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CT assessment of orbital volume in late post-traumatic enophthalmos

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Abstract The potential of CT to facilitate preoperative planning of reconstructive maxillofacial surgery by orbital volume quantification was analysed in 11 patients with traumatic enophthalmos as a late sequela of zygomatic fractures. We carried out biplanar CT examination of the orbits, and calculated total orbital and fat volumes for the healthy and enophthalmic sides. Displacement of the orbital floor and lateral wall was present in 11 and 7 cases respectively. Indentation of the medial wall was noted in 9 cases. Quantitative evaluation of the orbital cavity revealed a significant increase ($P < 0.0188$) in total volume on the enophthalmic side, the difference between the two sides ranging from 9.2 % to 36.4 %, mean 17.9 %. The degree of enophthalmos, measured radiologically as 2.5–5 mm, correlated with the increase in orbital cavity volume ($P = 0.000076$). Enophthalmos was 2.5–3 mm in 7 cases (63.6 %) and 3.5–5 mm in 4 (36.4 %). This corresponded with a mean increase in orbital volume of 3.4 ml (12.3 %) and 7.1 ml (27.8 %) respectively. Fat atrophy was not an aetiological factor in the production of post-traumatic enophthalmos.

Key words Enophthalmos · Orbital trauma · Orbital volume quantification · Computed tomography · Reconstructive surgery, orbit

Introduction

Enophthalmos is the most common persistent complication of orbital trauma [1]. The latter may consist of a "pure" blow-out fracture which by definition, spares the orbital rim. More common in our practice are "impure" blow-out fractures with a zygomatic fracture, which tend to involve the inferior or lateral orbital rim. "Enophthalmos" is defined as backward displacement of the globe into the orbit by at least 2 mm in relation to the unaffected eye [2], and reflects a discrepancy between the volumes of the orbital contents and the bony orbit. In the past, prevention and treatment of post-traumatic enophthalmos consisted of volumetric addition along the orbital floor on an empirical basis. However, post-traumatic enophthalmos was frequent, and the results of secondary corrective surgery proved unpredictable [3].

CT has become the established imaging modality for assessing the osseous and soft tissue sequelae of acute trauma. Three-dimensional volume measurements of the orbital contents and orbital cavity can be performed, allowing quantification of normal orbital volume [3, 4], orbital fat and muscle in Graves' disease [5], and soft tissue and orbital volume in post-traumatic enophthalmos [6, 7].

We investigated the potential of CT to provide useful information for management of patients with post-traumatic enophthalmos.

Patients and methods

We performed CT on 11 patients (7 males, 4 females, mean age 34.5 years) with clinical post-traumatic enophthalmos of 2.5–5 mm. The examinations were performed 1.5–6 years after a zy-

Table 1 Location and extent of orbital fractures

Patient	Displacement			Roof
	Floor	Medial wall	Lateral wall	
1	Severe[a]	Severe	Lateral	Fracture
2	Severe	Severe	Lateral	Defect
3	Severe[a]	Slight	–	–
4	Severe	Moderate	–	–
5	Severe	Moderate	Lateral	–
6	Moderate[a]	Moderate	–	–
7	Moderate	Moderate	–	–
8	Moderate	Moderate	Lateral	–
9	Moderate	–	–	–
10	Moderate	–	–	–
11	Moderate	Slight	Medial	–

