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ORIGINAL ARTICLE

The use of navigation (BrainLAB Vector vision^2) and intraoperative 3D imaging system (Siemens Arcadis Orbic 3D) in the treatment of gunshot wounds of the maxillofacial region

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Abstract
Purpose Gunshot wounds are a rare occurance during times of peace. The removal of projectiles is recommended; in some cases, however, this is a controversy. The reproduction of a projectile image can be difficult if it is not adjacent to an anatomical landmark. Therefore, navigation systems give the surgeon continuous real-time orientation intraoperatively. The aim of this study was to report our experiences for image-guided removal of projectiles and the resulting intra- and postoperative complications.
Patients and methods We investigated 50 patients retrospectively; 32 had image-guided surgical removal of projectiles in the oral and maxillofacial region. Eighteen had surgical removal of projectiles without navigation assistance.
Results There was a significant correlation (p=0.0136) between the navigated surgery vs. not-navigated surgery and complicaton rate, including major bleeding (n=4 vs. n=1, 8% vs. 2%), soft tissue infections (n=7 vs. n=2, 14% vs. 4%), and nerval damage (n=2 vs. n=0, 4% vs. 0%; p=0.038) and between the operating time and postoperative complications. A high tendency between operating time and navigated surgery (p=0.1103) was shown. When using navigation system, we could reduce operating time.
Conclusion In conclusion, there is a significant correlation between reduced intra- and postoperative complications, including wound infections, nerval damage, and major bleeding, and the appropriate use of a navigation system. In all these cases, we could present reduced operating time. Cone-beam computed tomography plays an important role in detecting projectiles or metallic foreign bodies intraoperatively.

Keywords Gunshot wounds · Projectiles · Imaging techniques · Cone-beam computed tomography · Navigated surgery

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Introduction

Gunshot wounds are a rare occurance during times of peace. Recently, however, there has been a general increase in the number and severity of these injuries [1]. They may be mainly caused by suicide attempts, violent conflicts, and negligent handling [2, 3].

For gunshot wounds, missile characteristics such as velocity, mass, caliber, composition, and angle of trajectory all influence the extent of injury [4]. The face is a region with a large number of important structures compressed into a relatively small anatomic area so that the severity and extent of injury may range from a simple small wound of soft tissues to a severe combined injury of the orbit, brain, and vascular system. Even if the gunshot injury itself does not cause major problems, the removal of projectiles can cause damaging of important anatomical structures, although coventional radiography, computed tomography, image-guided surgical removal, and cone-beam computed tomography (CT) have been applied to facilitate that procedure [5, 6].

On the other hand, remaining projectiles may lead to infection [7, 8] and migrate from the site of the entry [9], and it is well known that metal embedded in body tissue can be a source of potential exposure to toxic effects [10, 11]. Moreover, the pellets may dislocate within the soft tissue spontaneously. However, it does not seem appropriate to leave a pellet, as has been proposed previously, and is still a controversy [12, 13].

But, even if the exact position is known from imaging data, the accurate reproduction of this position in the physical space of the patient can be difficult if the projectile or foreign body is not adjacent to a definite anatomical landmark. Therefore, so-called navigation systems allow the registration of image space and physical space of the patient and gives the surgeon continuous real-time orientation intraoperatively.

The aim of this study was to report our experiences for image-guided removal of projectiles in the craniomaxillofacial region and whether there is a significant correlation to resulting intra- and postoperative complications caused by the surgical procedure.

Patients and methods

We investigated 50 patients (aged between 17 and 77 years); the frequency in males (39, 78%) was overwhelmingly higher than that in females (11, 22%). Thiry-two had image-guided surgical removal of projectiles in the facial region; 18 had surgical removal of projectiles without navigation assistance. In ten of the cases, we used cone-beam CT intraoperatively to detect spontaneously dislocated projectiles. All patients were being treated at the Department of Oral and Maxillofacial Surgery of the University Medical Center Hamburg-Eppendorf, between 1996 and 2008. The data for the study were obtained retrospectively from patient files and patient radiographs (conventional radiographs, cone-beam CT, and CT scans) and were sorted according to the age, gender, type and classification of facial injuries, diagnostic methods, treatment received, and complications. Depending on the pattern of injury, treatment planning often required different radiographic examinations not only to asses the extent of the hard and soft tissue destruction but also to locate the projectiles and plan the surgical procedure.

