Shape variation of the human orbital cavity

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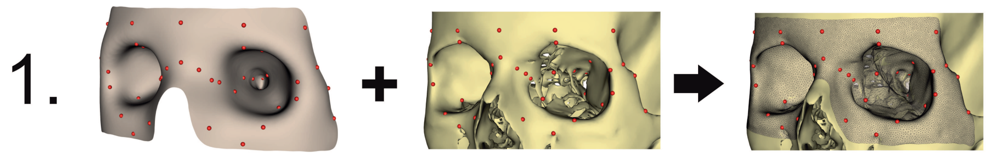
Introduction

The human orbital cavity has a smooth surface where only few anatomical landmarks can be identified. Also, automatic segmentations based on grey values of CT-scans often result in defective representations of the orbital walls. To overcome these constraints, a symmetric template mesh representing the orbital region was matched onto 656 skull representations automatically segmented from CT-Scans. This approach allows to analyze the shape of the orbital cavity with respect to the factors population affinity and sex.

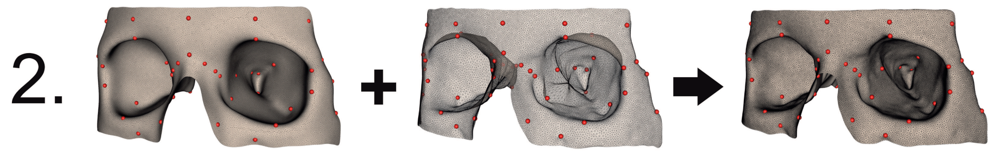
Methods



a) Symmetric template mesh with landmarks

b) Target individual with holes in orbital cavity due to automatic segmentation

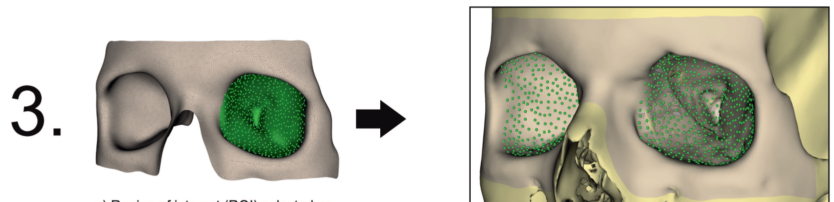
c) Template matched to target with distortions in the resulting mesh.



d) New symmetric template created from mean of all matched meshes (n=656).

e) Result of first matching.

f) New template matched to first matching.



g) Region of interest (ROI) selected on one side of the new symmetric template d).

h) Subsample of ROI (n=600 points) mirrored and transferred to targets via barycentric coordinates.

Materials

CT-scans of 656 individuals of European (♀:n=164, ♂:n=164) and Chinese (♀:n=164, ♂:n=164) origin were segmented based on grey values and the skull representations were exported. Forty-six landmarks were placed manually on these surfaces. Only individuals aged over 18 were used in this study.

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1. A one-layered symmetric template mesh was created using the software "Blender" (a). On the basis of this template a statistical model was computed using the R-package "RvtkStatismo", an "R" implementation of "Statismo", a framework for statistical shape modeling. The 46 manually set landmarks were used for an initial fit. Then, the template mesh was matched to the target skulls in 100 iterations (b). The resulting meshes often showed distorted topology (c).

2. To overcome this drawback, the mean of all 656 matches was remeshed and symmetrized by mirroring it along the middle axis (d). This new template was then matched onto all results of the first matching round with 50 iterations (e). This way, a uniform mesh representation of the orbital region was generated and the defects in the orbital walls were interpolated (f). The matching quality was tested on 12 segmentations with intact orbital walls where holes were created artificially.

3. Next, a region of interest representing the orbital cavity was defined in "Blender" on one side of the template (g) and mirrored to the other side. A subsample of 600 evenly distributed bilateral points was computed and placed automatically on each individual via barycentric coordinates (h). All further analyses were carried out on those pseudo-landmarks.

Procrustes analysis and principal component analysis (PCA) were performed. Further analyses were undertaken on the PC scores of those PCs accounting for 98% of the total shape variance. The influence of the factors *population affinity* and *sex* on shape was modelled and tested with permutation testing, classical MANOVA, and 50-50 MANOVA. The level of significance was 0.05. Canonical Variate Analysis (CVA) and the more conservative between-group PCA were chosen for classification testing.

Results

The influence of population affinity and sex is highly significant (Tab.1). The explained variance is 8.4% for population affinity and 1.7% for sex.

The interaction between the two factors is significant when analyzed with MANOVA, but not with 50-50 MANOVA with non-standardised responses. Permutation testing resulted in just significant p-values for the angle and the distance between the mean shapes of the subgroups.

Groups	MANOVA	50-50 Manova	Permutation test
Pop	< 2e-16 ***	< 2e-16 ***	1e-04 ***
Sex	< 2e-16 ***	7.27e-07 ***	1e-04 ***
Pop*Sex	0.0002 ***	0.07	Angle: 0.045 .
			Distance: 0.0203 .

Tab. 1. P-Values of MANOVA, 50-50 Manova and permutation testing of the linear model shape~population affinity*sex.

