Annals of Anatomy 216 (2018) 9–22

Contents lists available at ScienceDirect

Annals of Anatomy

journal homepage: www.elsevier.com/locate/aanat

RESEARCH ARTICLE

Morphological characteristics and variations of the human quadratus plantae muscle

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ARTICLE INFO

Article history:
Received 23 April 2017
Received in revised form 2 September 2017
Accepted 23 October 2017

Keywords:
Quadratus plantae
Flexor digitorum accessorius
Flexor digitorum accessorius longus
Peroneocalcaneus internus
Tarsal tunnel syndrome
Accessory muscles
Foot deformities

ABSTRACT

The quadratus plantae (QP) is a highly variable structure. A number of partly inexact descriptions of this entity have been provided in textbooks of anatomy. Although several authors have examined the QP, its exact site of origin and type of insertion have hitherto not been specified. The aim of this study has been to provide detailed qualitative and quantitative data about the number of heads, points of origin, and type of insertion of the QP. The QP in both feet of 50 formalin-fixed specimens of body donors (25 men and women) were analyzed by gross anatomical dissection. It was composed of one (34%), two (57%) or three heads (9%). The latter condition was observed only in men. The lateral head was absent in 31 feet, and the medial head only in one right foot of a man. The medial head arose, amongst others, in 100% of the examined cases from the medial calcaneal surface, in 93% from the long plantar ligament and in 80% from the plantar calcaneocuboid ligament. The lateral head arose, amongst others, from the long plantar ligament in 90%, and from the lateral process of the calcaneal tuberosity in 64% of the examined feet. The type of insertion was always a mixture of at least two of three types; i.e. muscular (84%), tendinous (89%) and aponeurotic (45%). As additional findings, the flexor digitorum accessorius longus (FDAL) and the peroneocalcaneus internus (PCI) were observed in 12% of all individuals and in 20% of men. The present investigation revealed that the QP may be classified according to the number of heads, but no classification can be given for its points of origin or type of insertion. The present data are mandatory for anatomical and surgical practice and will hopefully lead to further imaging and biomechanical studies.

1. Introduction

The quadratus plantae (QP) was first referred to as “moles carnea” by Jacobus Sylvius, one of the teachers of Andreas Vesalius (Sylvius, 1560). It was then named “massae carnae (Jacobi Sylvii)”, which was later modified to “caro plantae pedis quadrata” and finally to “caro quadrata” (Kaplan, 1959; Wood Jones, 1949). According to Wood Jones, the name “flexor digitorum accessorius” given by Winslow was a well-accepted term until the Basler Nomina Anatomica (BNA) of 1895 renamed it the “quadratus plantae”. Since the Birmingham Revision in 1933, both names – quadratus plantae and flexor digitorum accessorius – are commonly used (Wood Jones, 1949). This also holds true for the currently used International Anatomical Terminology (Federative Committee on Anatomical Terminology, 1998). Previous anatomists did not regard the QP as an independent muscle, but as the plantar head of the flexor digitorum longus (FDL) (Henle, 1871; Hyrtl, 1870).

The QP is an intrinsic muscle in the sole of the foot, with no equivalent in the hand (Wood Jones, 1949). It is said to arise with two heads from the calcaneus and insert into the tendon(s) of the FDL (Palastanga and Soames, 2012; Salmons, 1995; Testut, 1884; Weidenreich, 1922). However, this description is inadequate because the QP originates in a very variable manner (Hur et al., 2011; Lewis, 1962; Macalister, 1871; Turner, 1865; Weidenreich, 1922; Winckler and Gianoli, 1955; Wood, 1868). Its diversity concerns the number of heads and their sites of origin (Athavale et al., 2012; Gies, 1868; Hur et al., 2011; Nováková and Korbelár, 1976; Testut, 1884), as well as its manner of insertion (Lewis, 1962; Plaass et al., 2013; Winckler and Gianoli, 1955). As shown recently, the QP plays a major role in the formation of the chiasma plantare and the five long flexor tendons (Pretterklieber, 2017). Despite the quotations just mentioned an exact description of the QP including an exact photodocumentation is still lacking.

The derivation of the QP is not clear, although evidence has shown that it is a part of the flexor mass of the leg which is generated during embryonic development (Nováková and Korbelár, 1976). The QP is commonly present in many mammals, but these only possess the lateral head of the human QP (Lewis, 1962;

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https://doi.org/10.1016/j.aanat.2017.10.006
0940-9602/

Weidenreich, 1922; Wood Jones, 1949). The precise function of the QP remains unexplained; a variety of opinions and arguments have been proposed (Kaplan, 1959; Kelly et al., 2014, 2012, 2015; Schroeder et al., 2014; Weidenreich, 1922).

The flexor digitorum accessorius longus (FDAL) is seen as a part of the QP. Its occurrence varies from 2% to 22% (Al-Himdani et al., 2013; Canter and Siesel, 1997; Cheung et al., 1999; Del Sol et al., 2000; Hur et al., 2014; Lewis, 1962; Nathan et al., 1975; Peterson et al., 1995; Turner, 1865; Wood, 1868). It arises mainly from the fibula, the tibia, the deep fascia of the leg, the flexor hallucis longus (FHL), or the FDL, and inserts into the regular QP or the tendon of the FDL (Gies, 1868; Henle, 1871; Hyrtl, 1870; Macalister, 1871; Turner, 1865; Wood, 1868). Another muscle around the medial malleolus, the peroneocalcaneus internus (PCI) – first described by Macalister (1871) – is a rare entity and was found in a mere 1% (Mellado et al., 1997). It originates from the lower third of the fibula and inserts into the medial or plantar aspect of the calcaneus (Al-Himdani et al., 2013; Lambert et al., 2011; Macalister, 1871; Mellado et al., 1997).

