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Why Does Man Have a Quadratus Plantae? A Review of Its Comparative Anatomy

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Abstract Quadratus plantae is a muscle in the sole of the foot, typically originating from the calcaneus and inserting into the posterolateral surface of the tendons of flexor digitorum longus. It is implicated in heel pain, claw toe deformity and diabetic polyneuropathy. Phylogenetic considerations suggest that quadratus plantae is getting bulkier, implying its significance in human locomotion. Is it simply an accessory flexor that brings the line of pull of flexor digitorum longus in line with the long axis of the foot, as its name would suggest? We cite evidence from electromyographic studies that suggest it actually acts as a primary toe flexor in voluntary movements, being preferentially recruited over flexor digitorum longus. From comparative anatomical considerations it also seems likely that quadratus plantae is an intrinsic evertor of the foot. Eversion is an important evolutionary asset, especially in erect bipedalism. Human electromyographic experiments have yet to confirm this. However, they do suggest that quadratus plantae functions to resist extension of the toes during the stance phase of locomotion, which serves to increase the stability of the foot. Future electromyographic experiments may provide more information on the role of quadratus plantae in human locomotor evolution and in foot eversion in particular.

The quadratus plantae muscle was first named *massa carnae* by Jacque DuBois, better known by his latinized name of Jacobus Sylvius. Anatomists later named the muscle *caro plantae pedis*, then *caro quadrato*, and then quadratus plantae. Even though the term flexor accessorius was adopted as an alternative to quadratus plantae by the Nomina Anatomica Parisiensia in 1955, the most recent Terminologia Anatomica from 1998 still uses quadratus plantae as the more accepted form (1,2).

Quadratus plantae is a muscle that is commonly present in mammals, including some members of the orders Monotremata, Marsupiala, Edentata, Rodentia, Carnivora, Tubulidentata, and Primates (3). There is no analogous muscle in the hand. In man, this muscle arises by two heads; its smaller lateral head, which is present in other mammals, arises from the lateral border of the plantar surface of the calcaneus. In fact, the mammalian calcaneus has developed a trochlear process to provide the origin for this head of quadratus plantae as well as acting as a supporting shelf for the peroneal tendons (4). The large medial head arises from the medial (concave) surface of the calcaneus and is unique to man (3). In man, the two heads unite at an acute angle and end in a flattened band that inserts into the posterior surface of the tendons of the flexor digitorum longus (Fig. 1). The long plantar ligament separates the two heads from each other. It was originally thought that the fibers of the quadratus plantae send slips to those tendons of flexor digitorum longus that pass to digits two to five in the foot, but it is now known that there is much variability in this pattern (5).

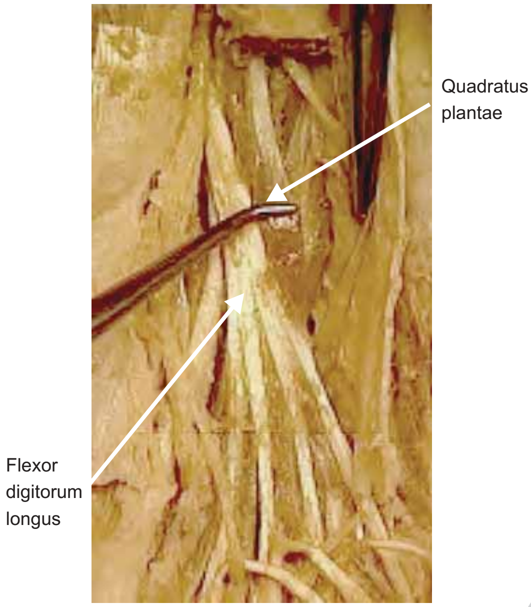

Figure 1. Quadratus plantae in humans.

Developmental Aspects

For descriptive purposes, the quadratus plantae is said to belong to the second layer of the muscles in the foot but is in fact not related to any of the four layers. Lewis (6) tried to correlate the existence of the foot muscles with that of the calf muscles, but with no success. However, the lateral head can be regarded as having descended from the deep calf layer in the earlier mammals, whilst the medial head is a more recent development confined to man.

