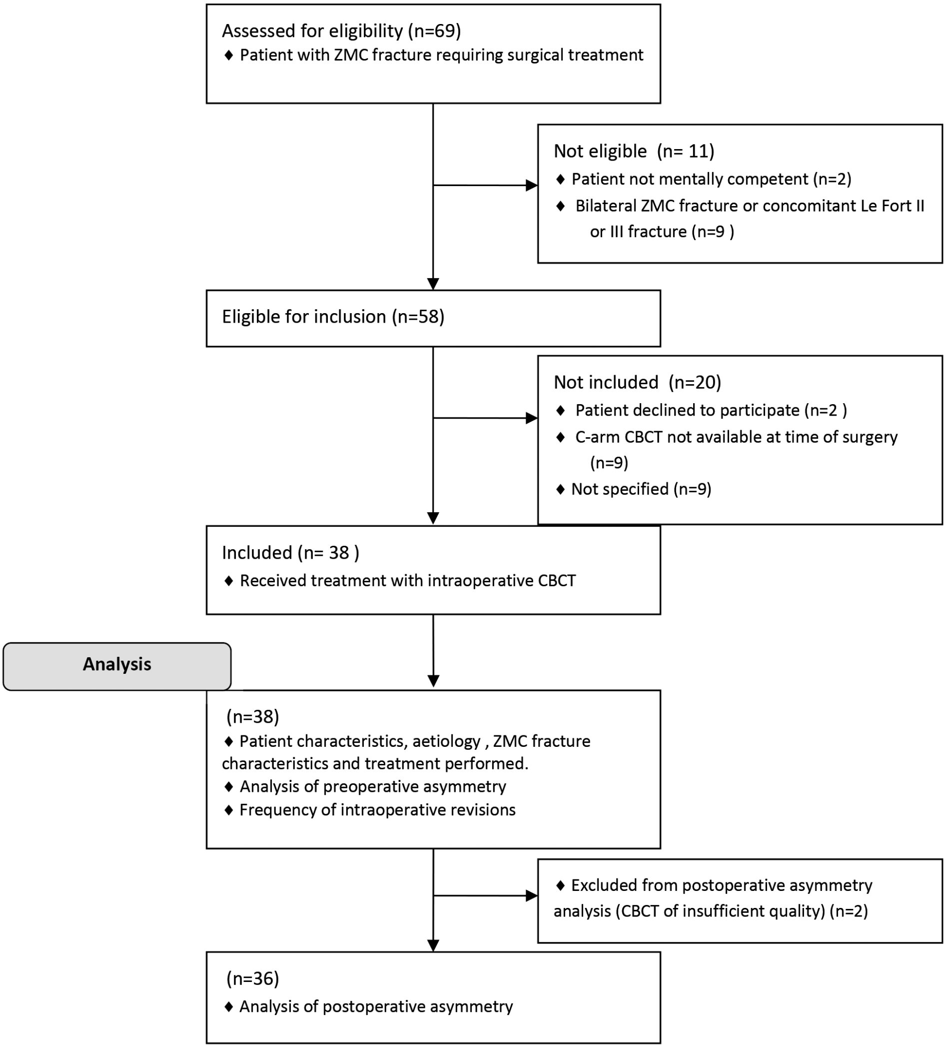

Figure 6: Study flow chart.

Patient and fracture characteristics

Patient characteristics, aetiology, ZMC fracture classification and treatment performed are provided in Table 1.

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

	All patients (n=38)
Patient characteristics	
Mean age	43
Male-to-female ratio	25:13
Other maxillofacial fractures	8 (21%)
Dental injuries	3 (8%)
Ophthalmic injuries	1 (3%)
Other injuries (non-maxillofacial)	14 (37%)
Aetiology	
Traffic accident	18 (47%)
Interpersonal violence	7 (18%)
Sports accident	3 (8%)
Fall from height	3 (8%)
Work-related accident	3 (8%)
Stumbling	2 (5%)
Animal related accident	2 (5%)
ZMC fracture characteristics	
Left-right distribution	24:14
A-type fractures	14 (37%)
B-type fractures	17 (45%)
C-type fractures	7 (18%)
Primary indication for OF treatment	6 (16%)
Treatment performed	
Closed reduction, no OF treatment	15 (39%)
ORIF, no OF treatment	19 (50%)
ORIF, with OF treatment	4 (11%)

ORIF: Open reduction and interal fixation.

Preoperative ZMC asymmetry

Preoperative asymmetry was higher than the asymmetry in healthy controls (2.37mm vs 1.40mm; independent samples T-test $p<0.01$). Fracture classification correlated with preoperative asymmetry, ZMC asymmetry was found to increase from fracture category A to B to C (Spearman Rank Correlation $p=0.01$).

Accuracy of ZMC fracture reduction

ZMC asymmetry after final fracture reduction was quantified in 36 cases. In 2 cases the intraoperative CBCT after final fracture reduction was of insufficient quality for analysis of symmetry due to scattering and movement artefacts.
ZMC fracture reduction significantly decreased the asymmetry(2.69mm vs 1.67mm; paired samples T-test p<0.01). No difference in postoperative asymmetry was observed between the fracture categories (ANOVA p=0.84). Postoperative asymmetry was comparable to the asymmetry in healthy controls (1.67mm vs 1.40mm; independent samples T-test p=0.31).

Table 2: Preoperative asymmetry and postoperative ZMC asymmetry.

	A-type, incomplete fractures (n=14)	**B-type, tetrapod fractures (n=17)**	**C-type, comminuted fractures (n=7)**	**All patients (n=38)**	**Healthy controls (n=15)**
Average ZMC asymmetry measurements in mm (MSD)					
Preoperative*(p=0.01)	2.37 (SD 1.00)	2.69 (SD 0.88)	3.33 (SD 0.79)** P=0.01	2.69 (SD 0.95)	1.40 (SD 0.54)
Postoperative (after final fracture reduction)	1.67 (SD1.09) #	1.68 (SD0.93)	1.66 (SD0.37)	1.67 (SD 0.89)	NA

*: Statistically significant correlation with fracture classification (Spearman Rank Correlation).
**: Statistically significant association with fracture category (Independent Samples T-test).
#: Postoperative asymmetry was determined in 12 cases of the A-type fractures, the CBCT was of insufficient quality for analysis in 2 cases.

Consequences of intraoperative CBCT on treatment performed

The intraoperative CBCT was followed by a treatment revision in 11 cases (29%). These treatment revisions consisted of revisions of ZMC position (n=6), revisions of OF treatment (n=2), revisions of both ZMC position and OF treatment (n=2), and 1 “other” type of revision.
Treatment revisions were associated with C-type fractures (86%; Pearson Chi Square p<0.01) and the revision rate was found to increase from fracture category A to B to C (Spearman Rank Correlation p<0.01). A-type fractures needed revision less frequently (7%; Pearson Chi Square p=0.02).
ZMC fractures with comminution and/or significant disruption of the OF were associated with treatment revisions after intraoperative CBCT (89%; Pearson Chi Square p<0. 01); in cases without comminution and no indication for OF treatment, treatment revisions were performed in 10% of the cases. The predictive value of this single parameter (comminution of the ZMC and/or primary indication for OF treatment) for the occurrence of treatment revisions after intraoperative CBCT showed a sensitivity and

specificity of 73% and 96%, with a positive predictive value of 89% and negative predictive value of 90%.

Table 3: Immediate revisions performed after intraoperative imaging.

	A-type, incomplete fractures (n=14)	B-type, tetrapod fractures (n=17)	C-type, comminuted fractures (n=7)	All patients (n=38)
Revisions after intraoperative imaging				
ZMC position* (p=0.02)	1 (7%)	3 (18%)	4 (57%)** p=0.01	8 (21%)
OF treatment* (p=0.05)	0 (0%)	2 (12%)	2 (29%)	4 (11%)
Other	0 (0%)	0 (0%)	1 (14%)** p=0.03	1 (3%)
Any* (p<0.01)	1 (7%)** p=0.02	4 (24%)	6 (86%)** p<0.01	11 (29%)

*: Statistically significant correlation with fracture classification (Spearman Rank Correlation).
**: Statistically significant association with individual fracture category (Pearson Chi Square).

