Sacro-caudal musculoskeletal morphological diversity in catarrhines

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Introduction

Tail length in primates varies greatly and is considered an important feature for understanding primate adaptations and phylogeny. Especially in some catarrhine lineages, tails have become extremely reduced and finally completely lost. In order to clarify the evolutionary process and the reason for tail reduction in catarrhines, understanding the correlation between muculoskeletal morphological variation, tail function, and tail length variation in catarrhines must be necessary. Thus, this study applied three different approaches (geometric morphometrics of the sacra, comparative dissection of lumbo-sacro-caudal region, and comparing of the number of proximal caudal vertebrae) and aimed to clarify the musculoskeletal morphological variation in catarrhines with different tail length.

Materials and Methods

In total, the sacra of 221 individuals from 5 museums and research collections (the Primate Research Institute of Kyoto University in Inuyama, Museum für Naturkunde in Berlin, Le Muséum National d'Histoire Naturelle in Paris, the Natural History Museum in London, and the American Museum of Natural History in New York) were used in this study. The sample included 39 different species of Old World monkeys. Both males and females were included. All samples used in this study possessed three sacral vertebrae. In this study, hominoid samples were excluded because the numbers of sacral vertebrae are markedly different between extant apes and Old World monkeys. Only adults with all third molars fully erupted were used as samples.

Methods

In the comparative anatomical study, I performed comparative dissection of both the dorsal and ventral side of the lumbo-sacro-caudal region in 12 individuals of seven species of catarrhines (*Macaca fascicularis*, *M. cyclopis*, *Papio hamadryas*, *M. mulatta*, *M. fuscata*, *M. arctoides*, and *Pan troglodytes*) with different tail length. Before the dissection, the tail lengths of all specimens were measured using a tape measure (Table 1). However, most of the specimens were not intact and their conditions showed wide variation, and other somatometric measurements, including sitting height and body weight, were not available. After the tail length measurements, the specimens described above were dissected. In this study, nine caudal muscles (ventral side: mm. extensor longus, mm. extensor brevis, mm. iliocaudalis, mm. pubocaudalis, and

mm.ischiocaudalis; dorsal side: mm. flexor lateralis, mm. flexor medialis, mm. abductor lateralis, and mm. abductor medialis) were exposed, and the locations of their origin, insertion, and tendonization were observed.

Results

Theses three analyses revealed two important results as follows: 1) sacral morphology and the number of proximal caudal vertebrae are strongly related to tail length, but other phylogenic differences (terrestriality, tail usage, and phylogeny itself) also influence these morphologies. 2) all caudal muscles tended to insert or be tendinous more cranially in shorter-tailed catarrhines, and dorsal extension and abduction seemd to be much important tail function than ventral flexion. These results have implications for reconstructing not only the tail length but also phylogenies and tail function from fossil specimens in the future.

Conclusions

The studies about sacro-caudal skeletal morphology revealed the following important observations: 1) The morphology of the last sacral vertebra was shown to be an important feature reflecting tail length quantitatively in catarrhines with intermediate-length tails. 2) Quantitative tail length estimation is possible in catarrhines with intermediate-length tails. 3) The methods derived by this study require only minimal measurements and are readily applicable to fossil specimens. However, this study also revealed the difficulty in predicting very long or very short tail lengths using only the formulae for catarrhines with intermediate tail lengths. The formulae tend to underestimate RTLs in long-tailed catarrhines and to overestimate RTLs in diminutive-tailed catarrhines. Perhaps other morphological traits (or different combination of traits) that were not used in this study are applicable for tail length variation in those categories. In this study, standard osteometric techniques were employed. However, future studies might be encouraged to adopt finergrained methods (e.g. 3-D digitizer or photogrammetry) or more detailed analyses of the relationships between the morphology of the proximal caudal vertebrae and tail length.

This study provided four important findings about caudal muscle attachments. 1) All caudal muscles observed in this study tended to insert or become tendinous more 445 cranially with tail reduction, 2) Extensors are completely lost after *Macaca arctoides* with very-short tail, 3) Pelvocaudal muscles are present regardless of the tail length, though their major function changes from tail movement to maintenance of the pelvic viscera with tail reduction, and 4) Dorsal caudal muscles become reduced but are

never lost even as the tail becomes shorter. When combined with insights about skeletal morphological variations, the insights obtained in this study will be helpful for understanding the changes of tail function, and eventually the reasons for tail reduction, in catarrhines in the future.