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ORIGINAL COMMUNICATION

Anatomical Variations of the Plantaris Muscle and a Potential Role in Patellofemoral Pain Syndrome

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The plantaris muscle has been given little attention in the reviewed literature. It is most commonly mentioned only when absent from a specimen. This study aimed to document the anatomy of the plantaris muscle and to discuss the clinical significance of the observations. Cadaveric knees ($n = 46$) were dissected to identify the possible variations of the plantaris muscle. The muscle conformed with standard descriptions ($n = 26$; 56.52%), was present but varied from previous descriptions ($n = 14$; 30.44%), or was absent ($n = 6$; 13.04%). The variations consisted of distinct interdigitations with the lateral head of the gastrocnemius muscle ($n = 9$; 19.57%) and a strong fibrous extension of the plantaris muscle to the patella ($n = 5$; 10.87%). The presence of interdigitations strengthen the argument that the plantaris muscle supplement the activity of the lateral head of the gastrocnemius muscle whereas the patellar extension suggests an involvement with patellofemoral dynamics and may play a role in the various presentations of patellofemoral pain syndrome. Greater understanding of the relationship between these and other posterior knee structures will facilitate more precise interpretation and treatment of knee injuries. Clin. Anat. 21:178–181, 2008.

Key words: plantaris; patella; anatomical variation

INTRODUCTION

The plantaris muscle is often believed to contribute to plantar flexion of the ankle and flexion of the knee and often has minimal effect (Colburn and Skandalakis, 1993; Standring, 2004). Because of the paucity of information concerning the plantaris muscle, the anatomical and functional understanding of this muscle is limited. Consequently, investigations into the plantaris muscle have the potential to advance functional understanding of the knee. Advancements in anatomical understanding of the structures that may influence a joint may subsequently lead to improved surgical interventions and rehabilitative procedures.

An absence of the plantaris muscle in approximately 10% of the population (Sinnatamby, 1999; Standring, 2004) is the only variation of the plantaris muscle reported within the reviewed literature. It is not known if the absence of the muscle alters the dynamics of the joint. However, should the plantaris muscle be determined to significantly influence knee joint mechanics, improved understanding of its role may alter the assessment and repair of knee injuries. Continued study and discussion of differences in knee structure will facilitate greater understanding of the influence such variations have over the knee and may improve patient outcomes for a variety of knee

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disorders (LaPrade, 2006). Clearer descriptions of muscular anatomy around the knee may facilitate more refined mechanical and functional studies in the future.

Patellofemoral pain syndrome (PFPS) is a generalized term describing retropatellar or peripatellar pain resulting from overuse/disuse and physical or biochemical changes through the patellofemoral joint and most frequently centering around the patellar tendon. Muscles commonly contributing to dysfunctional patellar tracking, one cause of PFPS, include the quadriceps, hamstrings, triceps surae, and tensor fascia lata (through the iliotibial band) muscles (Callaghan and Oldam, 2004). The recurring theme in most PFPS patients is poor positioning and tracking of the patella. Poor patellofemoral dynamics may be the result of force applied directly to the patella (i.e., tissues connected directly to the patella) or indirectly to the patella (i.e., structures that alter position of the femur upon the tibia, thus altering patellofemoral dynamics) (Ward and Powers, 2004). This study aims to describe the observed variations of the plantaris muscle in a sample population and to discuss the functional significance of such variations, particularly in relation to typical modalities of knee dysfunction.

MATERIALS AND METHODS

Cadaveric specimens ($n = 46$, mean age 71 ± 12 years) were dissected with the ethical approval of the Chairman of the Department of Anatomy and Embryology and as per local cadaveric tissue laws. Sex and occupation of each specimen was noted and included in initial analyses, but no notable correlations could be found and hence will not be discussed further.

The posterior aspect of the knee was dissected using standard surgical equipment and dissection techniques. The plantaris muscle was isolated and carefully traced to the proximal attachment, preserving any connections with surrounding tissue. Any variations in the muscle, its attachment, or relationship to surrounding tissues were noted and photographed using a digital camera (Nikon Coolpix 8800).

To provide context between the observed results of this study, data were collected from three commonly used anatomy texts (Putz and Pabst, 2001; Abrahams et al., 2003; Agur and Dalley, 2004; Standring, 2004; Netter, 2006). The maximum intercondylar width from relevant figures in each text was scaled against that of a posterior dissection from the sample population. Using this measure to determine a common scale for each image, the position (proximal and distal points of attachment, relative to the tibial plateau) and area of each plantaris attachment was measured using Image J (Rasband, 1999–2007). The same measures were performed on digital images of each dissected specimen. All measures were done in duplicate by two observers and repeated again one week later in an arbitrary sequence. The interobserver and intraobserver measures were analyzed for statistically significant differences, but none were found significant ($P > 0.05$). The mean values of dissected and textbook groups were then compared.