Revision of ZMC position

The intraoperative CBCT was followed by a revision of ZMC position in 8 cases (21%). Revision of ZMC position was associated with C-type fractures (57%; Pearson Chi Square p=0.01) and the revision rate increased from fracture category A to B to C (Spearman Rank Correlation p=0.02).

In these cases preoperative asymmetry was 2.65mm MSD, asymmetry after initial reduction was 1.79mm MSD, and after revision of reduction 1.60mm MSD. An average reduction of asymmetry of 0.19mm MSD was thus achieved with intraoperative revision of ZMC position, however the reduction did not reach statistical significance (paired samples T-test p=0.44).

Revision of OF treatment

The intraoperative CBCT was followed by a revision of the OF treatment in 4 cases (11%). OF revision rate was found to increase from fracture category A to B to C (Spearman Rank Correlation p=0.05).

In 2 cases the position of the OF implant was found insufficient after OF reconstruction. A revision was performed to improve the OF implant position (Figure 7).

In the first case the orbital volume of the intact orbit was 26.0cc. Orbital volume of the injured orbit was 30.4cc after the primary reconstruction (a 4.4cc or 17% increase), after the revision orbital volume was 27.1cc (a 1.1cc or 4% increase).

In the second case the orbital volume of the intact orbit was 27.5cc. Orbital volume of

the injured orbit was 27.0cc after the primary reconstruction (a 0.5cc or 2% decrease), after the revision orbital volume was 27.1cc (a 0.4cc or 1% increase). In this case a direct high impact trauma to the orbit and globe had caused a scleral rupture and severe comminution of the orbital walls. Evisceration of the eye was performed in a secondary surgical procedure by the ophthalmologist.
In 2 cases an indication for exploration of the OF was seen on the preoperative CT, however reduction of the ZMC fracture had realigned the OF fracture. Consequently no OF exploration and thus no surgical approach through the lower eyelid were performed. No case was encountered in which reduction of the ZMC fracture resulted in disruption of a previously not severely disrupted OF fracture.

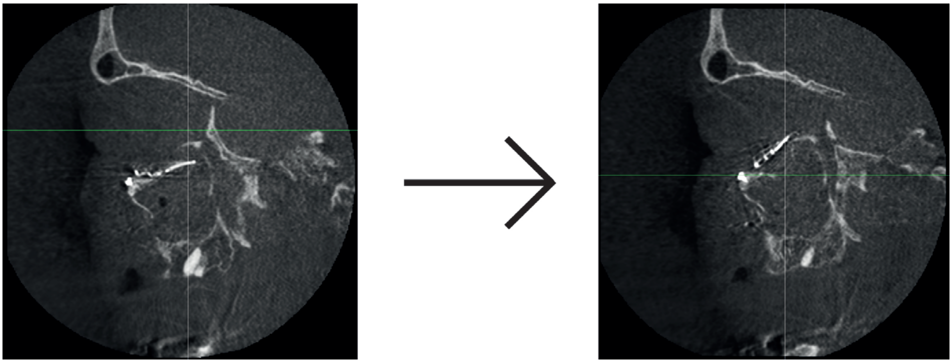

Figure 7: Revision of OF implant position in Case 1, repositioning of the titanium mesh onto the posterior orbital ledge.

Other revisions
In 1 case, a C-type fracture with comminution of the lateral orbital rim, a bone fragment of the lateral orbital wall was dislocated into the orbit. This was visible on the intraoperative CBCT after reduction of the ZMC and the fragment was removed from the orbit.

Rate of secondary surgical interventions
Outpatient follow-up was performed in 37 cases (97%), average follow-up length was 109 days (SD 15). A secondary (separate) surgical intervention was performed in two cases (5%). In one patient extraocular muscle correction was performed by the ophthalmologist to correct persisting diplopia. In the other case evisceration of the eye was performed; this is the above mentioned case in which a traumatic scleral rupture had occurred. No secondary surgical interventions of the ZMC or OF were performed.

Discussion

In our cohort, treatment of ZMC fractures with intraoperative imaging resulted in accurate ZMC fracture reduction in all fracture categories. A statistically significant reduction in asymmetry of 1.02mm was achieved by treatment (paired samples T-test $p<0.01$). ZMC asymmetry after ZMC fracture reduction was comparable to ZMC asymmetry in the healthy control group (independent samples T-test $p=0.31$).

C-type fractures were associated with intraoperative revisions (86%; Pearson Chi Square $p<0.01$) and specifically with revisions of ZMC position (57%; Pearson Chi Square $p=0.01$). A study by Gander et al.[10] on the application of intraoperative imaging in ZMC fractures also found an association of comminuted fractures with immediate revisions.
Our hypothesis was that comminuted ZMC fractures and/or ZMC fractures with OF involvement are most likely to benefit from intraoperative imaging. This hypothesis was confirmed as a strong association with immediate revisions was found for this group (Pearson Chi Square $p<0.01$). Both the positive predictive value (89%) and the negative predictive value (90%) of this single parameter (comminution of the ZMC and/or primary indication for OF treatment) for the occurrence of treatment revisions after intraoperative CBCT are high. It is thus a suitable parameter to decide which ZMC fractures should be treated with intraoperative imaging.

In the 8 cases in which the position of the ZMC was revised, asymmetry was only slightly decreased by the revision (0.19mm MSD on average), this was not statistically significant (paired samples T-test $p=0.44$). The lack of statistical significance is possibly explained by the small number of patients in which a revision of the ZMC was performed.

The surgeons also mentioned the advantage that intraoperative CBCT helped to perform less invasive surgery by obviating the exposure of additional buttresses to confirm adequate reduction. This is of particular benefit in cases with extensive edema, as this hampers the visual inspection and palpation to verify adequate fracture reduction.
Revision of the OF reconstruction after intraoperative imaging was performed in 2 cases. No statistical analysis on improvement of orbital volume could be performed as the group is too small, but the outcome in these 2 cases is reported. In 1 of these 2 cases the revision clearly improved the orbital volume symmetry; orbital volume increase on the affected side was decreased from 4.4cc to 1.1cc. Orbital volume increase is believed to have a linear correlation with enophthalmos, 1 cc of orbital volume increase leads to 0.5-0.9 mm enophtalmos[11–13]. In this case the estimated enophthalmos was reduced from 2.2 – 4.0 mm to 0.6 – 1.0 mm. This reduction is clinically relevant as enophthalmos of >2mm has been reported to be aesthetically disturbing[11–14].

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In the 2 cases in which the intraoperative CBCT obviated the need for OF exploration, a surgical approach through the lower eyelid could be avoided. Lower eyelid approaches are prone to sequelae such as ectropion, entropion, lower lid retraction, and canthal dystopia[4,15]. The risk of such sequelae was avoided in these patients. This advantage of intraoperative CBCT imaging has also been addressed by Wilde et al.[16], who showed intraoperative CBCT-images of several patients in which a displaced OF fracture was reduced by reduction of the ZMC fracture.

In this prospective cohort no secondary surgical interventions of the ZMC or OF were performed. We previously published the results of a retrospective cohort of 153 patients with ZMC fractures treated without intraoperative imaging[5]. The rate of secondary surgical interventions to improve ZMC position or OF reconstruction was 8% in the patients that were treated without intraoperative imaging in the retrospectieve cohort study, versus 0% in this study (Pearson Chi Square p=0.06).

Cuddy et al.[17] investigated the use of intraoperative CT-imaging in different types of maxillofacial fractures. Rates of revision after intraoperative imaging were highest in isolated orbital fractures, ZMC fractures, naso-orbital-ethmoidal fractures, and Le Fort II or III fractures. Sing et al.[18] advises the use of intraoperative CBCT imaging in panfacial fractures and revisional procedures, as anatomical landmarks are distorted in these cases.

In our clinic the mobile CBCT scanner is also routinely applied in the treatment of ZMC fractures and orbital wall fractures. The decision whether to use the intraoperative CBCT in panfacial fractures and revisional procedures is made on a case-by-case basis. Mandibular, midfacial and frontal sinus fractures are usually treated without intraoperative imaging as fracture reduction can be verified visually and/or by the occlusion.

