Pediatric Orbital Depth and Growth: A Radiographic Analysis

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Background: Orbital reconstruction requires knowledge of orbital depth in order to prevent optic nerve injury. Numerous analyses of adult orbital dimensions have been undertaken previously in order to characterize this measurement, including skull specimen and computerized tomography studies. However, there is a paucity of information regarding the pediatric orbit.

Methods: The authors used pediatric magnetic resonance imaging (MRI) studies in order to quantify the change in orbital depth in relationship to patient age, and to develop methods to estimate and calculate orbital depth for individual pediatric patients. MRIs of the head in normal pediatric patients were reviewed retrospectively. Orbital depths were measured and correlated with age and cephalometric dimensions. In a randomly selected subgroup of patients, measurements were repeated by an independent investigator to determine interobserver reliability.

Results: Measurements were obtained in 72 patients ranging from 3 months to 18 years of age (mean = 7.8 years). There was a significant exponential relationship between orbital depth and patient age ($r^2 = 0.81$, $F(2,69) = 143.97$, $P < 0.001$). Depth increased more rapidly in the first 6 years of life, but leveled off in the early teen years toward a horizontal asymptote of approximately 45 mm. There was also a significant relationship between orbital depth and the sum of the biparietal width plus the anterior–posterior length ($r^2 = 0.72$, $F(2,69) = 87.44$, $P < 0.0001$). There was high interobserver reliability in measurements between 2 independent investigators ($r = 0.79$, $P < 0.0001$).

Conclusion: In children, orbital depth increases predictably with rising age and increasing head size. Knowledge of this growth curve and the relationship between head size and orbital depth can complement careful surgical dissection to improve safety and efficacy in pediatric orbital reconstructions.

Key Words: Facial fracture, facial trauma, orbit, orbital depth, orbital floor, orbital fracture, orbital trauma, pediatric facial fracture

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Orbital reconstruction requires a precise knowledge of anatomy to avoid injury to critical structures.[1] While adult orbital anatomy has been well studied, there is a paucity of data regarding the anatomy of the growing pediatric orbit.[2] Optic nerve injury, which can potentially result in blindness, is a well-described complication that can occur if dissection encroaches upon, or an implant impinges on the optic nerve.[3–12] To minimize the risk of optic nerve injury, surgeons must restrict dissection to the zone of safety. Distances to critical posterior orbital structures in adults have been delineated in radiographic and cadaveric studies (Table 1).[13–20] These studies report mean adult orbital depth measurements between 39 and 50 mm, with some of the variation attributable to different choices of reference points, limited ethnic subgroups, and diverse methodologies.

While pediatric orbital fractures are common, accounting for up to 20% of all orbital floor reconstructions and up to 45% of all pediatric facial fractures, there is little data on pediatric orbital anatomy and how it changes with growth.[2,21–23] Surgeons performing orbital reconstructions are familiar with adult reference measurements for safe orbital dissection and implant positioning, but similar guidelines are not available for pediatric patients. The purpose of our study is to quantitatively determine orbital depth in pediatric patients, to describe the relationship between orbital depth and age, and to elucidate the relationship between orbital depth and cranial size. Such critical data can improve both efficacy and safety in pediatric orbital floor reconstruction.

METHODS

After institutional review board approval, we reviewed charts of consecutive pediatric patients (birth to 18 years of age) who underwent magnetic resonance imaging (MRI) of the head between July and December 2010. We excluded patients with congenital or traumatic craniofacial diagnoses as well as those with incomplete or poor quality MRI data.

MRI scans were obtained on a Siemens Magnetom Espree 1.5T MRI scanner (Siemens AG, Erlangen, Germany). The routine pediatric brain protocol included an axial magnetization-prepared rapid acquisition with gradient echo (MPRAGE) sequence acquired at a slice thickness of 1.5 mm, and reconstructed into 1.5 mm sagittal images. MPRAGE sequences provide increased T1 contrast with high spatial resolution useful for defining orbital anatomy.

