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Automatic Volumetry for Surgical Reconstruction of the Orbit

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Abstract

Fractures of the orbital floor are within the most frequent in craniomaxillofacial surgery. For surgical reconstruction, the orbital volume must be restored exactly to maintain the vision abilities of the subject. In this paper, we present an automatic segmentation and volume determination of human orbit based on a general discrete contour model applied to CT volumes of the skull. The coefficient of variation for manually placed start points is below 2%. The system is evaluated based on six subjects, where the difference between left and right eye- assumed to be zero – is determined experimentally. Here, the mean variation is 1.52%. Therefore, our method is sufficiently robust and applicable for surgery planning and follow-up studies.

Keywords:

surgery planning, orbit reconstruction,
image processing, active shapes, segmentation,
quantitative measurements

Introduction

Just after fractures of the mandible and the zygomatic bone the fracture of the orbital floor is the most frequent one in craniomaxillofacial surgery [1]. It is often diagnosed as an isolated blow-out-fracture or in combination with a fracture of the zygomatic bone. As much as 40% of all midface fractures are associated with defects of the orbital floor. This leads to a descent of the orbital soft tissues and a consecutive increased orbital volume [2]. Moreover the bulb of the affected eye moves towards a more inferior and posterior position which leads to double vision or diplopia, which causes visual impairment and thus a high economic deficit [3]. According to our investigations, 58% – 86% of all blow-out-fractures and 13% – 20 % of all midface fractures seem to be associated with diplopia.

In most cases, the smallest fragments are not subject to a reposition via osteosynthesis. The medial wall of the orbit and the transition to the orbital floor are frequently affected. The current standard procedure comprises an insertion of an alloplastic foil or a titan mesh via a transconjunctival approach [4,5]. Regarding defects smaller than 2cm², the use of a resorbable alloplastic membrane is recommended [6].

The treatment of fractures of the orbital floor and the medial wall of the orbit is still a big issue in craniomaxillofacial surgery [7]. However, there is still no solution for an exact determination of the orbital volume in case of fractures of different orbital walls.

Automated segmentation of osseous structures of the midface from acquired CT data sets is yet unsatisfying, because typical partial volume effects according to the CT data lead to discontinuities in the virtual reconstruction. Further difficulties result from the distinct recalculation of an anterior and posterior border of the orbit, which is unavailable up to now. Only distinct borders can describe a self-contained volume which can be compared to the unaffected side or with standard values. The lack of reliable segmentation procedures becomes crucial if individual preformed titanium meshes are used for reconstruction of orbital fractures [8].

Unsupervised image segmentation is one of the major challenges in medical image processing [9,10]. In this paper, we apply an general discrete contour model [11] for automatic segmentation and measurement of orbit volumes. The method is evaluated based on six healthy subjects.

Materials and methods

Subjects and image data

Based on the image data obtained at the Department of Craniomaxillofacial Surgery, University Freiburg, Germany, six subjects without orbit fractures were selected and included in this study. Computed tomography was performed using a Siemens sensation 64 scanner (Siemens Medical Solutions, Forchheim, Germany), with 120 kV at 82 mA. Anisotropic volumes were obtained with 1 mm slice thickness and a spatial resolution of 512 x 512 voxel in $x - y$ direction. The number z of slices varied between 139 and 261 (Table 1).

The discrete contour model

For the segmentation of the orbit, a general contour model was applied to the three-dimensional (3D) data [11]. In two dimensions, the contour is represented by a simplex mesh, i.e. by vertices and edges. The segmentation proceeds iteratively, taking into account different powers to calculate the configuration of the next step. In each step, vertices

may be deleted, because they are located too close to each other, and others maybe inserted to reduce the distance between two vertices. In contrast to other active contour approaches, the vertices are not limited to positions within the slices.

The effecting powers are pressure, deformation and external influences. When these three powers reach an equilibrium a vertex is fixed.

- *Pressure* stays constant during the entire segmentation process and therefore constantly moves the vertices towards the searched edges. The start configuration of a contour can be a minimal sphere around a given starting point or a mesh along the outside border of the image space. In the first case, pressure is a positive power pressing vertices towards the outside, and in the second case, the pressure pulls vertices towards the inside.
- *Deformation* prevents the contour from accepting too sharp bends. It is calculated modeling the properties of biological membranes.
- *External influences* are derived from the individual CT data. In contrast to other active contour approaches, external influences regionally depend on the Hounsfield Units of the neighborhood of the considered vertex and the edges between the vertices.

This 3D model can be compared to a balloon, which is slowly blown up inside an image. For further details to this model, which was generally developed for two, three and four dimensions, see [1].