The mobile CBCT scanner proved easy to use after some initial experience had been gained by the surgeons. If adequate preparations had been made, i.e. starting up the software and positioning the scanner parallel to the patient prior to the start of surgery, the extra operating time for performing and evaluating the CBCT scan was approximately 15-20 minutes.

The ideal method for assessing quality of ZMC fracture reduction would be to compare the ZMC position after fracture reduction to the pre-trauma position of the ZMC as registered on a CT-scan obtained prior to the fracture. However, such a CT-scan is seldom available in trauma patients. ZMC symmetry is thus used instead as a parameter for quality of fracture reduction.
The method we used for measuring ZMC symmetry uses a mirroring and surface based

matching technique. Our method has some similarities with the methods used by Ho et al.[19,20] and Gibelli et al.[21]. However an essential difference is the reference area used for the surface based matching. In our method the ACF is the reference area. Consequentially the outcome of our method reflects both the level of asymmetry induced by difference in the shape of the ZMC as well as the asymmetry caused by the difference in position of the ZMC within the viscerocranium. We feel this aspect is essential; as not only the form 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 thus for facial appearance.
The method for measuring ZMC symmetry is discussed more extensively in a separate publication[8].

A methodological limitation of our study is the design. A randomised controlled trial has the highest level-of-evidence in medical research. We chose to perform an observational prospective cohort study because the intraoperative CBCT was already part of our standard treatment protocol before the start of this study.
A second limitation is the relatively high number of eligible patients that were not included in the study. This is mainly due to the limited availability of the CBCT-scanner, as the scanner is shared with other surgical specialties.

Conclusion

Treatment of ZMC fractures with intraoperative imaging leads to accurate fracture reduction, postoperative asymmetry is comparable to the asymmetry in the healthy population.
The intraoperative CBCT is often followed by a treatment revision (29%). The relevance of the revisions after intraoperative imaging to improve ZMC position or OF reconstruction was not confirmed in this study. This study did show a trend towards fewer secondary surgical interventions to improve ZMC position or OF treatment in patients treated with intraoperative imaging. This arguably is indirect proof of the relevance of the revisions performed after intraoperative imaging.
ZMC fractures with comminution and/or OF involvement are associated with treatment revisions after intraoperative CBCT imaging (86%; Pearson Chi Square $p<0.01$). The presence of comminution and/or OF involvement has a 89% positive predictive value and a 90% negative predictive value for the occurrence of treatment revisions after intraoperative CBCT. The presence of comminution and/or OF involvement is thus a suitable parameter to decide which ZMC fractures should be treated with intraoperative imaging.
Based on the outcome of this study the authors recommend to use intraoperative imaging in ZMC fractures with comminution (C-type fractures) and/or ZMC fractures with an indication for OF treatment.

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Chapter 7

General discussion

The rationale behind the application of intraoperative conebeam computed tomography (CBCT) imaging in zygomaticomaxillary complex (ZMC) fracture repair is that allows for direct on-table assessment of the operative result. In this way insufficient treatment results can be recognised during surgery, offering the chance of a direct revision to improve the treatment result. This could potentially improve surgical outcome and prevent reoperations.
A second advantage of the use of intraoperative CBCT is that it could reduce surgical trauma. In cases in which the intraoperative clinical assessment of the position of the ZMC is hampered, the position of the ZMC can be verified after fracture reduction without the need for further surgical exposure to facilitate visual inspection. Additionally, an intraoperative CBCT scan after reduction of the ZMC fracture can prevent unnecessary orbital floor exploration in cases in which reduction of the ZMC fracture also realigned the orbital floor[1,2].

Intraoperative (CB)CT imaging is increasingly applied in maxillofacial fracture treatment. Many publications on the subject exist[1–10]. Moreover, the use of intraoperative (CB)CT imaging is incorporated in the AO Surgery Reference for the treatment of ZMC fractures[11]. The AO reference guide states that intraoperative imaging should be used whenever available.
However, careful selection of patients to be treated with intraoperative imaging would make it possible to improve treatment outcome where it is most needed, while keeping patient care, use of scarce operating room capacity, and the expenditure of healthcare resources efficient.
The goal of this thesis was to contribute to the body of evidence on the use of intra-operative imaging in ZMC fractures. With the aim to elucidate the position of intraoperative CBCT imaging in the treatment of ZMC fractures.

*In **Chapter 2** we performed an epidemiological study of patients treated for maxillofacial fractures in the period 2005-2010 in the University Medical Center Utrecht. We assessed incidence of maxillofacial fractures and trends in incidence, with the aim to aid in capacity planning, and to identify opportunities for preventive measures.*

On average 66 patients per year received surgical treatment for maxillofacial fractures in our hospital. Men, in the 2nd and 3^{d} decade of their life, appeared particularly at risk. This group accounted for 35% of all patients. Traffic accidents were the most frequent aetiology (42%); bicycle accidents accounted for 18% of all fractures, car accidents for 13% and motorised 2-wheelers for 9%. The incidence of maxillofacial fractures was higher from Thursday through Sunday than in the beginning of the week, 67% of the fractures occurred on Thursday through Sunday.
This means that in our population, preventive measures are best addressed at preventing maxillofacial fractures due to traffic accidents. In cyclists, helmet use is a

possibility to prevent maxillofacial injury. The incidence of maxillofacial injuries in bicycle accidents is higher in cyclist without a helmet than in cyclist that wear a helmet[12–14]. A reduction in incidence of maxillofacial injuries (fractures and soft tissue injuries) of 23-33% was observed in cyclist wearing helmets[13,14]. Benjamin et al.[12] investigated the incidence of maxillofacial fractures in cyclists that visited an emergency department or trauma centre after an accident (n=85.187); incidence of maxillofacial fractures was 12.6% in cyclists not-wearing a helmet vs. 8.8% in cyclists wearing a helmet, a reduction of 30%.
Similarly in motorcyclist accidents, helmet use is associated with reduced incidence of maxillofacial injuries[15,16]. And in car accidents, seatbelt and airbag use is associated with reduced incidence of maxillofacial injuries[17,18].
For planning purposes, it could be considered to reserve operation time in the beginning of the week to treat the patients with maxillofacial fractures that occurred over, or just before, the weekend.
Two important limitations need to be addressed. Firstly, one should be careful in extrapolating the data from our patient group to other regions and through time. Although most epidemiological studies on maxillofacial injuries report a higher incidence of maxillofacial injuries in men with a peak incidence in the 2nd and 3^{d} decade of life, the fracture patterns and aetiology differ between regions and change over time[19–26]. Preventive measures are likely to be most effective if addressed at the most common cause of trauma.
Secondly, only patients with maxillofacial fractures that required surgical treatment in a level 1 trauma centre were analysed. Consequently a selection bias is built in in the study design. The population affected by trauma in general is a different population. This can be deduced from the National Trauma Registration[27], which reports on approximately 80.000 patients per year in the Netherlands. In this population male-to-female ratio was 1:1 and patients of 80 years and older formed a large part of the affected population (27%). For preventive measures aimed at preventing traumatic injury in general, different measures are likely to be more efficacious.

*In **Chapter 3** a retrospective cohort study of 153 patients with ZMC fractures was performed. All patients in this cohort were treated without intraoperative imaging or other technological aids such as computer-assisted surgery or intraoperative navigation. The aims of this study were to assess treatment outcome in ZMC fractures treated without intraoperative imaging and to identify which ZMC fractures might benefit from the use of additional technical means to improve treatment outcome.*

Treatment outcome in C-type (comminuted) ZMC fractures proved inferior to treatment outcome in A-type (incomplete) and B-type (complete/tetrapod) ZMC fractures. C-type ZMC fractures were associated with an increased incidence of secondary surgical interventions compared to A- and B-type fractures (absolute risk 21% vs 6%; p=0.01);

specifically secondary surgical interventions for correction of ZMC malposition (absolute risk 12% vs 6%; p=0.03), secondary orbital floor corrections (absolute risk 10% vs 0%; p<0.01), and extraocular muscle corrections for the treatment of persisting diplopia (absolute risk 5% vs 0%; p=0.02).
Additionally, a tendency towards an increased incidence of facial asymmetry (21%), enophthalmos (13%), diplopia (13%), transient facial nerve palsy (5%), persistent facial nerve palsy (3%), and wound infection (7%) was observed in C-type fractures. The unfavourable treatment outcome in comminuted ZMC fractures is also described in several other publications[28–30].
In this retrospective cohort study it is suggested that in C-type (comminuted) ZMC fractures, technologies such as intraoperative (CB)CT imaging or computer-assisted surgery with surgical navigation devices and 3D-planning software are most likely to improve treatment outcome. As in these fractures treatment outcome is inferior when treated without technological aids.