We imported the raw Digital Imaging and Communications in Medicine (DICOM) data into MicroView (General Electric PreClinical open source software, http://microview.sourceforge.net) for postprocessing. This software allows display, manipulation, and measurement of radiographic images as 3-dimensional (3D) models. The models can be freely rotated, allowing reconstruction of oblique slice sequences in addition to the standard orthogonal axial, coronal, and sagittal planes. This is required to accurately and directly measure landmarks of the bony orbital floor, which lie on a plane oblique to the axial, coronal, and sagittal planes.

To determine the most clinically useful measurement, we defined orbital floor depth as the distance from the most anterior

TABLE 1. Studies of Adult Orbital Anatomy That Delineate Orbital Depth

	Landmarks		n	Mean (mm)	Range (mm)
Rontal et al[13]	Inferior orbital rim	Optic canal	48	48	NA
Katsev et al[14]	Inferior temporal orbital rim	Nasal entrance of optic foramen	120	NA	42–54
McQueen et al[15]	Intraorbital foramen	Optic canal	54	49.73 (±2.71)	NA
Karampatakis et al[16]	Junction of lateral and middle third of inferior orbital rim	Lateral border of optic foramen	25	49.62 (±2.46)	NA
Danko et al[17]	Midpoint of inferior orbital rim	Orbital apex	16	39.4 (±2.9)	32.4–42.1
Karakas et al[18]	Infraorbital foramen	Inferior aspect of optic canal	62	50.3 (±3.2)	NA
Huanmanop et al[19]	Orbital rim above infraorbital foramen	Optic canal	100	46.2 (±2.8)	NA
Nitek et al[20]	Infraorbital foramen	Optic canal	93	48.1 (±3.2)	40.5–57.0
Cheng et al[37]	Infraorbital foramen	Optic canal	181	44.38 (±3.55)	31.6–52.1

NA = not available.

projection of the inferior orbital rim to the inferomedial aspect of the optic canal. First, we converted each MRI sequence to a 3D model with standard orthogonal slicing. We next identified the inferomedial point of the optic canal on an axial slice, and rotated the 3D model around a cephalad-to-caudal axis in order to place this point in the same oblique plane as the most anterior projection of the inferior orbital rim. We then made a linear orbital depth measurement between these 2 points (Fig. 1).

Orbital depth was compared to age and cranial size. In order to characterize cranial size, we obtained 2 additional cephalometric measurements from the MRI: biparietal width as measured from euryon to euryon (EU–EU), and anterior–posterior length measured from nasion to opisthocranion (N–OP) (Fig. 2).[24,25] We used the sum of EU–EU and N–OP as a metric for cranial size. These cephalometric measurements correspond to anthropometric landmarks that can be easily measured directly on a patient in clinic. An independent investigator repeated orbital depth and head size measurements for a randomly selected subgroup of 20 subjects. We used the Spearman's correlation coefficient (r) to evaluate the interobserver reliability of orbital measurements.

Based on prior data models of orbital depth, we used a second-order polynomial regression model to evaluate the potential relationship between orbital depth and age as well as between orbital depth and head size.[23,26] All calculated P values were 2-tailed and considered significant if <0.05. Statistical analyses were performed using StataSE version 11.1 (Statacorp, College Station, TX).

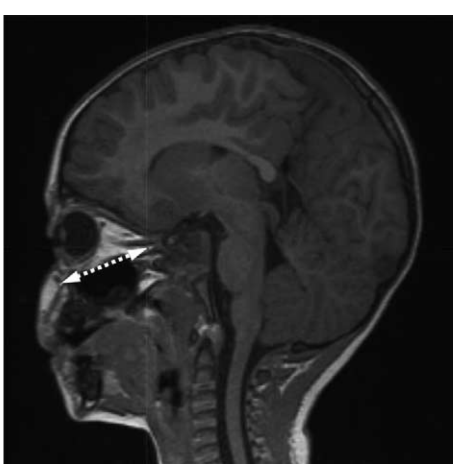

FIGURE 1. Orbital depth measurement from the most anterior aspect of the inferior orbital rim to the inferomedial aspect of the optic canal.

