Dietary correlates of temporomandibular joint shape

Claire E. Terhune, *Department of Community and Family Medicine, Duke University School of Medicine*
Institute of Human Origins, School of Human Evolution and Social Change, Arizona State University

1. INTRODUCTION

Previous analyses of the masticatory apparatus have demonstrated that the shape of the temporomandibular joint (TMJ) is functionally and adaptively linked to variation in feeding behavior and diet in primates (e.g., Hinton and Carlson, 1979; Smith et al., 1983; Bouvier, 1986a,b; Wall, 1995, 1999; Vinyard, 1999; Taylor, 2002, 2005, 2006; Vinyard et al., 2003). **The research presented here further hypothesizes that TMJ morphology covaries with documented differences in food material properties, use of the anterior or posterior dentition during ingestion and mastication, and jaw gape.**

Specifically, it was predicted that:
- Taxa that tend to consume more resistant food objects should exhibit TMJ features associated with increased joint reaction force and range of motion, such as larger joint surface areas and joint processes.
- TMJs of taxa that intensively use their anterior teeth should be able to resist larger centrally or medially located joint reaction forces, while taxa that repetitively load their posterior teeth should be able to dissipate increased joint reaction forces on the lateral surface of the TMJ. These functional differences would be represented by changes in the relative mediolateral and anteroposterior dimensions of the joint.
- Taxa with relatively large gapes should have adaptations in their TMJ related to increased range of motion, such as an anteroposteriorly long TMJ and large preglenoid plane.

2. METHODS

Two- and three-dimensional morphometric methods were used to quantify TMJ shape across a broad sample of 48 anthropoid primates, and more narrowly among small groups of closely related taxa with documented dietary differences (Table 1). Each of these groups contains species which utilize foods that are believed to differ in their material properties and/or have been documented to rely on the use of their anterior or posterior dentition to differing degrees.

Three-dimensional geometric morphometric methods (e.g., Generalized Procrustes Analysis, principal component analysis, and wireframe diagrams) were used to explore shape variation in each group, and a Kruskal-Wallis test with multiple post-hoc comparisons was used to test for significant differences in TMJ shape among species. Correlations among variables describing gape were examined across the entire sample; data were corrected for phylogenetic covariance using independent contrasts (Felsenstein, 1985).
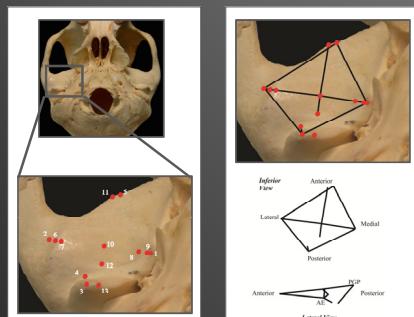

Table 1. Taxa included in this analysis. Boxes indicate species included in each of the four comparative groups.

Ateles geoffroyi
Lagothrix lagothrica
Alouatta seniculus
Alouatta belzebul
Alouatta palliata
Aotus trivirgatus
Cebus albifrons
Cebus apella
Cebus capucinus
Cacajao melanocephalus
Chiropotes satanas
Pithecia pithecia
Saimiri sciurius
Cercopithecus mitis
Cercopithecus nictitans
Miopithecus talapoin
Erythrocebus patas
Colobus polykomos
Trachypithecus obscurus
Procolobus badius
Procolobus verus
Semnopithecus entellus
Nasalis larvatus

Lophocebus albigena
Cercocebus torquatus
Mandrillus sphinx
Papio anubis
Papio cynocephalus
Papio ursinus
Theropithecus gelada
Macaca fascicularis
Macaca fuscata
Macaca nemestrina
Macaca sylvanus
Macaca thibetana
Hylobates agilis
Hylobates klossi
Hylobates lar
Symphalangus syndactylus
Gorilla beringei
Gorilla gorilla
Pan paniscus
Pan troglodytes
Pongo abelii
Pongo pygmaeus
Homo sapiens

Figure 1. Inferior views of a *Papio anubis* glenoid showing landmarks and wireframe diagrams used in this study. Features indicated on the lateral view wireframe are the articular eminence (AE) and postglenoid process (PGP).