*In **Chapter 4** a literature review was performed of publications on the use of intraoperative imaging in ZMC fracture repair. The aim of this study was to review the existing literature on the frequency of direct treatment revisions after intraoperative imaging; the quality of ZMC fracture reduction with intraoperative imaging; and the effect of direct treatment revisions after intraoperative imaging.*

In total 15 publications on the use of intraoperative imaging in the treatment of ZMC fractures were included. No publications were found on the effects of intraoperative imaging on facial symmetry or on the accuracy of fracture reduction. No studies were found that compared the intraoperative radiographic images obtained after the initial treatment but before revision of the reduction of the zygoma or orbital floor, with radiographic images obtained after the revisions. A meta-analysis was performed of 6 publications on the frequency of direct treatment revisions after intraoperative imaging. A treatment revision after intraoperative imaging was performed in 22% (95%-CI 14.1%-31.5%). Revision of the reduction of the zygoma was performed in 18% (95%-CI 10.5%-29.0%), and revision of the orbital floor treatment was performed in 9% (95%-CI 3.6%-17.2%).
Based on this systematic review, it was concluded that information obtained from intraoperative imaging often has consequences on the surgical management of ZMC fractures. However, the clinical relevance of these treatment revisions is yet to be established.

*In **Chapter 5** we developed a novel method to assess the symmetry of the ZMC on (Conebeam) Computed Tomography (CBCT). The goal was to create a reliable and accurate method to assess the symmetry of the ZMC that can be used to assess the quality of ZMC fracture reduction.*

A 3D virtual method was developed that makes use of mirroring and surface-based matching techniques to measure ZMC symmetry. The outer surface of the contralateral ZMC is mirrored and placed in the symmetrical position. The symmetrical position is determined by the symmetry of the anterior cranial fossa (ACF), and the spatial relation between the ZMC and the ACF. Subsequently, the mean surface distance (MSD) between the ZMC-surface and the mirrored-contralateral ZMC-surface (in the symmetrical position) is calculated. This is a measure for ZMC asymmetry.

Reliability of the method was assessed in the CT-scans of 15 healthy patients (without ZMC fracture). The intra-rater ICC of the ZMC MSD was 0.97 with an intra-rater variability of 0.09mm ± 0.11mm (95% CI 0.03–0.15). The inter-rater ICC of the ZMC MSD was 0.95 with an inter-rater variability of 0.12mm ± 0.13mm (95% CI 0.04–0.19).

Accuracy of the method was assessed in the CT-scans of 38 patients with a ZMC fracture that required surgical treatment (and were thus deemed displaced by the clinician). The asymmetry in the ZMC fracture patients was higher than the asymmetry in the healthy control patients (2.69mm vs 1.40mm, $p<0.01$). This finding corresponded with the clinical perception that the ZMC fractures were displaced. Moreover the asymmetry in the ZMC fractures correlated with the classification for ZMC fracture severity, increasing asymmetry was observed from A-type, to B-type, to C-type ZMC fractures ($p=0.01$).

An important difference with other publications describing methods to measure ZMC symmetry on (CB)CT images, is the choice of reference area[31–33]. Ho et al.[32,33] and Gibelli et al.[31] chose areas directly adjacent to the ZMC or the ZMC itself as reference area to determine the symmetric position of the mirrored contralateral ZMC. This introduces two disadvantages. Firstly, in ZMC fractures these reference areas are distorted by the fracture, which is likely to influence the reliability of the method. Secondly, the asymmetry introduced by alteration of the position of the ZMC within the viscerocranium is not reflected in the outcome.

By choosing the anterior cranial fossa as a reference area, the reference area is less likely to be distorted by the trauma and the asymmetry of the position of the ZMC within the viscerocranium is reflected in the value for ZMC asymmetry.

Two limitations of our method remain. The main limitation is the way in which the surface distance is measured: from every point on the left-side ZMC the shortest distance to the surface of the mirrored right-side ZMC is calculated. In the ideal method, every point on the surface of the ZMC would be indexed with its corresponding point on the surface of the mirrored ZMC. The average distance of every two corresponding points would better reflect the true ZMC asymmetry. The current method results in an underestimation of ZMC asymmetry as the distance from a point on the ZMC to the corresponding point on the mirrored ZMC surface is often larger than the distance to the closest point on the mirrored ZMC surface. To the best of our knowledge, all studies on this subject have been performed with this limitation as the described ideal method does not yet exist.

A second limitation of our method is that it is less suitable in cases with asymmetry at the level of the anterior cranial fossa. This might be the case in certain congenital craniofacial asymmetries.
It is concluded, that the developed method is both reliable and accurate and can be used in a prospective study.

*In **Chapter 6** a prospective cohort study was performed on the use of intraoperative CBCT imaging in the treatment of ZMC fractures. In this study the goal was to assess the quality of ZMC fracture reduction with intraoperative imaging; to assess the frequency of direct revisions after intraoperative imaging; to evaluate the effect of direct treatment revisions after intraoperative imaging; and to identify which ZMC fractures are most likely to benefit from intraoperative imaging.*

Included were 38 patients with a unilateral ZMC fracture. Average preoperative ZMC asymmetry was 2.69mm (SD 0.95), and postoperative asymmetry was 1.67mm (SD 0.89). A significant improvement in ZMC symmetry was achieved by the surgery ($p<0.01$).Postoperative ZMC asymmetry was comparable to the ZMC asymmetry in the healthy population ($p=0.31$).
Intraoperative CBCT was followed by a treatment revision in 11 cases (29%). In ZMC fractures that were comminuted (C-type) or with a primary indication for orbital floor treatment, the revision rate after intraoperative imaging was 89%, vs. 10% in non-comminuted ZMC fractures (A- and B-type) without an indication for primary orbital floor treatment ($p<0.01$). The presence of comminution and/or an indication for orbital floor treatment had a 89% positive predictive value and a 90% negative predictive value for the occurrence of treatment revisions after intraoperative CBCT. The presence of comminution and/or an indication for orbital floor treatment is thus a suitable parameter to predict in which ZMC fractures the treatment is likely to be influenced by the intraoperative imaging.
In the 8 cases in which the position of the ZMC was revised, the decrease in asymmetry by the revision was small (0.19mm MSD on average), which was not statistically significant ($p=0.44$). A possible explanation for the lack of statistical significance is the small number of patients in which a revision was performed (study power).
Revision of the orbital floor reconstruction after intraoperative imaging was performed in two cases. In one of these two cases the revision clearly improved the orbital volume symmetry; orbital volume increase on the affected side compared to the healthy side was decreased from 4.4cc to 1.1cc. In this case the estimated enophthalmos was reduced from 2.2 – 4.0 mm to 0.6 – 1.0 mm. This reduction is clinically relevant as enophthalmos of >2mm is considered aesthetically disturbing[34–37]. As a revision of the orbital floor reconstruction was performed in 2 patients only, no statistical analysis on improvement of orbital volume could be performed.

In the two cases in which the intraoperative CBCT obviated the need for orbital floor exploration, a surgical approach through the lower eyelid could be avoided. Lower eyelid approaches are prone to sequelae such as ectropion, entropion, lower lid retraction, and canthal dystopia; a 22% risk of such sequelae was found in **Chapter 3**. The risk of such sequelae was avoided in these 2 patients. This advantage of intraoperative CBCT imaging has previously been addressed by Wilde et al.[2], who published intraoperative CBCT-images of several patients in which a displaced orbital floor fracture was reduced by reduction of the ZMC fracture.
Taking all treatment revisions after the intraoperative CBCT in consideration, the benefit of the treatment revision is clear in 3 of the 11 patients (27%), yet only on a case-by-case basis analysis; in 2 patients a lower-eyelid surgical approach and the risk of sequeale thereof was avoided, and in 1 patient orbital volume increase and the associated risk of enophthalmos was prevented. The relevance of the revisions after intraoperative imaging to improve ZMC position or the orbital floor treatment could not be confirmed statistically at group level in this study.
This study did show a trend towards fewer secondary surgical interventions to improve ZMC position or orbital floor treatment in patients treated with intraoperative imaging. The rate for secondary surgical interventions to improve ZMC position or orbital floor reconstruction was 0% in this study, vs 8% in the patients that were treated without intraoperative imaging in **Chapter 3** (p=0.06). This arguably is indirect proof of the relevance of the revisions performed after intraoperative imaging.