The digital flexor tendons into which the quadratus plantae is inserted in the primate foot are derived from the tendons of the flexor digitorum longus and the flexor hallucis longus. It was postulated that both the flexor tibialis and fibularis gave a tendon to each of the five digits in the primitive prosimians, and that the varying muscular patterns that resulted were from a loss of one or the other member of these pairs of tendons in a haphazard manner (3). However, it has more recently been suggested that in primitive mammals and in the embryonic condition of the more specialized mammals (including man) both flexor muscle tendons merge into a common tendon plate that divides distally into the digital flexor tendons (4). The varying definitive patterns in different species are due to a different ontogenic splitting of this common plate (3). In man, the flexor tibialis forms the superficial layer and passes laterally to form digital tendon five and part of tendons two to four. It may also contribute a small part to the hallucial tendon. The deep layer is made up of the flexor fibularis which forms most, or all, of the hallucial tendon and gives a contribution to the other tendons. The medial head of quadratus plantae constitutes the remainder of the deep layer and also gives contributions to the digital tendons. It has been proposed that this head represents the deep head of the flexor digitorum brevis (7).

The medial head of the quadratus plantae arises far back from the calcaneus and flanks the flexor hallucis longus (flexor fibularis) as it enters the sole. It seems likely that it is thus a part of the flexor hallucis longus that has "descended" into the sole, especially as a remnant of its descent, the quadratus plantae longus, is sometimes found originating close to that of the flexor hallucis longus on the fibula (7). Further evidence for this "descent" theory comes from human embryonic studies which show that, during ontogenesis, the origin of quadratus plantae is initially in the malleolar canal next to the lateral plantar nerve which innervates it, and sometimes even from the flexor hallucis longus tendon, and then progresses onto the calcaneus during later embryogenesis (8). However, there is no evidence that this is the medial head. Wood Jones (7) recorded the presence of a quadratus plantae longus in up to 8% of adult human lower limbs and it has even been implicated clinically in tarsal tunnel syndrome (9,10). The lateral head of the quadratus plantae lies between the flexors tibialis and fibularis tendons (flexor digitorum longus and flexor hallucis longus, respectively) and terminates on the superficial surface of the flexor fibularis tendon, thus contributing to the digital tendons. This is the same relationship it has as the quadratus plantae of other primates (3).

Anatomical Variations

A number of studies into the existence of quadratus plantae have highlighted some important variations with regards to its functional attributes (2,3). Investigations have shown that in some cases this muscle may be reduced in size. In other cases the heads may be duplicated in size or divided into superficial and deep parts, or have high origin from the lower third of the fibula. The medial head may contribute to digital tendon two, tendons two and three or tendons two to four (most common). It may partly attach to the lateral border of the flexor digitorum longus tendon, especially if the lateral head is absent. The lateral head may cross superficial to the medial head, as is the most common arrangement, or it may merge with the lateral border of the medial head, or absent.

Classic Role of Quadratus Plantae

Originally it was postulated that the quadratus plantae assisted the flexor digitorum longus in the flexion of the lateral four toes (hence its name). This is supported by pathologies such as clawing of the lesser toes from late contracture of the quadratus plantae following calcaneal fractures (11). This view was later refined to state that the quadratus plantae flexes the toes when the flexor digitorum longus, in the plantarflexed foot, is unable to shorten further (2). Electromyographic studies by Reeser (12) confirmed this view, but also found that quadratus plantae actually acts as a primary toe flexor in voluntary movements, being preferentially recruited over the flexor digitorum longus.

Investigations by Kaplan (2) have shown that the flexor digitorum longus has an oblique pull in tension. The quadratus plantae was also originally said to straighten this pull and bring the toes back in line with the axis of the foot. In this action it is analogous to the extensor digitorum brevis, which corrects the obliquity of the toes when they are extended by extensor digitorum longus. Wood Jones (7) comments that it would be inefficient to employ an actively contracting muscle to pull upon a tendon that is always running in a direction that is in need of correction. A careful consideration of the anatomy also discredits this classic role attributed to the quadratus plantae. The quadratus plantae inserts into the flexor digitorum longus much more proximal than the metatarsophalangeal (MTP) joints. The flexor digitorum longus tendons run over the MTP joints in closed fibrous tunnels, which direct the tendons such that they lie in the line of rotation of the interphalangeal joints. Thus any shearing torque that quadratus plantae could apply is minimized (2).

Existence of Quadratus Plantae in Other Species

Investigating its existence in other species has given further insight into the functional role of quadratus plantae. In bovine, porcine, and ovine species there is no quadratus plantae around the structures surrounding their hooves. Only ligamentous and tough tendinous structures are seen here to reduce the weight and decrease unnecessary energy expenditure during activity. However, the flexor digitorum longus and other digital flexors are present (13). In these domestic species the bones of the lower extremities develop in different orientations and their toes are not deviated laterally, hence reducing the need for quadratus plantae. Equine species possess the flexor digitorum superficialis, profundus, and longus, but no flexor hallucis longus nor quadratus plantae (13). However, there is an accessory ligament of the flexor digitorum profundus. Hence we postulate that the flexor digitorum profundus and its accessory may play the role of quadratus plantae or be its evolutionary equivalent, but there are no veterinary studies that comment on this.

