Reasonable classical concepts in human lower limb anatomy from the viewpoint of the primitive persistent sciatic artery and twisting human lower limb

By

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Summary: The main aim of this review is (1) to introduce the two previous studies we published human lower limb anatomy based on the conventional macroscopic anatomical criteria with hazardous recognition of this description, (2) to activate the discussion whether the limb homology exists, and (3) to contribute to future study filling the gap between the gross anatomy and embryology.

One of the topics we discussed was the human persistent sciatic artery. To date, numerous human cases of persistent sciatic artery have been reported in which the anomalous artery was present in the posterior compartment of the thigh alongside the sciatic nerve. As one of the important criteria for assessing the human primitive sciatic artery, its ventral arterial position with respect to the sciatic nerve is reasonable based on the initial positional relationship between ventral arterial and dorsal nervous systems and comparative anatomical findings. We also discuss ways of considering the topography of muscles of the lower limb and their innervations compared to those of the upper limb. We propose a schema of the complex anatomical characteristics of the lower limb based on the vertebrate body plan. According to this reasonable schema, the twisted anatomy of the lower limb can be understood more easily.

These two main ideas discussed in this paper will be useful for further understanding of the anatomy of the lower limb and as a first step for future. We hope that the future study in lower limb will be further developed by both viewpoints of the classical gross anatomy and recent embryology.

Introduction


Although detailed anatomical features of the limbs have been described by the above authors, there are controversies regarding the homology/similarity between upper and lower limbs with regard to the anatomical understanding of the twisting of the lower limbs, the morphological principle of the penetration of nerves into the sacrotuberos ligaments, and pelvic muscles. For example, it is difficult to correlate between the upper and lower limbs because of the twisting and hominization
of the lower limbs as a result of bipedal locomotion. In order to understand the anatomy of the lower limb more clearly, it is useful to consider vertebrate body plan. Our previous papers have contributed to the understanding of the anatomy of the lower limb (Ogoshi et al., 2001; Yoshitomi et al., 2004; Hoshino et al., 2004). Unfortunately, these papers were written in Japanese and remain unknown to gross anatomists and researchers in other relevant fields. Thus, although our papers contain many useful findings and schemas for understanding the complicated anatomy of the lower extremity, anatomical studies and reports have been published without citing our previous studies. Therefore on the basis of important and reliable criteria, we introduce two significant considerations, namely the human primitive sciatic artery and the topographical morphology of the twisted human lower limb as a first step. Recently, Aizawa and Horiguchi (2000) suggested that the limbs might not have a homologue based on their positions and distributions of the cutaneous nerves in rat embryo. In addition, Panchen and Smithson (1990) suggested that the first mesomere of the pelvic fin of Eusthenopteron is the homologue of the second mesomere of the pectoral fin (i.e. Humerus is the homologue of Fibula). Therefore, it might be difficult to compare the limbs correctly without embryological advances. Although we aware the danger of the description based the classical gross anatomical findings, it would be useful as a first step for understanding the limbs completely.

What is the human persistent sciatic artery?

According to some prestigious textbooks on human development (Arey, 1954; Patten, 1968; Moore and Persaud, 1998), the sciatic artery joining from the internal iliac artery, is regarded as the primitive dorsal axial artery in the lower limb bud, whereas the femoral artery, joining from the external iliac artery, is regarded as the ventral axial artery in the proximal (femoral) region of the lower limb bud. Usually, the femoral artery replaces the main arterial trunk throughout the lower limb by joining with the popliteal artery. On the other hand, the sciatic artery is interrupted shortly and distributes mainly to the gluteal muscles as the inferior gluteal artery. Accordingly, an anomalous long artery that branches from the inferior gluteal artery has been customarily considered to be the human persistent sciatic artery among anatomists if this anomalous artery accompanies the sciatic nerve, distributes to the lower part of some femoral flexor muscles or anastomoses to the popliteal artery (Adachi, 1928; Yokoo, 1932; Job, 1933; Finerty, 1947; Mada, 1955; Nakamura and Kasai, 1956; Kubota et al., 1958; Blair and Nandy, 1965; Yoshimura et al., 1988; Ukeshima et al., 1990; Emura et al., 1991; Inoue et al., 1993; Tohno et al., 1993; Sekiya et al., 1997; Kodama, 2000) (Fig. 1). Some of the above authors, without any evidence, regarded this long anomalous artery as the primitive persistent sciatic artery, based on the weak femoral artery.

Kodama (2000) claimed that the knowledge of the anatomical relationships among the primary sciatic artery, sciatic nerve, branches from the femoral artery, and comparative anatomical data are essential for understanding the morphogenesis of the sciatic artery. We agree with his assertion because these arteries cannot be regarded as a truly primitive sciatic artery or secondary anastomosis between the inferior gluteal and popliteal arteries.