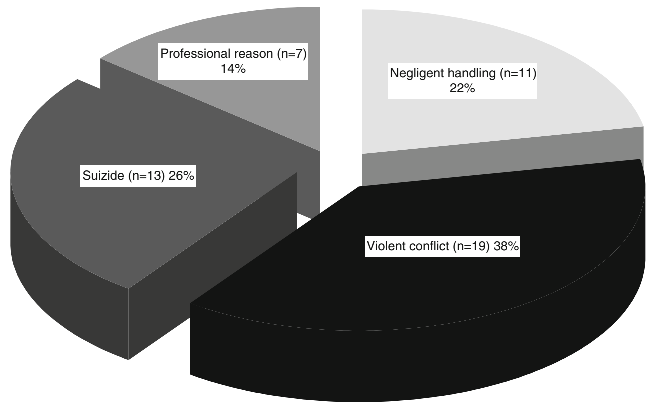

Fig. 1 Motivation causing gunshot wounds to the maxillofacial region

Statistical analysis

For statistical analysis, SPSS® for Windows® (Version 11.5.1; SPSS Inc., Chicago, IL) was used. Significance statements refer to p values of two-tailed tests that were less than 0.05.

Results

In 23 of the cases (46%), we had a retained projectile, 13 times (26%), a full penetration, in 11 cases (22%), a grazing shot, and 3 injuries (6%) because of shotguns. The majority of the injuries were caused by violent conflicts, followed by negligent handling, and by suicide attempts or because of professional reasons (Fig. 1).

All patients had soft tissue injuries and in 50% of the cases (n=25), combined with hard tissue injuries to the viscerocranium (Fig. 2). Following the classification of Gant et al. [14], there were frontal bone fractures, facial injuries, and supraorbital rim fractures in the upper third

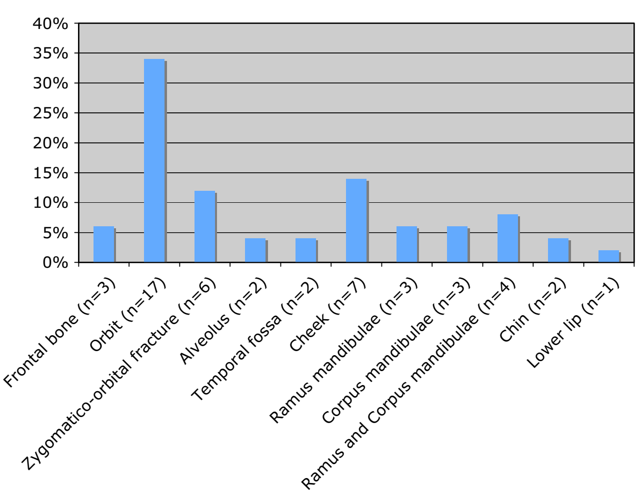

Fig. 2 Patterns of injury (n=50)

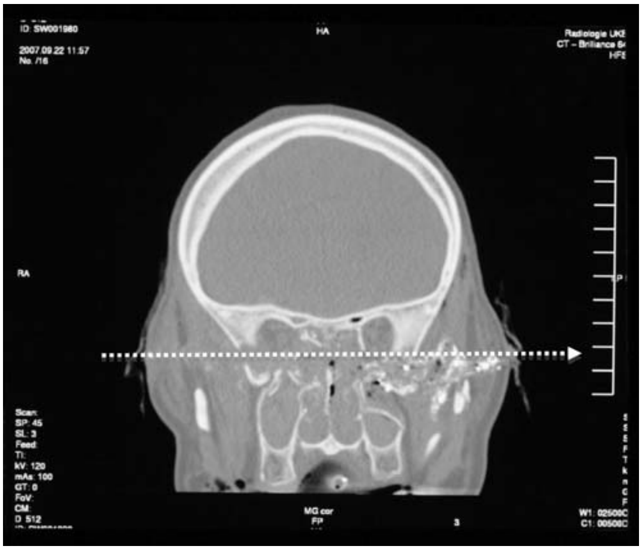

Fig. 3 CT scan showing midfacial destruction after a suicide attempt

followed by soft tissue injuries to the temple. In the middle third of the viscerocranium, we found lateral midfacial fractures (zygomatico-orbital), followed by dentoalveolar fractures, and soft tissue injuries to the cheek. These injuries constituted the greatest amount of injuries of the viscerocranium in this study. Finally, the lower third injuries including the mandible and its related structures ranged from simple penetrating wounds of the chin to gross destruction with bony defects (Fig. 2).

