The Relationship of the Globe to the Orbital Rim

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Objective: To present a novel method for accurately characterizing the position of the globe relative to the orbital rim. The appearance and function of the eyelids are dependent on the underlying orbital bony architecture and globe position; however, no comprehensive language to describe these complex 3-dimensional relationships exists.

Methods: Three-dimensional orbital reconstructions were generated from computed tomographic scans of 15 Occidental and 12 Oriental orbits without orbital pathologic disease. Globe and orbital rim anatomy were identified and outlined. Reference points were measured along 2 independent axes: (1) the distance between a plane defined by the corneal apex and the sagittal projection of the orbital rim and (2) the distance between the circumference of the globe and the coronal projection of the orbital rim.

Results: For Occidental orbits, the mean (SD) elevation of the sagittal projection of the orbital rim relative to the anterior projection of the globe was 4.6 (4.2) mm superiorly, 5.9 (3.0) mm nasally, 12.6 (3.7) mm inferiorly, and 20.6 (2.6) mm laterally. The mean (SD) radial distance between the coronal projection of the orbital rim and the circumference of the globe was 3.7 (2.1) mm superiorly, 7.6 (1.8) mm nasally, 6.6 (2.2) mm inferiorly, and 4.6 (2.3) mm laterally. For Oriental orbits, the mean (SD) elevation of the sagittal projection of the orbital rim relative to the anterior projection of the globe was 5.0 (4.5) mm superiorly, 6.8 (4.1) mm nasally, 11.1 (4.3) mm inferiorly, and 17.5 (3.3) mm laterally. The mean (SD) radial distance between the coronal projection of the orbital rim and the circumference of the globe was 2.1 (1.2) mm superiorly, 8.2 (2.0) mm nasally, 6.5 (1.9) mm inferiorly, and 4.5 (1.7) mm laterally.

Conclusions: Comparison of Occidental and Oriental orbital rim and globe configurations revealed quantitative and qualitative differences. In addition to differences in soft-tissue anatomy, bony architectural variations may contribute substantially to racial differences in the surface anatomy of the periorbital area. Anatomic analysis, based on 3-dimensional orbital imaging, may provide a rational approach to surgical planning for aesthetic and reconstructive orbitofacial surgery.


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arrangement of the globe and orbital rim. We further investigated variations in these relationships between Occidental and Oriental patients. Anatomic analysis of orbital bony contours relative to the globe, based on 3D orbital imaging, may provide a rational approach to surgical planning for aesthetic and reconstructive orbitofacial surgery.

**METHODS**

A retrospective review of the electronic patient registry (McCann Medical Matrix, St Louis, Missouri) of the Orbital and Ophthalmic Plastic Surgery Division of the Jules Stein Eye Institute at the University of California, Los Angeles, was conducted. Patient records that included high-resolution spiral computed tomographic (CT) scans (1-mm slice width or less) of the orbits were identified. Medical records were then reviewed to exclude patients with bilateral orbital trauma, tumors, thyroid-related orbitopathy, or other orbital pathology. Finally, self-reported demographics were used to identify Occidental and Oriental data sets. Twelve Occidental (mean age, 46 years) and 7 Oriental patients (mean age, 32 years) were identified, yielding 15 Occidental and 12 Oriental orbits without orbital pathologic conditions. The study was approved by the University of California, Los Angeles, institutional review board.

Digital Imaging and Communications in Medicine (DICOM) files were imported into ImageJ (National Institutes of Health, Bethesda, Maryland), a public domain image processing program, and volume-rendering 3D orbital reconstructions were generated with the Volume Viewer plug-in (Internationale Medieninformatik, Berlin, Germany). Reconstructions were generated in both the coronal and the sagittal planes, and transections through the skull with attention to the skull base were rendered to align the clinoid processes as well as the sella nasiens, thereby orienting the skull in 3 dimensions for further analysis.

Next, transections displaying both soft and bony tissues through the orbits at the depth of the equator (circumference) of the globes were generated (Figure 1A). The rendering depth was then adjusted to display the orbits from a perspective anterior to the orbital rim, and the rendering threshold was adjusted to exclusively display bony tissue (Figure 1B). These 2 sets of images were then imported into Adobe Illustrator (Adobe Systems Incorporated, San Jose, California) and overlaid into a single composite reconstruction of the globe and coronal projection of the orbital rim (Figure 1C).