In canine and feline species (Figs. 2 and 3), the quadratus plantae is present in the hind paw but is said to be a highly insignificant muscle that unites with the tendon of the flexor digitorum (13,14).

In the canine species, the quadratus plantae has been described to be the tarsal head of

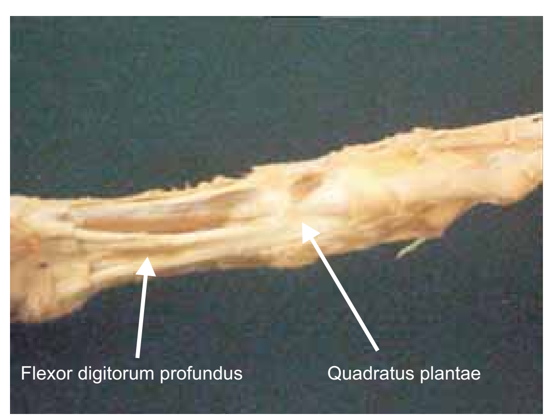

Figure 2. Quadratus plantae found in the hindfoot of canine species. Specimen courtesy of the Royal Veterinary College, London, UK.

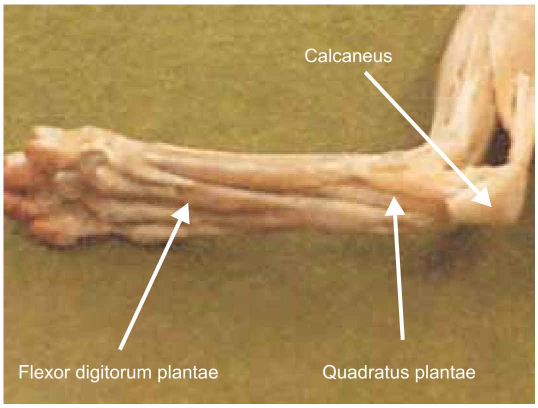

Figure 3. Quadratus plantae found in the hindfoot of feline species. Specimen courtesy of the Royal Veterinary College, London, UK.

the flexor digitorum profundus. This supports the notion that in equine species the accessory ligament of the flexor digitorum profundus may be the precursor of the quadratus plantae (15).

The absence of the quadratus plantae in lower primates is pronounced in prosimian species, such as the tree-dwelling Madagascan lemur (16). Studies have shown that the lack of quadratus plantae in these species can be explained by the need for their feet to work synergistically with their hands as grasping tools when swinging from branch to branch. This would explain why in the monkey foot, adductor hallucis and other thenar muscles are well developed, making opposition between the hallux and other toes strong. In contrast, human feet do not have an opposable hallux or bulky thenar muscles, as they are better adapted to bipedal locomotion rather than grasping objects or branches (17-19).

However, a contradictory view is held by Hicks (20) who provides evidence that the grasping action of the toes for gripping the ground during locomotion is brought about by the plantar aponeurosis rather than the muscles of the foot. During weight bearing, the arch of the foot is said to flatten. The plantar aponeurosis then acts to restrict excessive flattening and thus contracts to maintain the high arch. This results in flexion of the toes and consequent gripping. This action is known as the reverse windlass mechanism (21,20) and is independent of muscle action.

Role of Quadratus Plantae in Locomotion

In primates such as the New World Monkey, it is apparent that the quadratus plantae is present as an intrinsic foot muscle, gaining origin from a well-defined trochlear process on the calcaneus (4). They have a mobile foot that is easily orientated for a variety of activities from grasping to walking. Although apes and chimpanzees show the existence of a well-defined trochlear process, the chimpanzees seldom have a quadratus plantae (4). Chimpanzees are quadrupedal in locomotor posture, although terrestrial bipedalism is evident in chimpanzees when carrying objects, standing to obtain a better view, and engaging in play. Moreover, in young chimpanzees and some adults it is evident that the foot is inverted slightly when the second to fifth toes are flexed. This may be due to an underdeveloped quadratus plantae. It has been found that inversion occurs when the long flexors flex the toes in species with free movement of their subtalar joints (2).