RESULTS

We identified 98 patients with MRI sequences during the defined study period. Twenty-six were excluded: 2 for craniofacial diagnoses (congenital and acquired), 17 for incomplete data, and 7 for incomplete or poor quality imaging. We included 72 patients for review, ranging from 3 months to 18 years of age (mean = 7.8 years, standard deviation = 5.1 years). Patient characteristics are presented in Table 2. Orbital depth measurements between 2 investigators (interobserver reliability) were correlated with high statistical significance ($r = 0.79$, $P < 0.0001$).

We found a significant relationship between orbital floor depth and patient age ($r^2 = 0.81$, $F(2,69) = 143.97$, $P < 0.001$; Fig. 3).

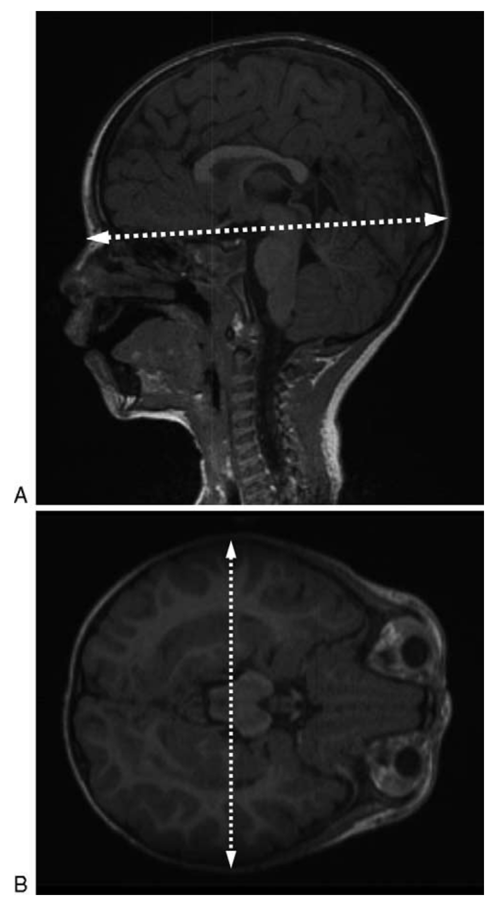

FIGURE 2. (A) Anterior–posterior length (N–OP) and (B) biparietal width (EU–EU). N–OP, nasion to opisthocranion; EU–EU, euryon to euryon.

TABLE 2. Patient Characteristics

	n = 72
Age (years)	
Mean	7.8
Standard deviation	5.1
Range	0.25–17.80
Gender (male:female)	37:35

This means that approximately 81% of the variance of orbital depth is accounted for by the model. Depth increased more rapidly in the first 6 years of life, but leveled off in the early teen years toward a horizontal asymptote of approximately 45 mm. The best-fit second-order polynomial function describing the relationship is: $y = 31.9 + 1.7x - 0.06x^2$ (where y = orbital depth, x = age).

We also evaluated the relationship between orbital depth and cephalometric measures of head size, which are related to clinically measurable anthropometric landmarks. Comparing orbital depth to the sum EU–EU + N–OP, we found a significant relationship ($r^2 = 0.72$, $F(2,69) = 87.44$, $P < 0.0001$). This means that approximately 72% of the variance of orbital depth is accounted for by the model (Fig. 4). The best-fit second-order polynomial function describing the relationship was determined to be: $y = -196.5 + 1.3x - 0.002x^2$ (y = orbital depth, x = EU–EU + N–OP).

DISCUSSION

While blindness is a rare occurrence following orbital floor reconstruction, it is a devastating complication that may be avoided with a thorough knowledge of anatomy as well as careful pre and intraoperative planning. Visual loss is well-reported in conjunction with facial trauma, but is probably under-reported as an iatrogenic complication of surgical repair.[7] In a series of 189 orbital floor reconstructions, Gosau et al[5] reported 1 patient with partial vision loss and 1 patient with complete blindness. In an effort to prevent surgical injury to the optic nerve, numerous studies have elucidated orbital anatomy and orbital depth for the adult orbit using a variety of techniques (Table 1).[13–20] In the adult facial skeleton, the optic nerve is typically 40–50 mm from the infraorbital rim, with some variation depending on chosen landmarks, subject ethnicity, and methodology.