In order to clarify the nature of the primitive sciatic artery, we performed comparative anatomical research focusing on the relationship between the sciatic artery and its surrounding structures in several amniotes, including our human case of persistent sciatic artery, on the basis of the vertebrate body plan (Hoshino et al., 2004).
Reasonable anatomical concepts of human lower limb

Our recent dissection of mammals as well as our earlier examination of five mammalian species have revealed no sciatic artery. The inferior gluteal artery consistently branched from the internal iliac artery ventrally to the sacral plexus at its origin, then penetrated the roots of the sacral plexus, and gave off branches to the gluteal muscle group without issuing any long arterial branch along the sciatic nerve.

On the other hand, the iguana (Reptile) and domestic fowl (Avian) consistently showed a primitive sciatic artery as a principal axial artery in the lower limb (Fig. 2). Their femoral arteries were very weak and short branches were distributed only to the femoral extensor muscles. According to Hafferl (1933), the sciatic artery persists throughout life in amphibians, reptiles, and birds as an axial artery in their lower limbs.

Remarkably, our findings show that the course of the primitive sciatic artery in reptiles and birds is ventral to that of the sciatic nerve, while only the inferior gluteal artery, branching from the primitive sciatic artery, penetrates the sacral nerves and is then positioned dorsal to the sciatic nerve and sacral plexus. Although reports on other vertebrates by Hafferl (1933) did not describe the topographical relationship of the truly sciatic artery with the sciatic nerve, our recent additional observations in reptiles support our previous findings. Therefore, the primitive sciatic arteries in reptiles and birds are fundamentally distinct from the human anomalous persistent sciatic artery, especially in their relationship to the somatic nervous system. This constant positional relationship, the ventrally located artery and dorsally located nerve, would be reasonable because of the preservation of their initial positions. The course of somatic peripheral nervous system leaving the spinal cord is dorsal to the other structures, whereas the great arteries are ventral to the vertebral column. Therefore, it is easy to recognize that the primitive sciatic artery courses ventral to the sciatic nerve, joining the popliteal artery ventral to the tibial and common peroneal nerves.

From these comparative anatomical findings, it seems possible to decide whether there is a true primitive sciatic artery or a secondary anastomosis between the inferior to the sciatic nerve and sacral plexus. Although reports on other vertebrates by Hafferl (1933) did not describe the topographical relationship of the truly sciatic artery with the sciatic nerve, our recent additional observations in reptiles support our previous findings. Therefore, the primitive sciatic arteries in reptiles and birds are fundamentally distinct from the human anomalous persistent sciatic artery, especially in their relationship to the somatic nervous system. This constant positional relationship, the ventrally located artery and dorsally located nerve, would be reasonable because of the preservation of their initial positions. The course of somatic peripheral nervous system leaving the spinal cord is dorsal to the other structures, whereas the great arteries are ventral to the vertebral column. Therefore, it is easy to recognize that the primitive sciatic artery courses ventral to the sciatic nerve, joining the popliteal artery ventral to the tibial and common peroneal nerves.

From these comparative anatomical findings, it seems possible to decide whether there is a true primitive sciatic artery or a secondary anastomosis between the inferior
gluteal and popliteal arteries based on the vertebrate body plan (Fig. 3). Hence, the anomalous arterial branch in the posterior thigh should be regarded as a secondary anastomosis between the inferior gluteal and popliteal arteries if the estimated human sciatic artery runs dorsal to the sciatic nerve regardless of the growth of the femoral artery.

Based on these criteria, most reports on the human persistent sciatic artery including our one case are not considered to describe a truly primitive sciatic artery (Fig. 1B), and the artery should be referred to as representing an anomalous anastomosis between the inferior gluteal and popliteal arteries and/or the long descending branch of the inferior gluteal artery.

How should the twisting of the human lower limb be interpreted?

Although several reports have provided rough anatomical comparisons between the upper and lower limbs, there is still no systematic understanding of the topographical comparison between the limbs. In order to make this comparison, positional changes and similarities of the limbs have to be taken into account based on the vertebrate body plan. Since bones tend to be preserved well for long natural period, a number of paleobiological
Reasonable anatomical concepts of human lower limb and comparative osteological changes among the vertebrates, especially from fish to tetrapod mammals exclusive of humans, have been reported (Gegenbaur, 1878; Bolk, 1938; Goodrich, 1958; Romer, 1963; Stark, 1979). As is well known, the femur is twisted and the angle of torsion is given as 14 degrees in an adult Japanese individuals and about 30 degrees in adult European and Americans individuals in textbooks of physical anthropology and orthopedics (Fig. 4A).

Furthermore, it is well known that the parallel segmental innervations of the long axis of the dermatomes and myotomes in the human upper limb are well preserved, whereas those in the lower limb have been observed to be twisted. The corresponding twist can also be seen in the hip ligaments (Fig. 4B–C). If this twist of the hip joint were to become straight, the tension of the hip joint would be relaxed.

In an excellent description of the peripheral nerves of the lower limb, Aizawa (1992) classified human femoral nerve branches into three layers, and provided an excellent schema regarding the rotation of the femoral nerve. Although the twisting lower limb has thus been disclosed fragmentary, the anatomical representation between the muscles and nerves on the twist in entire lower limb has never attempted until our report (Ogoshi et al., 2001). After our publication, Fukazawa et al. (2006, 2007) investigated whether the twist of the branching positions of the muscular branches from the sciatic nerve actually exists.