Between-group PCA resulted in 67.38% correct classifications (Fig. 2). The overall classfication accuracy of CVA was 83.69%.

Symmetric shape differences between European and Chinese mean shapes (Fig. 3a) are most prominent in the infero-posterior part of the orbital cavity, where the Chinese mean shape shows stronger curvature, leading to a more narrow posterior part in vertical dimensions. It is emphasized that these are pure shape differences without information about size.

Sexual dimorphism (Fig. 3b) is only very subtle when only symmetric shape differences without size are analyzed. Females show a slightly more curved inferior part than males.

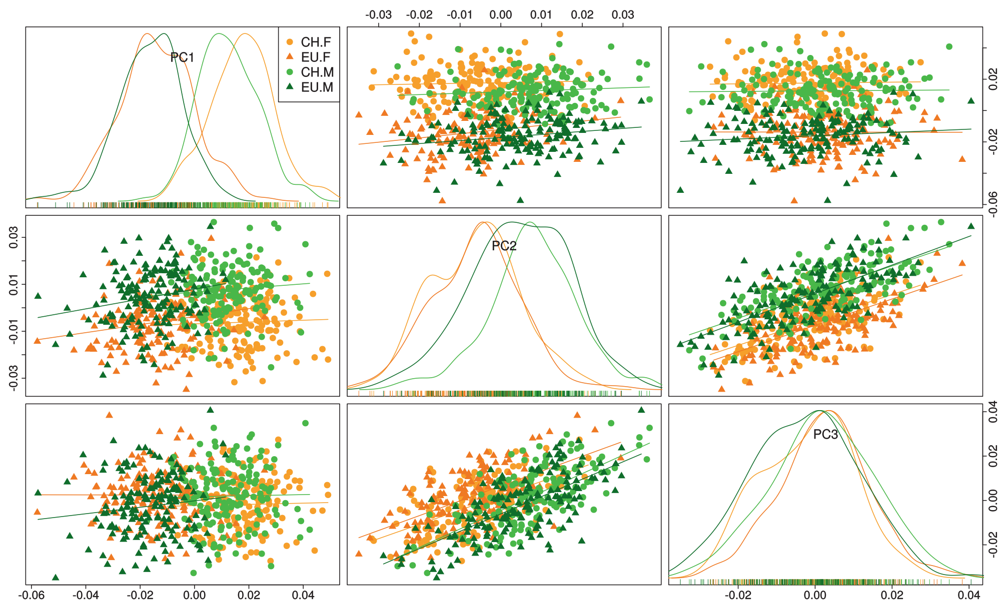

Fig. 2. Between-group PCA of the four groups European (EU) and Chinese (CH) Males (M) and Females (F).

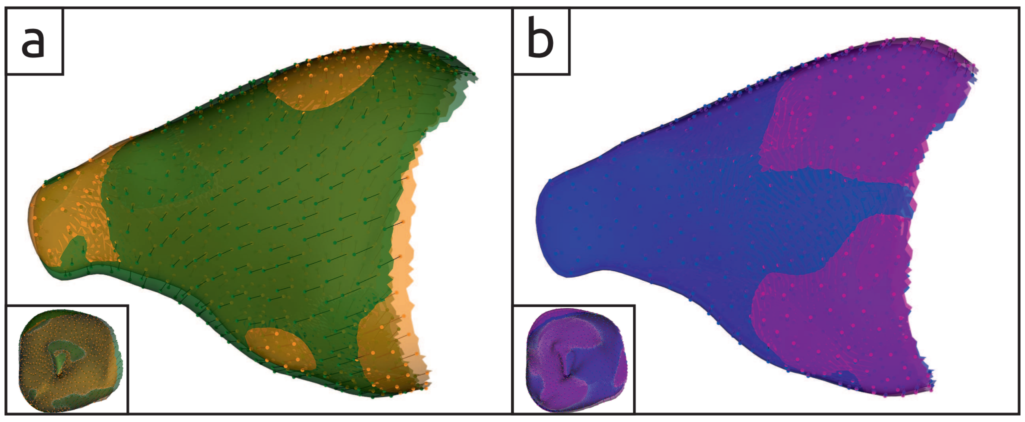

Fig. 3. Mean shape differences of right orbital cavity, exaggerated by factor 1.5. Large: Lateral view, small: frontal view. **a**: European (green) and Chinese (orange). **b**: Female (magenta) and male (blue).

Discussion

The method applied in this study offers new ways of analyzing the shape of the orbital cavity. Shape differences due to population affinity and sex are very subtle and account for only 8.4% and 1.7% of total shape variation. But especially for population affinity, further investigation with other populations might give further insight into shape variation. Other aspects of shape can be addressed with this method as, for example, asymmetry or allometric effects in the orbital cavity.

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Acknowledgements

I gratefully thank Dr. Stefan Schlager for providing the R-packages Morpho, mesheR, RvtkStatismo, and Rvcg and Prof. Dr. Dr. Marc Metzger from the Department of Oral and Maxillofacial Surgery, Uniklinik Freiburg, Germany, and Prof. Dr. Xianqun Fan from the Ninth People's Hospital in Shanghai for providing the CT-data.