Segmentation of the orbit

When adapting the general model to the orbit, several difficulties occur. To facilitate further processing, images are smoothed (Fig. 1a) and binarized (Fig. 1b) such that only bone structures receive gray value 255 (white) and everything else gray value 0 (black). Resulting from the normilazed nature of CT Hounsfield Units, the perfect threshold varies only little between different image series and is regarded as constant.

The main problem is that the orbit is not cohesive. The front is completely open and it is not obvious where the segmentation should end. The images do not clearly display a limit between orbit and the surface of the face. Two methods have been applied to artificially insert a limit. Both work on the two dimensional slice images.

First, the orbit is closed by a straight line connecting the nasal bone with the cranial bone bordering the orbit (Fig. 1c). The nasal bone is identified as the first white pixel in the image when testing row by row from front to back. Then a straight line is tilted left and right from this point, until it touches another white pixel. The entire area above these lines is filled white to mark the new limit.

A second strategy applies two dimensional segmentation of cranial bones with the same active contour model as later used for the segmentation of the orbit. Here, however, the segmentation starts with a mesh on the outside image border and slowly encloses the cranium (Fig. 1d). The deformation power is high to prevent the contour from entering the orbit. The maximal distance between two vertices in the contour is small to assure that the thin bone structures around the orbit are recognized and cannot slip through between two vertices. The external influences are highly weighted, because in the binarized image a white pixel stands where bone was with high certainty and vertices near bone should be fixed immediately. Once the segmentation identified an area as the cranium, everything outside this area is filled white in the original binarized image.

Figure 1 - Noise reduction, binarization, linear,and contour-based outer boundary of the orbit

The opening at the front of the orbit is not the only one, but there are several canals in the back of the orbit. Furthermore, the ethmoid bone between both orbits is extremely thin, and is not always visible cohesively. These difficulties must be overcome by suitable parameterization. Deformation cannot be chosen too high because the orbit becomes narrow to the back. The external influences must be set rather high to identify bone structures accurately. Pressure comes from the inside, but is of no relevance here. Far more important is the manual choice of a starting point, which is placed manually in the center of the orbit. However, this step can easily be easily performed automatically using the a-priori knowledge of the general geometry of the human skull.