Conclusions

Maxillofacial injuries occur mostly in young males, with a peak incidence in the 2nd and 3^{d} decade of life. Traffic accidents are the most common cause of maxillofacial fractures in the Dutch population. Preventive measures aimed at decreasing the incidence of maxillofacial fractures in the Dutch population are likely to be most efficacious if addressed at preventing maxillofacial injuries due to traffic accidents.
In ZMC fractures treated without intraoperative imaging, comminuted fractures are associated with inferior treatment outcome. Intraoperative imaging often leads to direct treatment revisions, especially in comminuted ZMC fractures and in ZMC fractures in which treatment of the orbital floor is indicated. The presence of comminution of the ZMC and/or an indication for orbital floor treatment has a 89% positive predictive value and a 90% negative predictive value for the occurrence of treatment revisions after intraoperative CBCT. Comminuted ZMC fractures and/or ZMC fractures in which treatment of the orbital floor is indicated are therefore most likely to benefit from intraoperative imaging.
Treatment of ZMC fractures with intraoperative CBCT imaging leads to accurate fracture reduction.

The relevance of the revisions after intraoperative imaging could not be confirmed statistically at group level in this thesis. This thesis did show a trend towards fewer secondary surgical interventions to improve ZMC position or orbital floor treatment in patients treated with intraoperative imaging, compared to patients treated without intraoperative imaging. This arguably is indirect proof of the relevance of the revisions performed after intraoperative imaging.
The proposed method for measuring ZMC asymmetry with mirroring of the ZMC and surface-based matching of the anterior cranial fossa is reliable, accurate, and suitable for the evaluation of treatment outcome in ZMC fracture repair.

Recommendations based on this thesis

1. Comminuted ZMC fractures should be treated with intraoperative imaging.
2. ZMC fractures in which treatment of the orbital floor is indicated should be treated with intraoperative imaging.
3. In non-comminuted ZMC fractures without an indication for orbital floor treatment, treatment can be performed without intraoperative imaging.

Future perspectives

As no direct evidence of the relevance of treatment revisions performed after intraoperative imaging has yet been provided in the literature, this merits further research. In my view this is a study-power issue that could possibly be resolved by studies with more patients.
A randomised controlled trial on intraoperative imaging in ZMC fractures has been announced in New-Zealand[38]. Unfortunately no objective measurement of ZMC fracture reduction is intended by the investigators, but it will be interesting to see their results on clinical parameters such as facial profile restauration and need for revision surgery.
Furthermore the place of computer assisted surgery and the use of surgical navigation needs to be established. I expect these technological aides are to be recommended in revision cases and secondary reconstructions. It is questionable whether scientific proof for the added value of these techniques for this indication will appear, otherwise the level of recommendation may remain at the level of expert opinion.
A research project on the application of augmented reality in maxillofacial surgery is currently being developed in our centre. Augmented reality is another technological aid that could contribute towards better treatment results in revision cases and secondary reconstructions of ZMC fractures and other maxillofacial fractures.
Naturally, intraoperative CBCT imaging can also be of use in the treatment of other maxillofacial fractures. Specifically in orbital floor and/or medial wall fractures, naso-orbito-ethmoid fractures, and complex midface fractures treatment can be challenging and intraoperative imaging might further improve the surgical results.

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Appendices

Summary in English

Maxillofacial injuries are common in trauma patients in The Netherlands. The Oral and Maxillofacial Surgeon plays a central role in the treatment of maxillofacial trauma, as the Oral and Maxillofacial Surgeon is trained to treat the full scope of maxillofacial injuries consisting of maxillofacial bone fractures, dental injuries and soft tissue injuries. The subject of this thesis is the treatment of zygomaticomaxillary complex (ZMC) fractures. In the treatment of ZMC fractures, the displaced ZMC is first repositioned. If the reposition is unstable, internal fixation with miniplates is applied. As the zygoma is a part of the orbital floor, the orbital floor often requires treatment as well (in approximately 20%).
In this thesis the intraoperative use of a Conebeam Computed Tomography (CBCT) scanner was investigated. By performing the scan during the operation at the end of the surgical procedure, instead of postoperatively, there is the possibility to immediately revise the operative result if necessary. This can be a revision of the position of the ZMC and/or a revision of the treatment of the orbital floor.

In **Chapter 2** a retrospective epidemiological study was performed of patients treated for maxillofacial fractures by the Oral and Maxillofacial Surgery department of the University Medical Center Utrecht in the period 2005-2010. Men, in the 2nd and 3^{d} decade of their life, appeared particularly at risk. This group accounted for 35% of all patients. Traffic accidents were the most frequent aetiology (42%); bicycle accidents accounted for 18% of all fractures, car accidents for 13%, and accidents with motorised 2-wheelers for 9%.

In **Chapter 3** a retrospective cohort study of 153 patients with ZMC fractures was performed. All patients in this cohort were treated without intraoperative imaging or other technological aids such as computer-assisted surgery or intraoperative navigation. Treatment outcome in comminuted ZMC fractures (C-type) was inferior to the outcome in non-comminuted ZMC fractures (A-type and B-type).
C-type ZMC fractures were associated with an increased incidence of secondary surgical interventions compared to A- or B-type fractures (absolute risk 21% vs 6%; p=0.01); specifically secondary surgical interventions for correction of ZMC malposition (absolute

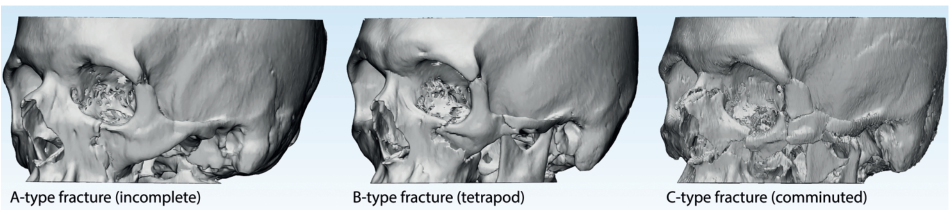


Figure 1: ZMC fracture classification.

risk 12% vs 6%; p=0.03), secondary orbital floor corrections (absolute risk 10% vs 0%; p<0.01), and extraocular muscle corrections for the treatment of persisting diplopia (absolute risk 5% vs 0%; p=0.02).

In **Chapter 4** a literature review was performed of publications on the use of intraoperative imaging in ZMC fracture repair. In total 15 publications on the use of intraoperative imaging in the treatment of ZMC fractures were included, 6 of these publications reported on the incidence of direct treatment revisions after the intraoperative imaging.
Meta-analysis of the results of these 6 studies was performed. A treatment revision after intraoperative imaging was performed in 22% (95%-CI 14.1%-31.5%). Revision of the reduction of the zygoma was performed in 18% (95%-CI 10.5%-29.0%), and revision of the orbital floor treatment was performed in 9% (95%-CI 3.6%-17.2%).

In **Chapter 5** we developed a digital method to assess the symmetry of the ZMC on (CB)CT data. Asymmetry of the ZMC was measured using a mirroring and surface-based matching technique that uses the anterior cranial fossa to determine the symmetrical position of the ZMC. The mean surface distance (MSD) between the ZMC-surface and the symmetrical position was calculated. This is a measure for ZMC asymmetry.
Reliability of the method was assessed in the CT-scans of 15 healthy patients (without ZMC fracture). The intra-rater intraclass correlation coefficient was 0.97 with an intra-rater variability of 0.09mm ± 0.11mm (95%-CI 0.03–0.15). The inter-rater intraclass correlation coefficient was 0.95 with an inter-rater variability of 0.12mm ± 0.13mm (95%-CI 0.04–0.19).
Accuracy of the method was assessed in the CT-scans of 38 patients with a ZMC fracture that required surgical treatment (and was thus deemed displaced by the clinician). The asymmetry in the ZMC fracture patients was higher than the asymmetry in the healthy control patients (2.69mm vs 1.40mm; p<0.01). This finding corresponded with the clinical perception that the ZMC fractures were displaced. Moreover the asymmetry in the ZMC fractures correlated with the classification for ZMC fracture severity, increasing asymmetry was observed from A-type, to B-type, to C-type ZMC fractures (p=0.01).