The orbital reconstructions were subsequently rotated 90° along the horizontal plane to yield sagittal projections. Once again, transections displaying both bony and soft tissues through the center of the cornea were generated (Figure 1D). The rendering depth was then adjusted to display the orbits from a perspective lateral to the orbital rim, and the rendering threshold was adjusted to display exclusively bony tissue (Figure 1E). As before, these 2 sets of images were imported into Adobe Illustrator and overlaid into a single composite reconstruction of the globe and coronal projection of the orbital rim (Figure 1F).

For clarity, globe and orbital rim anatomy were outlined with Adobe Illustrator (Figure 2A and B), and 360° polar plots were overlaid. The anatomic configuration of the axial cross-section of the globe was approximated as a circle. For both the right and left orbits the medial orbital rim was assigned 0°, the

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**Figure 1.** Reconstruction of orbital rim and globe. A, Coronal transection through equator of the globe. B, Coronal reconstruction of the orbital rim. C, Coronal transection and reconstruction superimposition. D, Sagittal transection through the apex of the cornea. E, Sagittal reconstruction of the orbital rim. F, Sagittal transection and reconstruction superimposition.

**Figure 2.** Orientation and landmark identification of orbital rim and globe. Outline of the orbital rim and globe in coronal plane (A) and sagittal plane (B). Overlay of polar plot in coronal plane (C), identification of corneal apex and cardinal points in sagittal plane (D), and alignment of coronal and sagittal reconstructions (E).
inferior orbital rim was assigned 90°, the lateral orbit was assigned 180°, and the superior orbit was assigned 270° (Figures 2C and D). Thus, the orientation of the right and left orbits are a mirror image of one another, and the localization of points along the orbital rims may be readily compared between right and left orbits. The coronal and sagittal reconstructions were then aligned, and the precise localization of points at 30° intervals were projected from the coronal reconstruction to the sagittal reconstruction (Figure 2E).

The distances between the equator of the globe and the coronal projection of the orbital rim and between the corneal apex plane and the sagittal projection of the orbital rim were measured at 30° intervals with the measuring tool in Adobe Illustrator. The bony anatomy adjacent to the medial canthal tendon (0°), characterized by the broad confluence of the posterior and anterior lacrimal crest, precludes confident ascertainment of the orbital rim at this location. Therefore, this point was estimated, and as a result, detailed orbital rim analysis was carried out from 30° to 330°. Importantly, previous work has validated the utility of CT-based 3D volume rendering for the purpose of anthropological craniofacial studies of both bone and soft-tissue measurements.6 A set of 360° plots (Goldberg-Eckstein curves) were developed to graphically display these data sets (Figure 3). Measurements are reported as the mean (SD), and the 1-sided t test was used to identify significant (P ≤ .05) measurements.

RESULTS

Data from 15 Occidental orbits (representing 12 unique patients) and 12 Oriental orbits (representing 7 unique patients) were analyzed, and Goldberg-Eckstein curves were generated. For Occidental orbits the mean (SD) radial distance between the coronal projection of the orbital rim and the circumference of the globe was 3.7 (2.1) mm superiorly, 7.6 (1.8) mm nasally, 6.6 (2.2) mm inferiorly, and 4.6 (2.3) mm laterally. For Oriental orbits the mean (SD) radial distance between the coronal projection of the orbital rim and the circumference of the globe was 2.1 (1.2) mm superiorly, 8.2 (2.0) mm nasally, 6.5 (1.9) mm inferiorly, and 4.5 (1.7) mm laterally (Figure 4A).

Comparison of these measurements demonstrated a statistically significant greater distance between the edge of the globe and the superior orbital rim in Occidental patients compared with Oriental patients. Inferiorly, there was no significant difference in the relative positioning of the globe and orbital rim. These data revealed that the
Occidental orbit was taller than the Oriental orbit. That is, although the positioning of the globe in the coronal plane relative to the inferior orbital rim was equivalent in Occidental and Oriental patients, the orbital aperture extended further superiorly in Occidental orbits. Thus, the Occidental orbital rim demonstrated a superior “vault.”

