Form and function in a sample of platyrrhine primates: A three-dimensional analysis of dental and TMJ morphology

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Introduction

As integral parts of the masticatory apparatus, the morphology of the dentition and skull, and particularly the temporomandibular joint (TMJ), should be tightly linked. Fine control over condylar and mandibular movements guides the teeth into occlusion, while the topography and position of the dental arcade mediate mandibular movements. The dentition, as the portion of the masticatory apparatus that is most directly involved in triturating food items, has been shown to strongly reflect dietary regimens (e.g., Kay 1975; Rosenberg and Krexy 1976, Anapol and Lee 1999, Boyer 2008, Cooke 2011). Similarly, cranial form is correlated with differences in feeding behavior among taxa (e.g., Shea, 1983, Antón 1996; Taylor 2002, 2005; Norconk et al. 2009) and TMJ shape has been shown to reflect joint reaction forces and joint range of motion, both of which vary in relation to feeding strategy (Bouvier 1986a,b; Wall 1999; Vinyard et al. 2003; Terhune 2011a,b).

Materials and Methods

Three-dimensional x,y,z coordinate landmarks were collected on the canina and dentition of a mixed sex sample of ten platyrrhine species (Fig. 1-3). Six datasets were created from these landmark sets: upper molar, lower molar, cranial and glenoid, glenoid only, mandible and condyle, and condyle only.

For each of the six datasets, we performed the following analyses in the program R (R Development Core Team 2008) using the package geomorph (Adams and Otárola-Castillo 2012):

- Mean forms were calculated for each species and superimposed using Generalized Procrustes Analysis.
- The phylomorphetic signal was calculated and its significance assessed using a permutation test (9,999 iterations). We visualized this signal by overlaying the consensus tree on a plot of principal component (PC) axes 1 and 2.
- Allometry in the dataset was assessed by regressing the Procrustes aligned coordinates (shape) on the natural log of mandible length with (PGLS) and without a consideration of phylomorphetic covariance.

To examine covariation among the six datasets we performed two-block partial least squares (2B-PLS) analyses using the size and phylogeny adjusted regression residuals, shape variation along each PLS axis was examined using warparcs diagrams.

Results

While the finding that cranial/TMJ and dental shape covary in platyrrhines is not a surprising result, it is one that has not been previously demonstrated. With this information in hand, we can begin to explore the ways in which morphological covariation correlates with diet, phylogeny, body size or other variables pertinent to an organism's ecological adaptations. Additionally, while it is tempting to attribute these findings to functional differences among taxa, other explanations (e.g., modularity) must be also kept in mind.

Discussion and Conclusions

This study examined cranial and dental covariation in platyrrhine primates. By using PGLS regression we were able to control for phylomorphetic covariance, and by regressing shape on mandible length we standardized all of the datasets using a biometrically significant scaling variable.

- Although cranial shape differs substantially among these taxa, by controlling for size variation and phylogeny, smaller-bodied taxa that are more insectivorous (e.g., Saimiri) are revealed to be relatively similar in cranial and dental form to larger bodied folivorous taxa such as Alouatta. Interestingly, the small bodied nocturnal Aotus also appears similar to Alouatta in dental and cranial form. This similarity may be a result of a convergence in cranial form and basicranial flexion (Ross and Ravosa 1993) linked to the visual adaptations of Aotus, further analysis is warranted.
- Conversely, Chiropotes and Cacajao, two taxa that are well known for scleroderma foraging and consumption of hard foods (Norconk et al. 2009), cluster on the negative ends of both PLS axes, and exhibit highly flexed crania, laterally flaring zygomatic arches, laterally positioned TMJs relative to the tooth row, and low-cusped dentition. This TMJ position and cusp morphology acts to increase bite forces and disperse forces over a larger area.
- What is perhaps most intriguing about this analysis is that the observed patterns of covariance between cranial and dental form do not fall into neat, clean clusters. While it may not be possible to make a one-size-fits-all classification of these taxa, we do find that taxa that exhibit more generalized feeding strategies (i.e., frugivorous) also appear similar to Anason. Interestingly, the small bodied nocturnal Aotus also appears similar to Alouatta in dental and cranial form. This similarity may be a result of a convergence in cranial form and basicranial flexion (Ross and Ravosa 1993) linked to the visual adaptations of Aotus, further analysis is warranted.

Throughout this research, we have been able to demonstrate that cranial/TMJ and dental shape covary in platyrrhines. This finding suggests that coupling datasets may better elucidate the complex ways in which cranial and dental form interact during feeding.

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References


Cranial and glenoid fossa

Chiropotes satanas

Cercocebus torquatus

Aotus trivirgatus

Saimiri sciureus

Figure 4. PC plots for the upper molar (top) and cranial glenoid fossa (bottom); both plots include an overlay of a consensus phylomorphetic tree to illustrate the relationship between shape and phylogeny.

Table 1. A significant phylomorphetic signal (bolded p-values) was found for all datasets except the mandibular condyle.

Table 2. Results of the regression analyses of shape against the natural log of mandible length with and without phylomorphetic correction. Only cranial and glenoid shape are significantly correlated with mandible length, and only when phylogeny is not incorporated into the analysis. Significance of the regressions was assessed using a permutation test with 9,999 iterations.

Table 3. Results of the 2B-PLS analyses using the PGLS regression residuals of shape regressed on ln mandible length. Bolded values are significant after sequential Bonferroni correction (Rice 1989). All analyses are significant except for the relationships between dental and condylar shape. The significance of this relationship was assessed using a permutation test with 9,999 iterations.