The large majority of anatomy textbooks lack any description of these additional muscles (Drenckhahn, 1994; Hollinshead, 1951; Palastanga and Soames, 2012; Salmons, 1995), although they might be involved in the etiology of the tarsal tunnel syndrome (Al-Himdani et al., 2013; Duran-Stanton and Bui-Mansfield, 2010; Kinoshita et al., 2003; Mellado et al., 1997; Saar and Bell, 2011; Wittmayer and Freed, 2007) or the flexor hallucis syndrome (Eberle et al., 2002), and may even play a role in the pathogenesis of the congenital clubfoot (Abo El-Fadl, 2013; Dobbs et al., 2005; Grogono and Jowsey, 1965).

In the present study the number of heads and their possible points of origin were analyzed. As there are no quantitative data concerning the points of origin of the QP, absolute and relative frequencies of their occurrence were calculated. Differences in terms of sex and side as well as intra-individual symmetry were given attention. As a novelty, the type of insertion (i.e. muscular, tendinous or aponeurotic) into the five long flexor tendons was examined in detail. In addition, the FDAL and the PCI were registered as a secondary finding.

A simplified functional tensile test was performed for the FDL and the QP and the results discussed against previous biomechanical aspects. Phylogenetic and ontogenetic aspects are discussed to explain the variability and derivation of the QP. Exact knowledge of the variability of the QP is important for further imaging and biomechanical studies. Furthermore it may be important for surgeons treating patients with pathological conditions in the feet. The QP may be lacerated in trauma of the hindfoot, e.g. calcaneal fracture, or may cross the operation field used for the treatment of abscesses in the diabetic foot, congenital clubfoot or metatarsus adductus.

2. Materials and methods

2.1. Sample

Both feet of 50 specimens of Caucasian individuals (25 men and 25 women) fixed by perfusion and subsequent immersion with a mixture of 1,6% formol and 5% phenol were dissected in order to determine the number of heads forming the QP and the points of their origin. The same sample was the basis of a recently published study on the formation of the chiasma plantare (Pretterklieber, 2017). All of these individuals had donated their bodies to medical education and research at the Center of Anatomy and Cell Biology, Medical University of Vienna. In addition to the informed consent of the deceased individuals, the study was approved by the ethics committee of the Medical University of Vienna (approval number 1249/2014). None of the dissected feet had shown any signs of previous surgery or deformity in the lower leg or foot.

2.2. Dissection and analysis

The skin and subcutaneous tissue were removed from the plantar region of each foot as well as the lateral and medial ankle regions. The plantar aponeurosis was released and flapped proximally. The crural fascia in the ankle was removed. The tendons of the deep flexors of the toes, together with the lumbricals, the superficial plantar muscles, and the plantar vessels and nerves were dissected carefully. The flexor digitorum brevis, the abductor hallucis and the abductor digiti minimi were detached from their origin at the calcaneus. Vessels and nerves were removed in the majority of specimens. The QP and the formation of the chiasma plantare were exposed. After the identification of sex and side, the number of heads composing the QP were determined. All points of origin of the QP were specified. If an accessory tendon was found to insert into the QP, the chiasma plantare, or the calcaneus, its origin was additionally determined.

Finally, the entire chiasma plantare was removed from 44 specimens, detaching the QP from its different points of origin, cutting off the tendons of the FHL and the FDL below their muscle bellies, and releasing all five flexor tendons from their attachment at the distal phalanges of the toes and the lumbricals from the dorsal digital expansion. In these 44 cases, the insertions of the QP in the chiasma plantare and the five long flexor tendons were analyzed with regard to the type of insertion; i.e. muscular, tendinous and/or aponeurotic.

Along with this careful stratigraphic dissection and documentation, photographs were taken with a digital reflex camera (Canon OES 5D Mark I and II, Canon Inc., Tokyo, Japan). Cropping, scaling, and labeling of the pictures were performed with a standard professional image editing program (Adobe Photoshop CS6 extended Version 13.0; Adobe Systems Inc., San José/CA, USA).

Microsoft Office, Excel 2013 (Microsoft Corporation, Redmond, USA), was used for descriptive analysis. In accordance with common practice for qualitative data, statistical analysis was confined to the calculation of frequencies.

2.3. Functional analysis

To illustrate the possible function of the two heads of the QP, a simple tensile test was performed. Therefore, two formalin-fixed ankle joint specimens were anchored in a bench vice on a table. The direction of pull of the FDL as well as the medial and the lateral head of the QP were demonstrated by colored strings fixed on the toes. Tendon sheaths and the flexor retinaculum were imitated by wire slings. As it was intended to be a simplified test, the connection with the FHL in the chiasma plantare, and variations in manner of insertion of the QP were not taken into consideration.

3. Results

3.1. Number of heads

As shown in Fig. 1, a QP with two heads was the most common type (Fig. 2a). It was present in 57 feet (57%), with no remarkable difference between left and right feet, but occurred somewhat more frequently in women (32 feet or 56%). The one-headed QP (Figs. 1, 2b) was observed in one third of the feet, equally on the left and the right side, and with no striking differences between men and women. The nine cases with three heads (Fig. 2c) were observed exclusively in men, with no differences between the sides. In summary, 25 of the male feet (50%) had a QP consisting of two heads, 16 (32%) of one head, and nine (18%) of three heads. In women, 32