In order to understand the correspondences and topographical changes in the upper limbs, it is necessary to know their primitive and initial positions. The primitive and initial positions of the limbs are indicated by the limb roots before twisting as seen in the limb plexuses (Fig. 5).

Characteristics of the vertebrate body plan such as bilateral symmetry, dorso-ventral division, segmentation, and cranio-caudal axis, are preserved the entire upper limb. For example, the ventral (flexor) muscles are in-
nervated by the ventral division of the brachial plexus, whereas the dorsal (extensor) muscle is innervated by the dorsal division. In addition, the proximal muscles are innervated by the proximal layer of or the cranial branch originating from the brachial plexus, whereas the distal muscles are innervated by the distal and caudal branches. Consequently, the anatomical relationships between the muscles and their innervations can be easily recognized.

Although the characteristics seen clearly in the upper limb are not preserved in the lower limb and are rather complex in their present positions, the relationship between lower limb muscles and their innervations seems to indicate preservation of their initial positions, as a landmark for the dorso-ventral division, segmentation, and proximo-distal axis. Based on the body plan, we categorized the anatomical relationship between lower limb muscles and their innervations as shown in Table 1.

On the basis of these anatomical relationships among muscles, their innervating nerves, and the distribution area of the cutaneous nerves, we propose a systematic schema of the twisting of the lower limb (Fig. 6). Interestingly, the distortion depicted in this proposed schema corresponds to the other twisted structures such as bone, seen in the torsion angle of the femur, the hip ligaments, the rotation of the femoral nerve by Aizawa (1992), the dermatome, and the myotome. Although we have provisionally classified the lower limb muscles into five muscle groups in the present paper, in future we will need to compare this schema with five ventral and dorsal upper limb muscle group of the upper limb advocated by Sato (1977) and Kato and Sato (1978) for further understanding.

Conclusion

In this review, we introduce two unknown papers written in Japanese and by our past students. Both papers present reasonable and understandable concepts for the study of the anatomy of the lower limb because they are based on the vertebrate body plan. We hope that the ideas presented in these two papers will be useful as a first step in future anatomical research for discussing accurate relationship between the limbs and filling the gap between the classical anatomy and embryology.

| Table 1. Classification of the muscles and their innervations in the lower limb |
|-------------------------------|-------------------|-----------------|-----------------|
| **Division**                  | **Nerve**         | **Innervating muscles** | **Muscle position** |
| (Proximal lower limb girdle muscles) |                  |                    |                  |
| Ventral (vent.-intermed.)     | Branches to Iliopsoas | Psoas (Ps)        | intrapelvis     |
| Intermediate (vent.-dor.)     | Branch to iliacus  | Illiacus (IL)     | intrapelvis     |
| Dorsal                        | Branches to Quadratus lumborum | Quadratus lumborum(QL) | extrapelvis     |
|                               |                   |                   |                  |
| (Distal lower limb girdle muscles) |                  |                    |                  |
| Ventral                       | Branches to Obturator internus (Oi), Gemellus (Ge), and Quadratus femoris (Qf) | Obturator internus (Oi), Gemellus superior and inferior (GS), and Quadratus femoris (Qf) | intra- and extra-pelvis |
| Dorsal                        | Branch to Piriformis | Piriformis (Pr)   | extra-pelvis    |
|                               | Superior gluteal nerve (Gs) | Gluteus maximus (Glu-s) | intra- and extra-pelvis |
|                               | Inferior gluteal nerve (Gi) | Gluteus medius (Glu-m) and minimus (Glun-d), and Tensor fasciae latae (TF) | extra-pelvis      |
|                               |                   |                   |                  |
| (Femoral muscles)             |                   |                    |                  |
| Ventral                       | Obturator nerve (O) | Femoral Adductor muscles (Fa) | Medial thigh |
|                              | Tibial nerve (T)  | Femoral flexor muscles (Ff): long head of biceps (BI), Semitendinosus (SS), and Semimembranosus (SM) | Posterior thigh |
| Dorsal                        | Femoral nerve (F) | Femoral extensor muscles (Fe): short head of biceps (Bb) | Anterior thigh |
|                              | Common peroneal nerve (P) |                       | Posterior thigh |
| (Leg muscles)                 |                   |                    |                  |
| Ventral                       | Tibial nerve (T)  | Leg flexor muscles(Cf) | Posterior leg   |
| Dorsal                        | Superficial peroneal nerve (Ps) | Peroneus muscle (Cp) | lateral leg     |
|                              | Deep peroneal nerve (Pp) | Leg extensor muscles (Ce) | Anterior leg    |
| (Foot muscles)                |                   |                    |                  |
| Ventral                       | Plantar nerve from Tibial (T) | Plantar foot muscles | Plantar foot    |
| Dorsal                        | Deep peroneal nerve (Pp) | Dorsal foot muscles | Dorsal foot     |
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