Although when plotted as a Goldberg-Eckstein curve, the space between the globe and the orbital aperture in the coronal plane was found to have a greater area in Occidental patients (115.4 mm²) compared with Oriental patients (106.2 mm²), the observed superior vault of Occidental rims between 30° and 150° in the sagittal plane. Open circles represent individual data points; solid bars indicate mean value across all samples in the group.

Comparison of these measurements demonstrated a shallower orbit among the Oriental population compared with the Occidental population. The mean depth of the orbit (from peak at 150° to valley at 300°) was 15.4 mm in the Oriental group vs 18.7 mm in the Occidental group. This quantitative difference in the configuration of the orbital rim anatomy was particularly evident in the slope of the inferior orbital rim between 30° and 150°. In this region, the mean slope of the orbital rim in the Occidental population was 0.12 mm/degree, whereas the average slope of the orbital rim in the Oriental population was 0.10 mm/degree (Figure 5B)—a statistically significant difference (P = .01). Thus, in addition to the previously described superior vault, the average Occidental orbital rim is flared posteriorly when observed from the sagittal plane compared with the average Oriental orbital rim.

Traditional analysis of the periocular region has focused on the surface anatomy of this area. Because of the ease of observation and the facility of surgical manipulation, investigations have concentrated on numerous associated structures, including the architecture of the eyelids and the shape and position of the forehead and midface. However, the anatomy of this region is profoundly influenced by the deep tissue architecture—the 3D curvature of the orbital rim, the localization of the globe, and the complex interplay between the two. Although qualitative descriptions of this relationship abound, quantitative analysis of this anatomy is limited.

Historically, practitioners have relied on Hertel exophthalmometry to characterize this relationship. However, this instrument, and other similar devices, only permit measurement of the position of the globe relative to the lateral orbital rim. Moreover, it is affected by parallax errors as well as by bony or soft-tissue asymmetries between the right and left sides of the skull and face, which may be caused by disease processes, following trauma, or iatrogenically induced. In addition, measurements are significantly affected by both interobserver and intraobserver variation even with newer instruments.

Even if a perfect exophthalmometer could be developed, the measurement is limited to a single point of reference. More valuable for understanding and describing the relationship of the globe and its bony support is a 3D description across the entire 360° sweep of the orbital rim. We have presented a technique for describing the position of the globe relative to any point on the orbital rim. By exploiting advances in computing power and the availability of 3D reconstructions, this CT scan-based approach enables measurement in any anatomic axis. Previous studies have validated the accuracy of CT-derived exophthalmometry measurements.

One application of this imaging-based approach is better assessment of proptosis or enophthalmos in the set-
ting of soft-tissue swelling and posttraumatic conditions—
situations in which Hertel exophthalmometry frequently
fails. For example, the periorbital soft-tissue edema that
accompanies both preseptal and orbital cellulitis may lead
to placement errors with Hertel exophthalmometry. These
systematic errors may underestimate the distance be-
 tween the lateral orbital rim and the globe, resulting in
an underappreciation of relative globe proptosis.

Depression of the lateral orbital rim as is seen in or-
bitozygomatic fractures can also induce errors into Her-
tel measurements. If the absolute position of the globe
(relative to stable points on the skull, such as the su-
 perior orbital rim) is essentially unchanged, the globe will
falsely appear to be proptotic based on simple Hertel ex-
ophthalmometry (pseudoproptosis). Because a 3D im-
aging–based analysis enables quantification of the posi-
tion of the globe relative to multiple structures (such as
the superior orbital rim), it can better characterize the
globe position relative to these confounding bony changes.

Our comparison of Occidental and Oriental orbital rim
anatomy has revealed numerous qualitative and quanti-
tative differences in the shape of the orbital rim and the
position of the globe within the orbital aperture be-
tween these 2 groups. For instance, the Occidental orbit
rim vaults superiorly (in the coronal plane). This spe-
cific bony characteristic may affect the soft-tissue drap-
ing and contribute to observed racial differences in sur-
face anatomy. Likewise, our finding that the Oriental
orbital rim is flatter and shallower (in the sagittal plane)
than the Occidental oriental rim may help to explain the
differences in the surface anatomy of this region.

