Biomechanics of the sloping supraorbital torus of *Paranthropus boisei*

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Introduction

One of the most distinctive craniofacial features of *Paranthropus boisei* is its inferolaterally sloping supraorbital torus. This supraorbital descent pulls the entire orbital profile downwards, giving the orbits the appearance of inferolaterally sloping parallelograms. Rak (1983) proposed that by straightening out the junction of the lateral orbital wall and supraorbital torus to form a "downward sloping cord", the circumorbital structures of *P. boisei* would be better suited than other primates to resist deformation caused by powerful masseteric contraction.

Experimental studies in primates have shown that masseter contraction causes stresses in the circumobital structures associated with "unbending" or straightening of the lateral orbital wall. This obliquely lengthens the orbit (in a manner similar to the form of OH 5). This deformation leads to elevated tension at the superolateral orbital margin and elevated compression at the superomedial orbital margin (Ross et al., 2011).

Hypothesis and Predictions

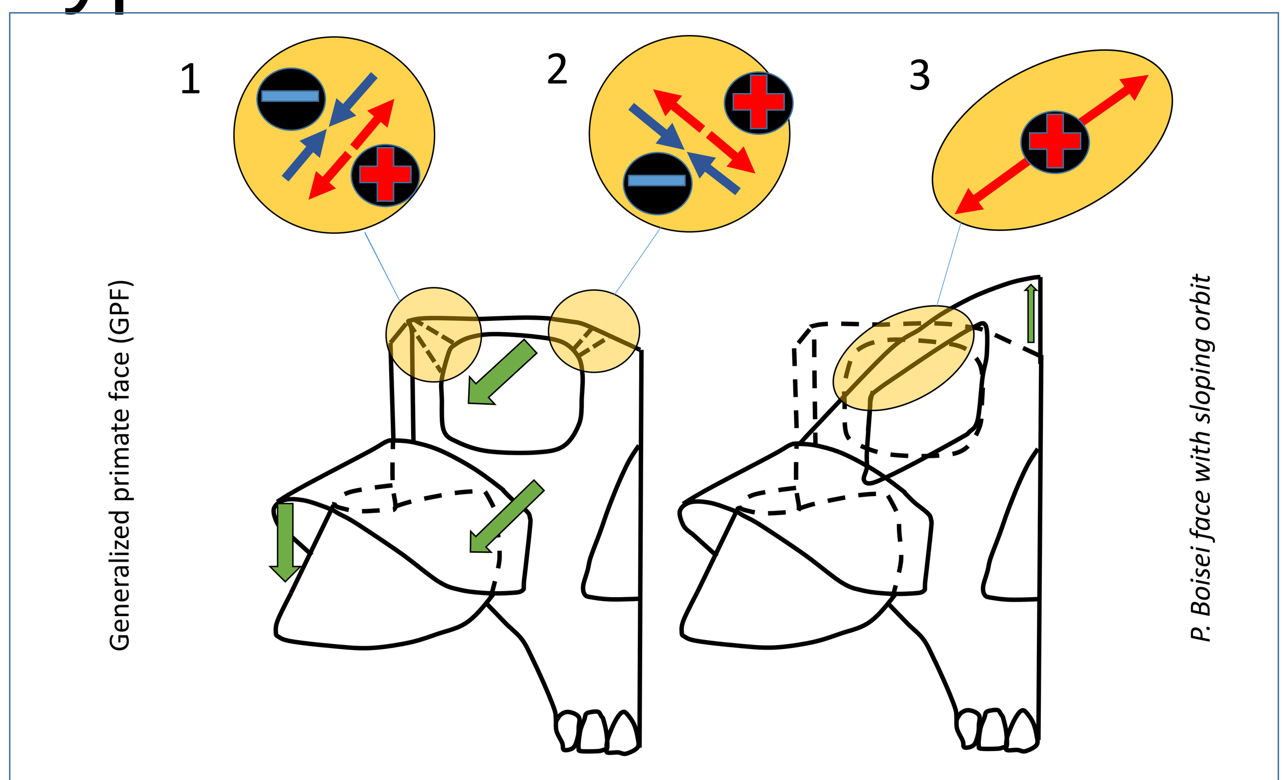
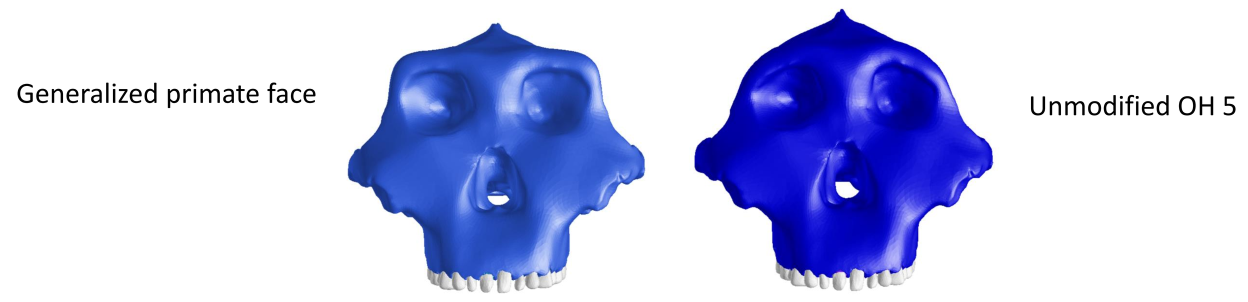