In **Chapter 6** a prospective cohort study was performed on the use of intraoperative CBCT imaging in the treatment of 38 patients with a ZMC fracture. ZMC fracture reduction in this group was accurate. A significant improvement in ZMC symmetry was achieved by the surgery (2.69mm -> 1.67mm; p<0.01). Postoperative ZMC asymmetry was comparable to the ZMC asymmetry in the healthy population (1.67mm vs 1.40mm; p=0.31). Intraoperative CBCT was followed by a treatment revision in 11 cases (29%). The benefit of the treatment revisions was clear in 3 of these cases (27%), but only on a case-by-case basis analysis. The relevance of the revisions could not be confirmed statistically at a group level in this study.

In ZMC fractures that were comminuted (C-type) or with a primary indication for orbital floor treatment, the revision rate after intraoperative imaging was 89%; the revision rate was 10% in non-comminuted ZMC fractures (A- and B-type) without an indication for primary orbital floor treatment ($p<0.01$). The presence of comminution and/or an indication for orbital floor treatment had a 89% positive predictive value and a 90% negative predictive value for the occurrence of treatment revisions after intraoperative CBCT.

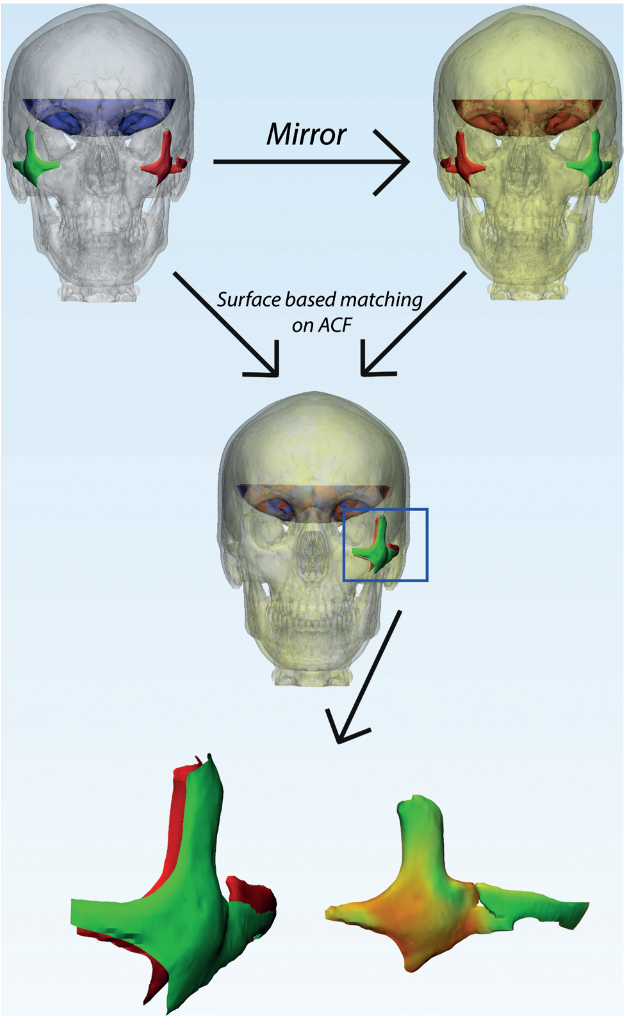


Figure 2: Method for measuring ZMC asymmetry.

The rate for secondary surgical interventions to improve ZMC position or orbital floor reconstruction was 0% in this study, vs 8% in the patients that were treated without intraoperative imaging in **Chapter 3** (p=0.06).

Figure 3: The mobile CBCT-scanner in use in the operating room.

Conclusion

Traffic accidents are the most common cause of maxillofacial fractures in the Dutch population. Therefore preventive measures aimed at decreasing the incidence of maxillofacial fractures are likely to be most efficacious if addressed at preventing maxillofacial injuries due to traffic accidents.

In ZMC fractures treated without intraoperative imaging, comminuted fractures are associated with inferior treatment outcome. Intraoperative imaging often leads to treatment revisions aimed to improve either ZMC fracture reduction or orbital floor treatment, especially in comminuted ZMC fractures and in ZMC fractures in which treatment of the orbital floor is indicated.
Treatment of ZMC fractures with intraoperative CBCT imaging leads to accurate fracture reduction. The relevance of the revisions after intraoperative imaging could not be confirmed statistically at group level in this thesis. However, a trend towards fewer secondary surgical interventions to improve ZMC position or the orbital floor treatment was observed in patients treated with intraoperative imaging (Chapter 6) in comparison to patients treated without intraoperative imaging (Chapter 3).
The proposed method for measuring ZMC asymmetry with mirroring of the ZMC and surface-based matching on the anterior cranial fossa is reliable, accurate, and suitable for the evaluation of ZMC fractures.

Recommendation

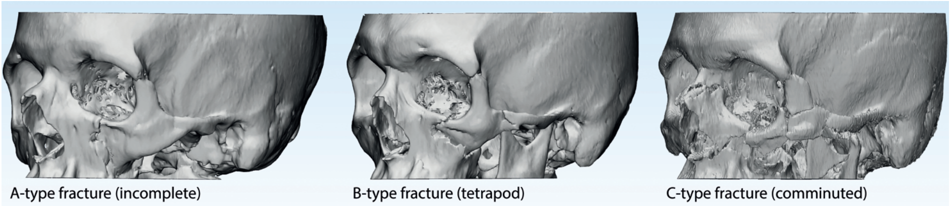
Based on the research in this thesis we recommend to use intraoperative imaging in ZMC fractures that are comminuted (C-type) and in ZMC fractures in which treatment of the orbital floor is indicated.

Nederlandse samenvatting (Dutch summary)

Aangezichtsletsel komt vaak voor bij trauma patiënten in Nederland. In de behandeling van aangezichtsletsel vervult de specialist Mondziekten, Kaak- en Aangezichtschirurgie een centrale rol, aangezien deze de expertise heeft om letsel op botniveau, tandniveau en weke delen niveau te behandelen.
Het onderwerp van dit proefschrift is de behandeling van fracturen van het zygoma (jukbeen). Bij de behandeling van zygomafracturen wordt het verplaatste zygoma weer in de oorspronkelijke positie gereponeerd. Indien de repositie instabiel is wordt het zygoma gefixeerd door middel van titanium mini-platen. Omdat het zygoma ook een deel van de orbitabodem vormt (de bodem van de oogkas), moet in een deel van de zygomafracturen ook de orbitabodem behandeld worden. Dit is in ca. 20% van de gevallen.
Specifiek is in dit proefschrift het gebruik onderzocht van een Conebeam Computed Tomography (CBCT) scanner gedurende de operatieve behandeling van het gefractureerde zygoma. Door deze controle scan te vervaardigen tijdens de operatie (peroperatief), in plaats van na de operatie, is het mogelijk om een onvoldoende behandelresultaat direct te corrigeren. Dit kan een correctie betreffen van de stand van het zygoma en/of van de behandeling van de orbitabodem.

In **Hoofdstuk 2** is een retrospectieve epidemiologische studie verricht van alle patiënten die operatief werden behandeld voor aangezichtsfracturen in de periode 2005-2010 door de afdeling Mondziekten, Kaak- en Aangezichtschirurgie in het Universitair Medisch Centrum Utrecht. Uit deze studie kwam naar voren dat een groot deel van de patiënten mannen betrof in de leeftijdscategorie 10-30 jaar, 35% van de patiënten behoorde tot deze groep. De meest voorkomende oorzaak was een verkeersongeval (42%); een verkeersongeval met de fiets was de oorzaak in 18% van alle patiënten, met de auto in 13%, en met brommer of motor in 9%.

