Dynamic 3D computer-assisted reconstruction of a metallic retrobulbar foreign body for diagnostic and surgical purposes.

Case report: orbital injury with ethmoid bone involvement

Published in:

Running headline: 3D C-FESS

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This study was in part supported by an unrestricted grant provided by the Ministry of Science and Technology, Republic of Croatia (Dr. Klapan)
ABSTRACT

The main goal of our dynamic 3D computer-assisted reconstruction of a metallic retrobulbar foreign body following orbital injury with ethmoid bone involvement was to use 3D-information obtained from standard computed tomography data (CT) to explore and evaluate the nasal cavity, ethmoidal sinuses, retrobulbar region, and the foreign body itself by simulated dynamic computed visualization of the human head. A foreign body, 10x30 mm in size, partially protruded into the posterior ethmoidal cells and partially into the orbit, causing dislocation and compression of the medial rectus muscle and inferior rectus muscle. The other muscles and the optic nerve were intact.

Various steps were taken in developing diagnostic and surgical activities. Thin CT sections of the nasal cavity, orbit and paranasal sinuses were performed on a conventional CT device at a regional medical center, CT scans were transmitted via computer network to different locations, and special views very similar to those seen on standard endoscopy were created. Special software for 3D modeling, specially designed and modified for 3D C-FESS purposes, was used, as well as a 3D-digitizer connected to the computer and multimedia navigation through the computer during 3D C-FESS.

Our approach provides the visualization of very delicate anatomical structures within the orbit in unconventional (non-standard) sections and angles of viewing, which cannot be obtained by standard endoscopy or 2D-CT scanning. Finally, virtual endoscopy (VE) or a 'computed journey' through the anatomical spaces of the paranasal sinuses and orbit substantially improves the 3D C-FESS procedure by simulating the surgical procedure prior to real surgery.
**Key words:** Endoscopy, Retrobulbar foreign body, Three-dimensional visualization,
Computer assisted diagnosis, Orbital surgery
INTRODUCTION

The main purpose of our three-dimensional computer assisted functional endoscopic sinus surgery (3D C-FESS) technique was to support standard functional endoscopic sinus surgery (FESS)\(^1\) with 3D-computer assistance and to develop a safer surgical procedure by producing a real and advanced visualization of the anatomy and pathology, using completely new computer and medical technologies\(^2-4\). Such an approach should allow a considerably better insight into the operating field and significantly greater safety of the procedure.

This approach appeared ideal for use in both the diagnosis and surgical treatment of a penetrating injury of the orbit and posterior ethmoidal cells of the paranasal sinuses inflicted by a metallic foreign body.

As a number of parameters necessary for a satisfactory outcome of the operation could not be positively determined by standard preoperative surgical planning, we embarked upon examination of the anatomical region of the nose, paranasal sinuses and orbit by use of the 3D C-FESS technique criteria. The use of this new technique in the surgery of the paranasal sinuses and adjacent anatomical regions proved advantageous since the retrobulbar foreign body could not be removed by the standard, 'classical' endoscopic and surgical technique, not even with the use of 2D-CT sections of the region.

The region of the paranasal sinuses and their surrounding structures, i.e. the orbital and skull base area, has a very complex anatomical architectonic, because a large number of anatomical structures are located within a relatively small space. Therefore, in addition to history and status data, computed tomography (CT) is a crucial method for diagnosing pathology in this region.
Standard stratified CT images suffer from some shortcomings; however, the new, third dimension (3D) approach in both preoperative and intraoperative head imaging provides a completely new insight in any surgical procedure.

Owing to advances in computer technology, computers employing various methods of digital image processing have become available that are capable of creating 3D models of the observed region from stratified digital images within a short period of time.
MATERIAL AND METHODS

Case report

A 28-year-old healthy man suffered a penetrating injury from a metallic object in the region of the left palpebral fissure: a 3-mm laceration of the eyelid edge and eyeball penetration involving the entire cornea diameter and continuing 4 mm into the orbit. The foreign body was almost completely retained in the orbit, with a minor segment protruding into the region of the posterior ethmoid sinus cells.