[a] Previous failed corrective surgery

Table 2 Orbital volume measurements

Patient	Bone volume		Fat volume		Enophthalmos (mm)
	Normal side ml	Difference ml (%)[a]	Normal side ml	Difference ml (%)[a]	
1	25.0	9.1 (36.4)	10.5	2.0 (19.0)	5
2	26.4	7.1 (26.9)	9.2	1.9 (20.6)	5
3	22.3	5.7 (25.6)	9.7	1.4 (14.4)	4
4	28.7	6.4 (22.3)	13.4	2.1 (18.6)	3.5
5	32.8	6.5 (19.8)	15.6	3.1 (24.8)	3
6	22.6	3.5 (15.5)	7.7	0.9 (13.2)	3
7	26.3	2.7 (10.3)	8.7	1.0 (11.5)	3
8	27.2	3.1 (11.4)	9.1	0.7 (7.7)	3
9	35.8	3.6 (10.0)	13.2	0.7 (5.3)	3
10	20.0	2.0 (10.0)	7.1	0.7 (9.8)	3
11	27.5	2.4 (9.2)	11.8	0.8 (8.0)	2.5
	26.8	4.7 (17.9)	10.5	1.40 (13.9)	3.45

[a] Trauma side minus healthy side

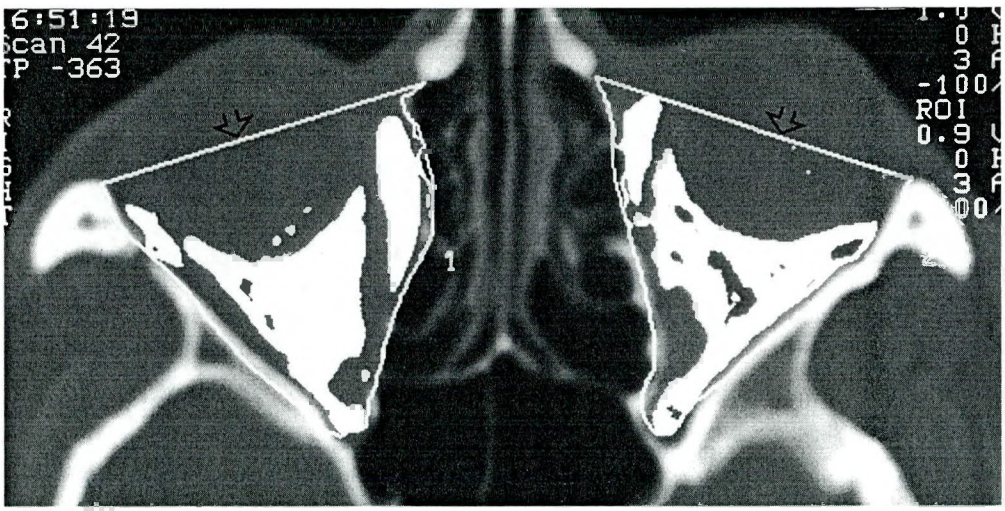


Fig. 1 Software method for orbital volume quantification shown a single slice: delineation of pixel values defined –100 HU to 0 HU to identify orbital fat *(white)* within manually-traced orbital boundaries. *Arrows* show anterior border of orbit

gomatic bone fracture. Primary surgery had been performed in 7 patients, including 3 with attempted corrective surgery of the orbital floor. CT comprised contiguous 2-mm slices in the coronal and axial planes at kV 133, mAs 475. Image documentation was on hard copy at soft-tissue window and high-resolution bone window settings. Analysis was focused on defects and displacements of the orbital walls, scar tissue or deformity of the eye, and herniation of orbital contents into adjacent sinuses (Table 1).

The orbital volume measurements used inherent software. They were obtained on the screen from 1024 × 1024 matrix images by summation of pixel counts, based on density ranges explicitly