While orbital fractures are common in children and surgical acuity may in fact be greater due to the increased incidence of muscular entrapment with trapdoor fractures, there is a surprising paucity of data regarding the anatomy of the growing pediatric orbit.[2,21,27,28] Studies of adult orbital dimensions as they relate to age have demonstrated significant enlargement of orbital aperture with advancing age, but as noted by Pesa and Rohrich in their discussion of this study, little is known about "how the orbit changes from infancy to youth."[2,23,29] We sought to answer the question of how orbital depth changes from birth through childhood, in an effort to improve safety and efficacy in pediatric orbital reconstructions.

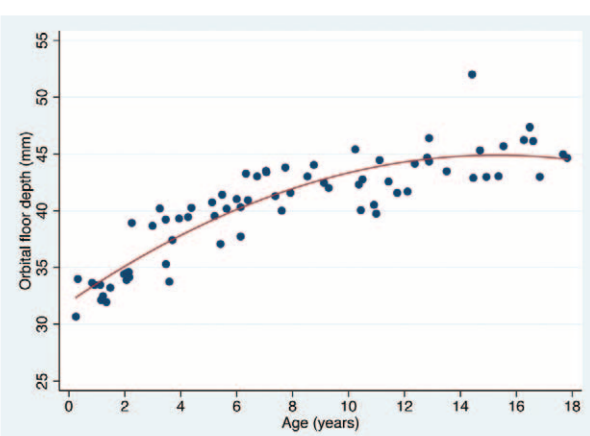

FIGURE 3. There is a significant relationship between orbital depth and age, described by the function $y = 31.9 + 1.7x - 0.06x^2$ (y = orbital depth, x = age) ($r^2 = 0.81$, $P < 0.001$).

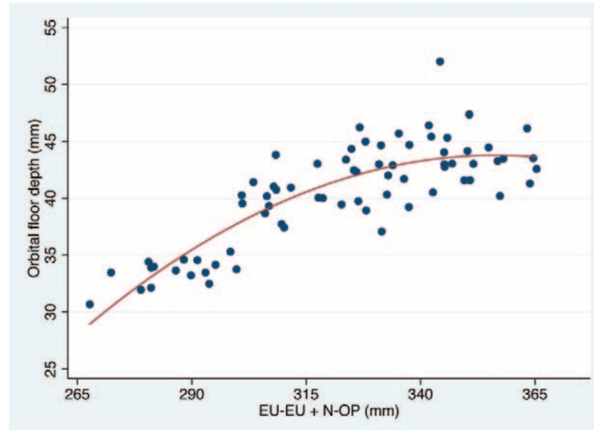

FIGURE 4. There is a significant relationship between orbital floor depth and the sum EU–EU + N–OP, described by the function $y = -196.5 + 1.3x - 0.002x^2$ ($r^2 = 0.72$, $P < 0.0001$). N–OP, nasion to opisthocranion; EU–EU, euryon to euryon.

To address this question, Rechner et al recently published a series of pediatric orbital depths calculated from indirect measurements on orthogonal computerized tomography (CT) images. We chose to use MRI data instead because of its ability to delineate the anatomy of the orbital apex, and because MRIs were available for a large population of children of various ages with no history of traumatic or congenital craniofacial diagnoses. The ability of MRI to accurately delineate soft tissue structures such as the optic nerve and orbital fat has been well established.[30–33] While MRI is less effective than CT for evaluation of bony trauma, normal bony anatomy is clearly delineated by the consistent presence of neighboring fat and marrow. In addition, in order to eliminate compounding of measurement errors, we chose to make direct measurements on reformatted 3D DICOM data rather than calculate orbital depth from indirect measurements.