All examinations and CT scanning were performed at a regional medical center.

 Orbital x-ray showed a shadow intensity characteristic of a metal object in the region of the medial and posterior segments of the orbit, with suspected fracture of the base of the orbit. CT scanning of the orbit revealed a foreign body, 10x30 mm in size, in the cribriform lamina region of the left orbit, which partially protruded into the posterior ethmoidal cells and partially into the orbit, causing dislocation and compression of the medial rectus muscle and inferior rectus muscle (Fig. 1). The other muscles and the optic nerve were intact. Pronounced chronic inflammatory changes with signs of ostiomeatal block were observed in the region of the ethmoidal cells and left maxillary sinus (Fig. 2).
Fig. 2

The patient was conscious on admission to the Department of Ophthalmology, Zagreb University Hospital Center. It was noticed that the eyeball was filled with blood, but with maintained tonus and sutures in the region of the upper eyelid, cornea, conjunctiva and orbit. The visual function was reduced to uncertain light perception. A normal finding was recorded on the right eye. Vitrectomy and suturing of the cornea and sclera were performed. Postoperatively, antibiotic therapy with local corticosteroids and mydriasis was prescribed.
CT scanning

Standard CT scans in 3-mm coronal sections and 5-mm transverse sections were performed at a regional medical center. The 5-mm transverse CT sections were performed in a plane parallel with the hard palate and with the patient in a supine position, whereas the 3-mm coronal CT sections were performed in a plane perpendicular to the hard palate and with the patient in a prone position with neck hyperextension.

Although we know that the use of 1.5 mm slice thickness for the orbit was introduced in the early 1980’s (Forbes, 1982 and Peyster, 1983) and that it was not recommended to use a thicker slice, we used 3 mm and 5 mm slices for the design of the static and dynamic 3D models of the paranasal sinuses because additional CT-scanning of the patient’s head was not possible at the time.

The two-dimensional coronal and transverse sections were compared with 3D models. The static and dynamic 3D models and VE of the sinuses were used for surgical planning and were available to the surgeon in the operating room throughout the procedure. All CT images obtained were stored on film and in digital form on a magnetic medium (hard disk).

Hardware used in 3D C-FESS:

**IMAGE DISPLAY:** SGI-O2 Workstation, Color 20’ monitor, 1280x1024x75Hz, $2^{32}$ colors, double buffered (32+32-bit)

**COMPUTER:** SGI-O2, 128 MB system RAM, CD, 4GB system disk, IRIX 6.3 operating system, 33600 Baud Modem, Fast Ethernet,

**PROCESSING POWER:** 4.6 SPEC int 95, 5.4 SPEC fp 95
USER INTERFACE: Mechanical mouse, Keyboard, X-wind./MOTIF/Indigo magic

CT or MRI INPUT: Ethernet using DICOM Standard

OTHER: NTSC/PAL S-video output, HP 1100 A Laser Printer.

Endoscopes, standard FESS-instruments, cold-light sources, monitors, endo-micro camera, video recorder.

Software used in 3D C-FESS:

