Comparative anatomical note on the origin of the long accessory styliiform cartilage of the Japanese giant flying squirrel, *Petaurista leucogenys*

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Abstract. The anatomy of the wrist of the Japanese giant flying squirrel *Petaurista leucogenys* was investigated, and, on the basis of myological data, a hypothesis was formed concerning the origin of the long accessory styliiform cartilage supporting the flying membrane. The styliiform cartilage in the forelimb of *P. leucogenys* lies along the ulnar side; its length is almost equivalent to that of the radioulna. During the present study, it was recognised that both the *flexor carpi ulnaris* muscle and the flexor retinaculum attach to the proximal end of the styliiform cartilage. The results of our anatomical studies suggest that in *P. leucogenys*, the styliiform cartilage is essentially homologous to the pisiform bone in other mammals and is presumed to have originally been derived from a sesamoid bone.

Key words: Japanese giant flying squirrel, *Petaurista leucogenys*, pisiform bone, sesamoid bone, styliiform cartilage.

Many studies have been made of the anatomy and morphology of flying squirrels, some of which have examined phylogenetic relationships and physiology (e.g. Grassé and Dekeyser 1955; Gupta 1966; Johnson-Murray 1977; Ando and Shiraishi 1984; Thorington Jr. 1984; Thorington Jr. et al. 1998). The origin of the structure that supports the flying membrane, however remains to be discussed. According to anatomical descriptions concerned with the gliding mechanism of flying squirrels, a specific long accessory styliiform cartilage (hereafter referred to as SC) in the forelimb plays an important role in supporting the flying membrane during leaping and gliding. In particular, Thorington Jr. et al. (1998) proposed that the SCs of flying squirrels serve to reduce induced drag during gliding, in much the same way that winglets work on an aircraft. Previously, the origins of the SC have only been discussed intuitively by Gupta (1966) and Thorington Jr. et al. (1998), therefore, in order to clarify the origins of the SC, we have undertaken anatomical studies of the bones and muscles of the Japanese giant flying squirrel *Petaurista leucogenys*.

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Materials and methods

An approximately six-month-old Japanese giant flying squirrel was obtained from a pet shop in Japan. Its forelimb skeleton was examined using X-ray photographs, and after fixation with 50% ethanol, the morphological details of the forelimb were studied macroscopically.

Results and discussion

In the forelimb of *P. leucogenys*, the SC is located along the ulnar side; its length is almost equivalent to that of the radioulna (Fig. 1). The wrist of this species has nine carpal bones: the trapezium bone (os carpale I), the trapezoid bone (os carpale II), the capitate bone (os carpale III), the hamate bone (os carpale IV), the triquetral bone (os carpi ulnare), the lunate bone (os carpi intermedium), the central bone (os carpi centrale), the scaphoid bone (os carpi intermedioradiale), and the radial sesamoid bone (os sesamoideum), in addition to the SC (Fig. 2a and b). In the present study, we have used the names for each bone as described by Langman and Woerdeman (1978) and the Japanese Association of Veterinary Anatomists (1996). The SC shares its articulation with the head of the fifth metacarpal and the triquetral bone (Fig. 2b). Such articulation is likely to provide significant mobility to the SC, and may form a particular structure such as a flail joint. The flexible movement of the SC in all directions may be useful in smoothly moving the flying membrane whilst gliding. The *flexor carpi ulnaris* muscle was found to be divided and inserted on the proximal end of the SC and the ulnar side of the triquetral bone (Fig. 3). Since no muscle attaches to the SC except the *flexor carpi ulnaris* muscle, it is suggested that *P. leucogenys* can not move the SC independently. In addition, the flexor retinaculum (transverse carpal ligament) was connected to the lateral side of the SC by a ligament (Fig. 3), as is also the case in *Glaucomys volans* (see Gupta 1966). The anatomical features of the SC in the wrist of *P. leucogenys* were found to be essentially identical to those found in *Pteromys volans* (Oshida et al., unpublished data).

Fig. 1. X-ray photograph of the right forelimb of *Petaurista leucogenys* (dorsal side). SC indicates the styliform cartilage.

Fig. 2. Dorsal views of the carpal bones and the styliform cartilage of the right wrist of *Petaurista leucogenys*, a: photograph, b: drawing. SC indicates the styliform cartilage, and I, II, III, IV, and V indicate the metacarpi (os metacarpale). The asterisk indicates a bone that is concealed superficially.

The SC is a unique and distinctive characteristic of flying squirrels, yet its origins have not been satisfactorily explained. Although Gupta (1966) suggested that the SC might be derived from an ulnar sesamoid bone, there was no evidence to support his hypothesis. Then, Thorington Jr. et al. (1998) claimed, on the basis of comparative anatomical analyses between flying and tree squirrels, that the SC was likely to be derived from a hypothenar cartilage, but they did not describe the muscle or ligament attachment to the hypothenar cartilage, and we do not share their opinion. Since the *flexor carpi ulnaris* muscle and the flexor retinaculum attach to the pisiform bone in various mammalian species (Evans and deLahunta 1973; Langman and Woerdeman 1978; Katoh 1979; Ueba 1996), it is suggested that the SC is in fact homologous to the pisiform bone. In the specimen used for the present study, with the exception of the SC, there was no carpal bone which corresponded to the pisiform bone of other mammals. Furthermore, it is also known that the pisiform bone is derived from the sesamoid bone (Katoh 1979; Ueba 1996). The special bone, with the surplus finger-like structure, next to the thumb in the wrist of the giant panda *Ailuropoda*

Fig. 3. Palmar view of an anatomized left forelimb of *Petaurista leucogenys*. SC=styliiform cartilage; FCU=flexor carpi ulnaris muscle; FR=flexor retinaculum; L* indicates a ligament connecting the SC with the FR.

melanoleuca has also been described as derived from a radial sesamoid bone (Davis 1964), as has a similar special bone next to the thumb in the red panda *Ailurus fulgens* (Davis 1964; Inaba and Takahashi 1996). Instead of a pisiform bone, *P. leucogenys* has a large radial sesamoid bone in the wrist. Thus the SC in this species seems to be derived from a sesamoid bone, as suggested by Gupta (1966). The sesamoid bone may be more likely, than other bones, to be transformed during the process of mammalian evolution.

Based on the morphological characteristics of the carpal bones, along with the *flexor carpi ulnaris* muscle and the flexor retinaculum, our results suggest that the origin of the styliiform cartilage in *P. leucogenys* is a pisiform bone. It is hoped that we may consolidate this hypothesis, by examining further specimens of *P. leucogenys*.

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