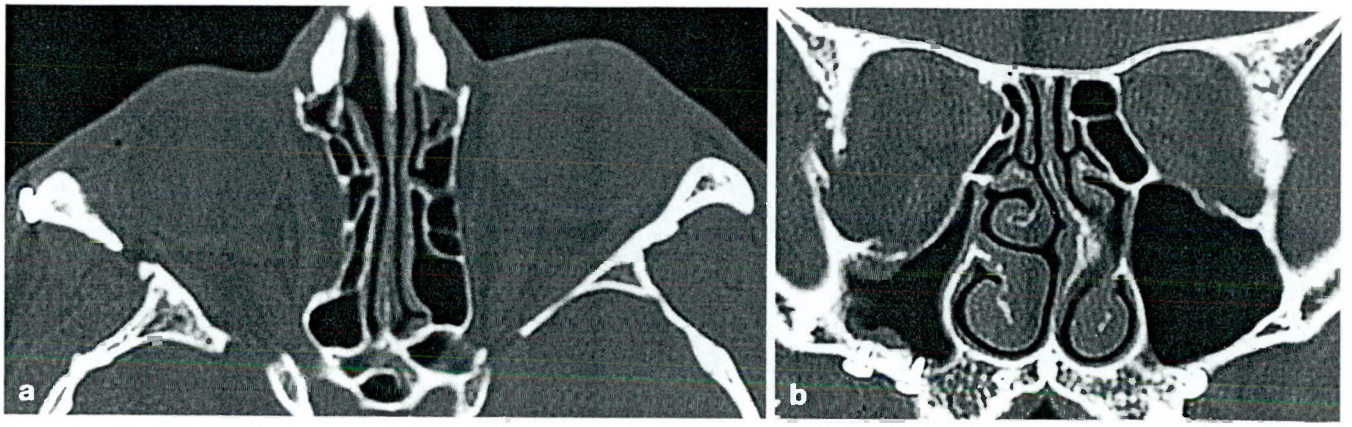


Fig. 2 Right enophthalmos (patient 2). Axial (**a**) and coronal (**b**) CT reveals persistent lateral wall displacement, with severe medial orbital wall and posterolateral orbital floor dislocation

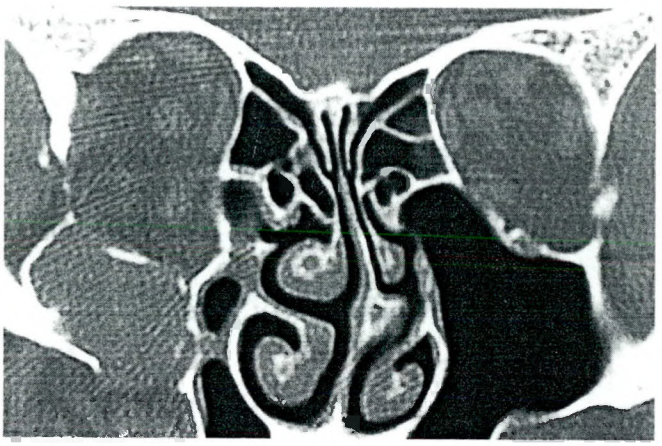


Fig. 3 Coronal CT in a patient with 2.5 mm right enophthalmos (patient 11): moderate depression of the posteromedial aspect of the orbital floor. Mucocele of the right maxillary sinus

chosen for individual slices. Density ranges were separately defined for orbital fat with −100 to 0 Hounsfield units (HU) and for total orbital volume with −1024 to 3071 HU. Pixel counts were limited to regions of interest defined by manually tracing the bony boundaries of the orbit in each single axial slice from the orbital roof to the floor. Measurements of orbital fat and total orbital volume were performed on both the enophthalmic and normal sides (Table 2). An example of the delineation of "fat volume pixels" in a single slice and the definition of the "orbital entrance plane" is provided in Fig. 1.

The degree of enophthalmos was calculated by measuring the distance from the orbital apex to the papilla, the normal side serving for comparison. At the level of the optic nerve this measurement corresponded to the distance from the orbital apex to the posterior globe employed by Bite et al. [7]. To validate these methods, total orbital volume was measured in 3 dried skulls and total orbital and fat volumes in 5 individuals with no difference in globe position, by the same observer (B.S.)

Statistical significance of orbital volume and enophthalmos correlation was determined by a one-sided t-test for Pearson's correlation coefficient.

Results

Dry skulls and normal orbits

Examinations of 3 dried skulls with intact orbital cavities, revealed total volumes with a mean of 20.4 ml. Volume calculations from axial CT examinations in 5 persons without enophthalmos revealed total orbital volumes of 22.8–30.1 ml, mean 25.6 ml. Fat volumes were 6.2–12.2 ml, mean of 7.8 ml. Intraindividual side-to-side differences for total orbital and fat volumes were in the range of 0.2–1.5 ml (mean 0.6) and 0.1–1.1 ml (mean 0.5).