Interestingly, on average, in both the Occidental and
Oriental populations, the “deepest” extent of the orbit
(as viewed from the sagittal plane) was inferior-lateral
at 150°. Because of its inherent geometric limitations, Her-
tel exophthalmometry has permitted measurement only
at 180° (presuming that the instrument is placed cor-
rectly), and thus has focused our attention at this point.
However, a more informative position may instead be
slightly inferior; the implication of this finding and its
significance to periocular soft-tissue anatomy remains to
be elucidated in future studies.

Numerous studies have focused on aging changes in the
bony elements of the face. In particular, a progress-
ive decrease in the glabellar angle and a suborbital
retrusion of the maxillary face has been observed in both
male and female skulls with advancing age. The au-
thors of these studies speculate that these changes may
contribute to brow ptosis, lateral orbital hooding, mid-
face descent, and increased prominence of the nasola-
bial folds.

Interestingly, examinations of age-related changes in
the bony anatomy of the orbital rim and periorbicular soft
tissue reveal inconsistent results. Studies by Mendelson
et al have demonstrated stable orbital floor length with
advancing age, whereas investigations by Pessa et al have
revealed a posterior retrusion of the inferior orbital rim
relative to the anterior cornea. However, these latter re-
 sults may be due to changes in retrobulbar orbital soft
 tissues (eg, orbital fat expansion) or sinus air cell expan-
sion, which may result in an apparent anterior displace-
ment of the globe relative to a stable orbital rim.

Changes in the structure of the orbital rim would be ex-
pected to have a direct and profound impact on the
overlying soft-tissue anatomy. A cross-sectional analy-
sis of age-related changes in the orbital aperture re-
vealed an increase in the superomedial height and in-
f erolateral depth of the coronal projection of the orbital
t rim. Importantly, however, no significant change in the
overall height or width of the orbital aperture was ob-
served. The authors speculate that the curve distortion
of the orbital rim may contribute to the appearance of
cantal malposition, the curve of the upper eyelid mar-
gin and supraciliary eyelid crease, the shape of the eye-
brow, and other aspects of eyelid surface anatomy and
aesthetics. Other studies have demonstrated a signifi-
cant relationship between the angle of the maxillary si-
nus face (shown to decrease with advancing age) and the
presence of a tear trough deformity, as well as the posi-
tion of the globe relative to the orbital rim and the pre-
sence of lower eyelid retraction.\textsuperscript{1,21,22}

For instance, variations in the deep, bony anatomy con-
tribute to soft-tissue findings such as upper eyelid crease
position and contour. Obvious examples are disorders
that significantly change the relationship between bone
and soft tissues, such as facial fractures, which alter the
peri orbital bony anatomy, and orbital diseases, which
produce enophthalmos or proptosis.

More subtle, but important, are the inherited vari-
ations and aging changes in the bony structures that un-
derlie the heterogeneity of periorbital appearance. Bony
asymmetry results in visible surface asymmetries of ey-
elid contour, such as crowded appearing orbits, eyebrow
asymmetry, sulcus and upper eyelid crease asymmetry,
and canthal asymmetry. Moreover, the 3D shape of the
inferior orbital rim bony support directly affects the vis-
ible contours and position of the lower eyelid soft tis-
sues and similarly contributes to lower eyelid asymme-
try. Improved understanding of the contribution of the
underlying bony anatomy to soft-tissue contour and sym-
metry may contribute substantially to planning for sur-
gical management of these important aesthetic con-
cerns. Therefore, 3D anatomic analysis may provide a
rational approach to surgical planning for aesthetic and
reconstructive orbitofacial surgery.

Oculofacial surgeons understand intuitively that deep-
tissue anatomy contributes substantially to the struc-
ture and function of the periorbital soft tissues. More-
over, the contour of the orbital rim and the relative
position of the globe subserve the aesthetics of the or-
bital facial subunit. The novel 3D anatomic analysis of
these complex relationships presented herein provides
a basis for a unique, comprehensive language with which
to quantitatively describe periocular bony architecture
and dependant soft-tissue anatomy as well as its natural
and pathologic variations.

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