3. RESULTS

- Taxa that utilize resistant food objects tend to have relatively larger joint surface areas (e.g., *Alouatta*, *C. apella*, *M. fuscata/ sylvanus/ thibetana*, *Gorilla*, *Pongo*) (Table 2).
- Taxa that rely heavily on their post-canine dentition for mastication have relatively mediolaterally wider glenoid fossae and mandibular condyles (e.g., *Alouatta*, *M. fuscata/ sylvanus/ thibetana*, *Gorilla*) (Figure 2, Table 2).
- The function of the articular tubercle and entoglenoid process are unclear. These processes tend to be smaller in taxa that rely heavily on their anterior dentition for food processing (*C. apella*, *M. fuscata*, *P. pygmaeus*) suggesting that the reduced size of these processes may allow for increased mediolateral movements at the TMJ as would be necessary with use of the anterior dentition.
- There is a strong correlation between measures of gape and anteroposterior length of the glenoid.
  - Glenoid length vs.
    - maxillary canine height (females: 0.22, p=0.15; males: 0.469, p=0.001)
    - TMJ height (females: 0.51, p<0.001; males: 0.54, p<0.001)
  - Preglenoid plane length vs.
    - maxillary canine height (females: 0.35, p=0.02; males: 0.53, p<0.001)
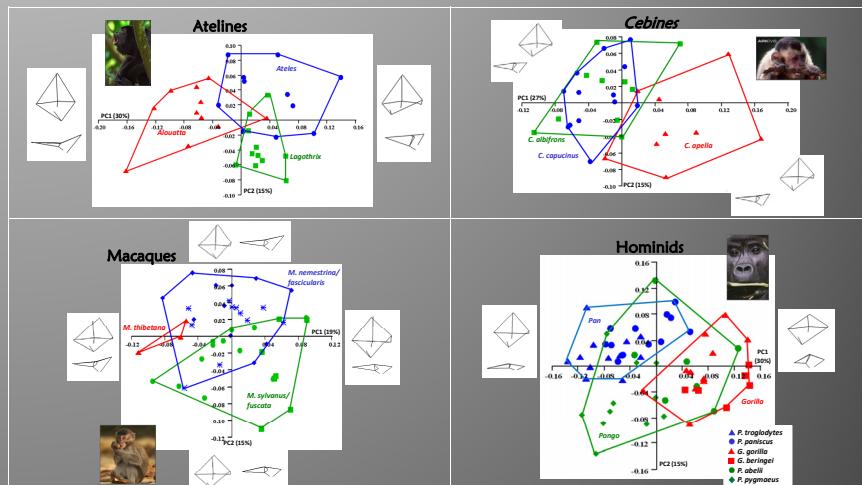   - TMJ height (females: 0.176, p=0.003; males: 0.31, p<0.001)

Figure 2. Wireframe diagrams and bivariate plots of PC1 (x-axis) and PC2 (y-axis) from the PC analyses of the glenoid configurations for each of the comparative groups.

Table 2. Results of Kruskal-Wallis test for significant differences among species in each of the comparative groups examined, presented by variable. NS= not significant

Variable	Atelines	Cebines	Macaques	Hominids
Articular Tubercle Height	*Alouatta* > *Ateles*	*C. albifrons* > *C. apella*	*M. nemestrina* > *M. fuscata*; *M. fascicularis* > *M. fuscata*	NS
Entoglenoid Height	*Alouatta* > *Ateles/ Lagothrix*	*C. capucinus* > *C. apella*	*M. nemestrina* > *M. fuscata/ M. thibetana*	NS
Glenoid Length	*Alouatta* > *Ateles*	NS	NS	*Gorilla/ Pan* > *Pongo*
Glenoid Width	NS	NS	*M. fuscata/ sylvanus/ thibetana* > *M. nemestrina*	NS
2D Glenoid Area	*Alouatta* > *Ateles/ Lagothrix*	NS	*M. fuscata/ sylvanus/ thibetana* > *M. fascicularis*	*Gorilla* > *Pongo* > *Pan*
3D Glenoid Area	*Alouatta* > *Ateles/ Lagothrix*	*C. apella* > *C. albifrons*	*M. fuscata/ sylvanus* > *M. fascicularis*; *M. fuscata* > *M. nemestrina*	*Gorilla* > *Pongo* > *Pan*
Preglenoid Length	NS	NS	NS	*Pan* > *Gorilla/ Pongo*
Condyle Width	NS	*C. apella* > *C. albifrons*	*M. thibetana* > *M. nemestrina*	*Gorilla* > *Pan*
Condyle Length	*Lagothrix* > *Ateles/ Alouatta*	NS	NS	NS
2D Condyle Area	*Alouatta/ Lagothrix* > *Ateles*	NS	*M. fuscata/ sylvanus/ thibetana* > *M. fascicularis*	*Gorilla/ Pongo* > *Pan*
3D Condyle Area	*Alouatta* > *Ateles/ Lagothrix*	NS	*M. fuscata/ sylvanus/ thibetana* > *M. fascicularis*	*Gorilla/ Pongo* > *Pan*