The variations observed on the dissected specimens were described in detail and then discussed in relation to their theorized functional and clinical importance.

RESULTS

Three anatomical variations of the plantaris muscle belly were observed in the sample population. The muscle was attached without contact with neighboring muscles ($n = 26$; 56.5%; Fig. 1A), was present but varied from previous descriptions ($n = 14$; 30.4%), or was absent ($n = 6$; 13%). The variations of observed plantaris muscles consisted of distinct interdigitations with the lateral head of the gastrocnemius muscle ($n = 9$; 19.6%; Fig. 1B) and a thick fibrous extension from the plantaris muscle to the patella ($n = 5$; 10.9%; Fig. 1C).

In all specimens with a plantaris muscle, the proximal attachment area was significantly greater than that of textbook descriptions (Fig. 2). The muscular variations were consistently bilateral in cases where both limbs were available for inclusion in the study. Absence of the plantaris muscle was unilateral when both limbs were available.

When the proximal attachment of the plantaris muscle was interdigitated with that of the lateral head of the gastrocnemius muscle ($n = 9$; 19.6%), the interdigitation begun distally as the muscles converged over the distal third of the lateral femoral condyle and was more prominent toward the termination of the proximal attachment, immediately proximal to the lateral femoral condyle (Fig. 1C).

In all cases dissected, the plantaris muscle attached to a large area, the most distal point of which covered a part of the oblique popliteal ligament on the posterior aspect of the knee joint capsule (Fig. 1). The most proximal point of attachment was typically proximal to that of the lateral femoral condyle ($n = 35$; 76%) or was raised from the bone to be attached to fibrous tissue that could be traced around the supracondylar bone before merging further proximally and anteriorly with the connective tissue immediately adjacent to the patella ($n = 5$; 10.9%) (Fig. 1C).

DISCUSSION

In this study, the plantaris muscle is shown to have a highly variable anatomy with three variations, two of which have not been previously mentioned in the reviewed literature. These additional variations suggest an increased spectrum of influence by the plantaris muscle over knee function and stability, consequently allowing the plantaris muscle to have varying roles in knee dynamics, injury, and rehabilitation.

The majority of the specimens from the sample population ostensibly conformed with standard plantaris muscle descriptions. However, the traditionally