Figure modified from Rak 1983; Rak and Marom 2017)

Compared to the GPF, the sloping supraorbital torus of OH 5 should confer structural strength by:

1. Reducing tensile strains laterally, at the inner aspect of the junction of the frontal process and supraorbital torus
   Expect: GPF to have higher strains relative to OH 5
2. Reducing tensile strains medially at the outer aspect of the junction of the frontal process and glabella.
   Expect: GPF to have higher strains relative to OH 5
3. Loading the entire supra- and lateral orbital elements in axial tension.
   Expect: OH 5 to have more even distribution of tensile strains than GPF

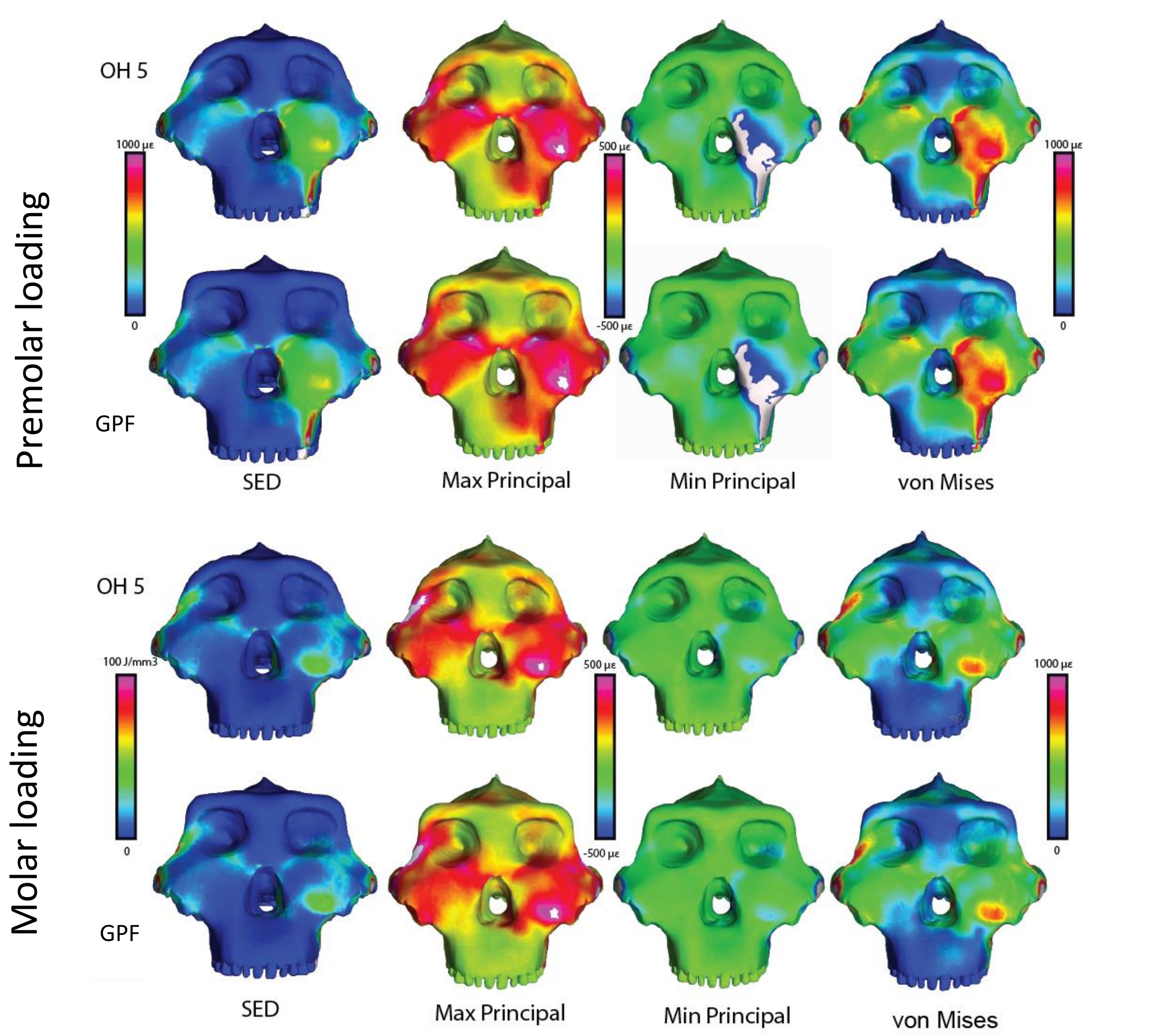
Materials and Methods

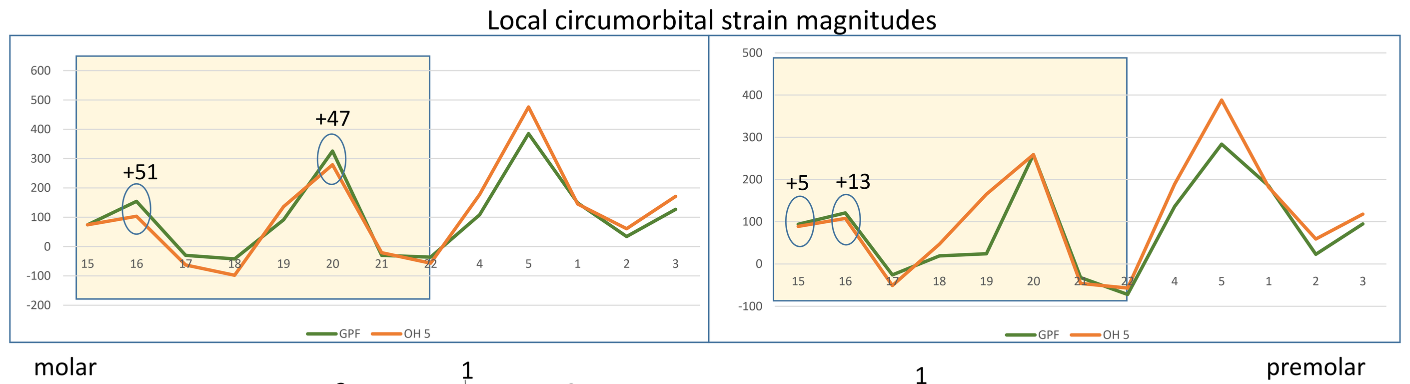


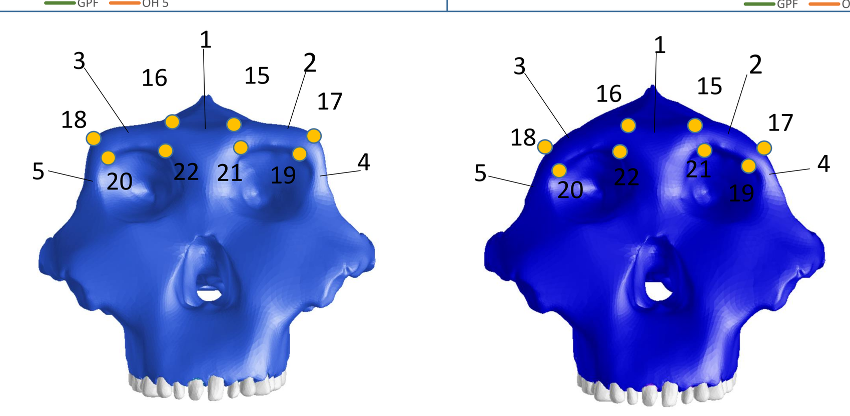
Two FE models based on a virtual reconstruction of OH 5 (Benazzi et al., 2011: Smith et al., 2015b) were used in this experiment. One model was modified by warping the orbital margin to conform to the more square GPF.

Strain magnitudes, mode and directions were compared between models to assess relative performance of the sloping and generalized primate supraorbital form.