In **Hoofdstuk 3** is een retrospectieve cohortstudie verricht van 153 patiënten met een zygomafractuur die werden behandeld zonder peroperatieve beeldvorming in het Universitair Medisch Centrum Utrecht. De behandeluitkomst in comminutieve (verbrijzelde) zygomafracturen, het C-type, bleek slechter dan in de niet-comminutieve zygomafracturen (A-type en B-type). In de C-type zygomafracturen werden vaker her-operaties verricht dan in de A- of B-type fracturen (absoluut risico 21% vs. 6%; p=0.01); specifiek ter correctie van de stand van het zygoma (absoluut risico 12% vs. 6%; p=0.03), ter secundaire correctie van de orbitabodem (absoluut risico 10% vs. 0%; p<0.01), en ter behandeling van dubbelbeelden d.m.v. een oogspier correctie (absoluut risico 5% vs. 0%; p=0.02).



Figuur 1: Classificatie van zygomafracturen.

In **Hoofdstuk 4** werd een literatuur onderzoek verricht over het gebruik van peroperatieve beeldvorming bij de behandeling van zygomafracturen. Er werden 15 publicaties gevonden die voldeden aan de selectiecriteria, in 6 van deze 15 publicaties werd de frequentie van directe behandelrevisies naar aanleiding van de peroperatieve beeldvorming vermeld.
Meta-analyse van de resultaten van deze 6 studies toonde dat in 22% (95%-CI 14.1%-31.5%) van de gevallen naar aanleiding van de peroperatieve beelden een behandelrevisie werd verricht. Er werd in 18% (95%-CI 10.5%-29.0%) van de gevallen een revisie verricht van de stand van het zygoma en in 9% (95%-CI 3.6%-17.2%) van de gevallen een revisie van de behandeling van de orbitabodem.

In **Hoofdstuk 5** werd een digitale meetmethode ontwikkeld om de symmetrie van het zygoma te evalueren op (CB)CT beelden. De asymmetrie van het zygoma werd gekwantificeerd door middel van een methode die gebruik maakt van spiegelen en oppervlak-gebaseerde superponatie, waarbij de voorste schedelbasis gebruikt wordt om de symmetrische positie van het zygoma te bepalen. De gemiddelde afstand tussen het oppervlak van het zygoma en de symmetrische positie van het zygoma werd berekend. Dit is een maat voor de asymmetrie van het zygoma.
De betrouwbaarheid van de methode werd geëvalueerd in de CT-scans van 15 gezonde patiënten (zonder fractuur). De methode bleek zeer goed reproduceerbaar. De intra-observer correlatie coëfficiënt was 0.97 met een variabiliteit van 0.09mm ± 0.11mm (95%-CI 0.03–0.15mm). De inter-observer correlatie coëfficiënt was 0.95 met een variabiliteit van 0.12mm ± 0.13mm (95%-CI 0.04–0.19mm).
De accuratesse van de methode werd geëvalueerd in de CT-scans van 38 patiënten met zygomafractuur waarvoor operatieve behandeling geïndiceerd was. De klinische inschatting was dus dat het zygoma in deze casus verplaatst was door de fractuur. In de patiënten met zygomafractuur werd een hogere waarde (meer asymmetrie) gevonden dan in de gezonde casus (2.69mm vs. 1.40mm; $p<0.01$). Deze uitkomst correspondeerde dus met de klinische inschatting dat het zygoma verplaatst was. Daarnaast correleerde de uitkomst in de zygomafracturen met de ernst van de fractuur, de assymmetrie nam toe van A-type, naar B-type, naar C-type zygomafracturen ($p=0.01$).

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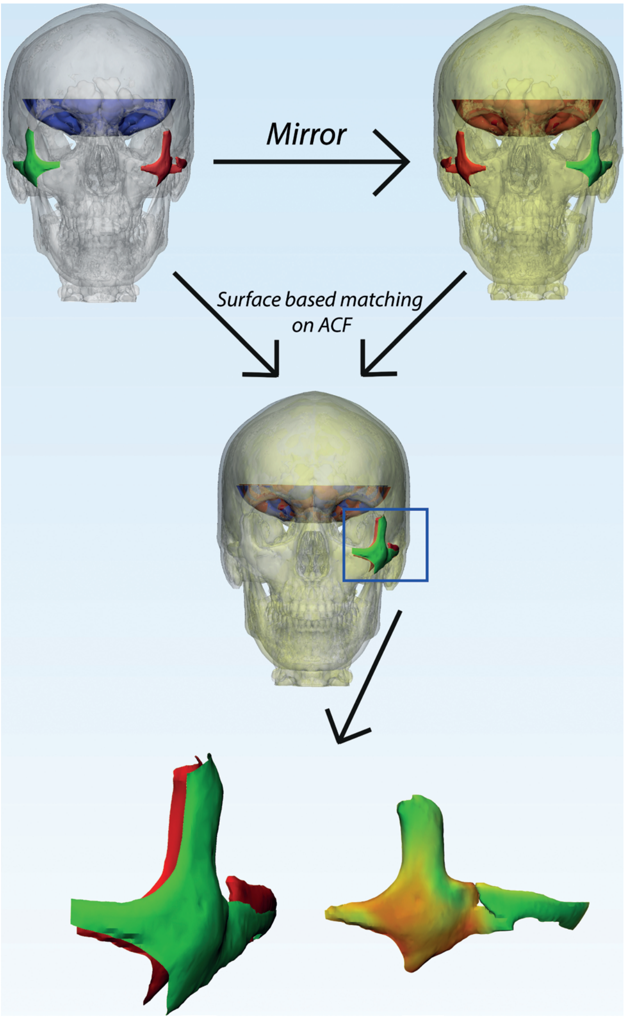

Figuur 2: Schematische voorstelling van de meetmethode.

In **Hoofdstuk 6** is een prospectieve cohortstudie verricht van 38 patiënten met een zygomafractuur die operatief werden behandeld met een peroperatieve CBCT-scan in het Universitair Medisch Centrum Utrecht. De repositie van het zygoma was in deze groep patiënten accuraat. Er werd een significante afname van de asymmetrie door de operatie bereikt (2.69mm -> 1.67mm; p<0.01). De postoperatieve asymmetrie was vergelijkbaar met de asymmetrie van het zygoma in de gezonde controlegroep (1.67mm vs 1.40mm; p=0.31).

Figuur 3: Gebruik van de mobiele CBCT-scanner op de operatiekamer.

NL

In 11 patienten (29%) werd naar aanleiding van de peroperatieve CBCT-scan een directe behandelrevisie verricht. De klinische relevantie van deze behandelrevisies was bij evaluatie op individuele basis in 3 van deze casus duidelijk (27%). Echter, in deze studie kon de relevantie van de behandelrevisies om de positie van het zygoma of de behandeling van de orbitabodem te verbeteren niet statististisch op groepsniveau aangetoond worden.
In comminutieve zygomafracturen en zygomafracturen waarbij de orbitabodem mee behandeld moest worden, leidde de peroperatieve CBCT scan vaker tot revisies dan in niet comminutieve zygomafracturen (A-type en B-type) waarbij er geen indicatie voor behandeling van de orbitabodem was (89% vs 10%; $p<0.01$). Deze parameter

(comminutie van het zygoma en/of indicatie voor meebehandelen van de orbitabodem) bleek een hoge voorspellende waarde te hebben voor de inschatting of een peroperatieve CBCT-scan invloed zal hebben op de behandeling (positief voorspellende waarde 89%, negatief voorspellende waarde 90%).
De frequentie van her-operaties aan zygoma of orbitabodem was in deze studie 0%, versus 8% in de patiënten die werden behandeld zonder peroperatieve beeldvorming in **Hoofdstuk 3** (p=0.06).