The majority of the sample (n=44, 88%) had no associated bodily injuries. The most common associated injuries were to the neurocranium (n=4, 8%), neck, and limbs (n=2, 4%), with the thorax and abdomen (n=1, 2%) being the least common.

No special investigations were required in 8% (n=4) of the sample; conventional X-ray films alone were requested in 18 % (n=9) and in combination with CT scans and cone-beam CT in 74% (n=37) of the cases. The conventional radiographs and CT investigations were done in our Department of Radiology. In case of invisibility of the projectiles on physical examination and inspection, or if the

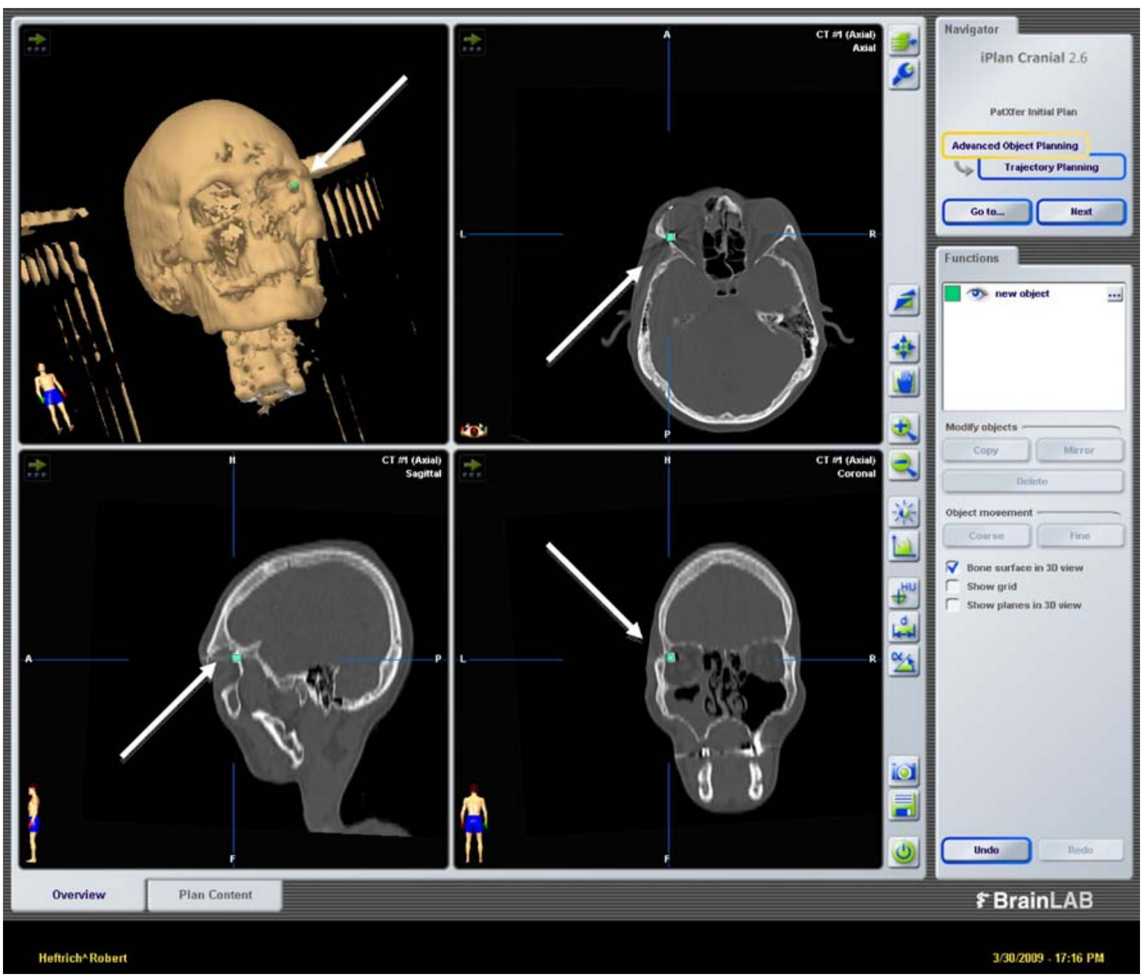

Fig. 4 Preoperative screenshot from the navigation system showing a triplanar view with the current position of the projectile inside the left orbit

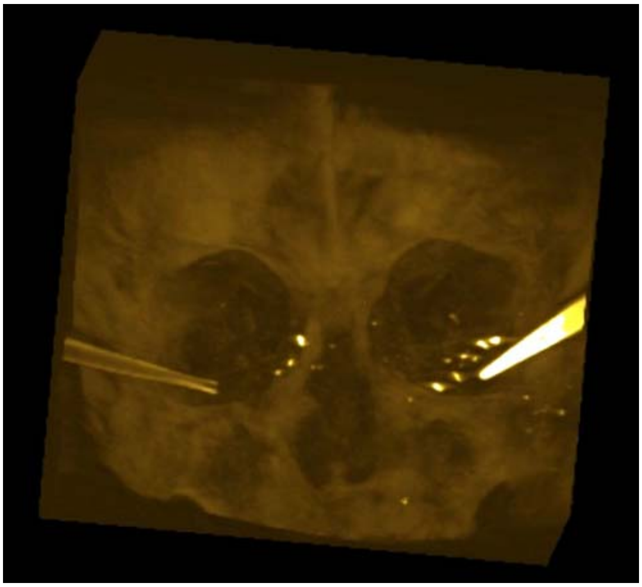

Fig. 5 Intraoperative imaging system (DVT) with pincers inside the gunshot wound

foreign body was close to important anatomical structures, navigation-assisted surgery was used.

Preoperatively, we found pathologic results in 70.8% of all conventional radiographs and in 84.2% of CT scans (Fig. 3).

For later registration, the image data were then transferred to the navigation system; the foreign bodies were located and marked within the planning software (Fig. 4).

The registration process is necessary for valid tracking. The tracking system consists of two infrared cameras that track the spatial positon and orientation of markers, which emit infrared light by LEDs. Intraoperatively, a rigid body is fixated at the patient's body, with bone