4. CONCLUSIONS

Results indicate that some aspects of TMJ shape covary with documented differences in masticatory function. In most of the comparative groups examined, taxa with more mechanically demanding diets separated in morphospace from taxa with less demanding diets, indicating an association between TMJ form and diet. These data therefore strongly suggest **that TMJ shape varies as a function of food material property and relative use of the anterior or posterior dentition.** However, further data regarding the magnitude of joint forces on the anterior teeth in comparison to taxa that repetitively load their posterior teeth is necessary to evaluate which of these patterns of masticatory loading is most significantly linked to TMJ shape variation.

Strong correlations were found between anteroposterior glenoid length and measures of gape, such as canine length and height of the TMJ above the occlusal plane. These data indicate that the amount of translation occurring at the TMJ during jaw opening and closing is important for maximizing linear gape, and those taxa with relatively wider gapes have more extensive anterior excursion of the mandibular condyle during wide jaw opening. These finding are consistent with recent analyses by Hylander and colleagues (Hylander and Vinyard, 2006; Hylander et al., 2008), who found a significant correlation between relative gape and canine crown height, and support the hypothesis that increased gape is partly manifested by alterations in joint surface area (Hylander, personal communication). Similarly, these data support the findings of Vinyard et al., (2003) who found that tree-gouging primates tended to have relatively AP longer glenoids than closely related taxa that do not practice tree-gouging.

REFERENCES

Bouvier M. 1986a. A biomechanical analysis of mandibular scaling in Old World primates. Am J Phys Anthropol 69:473-482.
Bouvier M. 1986b. Biomechanical scaling of mandible dimensions in New World monkeys. Int J Prim 7:551-567.
Felsenstein J. 1985. Phylogenies and the comparative method. Am Nat 125:1-15.
Hinton RJ, Carlson DS. 1979. Temporal changes in human temporomandibular joint size and shape. Am J Phys Anthropol 50:325-334.
Hylander WL, Vinyard CJ. 2006. The evolutionary significance of canine reduction in hominids: functional links between jaw mechanics and canine size [abstract]. Am J Phys Anthropol 129 (S42):107.
Hylander WL, McMillan AS, Lam EWN, Watanabe M, Langenbach GEJ, Stavness I, Peck CC, Palla S. 2008. From movements to models: a tribute to professor Alan G. Hannam. J Orofac Pain 22: 307-316.
Smith RJ, Petersen CE, Gipe DP. 1983. Size and shape of the mandibular condyle in primates. J Morphol 177:59-68.
Taylor AB. 2002. Masticatory form and function in the African apes. Am J Phys Anthropol 117:133-56.
Taylor AB. 2005. A comparative analysis of temporomandibular joint morphology in the African apes. J Hum Evol 48:555-74.
Taylor AB. 2006. Feeding behavior, diet, and the functional consequences of jaw form in orangutans, with implications for the evolution of *Pongo*. J Hum Evol 50:377-93.
Vinyard C. 1999. Temporomandibular Joint Morphology and Function in Strepsirhine and Eocene Primates. PhD Dissertation, Northwestern University.
Vinyard CJ, Wall CE, Williams SH, Hylander WL. 2003. Comparative functional analysis of skull morphology of tree-gouging primates. Am J Phys Anthropol 120:153-170.
Wall CE. 1995. Form and Function of the Temporomandibular Joint in Anthropoid Primates. PhD Dissertation, State University of New York at Stony Brook.
Wall CE. 1999. A model of temporomandibular joint function in anthropoid primates based on condylar movement during mastication. Am J Phys Anthropol 109:67-88.