Patients

Biplanar CT of 11 patients with post-traumatic enophthalmos revealed dislocation of the orbital floor in every case (Table 1; Fig. 2–4). In 7 patients, dislocation predominantly affected the posteromedial portion, while the posterolateral portion was preferentially involved in 4. Correction of the anterior portion of orbital floor fractures had been performed in 3 patients soon after trauma.

Medial wall fractures were present in 9 cases (82 %) (Fig. 2). These were termed severe when the displacement covered the whole anteroposterior length of the lamina papyracea, and moderate when two thirds of the medial wall were involved.

The lateral wall revealed signs of fracture at the sphenozygomatic suture in every patient, with displacement in 5 cases (45.5 %). Previous surgery had led to a successful reduction of lateral wall displacement in 5 of 6 cases, although in one patient significant displacement persisted (Fig. 2).

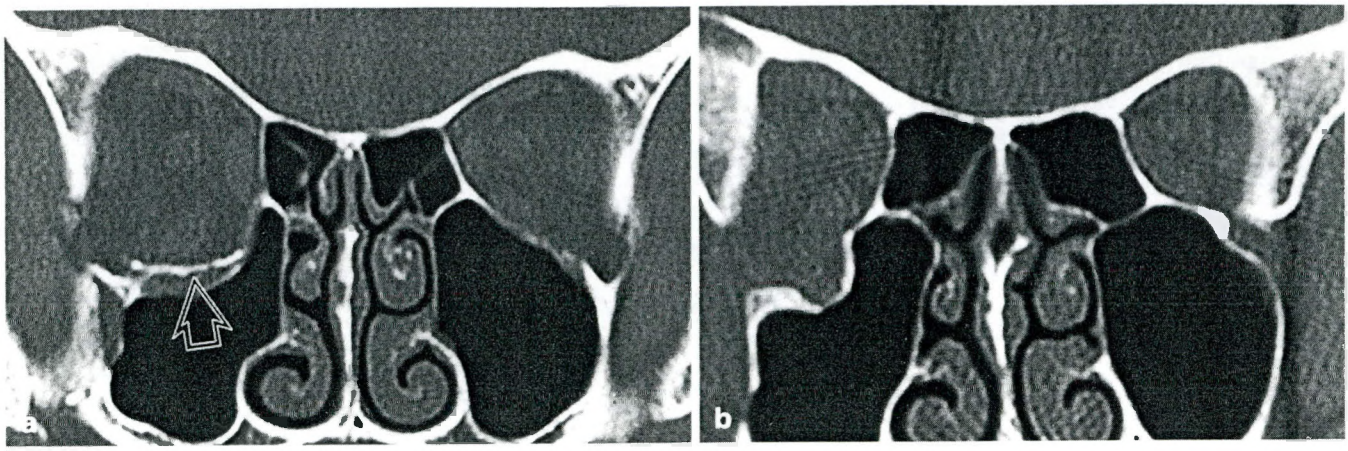


Fig. 4 a, b Coronal CT in a patient with 4 mm right enophthalmos (patient 3). Note increased orbital volume despite corrective surgery *(open arrow)*, which failed to reach posterior orbital floor

Orbital roof fractures present in 2 cases (18 %) were considered of minor importance.

Measurement on axial CT showed 4 patients (36.4 %) had enophthalmos of more than 3 mm, maximum 5 mm. The average normal orbital volume was 26.8 ml, slightly more than in the 5 healthy individuals (mean 25.6 ml) due to a higher proportion of males, with a 7:4 ratio as against 3:2. Orbital volumes on the side unaffected by the trauma were on average 21.6 ml in 4 females and 28.7 ml in 7 males.