screws directly to the skull, and is attached to the patient and to a pointing device. The tracking information is processed by the navigation system for seeing the tip of a pointer continously on the touch screen of the navigation system with a triplanar view of the image data as well as a 3D model of the patient's anatomy. The surgeon was therefore guided to the foreign body using a pointer tracked by the navigation system by an accurate match between image data and patients anatomy.

All projectiles could be removed via minimally invasive surgical access to the indicated location (Fig. 5 and 6). The surgical procedures were all uneventful. Patients were given antibiotics prophylactically. Patients with soft-tissue infection received antibiotic treatment by antibiograms.

The overall complication rate was 34%; there was a significant correlation ($p=0.0136$) between the navigated surgery vs. not-navigated surgery and the complicaton rate, including major bleeding ($n=4$ vs. $n=1$, 8% vs. 2%), soft tissue infections ($n=7$ vs. $n=2$, 14% vs. 4%), and nerval damage ($n=2$ vs. $n=0$, 4% vs. 0%; Fig. 7).

Furthermore, there was a significant correlation ($p=0.038$) between the operation time and postoperative complications, including mainly wound infections and major bleeding.

Another fact was a high tendency between operation time and navigated surgery (Fig. 8; $p=0.1103$). While using navigation system, we could reduce operation time. The average duration of a not-navigated surgical procedure was 164±73 min vs. 120±76 min for a navigated surgical procedure, including reference process.