Conclusie

Verkeersongevallen zijn de meest voorkomende oorzaak van aangezichtsfracturen. Preventieve maatregelen gericht op het verlagen van de incidentie van aangezichtsfracturen zijn daarom waarschijnlijk het meest effectief als zij gericht worden op het voorkomen van aangezichtsletsel door verkeersongevallen.
Comminutieve zygomafracturen die worden behandeld zonder peroperatieve beeldvorming zijn geassocieerd met een slechter behandelresultaat. Peroperatieve beeldvorming bij de behandeling van zygomafracturen leidt frequent tot revisie van de stand van het zygoma en revisie van de behandeling van de orbitabodem. Met name in zygomafracturen met comminutie en/of indicatie voor behandeling van de orbitabodem wordt de behandeling vaak beïnvloed door peroperatieve beeldvorming. Behandeling van zygomafracturen met peroperatieve CBCT leidt tot accurate fractuur reductie. De relevantie van de behandelrevisies na peroperatieve beeldvorming kon in dit onderzoek niet statistisch op groepsniveau worden aangetoond. Wel werd er een trend gesignaleerd tot minder her-operaties ter verbetering van de stand van het zygoma of ter verbetering van de behandeling van de orbitabodem in patiënten die werden behandeld met peroperatieve beeldvorming (Hoofdstuk 6) ten opzichte van patiënten die werden behandeld zonder peroperatieve beeldvorming (Hoofdstuk 3).
De beschreven methode om de symmetrie van het zygoma te kwantificeren is betrouwbaar, accuraat, en geschikt voor de evaluatie van zygomafracturen.

Aanbeveling
Op basis van het in dit proefschrift uitgevoerde onderzoek raden wij aan om peroperatieve beeldvorming toe te passen in de behandeling van comminutieve zygomafracturen en zygomafracturen met indicatie voor behandeling van de orbitabodem.

Dankwoord

Klaar! Het boek is af! Zonder de hulp en steun van onderstaande mensen was dit mij niet gelukt. Mijn dank aan jullie is groot.

Ten eerst natuurlijk de patiënten van wie ik de gegevens heb mogen gebruiken voor mijn onderzoek. Jullie medewerking draagt weer bij aan een betere behandeling voor jullie toekomstige lotgenoten.

Hooggeleerde Rosenberg, beste Toine, circa halverwege het traject nam jij de begeleiding van mijn project over. De inclusie van patiënten in de juist opgestarte prospectieve studie vlotte opeens een stuk beter.. En hoewel de laatste loodjes zwaar zijn wist je met je kenmerkende resolute stijl mij te stimuleren maar ook te faciliteren om in de afronding van mijn opleiding ook mijn promotie af te ronden.

Hoogeleerde Koole, professor, samen planden we in 2011 het traject onderzoek, TOVA en opleiding. Dank voor het vertrouwen om dit traject samen aan te gaan

Zeergeleerde Van Cann, beste Ellen, met name in de beginfase van mijn onderzoek-carrière was jij nauw betrokken in de begeleiding. Op de meest late tijdstippen kreeg ik mails terug met je revisies van mijn teksten. Mijn eerste artikel hebben we nog samen ’s avonds in het UMCU gesubmit. In de latere fasen liet je de teugels meer veren waardoor ik meer mijn eigen koers kon varen, maar kon ik nog steeds op jouw kritische blik op mijn teksten rekenen.

Geachte leden van de leescommissie, hooggeleerde De Boer, Cune, Hendrikse, De Ridder en Stokroos. Ik wil u bedanken voor de tijd en inspanning die u hebt besteed aan de beoordeling van mijn manuscript en in de oppositie tijdens de verdediging ervan. Zeergeleerde Gooris, beste Peter, dank voor het opponeren tijdens de verdediging van mijn onderzoek.

Mijn paranimfen, allereerst Willem, veel monnikenwerk werd door jou verricht in de analyses van de laatste 2 artikelen. Dank daarvoor! Terecht ben je daarom ook niet alleen auteur en coauteur in deze 2 artikelen, maar sta je mij bij in de verdediging van dit proefschrift.
Balthasar, we delen meerdere interesses, de wetenschap is er daar een van. Hoewel kruisbestuiving tussen een immunoloog en kaakchirurg niet voor de hand ligt, is hier wel degelijk af en toe sprake van. Fijn dat je me bij de verdediging bijstaat, dit gaat ons beter vast beter af dan omgekeerd bij jouw experimenten..

Michael Frank, het onderwerp voor dit boekje werd door jou geïnspireerd, jij was de eerste van onze collega's die de 3DRX gebruikte en bracht mij op het idee om hier onderzoek over te doen. Dank voor je inspiratie.

Mannen en vrouw van het 3D-facelab, en in het bijzonder Jaron Roubos, vele uren werden eerst door mij en later door Willem doorgebracht achter de computer in jullie kamer. Dank voor de gastvrijheid en gezelligheid in jullie lab. Jaron, dank voor je hulp met het uitzoeken van de software voor de analyses, het meedenken in de uitvoering ervan, en voor je enthousiasme en interesse!

Collega's van de afdeling kaakchirurgie in het UMC-Utrecht voor zover hier boven nog niet genoemd: Robert, Marvick, Nard, Silke, Kim, Francois, Hendrik, Egbert, Lodewijk, Elmer, Thomas, Barbara, Martine, Lodewijk, Kathelijne, Rob, Koen, Daan, Reilly en Joost. De patiënten in de laatste studie werden grotendeels door jullie geopereerd. In het begin vergde dit veel van het geduld om de CBCT-scanner op OK te bedienen.. Dank daarvoor, maar natuurlijk ook voor de fijne samenwerking afgelopen jaren.

En hoewel niet direct gerelateerd aan dit proefschrift, voelt dit toch ook als een afsluiting van mijn tijd als arts-assistent. Daarom, poli zusters en secretaresses in het UMC-U en Amphia ziekenhuis, verpleegkundigen van D5oost en D5west, en kaakchirurgen in het Amphia, dank voor de plezierige samenwerking de afgelopen jaren.

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Mijn ouders, mamma en pappa, jullie interesse, stimulatie en steun is nooit aflatend. Dank voor het warme nest en de mogelijkheden die jullie mij geboden hebben!

Mijn zussen, Afke en Elsbeth, jullie en jullie gezinnen mogen hier natuurlijk ook niet ontbreken! Ik ben blij dat we zo'n goede broeder-zusterlijke band hebben en geniet van het (inmiddels 5x!) oom zijn.

Evelyn, waar een feestje op de Waal al niet toe kan leiden. Inmiddels wonen we al weer een hele poos samen. Dank voor je begrip en geduld als ik weer eens druk was met werk en dienst, of wat dan ook. Ik kijk uit naar onze toekomst samen!

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A novel method for quantitative 3-dimensional analysis of zygomatico-maxillary complex symmetry.
Article submitted

van Hout WMMT, de Kort WWB, ten Harkel TC, Van Cann EM, Rosenberg AJWP
Zygomaticomaxillary complex fracture repair with intraoperative CBCT imaging. A prospective cohort study.
Article submitted

Curriculum Vitae

Wouter van Hout was born on the 13th of May 1986 in Wemeldinge. He graduated from secondary school "Pontes College, Het Goese Lycem" in 2004.
After secondary school he spent a gap year increasing his language skills in French and English, during which he spent a day in Operating Theatre at the Royal Sussex County Hospital in Brighton. This confirmed his interest in Medicine as a career.
Wouter commenced studying Medicine in 2005 at the University of Utrecht, graduating in 2011. During his studies he did clerkships at the Orofacial Cleft Team in the Utrecht Children Hospital (Wilhelmina Kinderziekenhuis) with the Plastic and Reconstructive Surgery department, the Head and Neck Surgical Oncology department (University Medical Center Utrecht), the Ophthalmology and Oculoplastic Surgery department (Royal Prince Alfred Hospital, Sydney, Australia), and of course the Oral and Maxillofacial Surgery Department (University Medical Center Utrecht). In the final years of his study Wouter performed research on Maxillofacial Trauma and Cleft Surgery.
After graduating in Medicine he worked as a non-training resident in General Surgery at the St. Antonius Ziekenhuis (Nieuwegein) and as a researcher at the Oral and Maxillofacial Surgery Department (University Medical Center Utrecht).
In 2013 Wouter commenced studying Dentistry at the Radboud University in Nijmegen, from which he received his degree in 2016. After a brief stint working in the Dentistry office "Tandartspraktijk Van Hout" in Yerseke and as a researcher working on this thesis, he commenced his training in Oral and Maxillofacial Surgery at the Utrecht Medical Center (department head: prof.dr. A.J.W.P. Rosenberg). Wouter completed his training in Oral and Maxillofacial Surgery in May 2020.
In his spare time he enjoys playing sports (hockey, cycling, running), gastronomy (both cooking and eating), and spending time with friends and family.