On the enophthalmic side, increases in orbital volume ranged from 9.2 to 36.4 %, mean 17.9 %, corresponding to 4.4 ml (Table 2). Fat volume was also found to increase by a mean of 13.9 % (1.4 ml). Enophthalmos was found to increase with the degree of orbital volume expansion ($P = 0.00076$; due to the small sample size, P is approximate, not an exact figure).

Discussion

Morphological findings

Post-traumatic enophthalmos is a serious late complication of orbital trauma. However, despite the attention drawn to blow-out fractures by the first report on post-traumatic enophthalmos by Lang in 1889 [8], and experiments on a cadaver [9] and a dry skull [10], which confirmed the mechanism of "blow-out fractures", enophthalmos is a more common sequela of midface and zygomatic fractures [1, 11]. In 53 patients with post-traumatic enophthalmos Pfeiffer [12], using plain films, attributed the enophthalmos to "external deformity ... involving the margin of the orbit" in 29 cases unlike the "internal" fractures, which spared the orbital margin, seen in 24 cases. While in all the latter patients the force was centred on the eyeball, in this series traffic accidents caused predominantly unilateral fractures, with the force focused on the zygomatic bone. Even though reposition of the zygomatic bone had been performed soon after trauma in 6 patients – with orbital floor reconstitution in 3 – the degree of enophthalmos was similar to that in cases treated conservatively. The high prevalence of frontal zygomatic process fractures in our patients (36.3 %) is evident when compared to Langen et al. [13] and Irnberger [14], who found 14.5–18 % of lateral orbital wall fractures in a CT study of 148 patients with acute trauma.

CT has contributed to recognition of a high incidence of medial orbital wall fractures associated with fractures of the floor. The sensitivity of CT surpasses that of conventional tomography, leading to increased recognition of medial wall fractures [15, 16]. These have been shown in 50 % of orbital floor fractures [17], and were present in 9 of 11 cases (82 %) of this study. Medial wall displacement had been present (probably unrecognised) in the 3 patients whose anterior orbital floor had been reconstituted at another hospital. The high proportion of medial wall fractures underlines the role of the orbital portion of the ethmoid bone as a contributing factor in the development of post-traumatic enophthalmos and a potential cause of failed corrective surgery.

The frequent failure of anterior orbital floor reconstruction is explained by similar considerations. Although convenient to perform, it ignores the pathogenesis of enophthalmos which in the majority of cases is due to posterior floor dislocation [1], present in all our cases.

Increase in orbital volume through orbital floor displacement has been acknowledged as an important aetiological factor in traumatic enophthalmos [1, 3, 6, 7, 12]. However, empirical observations of failure of corrective surgery after volume augmentation have given rise to additional theories, such as fat displacement and atrophy, scar contracture or neurogenic causes [7, 18].

The deficiency of corrective surgery has also prompted the search for an objective means of volume quantification [3–6].

Volumetric CT

CT has been used not only in the diagnosis of acute orbital trauma [11, 14, 19], but also for management of post-traumatic enophthalmos. Soft-tissue orbital contents, enophthalmos and total bony orbital volume have been quantified in patients with post-traumatic enophthalmos, using the uninjured orbit for reference [6, 7]. In a previous study we found volumetric orbital CT useful for the preoperative planning in many conditions that affect orbital volume relations, such as trauma, midface tumours and fibrous dysplasia [20].

In our preliminary study on dry skulls, volume calculations revealed racial differences [21] and were shown to be dependent on sex in the 11 patients described here. Normal orbital volumes have been measured by CT in males as 23.6–28.28 ml [4, 6, 7], our values of 28.7 ml being comparable to those of Manson et al. [6]. Orbital cavity volume in females was 21.6 ml in our study, as against 25.23 ml in that of Manson et al. [6]. The low volume of one female of Arab origin (patient 10, Table 2) may account for our low average values. Intraindividual side-to-side differences were 1–5 % mean 2.3 %, in normal persons compared to maximum values of 7.5 % in orbital impression models of Indian skulls [21] and 8 % on CT analysis [4].