3D Viewnix V1.1 - http://www.mipg.upenn.edu

Analyze AVW - http://www.mayo.edu/bir

T-Vox V1.0 - http://www.ht.com

Elscint OmniPro 2.2 - http://www.elscint.co.il

SGI Showcase V3.4.1 - http://www.sgi.com

Starvision StarMED - http://www.starvision.com
DISCUSSION

In our patient, the presence of a foreign body in the medial and posterior region of the orbit, with suspected fracture of the base of the region, was diagnosed by plain x-rays. As it was a high-density metallic foreign body, the basic diagnosis was quite easy to make; however, highly reflective structures such as bone tissue posed certain difficulties, especially in the borderline area toward the region of the posterior ethmoidal cells. The high-density foreign material in the orbit was detected with a high level of certainty by use of CT sections of the orbit and paranasal sinuses in axial and coronal sections. The foreign body was a tin fragment, 10x30 mm in size. Only its approximate location and possible contact with the vital anatomical structures within the orbit could be determined. Although it is known that a metallic foreign body of more than 0.3 mm in size within the orbital region can be visualized by CT scanning\textsuperscript{3,8}, in our case this approach proved efficient only for the diagnostic purpose of foreign body localization and its identification within the retrobulbar area. The basic contours of the foreign body and the structures surrounding the orbit could not be visualized with certainty, nor was it possible to determine whether there were two disparate, mutually connected fragments of the foreign body, or a single, irregularly bent tin fragment, or two foreign bodies close to one another. This is why we compared 3D and 2D-CT views of the metallic retrobulbar foreign body, as shown in Figure 3a, b, c and d.

In spite of the advantages of such a 3D presentation of the foreign body in our case report, this technique showed some shortcomings during preoperative planning, because we were aware of the fact that such a poor quality of some 3D models was due to the use of 3-mm and 5-mm slice thickness. Primarily, the 3D image presented in Fig. 3b clearly shows considerable
degradation of the image quality due to the use of thick slices. For example, there is no evidence of a smooth supraorbital margin. In addition, there is the problem of shading and lack of depth-encoding (the greater the distance from the observer, the darker the image). As a result, the superior orbital fissure on the left looks like a nasal bone fracture.

The main reason for insisting on precise determination of the shape, position and number of foreign bodies was the unfavorable location of the foreign body. With its proximal part, the foreign body was in tight contact with the dislocated and compressed medial rectus muscle and inferior rectus muscle. The other muscles and the optic nerve were intact; however, the distal, bent edge of the foreign body was very close to the optic nerve (Fig.4).

![Fig.4](image)

Although the position and location of the foreign body in the narrow retrobulbar area were very precisely determined by use of various 3D images, this approach also appears to deserve a critical commentary. It is readily observable that during the segmentation, the same
threshold was used for both the bone and the foreign body; however, a metal object requires a much higher threshold. As a result of this possible error, the foreign body may look larger than it really is (Figs. 3b, 3d and 4b); unfortunately, this diagnostic problem could not be solved by use of either plain x-rays or CT sections, which considerably hampered the process of preoperative planning. However, it should be emphasized that this presented no practical problem during the subsequent operative procedure.

Visualization of the region by magnetic resonance imaging (MRI) would not be permitted in this case because the patient had a metallic material inside the orbit.

Foreign bodies lying along the medial wall of the orbit are known to be quite difficult to visualize and to remove by the 'lateral' approach, while the approach through medial conjunctiva is quite questionable and limited. Thus, an approach combining medial and lateral orbitotomy may be tried in such cases. The approach with disinsertion of the medial rectus muscle with temporary dislocation of the eyeball provides quite a good view of the region of the orbital medial apex. However, this approach has proved satisfactory only in the case of small foreign bodies of a relatively flat surface, because large foreign bodies could significantly derange the anatomical relations in the region. The medial wall of the orbit is very delicate and susceptible to fracture or inflammatory changes induced by even a very low force. In our case, the suspected fracture of the base of the orbit required due consideration when choosing the surgical approach to the region.

The golden rule usually applied on removing large foreign bodies in the region is that these foreign bodies should be removed in a direction parallel to the axis of the entry wound, avoiding twisting or prying motions. Unfortunately, the rule could not be used in our case, because the foreign body was sharp and markedly bent and dentated on both sides. The eyeball and its bone structures that cannot be moved posed an additional problem. Therefore, the percutaneous surgical approach by a modification of Lynch incision appeared to be the most
favorable mode of treatment. The medial transconjunctival approach may also have provided
limited visualization of the foreign body and the borderline area of the orbit and posterior
ethmoids, but with a high probability of hemorrhage due to periosteal lesion and nasolacrimal
draining system impairment.