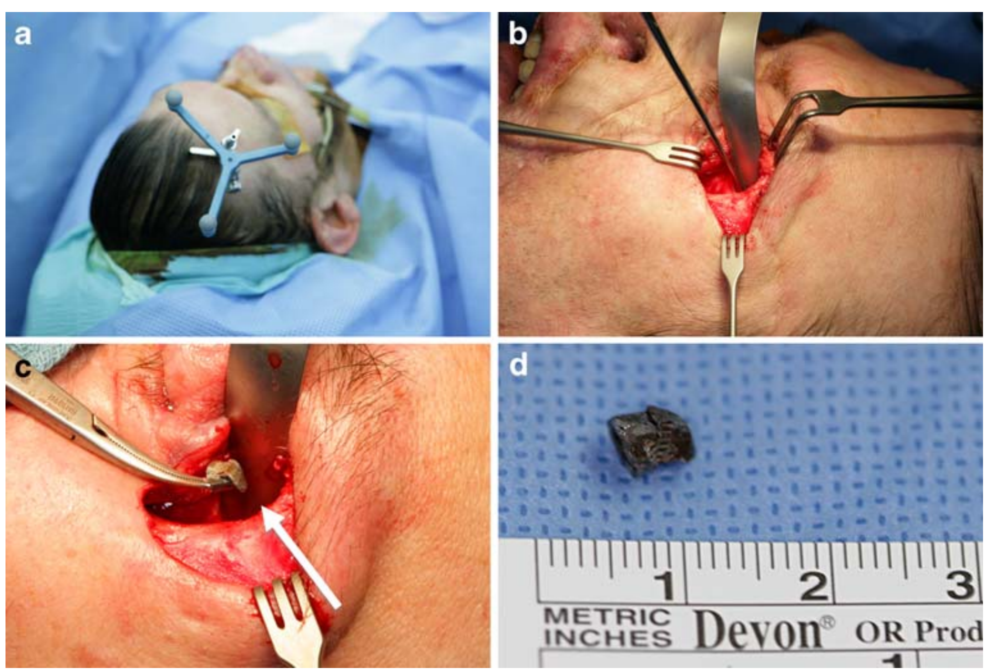

Fig. 6 Intraoperative situation showing the fixation of a rigid body to the skull (**a**), minimal surgical access to the left orbit (**b**), removal of the projectile (**c**), and the foreign body (**d**)

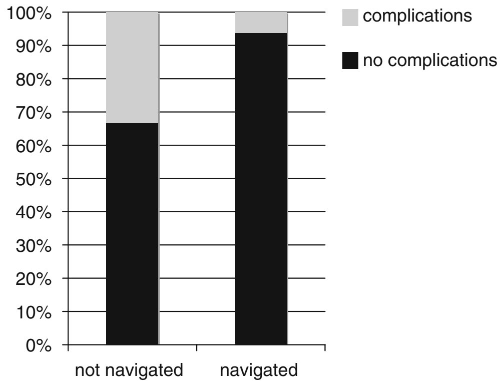

Fig. 7 Complication rate: surgical removal of projectiles with and without appropriate use of a navigation system

In 10 of the cases, we used a 3D imaging sytem (cone-beam CT) to reproduce the new position of intraoperatively dislocated projectiles (sinus maxillaris n=4, temporal region n=3, orbit n=3). The foreign bodies were found and removed uneventfully in all cases.

Altogether, all patients were hospitalized for at least 6 days; the mean stay was 14.3 days (±7.9).

Discussion

Gunshot injuries are rare in western Europe and usually the result of suicide, violent conflicts, and negligent handling. Literature on gunshot wounds to the maxillofacial region remains scarce. For optimal interdisciplinary management, a careful clinical examination, a sound knowledge of gunshot wounds, as well as ballistic knowledge and a well-planned preoperativ examination plan are necessary.

Projectiles should be removed surgically whenever possible considering the state of the patient and location of the foreign body [3, 15]. Gunshot wounds often show damaged tissue, altered anatomy, and projectiles often lying close to vital structures difficult to access surgically. To identify the exact position of a foreign body and assess the damaged surrounding tissue, a variety of radiological examinations is possible and are described in the literature. Since it is usually impossible to identify the exact position of a projectile by visual inspection alone, conventional radiographs, CT scans, and cone-beam CT, which was introduced a few years ago [16–18], eventually combined with a navigated system intraoperatively, are available.