The discrepancies in total orbital volume calculations among these studies are explained by the definition of orbital boundaries, which are subject to interpretation. The definition of these planes affects calculations of the intraorbital fat volume to an even greater extent. However, the fat volumes measured by CT revealed no significant difference in fat in a study of 10 patients with unilateral post-traumatic enophthalmos [7]. These findings are at variance with our finding of an average increase of 1.4 ml, equivalent to 13.9 % (Table 2). However, Manson et al. [6] also report an increase in fat volume on the enophthalmic side, mean 0.5 ml (5 %); they even noted increased fat density in post-traumatic orbits, not found in our study. In view of the increase in orbital fat volume, post-traumatic fat atrophy appears unlikely as an explanation for post-traumatic enophthalmos. Indeed, the increase might indicate an (ineffective) attempt to counterbalance the traumatic orbital volume expansion.

Total orbital volume on the enophthalmic side was increased in every patient in this study, exceeding the normal side by 9.2–36.4 %, mean 17.9 %, equivalent to 4.4 ml volume gain. The degree of enophthalmos and the size of the orbital cavity correlated significantly, as in the investigation by Manson et al. [6]. They reported a maximum increase of 18 %, and a typical volume difference of 12 %, corresponding to 4 ml, in 10 patients with enophthalmos. A smaller average increase of 6.7 % (1.6 ml) in males, but 13.4 % (3.05 ml) in females is mentioned by Bite et al. [7] in 10 patients with an average enophthalmos of 3.5 mm. On the other hand, a mean volume discrepancy of 2.2 ml (range 0.7–4.3) was found in 16 patients managed conservatively after pure blow-out fractures; only 2 of whom had enophthalmos [22].

Orbital volume increases were largely due to posterior orbital floor depression or defects. Expansion of the medial and lateral walls was an additional factor in the development of enophthalmos. While the individual contribution was difficult to assess, even by quantitative CT, Parsons and Mathogs [21] employed a model from dry Indian skulls to measure the effect of medial wall and orbital floor displacements. Dislocation of the medial and inferior orbital wall revealed a volume effect three times as great for orbital floor displacements. A volume change of 2.8 % resulted in a change in globe position of 1 mm. Our results indicate that in vivo a 5.2 % volume increase is necessary for 1 mm of enophthalmos. Not all volume changes have an identical effect on globe position. The effect of orbital wall displacement is dependent on its location with respect to the axis of the globe. This may be one factor in the differences in volume increase between patients with the same degree of enophthalmos.

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BOOK REVIEW

Paediatric Neuroimaging. Ed.: A. J. Barkovitch
2nd edition, Raven Press 1994.
ISBN 0-7817-0179-1, $ 186.50.

The second edition of this highly acclaimed textbook of paediatric neuroimaging retains all the clarity and constancy of a single author text. This edition, now some 6 years on from the first, has been radically revised and updated to reflect the growth of knowledge in the field. This growth has been largely generated by widespread application of MRI, and this edition, like the first, strongly emphasises the role of this technique and uses it for the bulk of its illustrations. The book does, however, cover other imaging modalities adequately where they play a useful role, although the author has chosen not to cover ultrasound in great depth.

The book covers comprehensively and well most aspects of paediatric neuroimaging including the spine and orbit divided by chapter on the basis of pathology. I have been particularly impressed by the simple and clear way brain development has been described and how the topics of developmental brain anomalies have been covered. In general the imaging findings of many of the conditions described have, where possible, been explained and enhanced by inclusion of basis concepts of neuroembryology and, at times, pathophysiology.

The chapter covering destructive brain disorders has also been well subclassified and illustrated. It covers the particularly difficult issues of hypoxic-ischaemic brain injury and trauma in children in a useful way.

This is an excellent textbook and all involved in paediatric neurosciences will find it useful. It also provides a useful reference to those radiologists who only occasionaly find themselves having to interpret paediatric MRI of the brain and spine.

T. Cox, London