A question to which no definite answer could be reached was whether an additional lesion
to the medial rectus muscle and inferior rectus muscle had occurred upon extirpation of the
foreign body by standard FESS through the borderline area of the posterior ethmoids where the
foreign body edge was discerned. Nor was it possible to determine whether this standard
endoscopic approach by uncontrolled 'rightward' or 'leftward' manipulation during foreign body
extirpation would have caused additional lesions to the muscular structure or the optic nerve (Fig.
5 a, b, c, d). Figures 5 a, b, c and d present four frames from the fly-through movies presenting
the foreign body and its relationship to the anatomic structures of the retrobulbar region. We
admit that a better insight into this anatomic region on a model of static imaging could have been
achieved by making separate segmentation of the air, soft tissue, bone and metal, thus giving
each of them appropriate transparency. The proper choice would be to image both the foreign
body and the paranasal sinuses with maximal opacity but with different hues of grey. We do
agree that this would allow the relationship of the foreign body with the ethmoid air cells to be
seen best, rather than as a cross-section, as seen in Fig. 5 a, b and c. However, the possibility of
interactive interfacing in the dynamic form of the anatomy and pathology, presented in the
mentioned computed journeys through the human head, provided better visualization in an
entirely new way.
As 3D C-FESS operations imply a surgical approach *per viam* standard FESS with computerized 3D support, an operative approach to the foreign body through the lateral wall of the posterior ethmoids and the medial wall of the orbit (lamina papiracea) had to be planned. The lateral wall had already suffered massive destruction by the penetrating force of the projectile. An additional problem was the periorbital fatty tissue that partially filled the posterior ethmoid labyrinth and considerably hampered the foreign body localization and removal (Fig. 6).

Fig. 6

Considering the extremely complex anatomical structure of the orbit and paranasal sinuses and the need of a precise diagnosis for 3D C-FESS-planning, a basic aim of our 3D C-FESS approach was to evaluate the reliability of the known 3D static model, as shown in Fig. 7a and b, in the diagnosis of the pathology in the paranasal sinuses and to test it on a dynamic 3D model and VE, using the possibilities offered by the sophisticated computer technology.
This final step in the diagnostic procedure yielded additional preoperative information that was of great importance in surgery planning, because we “simulated” the route of the endoscope preoperatively, after which images were generated by the computer (Fig 8,a,b).
Using “live” video image mapping on the anatomical region, 3D models provide a better survey of the procedure. In addition, by overlaying the respective region onto the volume rendered model, we are able to create various complex anatomical structures of the orbit and paranasal sinuses that provided a highly precise diagnosis as well as the most sophisticated guidance through the operation itself\textsuperscript{12}. Finally, the 3D C-FESS approach can also be used as a basic technique in telecomputer assisted surgical activities, as our team has already done\textsuperscript{13}.

During the 3D C-FESS operation, our main concern was to prevent any additional damage to the medial rectus muscle, inferior rectus muscle and the optic nerve during foreign body removal. As the proximal part of the double-bent tin fragment leaned against the medial rectus muscle, encircling it by its anterior bent edge along the medial wall of the orbit in parallel with the other bent edge, the act of extirpation had to be carried out in such a way as to slightly rotate the foreign body on its axis and drag it through the region of the posterior ethmoids to the nasal region (Fig. 9 a, b, c). These figures show only the frame of the computer assisted surgical navigation described in this case report.
Close contact of the distal part of the foreign body with the optic nerve posed an additional problem. On rotating, utmost care was taken not to move the distal part of the foreign body even by a millimeter to prevent damage to the optic nerve.

By use of the 3D C-FESS technique, the foreign body was removed in 10 minutes. No additional lesions to the medial rectus muscle or the optic nerve that may have been induced by
various instrumentarium manipulations during the 3D C-FESS procedure were observed (Fig. 10 a, b).
Upon completion of the operation, our assumption that there was a metallic foreign body, sharply bent on both ends and bent in its middle part, was confirmed (Figs. 11, 12).
The foreign body image in these figures is not sharp enough because they were taken as frames from the video record of the operative procedure.

During the postoperative course, atrophy of the eyeball developed. As the eye was without stimuli, a laminar prosthesis was used, which has since been well tolerated by the patient.
1. **Klapan I, Šimičić Lj.** The main difference between FESS and 3D C-FESS 1998; HMA, 22 (Suppl. 2): 52.