Jouffroy (17) has suggested that the absence of the quadratus plantae in prosimians is related to their laterally directed grasping by a predominant fourth digital axis, resulting in inversion. This inverted foot position seems to be necessary for their habitual lifestyle. Eversion became more important in cursorial monkeys to function in erect bipedalism, leading to the development of the quadratus plantae, and more importantly its medial (3). Kaplan (2) dissected two congenital club feet of a premature stillborn infant and found the quadratus plantae absent in both feet, further supporting the role of quadratus plantae in eversion.

The quadratus plantae may act simultaneously with the peroneus longus, flexor hallucis longus, and flexor digitorum longus, to suppress inversion of and thus stabilize the subtalar joint in the final push-off in the last stage of walking (2). However, electromyographic studies by Reeser (12), using indwelling electrodes and an advanced telemetry system, have failed to confirm this and found no recruitment of quadratus plantae during eversion. These electromyographic studies do however support the view of Wood Jones (7) that quadratus plantae functions to resist extension of the toes during the stance phase of gait, which serves to increase the stability of the foot. As the extensors then pull on the leg from the fixed and flexed toes, quadratus plantae acts to stabilize the tendons of flexor digitorum longus and flexor hallucis longus, thus allowing unopposed action of the leg extensors in pulling the body over the foot (7).

It has also been postulated that the quadratus plantae helps maintain the medial and lateral longitudinal arches in the foot as it inserts on to flexor hallucis longus and flexor digitorum longus respectively (5).

Clinical Significance

The quadratus plantae lies deep within the posterior compartment of the hindfoot, with a communication to the posterior compartment of the leg through the retinaculum behind the medial malleolus, following the neurovascular and tendinous structures. Contracture of the quadratus plantae within this calcaneal compartment results in clawing of the lesser toes (digits two to five) as a late sequela of calcaneal fractures (11). The muscle is also subject to necrosis from untreated central plantar space abscesses in the diabetic foot.

The quadratus plantae has also been implicated in the pathogenesis of heel pain by a number of authors (22). The lateral plantar nerve is of mixed type, consisting of sensory fibers for the calcaneal periosteum, plantar ligament, and medial head of quadratus plantae, and motor fibers to quadratus plantae. This means that when heel pain is initiated due to the entrapment of the lateral plantar nerve between the two heads, pain is felt over the calcaneus and the quadratus plantae muscle function is impaired (22). In a study concerning the lateral plantar nerve and heel pain, it was found that in fetal feet the first branch of this nerve penetrates the insertion of quadratus plantae. However, in adult feet this nerve always sends fibers to the periosteum around the medial process of the calcaneal tuberosity and long plantar ligament (22). Thus, it can be deduced that there may be redistribution in the nerve supply to this muscle during the development.

In a case study by Murphy (23), repeated myofascial therapy to quadratus plantae over a 4-month period, in combination with manipulation therapy to the ankle and intertarsal joints, brought dramatic improvement in a patient's symptoms and signs of diabetic polyneuropathy. From this study, it has been suggested that joint and/or myofascial dysfunction may be involved in the susceptibility to this condition and thus treatment may improve the neuropathy. The author proposes mechanisms by which this relationship may exist, including impaired afferent stimulation from the intertarsal joint receptors due to the loss of joint play and disturbed axoplasmic flow along the nerves affected by the neuropathy.

Conclusions

Phylogenetic evidence for the presence of quadratus plantae in humans is not found due to its abnormal development and morphology. A doubled-headed quadratus plantae is unique to man (6). The presence of quadratus plantae is subject to wide variation in man, and the human muscle is a composite structure where the lateral head is homologous to that in other mammals and the medial head is unique to man. Its role in realigning the pull generated by flexor digitorum longus can be supported by its site of insertion and position of the ankle joint but this effect is not nearly as important as had previously been advocated. Its role in suppressing inversion of the subtalar joint seems most plausible when the evolutionary standpoint is taken, yet electromyographic studies do not support this. Reeser (12) concluded that the main role of the quadratus plantae, together with the flexor abductor brevis, was to support flexor digitorum longus, and it had little, if any, role in eversion.

Studies by Hicks (20,24) have suggested that the plantar aponeurosis is most important for active flexion of the toes. This reverse windlass mechanism postulates that flexion of the toes can be achieved without contraction of flexor digitorum longus, making the role of quadratus plantae as a support of flexor digitorum longus seem even less important.

In summary, there is much conflicting evidence regarding the role of quadratus plantae. Further work is required to resolve this issue, but at present this muscle remains an enigma.

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