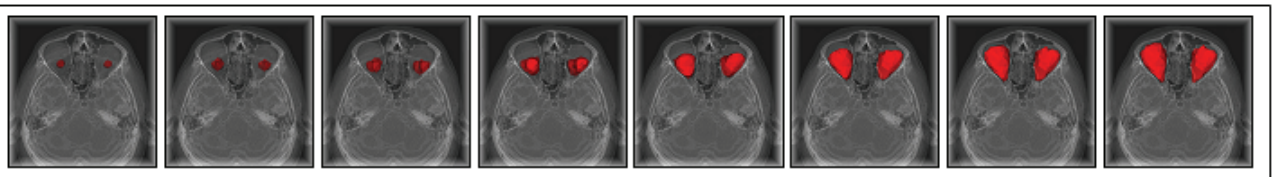

Figure 2 - Iterative orbit segmentation using a 3D balloon model

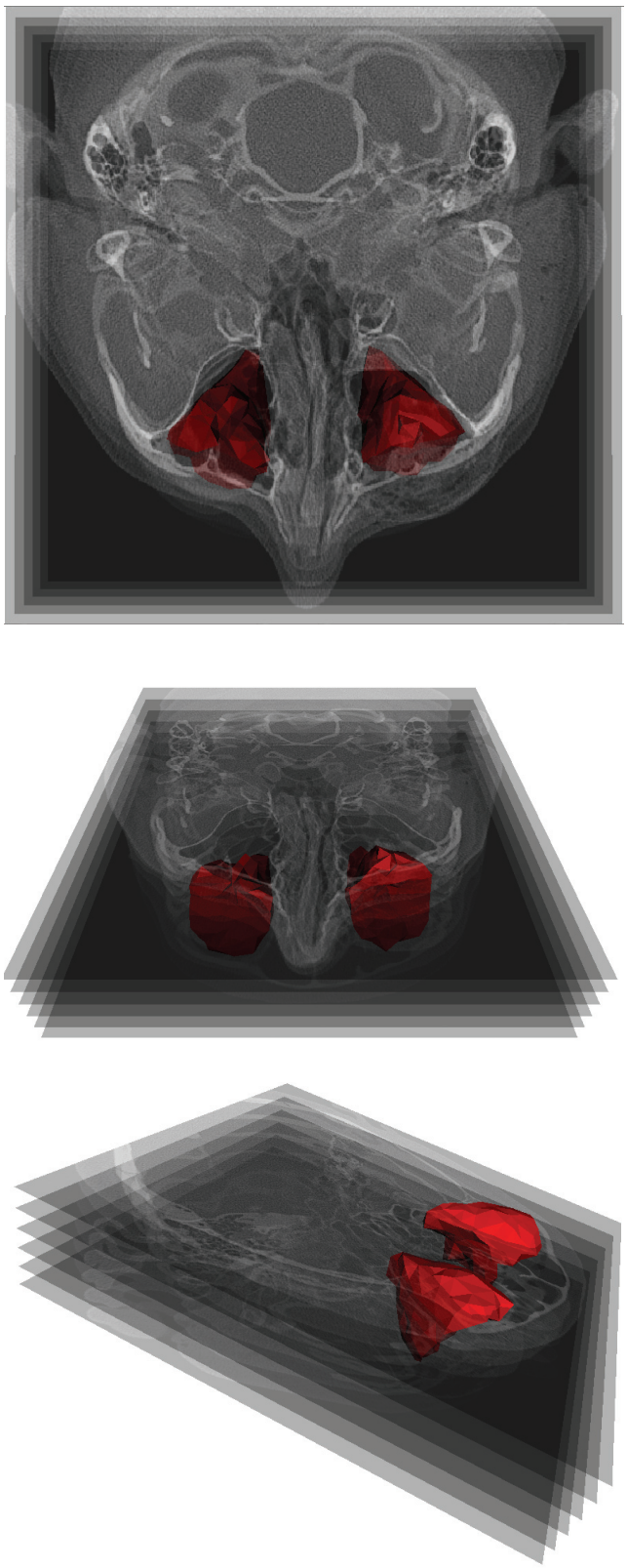

Figure 3 - Results on Subject 1

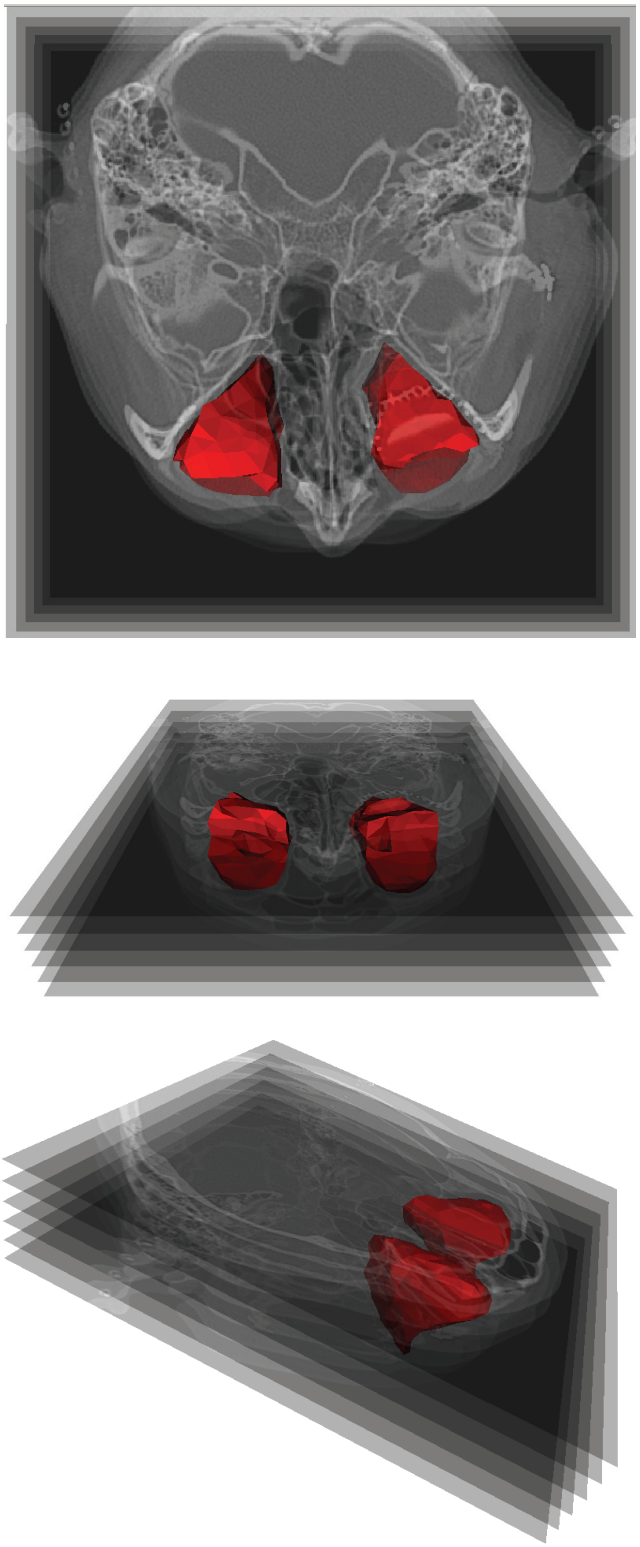

Figure 4 - Results on Subject 2

Results

A fixed set of parameters for the 3D active contour model was determined manually and applied to segment the six data sets selected arbitrarily from the clinical day-today routine.