Anatomic reference points were selected based on clinical utility.[24,25] Preoperatively, measurements of biparietal width and anterior–posterior length can be directly measured with calipers or easily obtained from radiographic imaging. Radiographic reference points for orbital depth measurements were also chosen for clinical utility; intraoperatively, the most anterior projection of the inferior orbital rim is routinely used to measure implant length. The clinical reproducibility of these measurements was an important consideration as well, and was established by the high degree of inter-observer reliability in this study.

This study suggests that orbital growth closely follows cranial growth. There is a period of rapid growth that decelerates with time. Orbital depth reaches 90% of adult dimensions by age 6, and 98% by age 13. In terms of growth, nearly 3 quarters of total growth is accomplished by age 6, and over 90% by age 11. This is analogous to cranial growth and explains the direct relationship between head measurements and orbital depth. Using this data, age and skull size can be used preoperatively to estimate orbital depth according to the relationships demonstrated in Figures 3 and 4.

These findings are interesting from the perspective of developmental anatomy, but also serve as operative guidelines when performing orbital floor dissections and placing implants. Nevertheless, one must be mindful that there is inherent variation between patients, and while these dimensions serve as a guide, there is no substitute for careful intraoperative dissection.[34] The results of this study provide a useful baseline understanding of pediatric orbital anatomy, filling a conspicuous gap in our knowledge base. Until intraoperative imaging becomes routine in orbital reconstruction, these findings can improve surgical efficacy in terms of adequate implant placement and improve surgical safety in pediatric orbital reconstruction.[35,36]