Sometimes projectiles tend to migrate within the soft tissue from the site of the entry. In these cases, navigation based on preoperatively acquired imaging data becomes useless for relocation of a foreign body. To replicate the new position of a projectile within the soft tissue or inside a sinus, cone-beam CT and C-arm systems are available intraoperatively, although there are limitations for soft tissue imaging [19–22]. However, they are seldom available in oral and maxillofacial operating theaters. An alternative technique is introduced, one that adopts a mobile dental X-ray device for the acquisition of conventional radiographs in two planes, with reference markers attached to the surgical site [23].

Once the extent of the damaged tissue has been assessed and the position of the projectile has been located, an individual treatment plan has to be established. In the literature, the removal of projectiles is recommended [15]; in some cases, however, this is a controversy, and some authors leave a projectile in situ [12, 13].

In more than 50% of the cases, we found combined soft tissue and hard tissue injuries. The number of soft tissue injuries alone appears high, considering the intricate anatomy of the maxillofacial region. These findings were similar to those reported earlier in the literature [14, 24].

The concepts of soft tissue repair have remained constant over the last years [25]. Closure of the wound and immediate definitive reconstruction after decontamination and debridement of the wound, to avoid any dead space, minimize wound tension and evert wound edges. The use of microvascular free tissue transfer and rotational flaps for

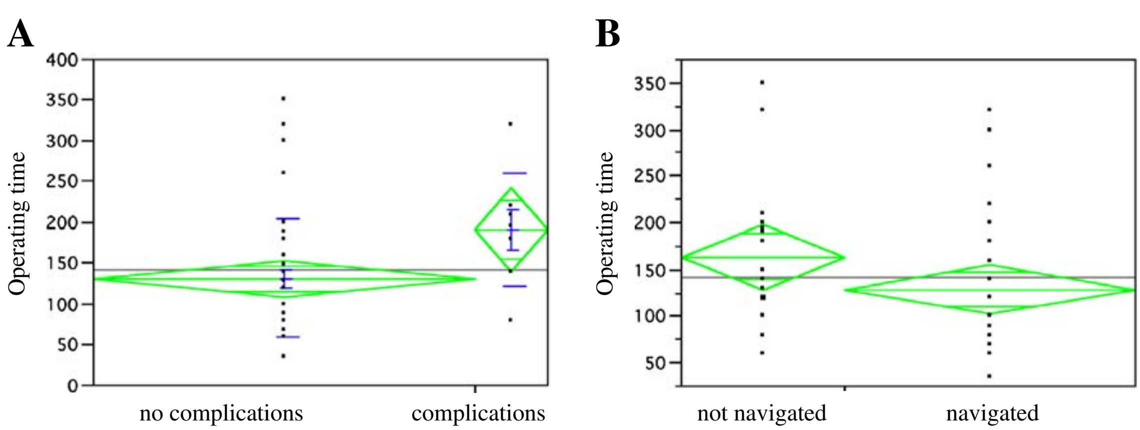

Fig. 8 The correlations between the complication rate and operation time (**a**) and the use of a navigation system and operation time (**b**)

primary closure of large defects has greatly improved results in appearance and function [26].

Similar to soft tissue repair, the techniques used in immediate reconstruction of boney defects caused by gunshot wounds are equally effective as those employed in routine reconstruction procedures [27].

The overall complication rate intra- and postoperatively was relatively high mainly caused by wound infections, nerval damage, and bleeding complications. These findings have been described before [24, 28]. A possible explanation may be the large wound surface and extended damage of tissue caused by either the pattern of injury or the operation itself. The findings of this study highlight the fact that another reason for these complications is a prolonged operating time, which can be reduced by the assistance of a navigation system. Furthermore, the collateral damage of tissue can be reduced by minimal surgical access in case of an appropriate use of a navigation system.

In conclusion, there is a significant correlation between reduced intra- and postoperative complications, including wound infections, nerval damage, and major bleeding, and the appropriate use of a navigation system. Furthermore, we could present reduced operation time in all these cases. Cone-beam CT plays an important role in detecting projectiles or metallic foreign bodies intraoperatively.

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Conflict of interest statement The authors declare that they have no conflict of interest.

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