Based on five segmentations on Subject 1 that were initiated with different starting points, the variation coefficients (standard deviation divided by the mean) of the volumes of left and right orbits were 0.98% and 1.28%, respectively. Since these coefficients are much smaller than 5 %, the method is considered as sufficiently stable.

The results of automatic orbit segmentation is visualized in Figures 3 and 4. For qualitative evaluation, the segmentation was confirmed by a skilled radiologist. The quantitative results obtained on the six patients are summarized in Table 1. The volume of left and right orbits are given by the number of segmented voxels. For all subjects, the relative differences

$$d = 100\frac{|l-r|}{l+r}$$

is below 5%, and the mean relative differences is $d_m = 1.52\%$.

Table 1 - Image data and results

Patient No	No of slices	Volume left l	Volume right r	Relative difference d
1	139	339819	350085	1.49 %
2	181	485792	491097	0.54 %
3	136	541376	521174	1.90 %
4	204	358029	365773	1.07 %
5	261	207250	221110	3.23 %
6	188	260264	255632	0.90 %

Discussion and conclusion

The general active contour model is applicable for automatic segmentation of orbits in CT data. The model consists of a membrane-like structure which is blown up from the interior of the orbit. Discontinuous surfaces caused by insufficient CT data are bridged with a defined surface tension of the membrane. The anterior border is defined as a vertical plane travelling along the infra-orbital rim. The posterior border is to be defined as a cone-like top of a pyramid.

The application of this virtual model to a real 3D model allows the exact pre-bending of a titan mesh for the surgical reconstruction of the orbital floor. First interventions with navigation guidance have shown that this mesh can be adapted with a geometric accuracy smaller than 1mm. Finally, in case of severe midface asymmetry, a preoperative transition of a virtual volume from an unaffected orbit to the affected side and consecutive integrative fusion with the mirrored orbital floor (morphing) can lead to an exact prediction of the reconstructed orbit. This will be evaluated in further studies.

References

[1] Shere JL, Boole JR, Holtel MR, Amoroso PJ. An analysis of 3599 modfacial and 1141 orbital blowout fractures amoung 4426 United States Army Soldiers, 1980-2000. Otolaryngology 2004; 130(2): 164-70

[2] Fan X, Li J, Zhu J, Li H, Zhang D. Computer-assisted orbital volume measurement in the surgical correction of late enophthalmos caused by blowout fractures. Ophthal Plast Reconstr Surg 2003; 19(3): 207-11

[3] Amrith S, Saw SM, Lim TC, Lee TK. Ophthalmic involvement in cranio-facial trauma. J Craniomaxillofac Surg 2000; 28(3): 140-7

[4] Dietz A, Ziegler CM, Dacho A, Althof F, Conradt C, Kolling G, von Boehmer H, Steffen H. Effectiveness of a new perforated 0.15 mm poly-p-dioxanon-foil versus titanium-dynamic mesh in reconstruction of the orbital floor. J Craniomaxillofac Surg 2001; 29(2): 82-8

[5] Ellis E, Tan Y. Assessment of internal orbital reconstructions for pure blowout fractures: cranial bone grafts versus titanium mesh. J Oral Maxillofac Surg 2003; 61(4): 442-53

[6] Buchel P, Rahal A, Seto I, Iizuka T. Reconstruction of orbital floor fracture with polyglactin 910/polydioxanon patch (ethisorb): A retrospective study. J Oral Maxillofac Surg 2005; 63(5): 646-50

[7] Marsh J. Measurement of orbital volume by a 3-dimensional software programm: An experimental study. J Oral Maxillofac Surg 2003; 58: 648

[8] Metzger MC, Schön R, Zizelmann C, Weyer N, Gutwald R, Schmelzeisen R. Semi-automatic procedure for individual preforming of titanium meshes for orbital fractures. Plast Reconstr Surg, submitted

[9] Duncan JS, Ayache N. Medical image analysis: Progress over two decades and the challenges ahead. IEEE Transactions on Pattern Analysis and Machine Intelligence 2000; 22(1): 85-106

[10] Lehmann TM, Meinzer HP, Tolxdorff T. Advances in biomedical image analysis. Past, present and future challenges. Methods of Information in Medicine 2004; 43(4): 308-14

[11] Bredno J, Lehmann TM, Spitzer K. A general discrete contour model in 2, 3, and 4 dimensions for topology-adaptive multi-channel segmentation. IEEE Transactions on Pattern Analysis and Machine Intelligence 2003; 25(5): 550-63

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