Results

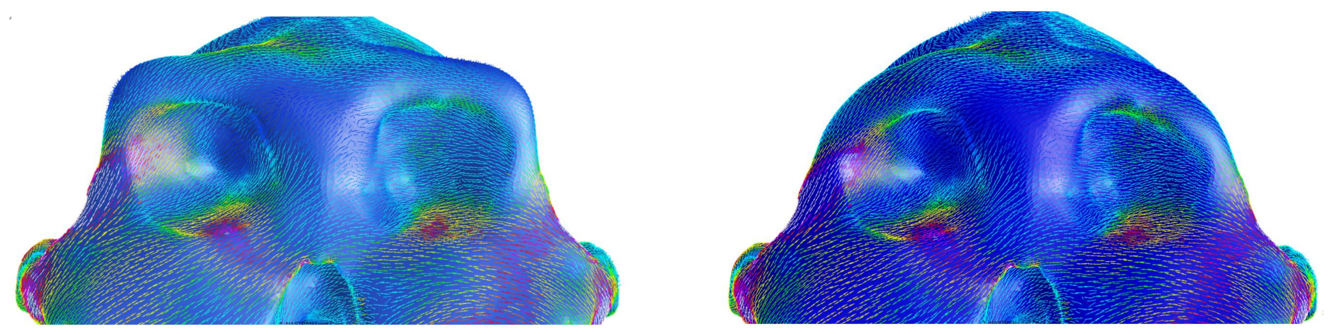






Highlighted area shows points with predictions about relative performance. Slightly higher strain in GPF at marked locations, but lower strains than OH 5 at other locations.
Note: Compressive points are drawn below 0. More strongly compressive points fall further below 0.

Circumorbital tensile strain orientations



Arrows represent direction of principal strain, colors represent magnitude of strain

Evaluation of hypothesis and predictions

Does the sloping orbital form of OH 5 confer a structural advantage over that of the GPF?

1. Are strains in GPF higher at the inner superolateral orbital margin (19-20)? Only on balancing side, molar bite. At the outer superolateral orbital margin, (17-18) strains are lower in GPF than OH 5. **This does NOT match prediction 1.**
2. At the outer superomedial orbital margin (15-16), GPF experiences slightly higher tensile strains than OH 5. At the inner superomedial orbital margin (21-22), GPF experiences compressive strains that are slightly lower than OH 5 on the working side, but higher on the balancing side. **This weakly matches prediction 2.**
3. Tensile strains are oriented axially in the postorbital elements of both models. OH 5 is consistently tensile-dominant, while the GPF are compressive in some loading scenarios. **This matches prediction 3.**

Conclusions

Results of our FE modeling experiment are not fully consistent with the predictions of Rak's hypothesis– a clear pattern of relative performance fails to emerge.

Overall, we find that absolute strain magnitudes in the supra- and postorbital elements are low and differences in relative performance between models are minimal.

It is not clear that differences between orbital slope, in isolation, are associated with sufficiently strong biomechanical differences as to suggest that this aspect of morphology is functionally significant during feeding.

Instead, the sloping supraorbital torus of OH 5 may reflect population level morphological variation due to stochastic processes or evolutionary processes entirely unrelated to feeding.

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