REFERENCES

1. Gentry LR. Anatomy of the orbit. *Neuroimag Clin N Am* 1998;8: 171–194
2. Rohrich RJ, Pessa JE. Discussion. Aging of the facial skeleton: aesthetic implications and rejuvenation strategies. *Plast Reconstr Surg* 2011;127:384–385
3. Girotto JA, Davidson J, Wheatly M, et al. Blindness as a complication of Le Fort osteotomies: role of atypical fracture patterns and distortion of the optic canal. *Plast Reconstr Surg* 1998;102:1409–1421
4. Girotto JA, Gamble WB, Robertson B, et al. Blindness after reduction of facial fractures. *Plast Reconstr Surg* 1998;102:1821–1834
5. Gosau M, Schöneich M, Draenert F, et al. Retrospective analysis of orbital floor fractures—complications, outcome, and review of literature. *Clin Oral Investig* 2011;15:305–313
6. Lederman I. Loss of vision associated with surgical treatment of zygomatic-orbital floor fracture. *Plast Reconstr Surg* 1981;68:94–99
7. Magarakis M, Mundinger GS, Kelamis JA, et al. Ocular injury, visual impairment, and blindness associated with facial fractures: a systematic literature review. *Plast Reconstr Surg* 2012;129:227–233
8. Marin PC, Love T, Carpenter R, et al. Complications of orbital reconstruction: misplacement of bone grafts within the intramuscular cone. *Plast Reconstr Surg* 1998;101:1323–1327
9. Villarreal P, Monje F. Porous polyethylene implants in orbital floor reconstruction. *Plast Reconstr Surg* 2002;109:877–885
10. Chi MJ, Ku M, Shin KH, et al. An analysis of 733 surgically treated blowout fractures. *Ophthalmologica* 2010;224:167–175
11. Cullen GC, Luce CM, Shannon GM. Blindness following blowout orbital fractures. *Ophthal Surg* 1977;8:60–62
12. Nicholson DH, Guzak SW. Visual loss complicating repair of orbital floor fractures. *Arch Ophthalmol* 1971;86:369–375
13. Rontal E, Rontal M, Guilford FT. Surgical anatomy of the orbit. *Ann Otol Rhinol Laryngol* 1979;88:382–386
14. Katsev DA, Drews RC, Rose BT. An anatomic study of retrobulbar needle path length. *Ophthalmology* 1989;96:1221–1224
15. McQueen CT, DiRuggiero DC, Campbell JP, et al. Orbital osteology: a study of the surgical landmarks. *Laryngoscope* 1995;105:783–788
16. Karampatakis V, Natsis K, Gigis P, et al. Orbital depth measurements of human skulls in relation to retrobulbar anesthesia. *Eur J Ophthalmol* 1998;8:118–120
17. Danko I, Haug RH. An investigation of the safe distance for internal orbit dissection. *J Oral Maxillofac Surg* 1998;56:749–752
18. Karakaş P, Bozkir MG, Oguz O. Morphometric measurements from various reference points in the orbit of male Caucasians. *Surg Radiol Anat* 2003;24:358–362
19. Huanmanop T, Agthong S, Chentanez V. Surgical anatomy of fissures and foramina in the orbits of Thai adults. *J Med Assoc Thai* 2007;90: 2383–2391
20. Nitek S, Wysocki J, Reymond J, et al. Correlations between selected parameters of the human skull and orbit. *Med Sci Monit* 2009;15:BR370–BR377
21. Grunwaldt L, Smith DM, Zuckerbraun NS, et al. Pediatric facial fractures: demographics, injury patterns, and associated injuries in 772 consecutive patients. *Plast Reconstr Surg* 2011;128:1263–1271
22. Chandler DB, Rubin PA. Developments in the understanding and management of pediatric orbital fractures. *Int Ophthalmol Clin* 2001;41:87–104
23. Martin MD, Rechner BP. Dimensional considerations for operative repair of the fractured pediatric orbit. *Plast Reconstr Surg* 2012;129:182e–183e
24. Farkas LG, Tompson B, Phillips JH, et al. Comparison of anthropometric and cephalometric measurements of the adult face. *J Craniofac Surg* 1999;10:18–25
25. Farkas LG, Tompson BD, Katic MJ, et al. Differences between direct (anthropometric) and indirect (cephalometric) measurements of the skull. *J Craniofac Surg* 2002;13:105–108
26. Kleinbaum D, Kupper L, Nizam A, et al. Polynomial regression. In: *Applied Regression Analysis and Other Multivariable Methods*. 4th ed. Belmont, CA: Duxbury; 2008:349–382.
27. Grant JH III, Patrinely JR, Weiss AH, et al. Trapdoor fracture of the orbit in a pediatric population. *Plast Reconstr Surg* 2002;109:482–489
28. Losee JE, Afifi A, Jiang S, et al. Pediatric orbital fractures: classification, management, and early follow-up. *Plast Reconstr Surg* 2008;122: 886–897
29. Shaw RB, Katzel EB, Koltz PF, et al. Aging of the facial skeleton: aesthetic implications and rejuvenation strategies. *Plast Reconstr Surg* 2011;127:374–383
30. Davis PC, Hopkins KL. Imaging of the pediatric orbit and visual pathways: computed tomography and magnetic resonance imaging. *Neuroimag Clin N Am* 1999;9:93–114
31. Hesselink JR, Karampekios S. Normal CT and MRI anatomy of the globe, orbit, and visual pathways. *Neuroimag Clin N Am* 1996;6:15–27
32. Hopper K, Sherman J, Boal D, et al. CT and MR imaging of the pediatric orbit. *Radiographics* 1992;12:485–503
33. Langer BG, Mafee MF, Pollack S, et al. MRI of the normal orbit and optic pathway. *Radiol Clin N Am* 1987;25:429–446
34. Evans BT, Webb AA. Post-traumatic orbital reconstruction: anatomical landmarks and the concept of the deep orbit. *Br J Oral Maxillofac Surg* 2007;45:183–189
35. Morrison C, Taylor H, Sullivan S. Applications of intraoperative navigation in craniofacial surgery. In: *The 53rd Annual Meeting of the New England Society of Plastic and Reconstructive Surgeons, Woodstock, VT*; 2012.
36. Markiewicz M, Dierks E, Potter B, et al. Reliability of intraoperative navigation in restoring normal orbital dimensions. *J Oral Maxillofac Surg* 2011;69:2833–2840
37. Cheng AC, Lucas PW, Yuen HK, et al. Surgical anatomy of the Chinese orbit. *Ophthal Plast Reconstr Surg* 2008;24:136–141