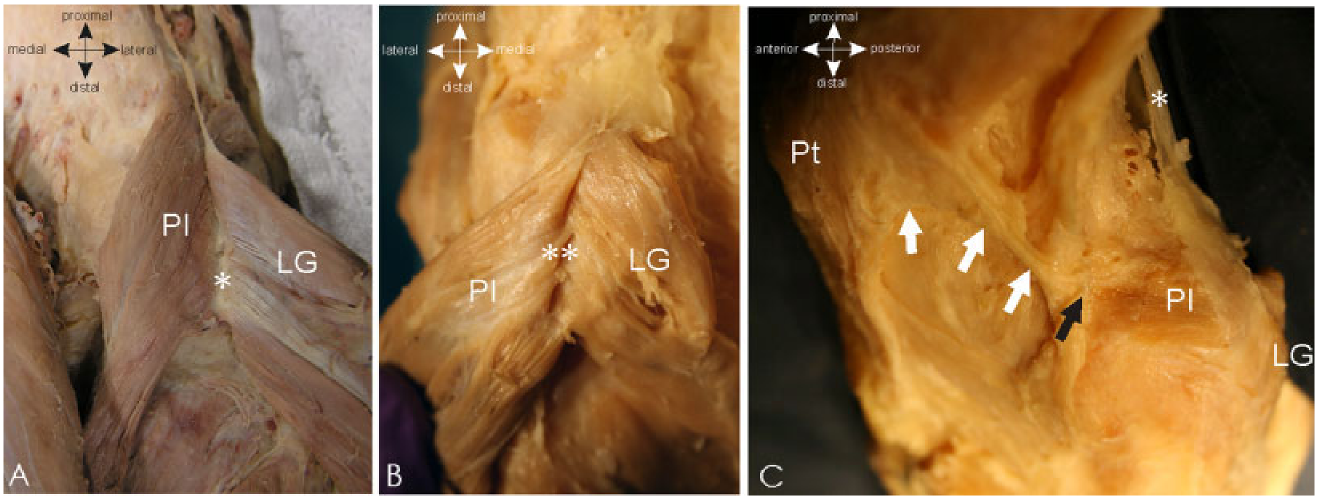

Fig. 1. Proximal attachment of the plantaris muscle. **A:** The ''normal'' plantaris muscle (Pl) covering the majority of proximal–distal length of the lateral femoral condyle, with a distinct separation (*) from the lateral head of the gstrocnemius muscle (LG). **B:** The interdigitation (**) between the plantaris muscle (Pl) and the lateral head of the gastrocnemius muscle (LG), which becomes more prominent toward the proximal end of the attachment. **C:** The anterior fibrous extension (white arrows) from the plantaris muscle (Pl) through the fibromuscular connection (black arrow) to the patella (Pt). Note a similar fibrous extension (*) from the lateral head of the gstrocnemius muscle (LG). [Color figure can be viewed in the online issue, which is available at www.interscience.wiley.com.]

described plantaris muscles are described with a small, almost circular, attachment site superior to the lateral femoral condyle. The specimens in this study presented with attachment areas significantly ($P < 0.05$) larger than those outlined in commonly used reference texts (Putz and Pabst, 2001; Abrahams et al., 2003; Agur and Dalley, 2004; Standring, 2004; Netter, 2006), which further suggests an increased influence over knee function and stability.

The absence of the plantaris muscle is the only variation that has been previously mentioned within the reviewed literature (Sinnatamby, 1999; Standring, 2004).The functional influence of this absence has not been previously discussed, particularly in relation to knee dysfunction. The absence of the plantaris muscle may cause weakness in initial flexion of the knee and an increased laxity of the knee during medial and lateral rotation, subsequently increasing the risk of injury to the primary stabilizing ligaments of the knee (Ward and Powers, 2004). Heavy loading of the knee without a plantaris muscle may give the patient a distinct impression of instability or promote uncertainty in their ability to withstand such loads. Observations showed that the absence of the plantaris muscle was primarily unilateral and therefore could result in preferred usage of the leg in which the plantaris muscle was present. The congenital absence of the plantaris muscle may therefore have considerable consequences for the development of mechanical, and certainly more intricate, athletic skills in a young individual.

Interdigitation of the plantaris muscle and the lateral head of the gastrocnemius muscle suggest an increased interaction between the two muscles and the possible sharing of functional control over the posterolateral aspect of the joint. Intrusion of the plantaris muscle proximal attachment into that of the lateral head of the gastrocnemius muscle may simply be a result of demand for increased mechanical advantage for the plantaris muscle. This may result in greater muscular output or an increased range of effective contraction that may influence total knee function. Estimated increases in proximal area of

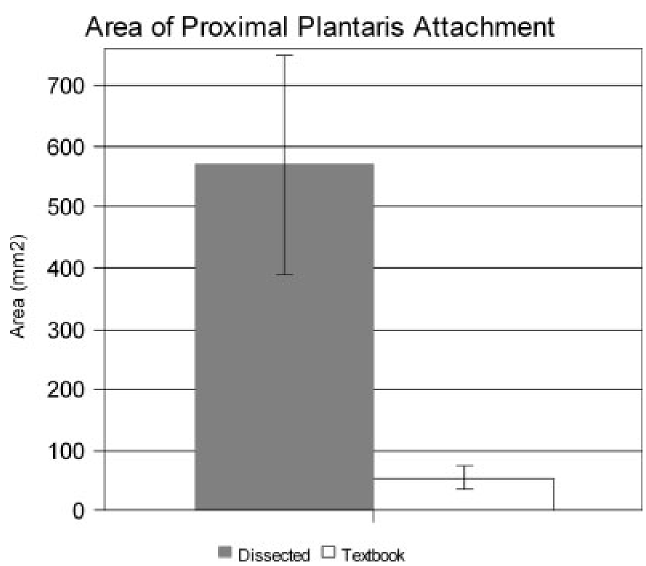

Fig. 2. Area of proximal plantaris muscle attachment. The mean area measured on dissected specimens is significantly ($P < 0.05$) greater than the mean measure from commonly used anatomy textbooks.

the plantaris muscle are commonly associated with "better than average" performance in timing-related activities, such as jumping and rapid direction change. Greater attachment area may facilitate greater development of these activities through increased proprioceptive input and mechanical output.

The least common variation, fibrous extensions from the plantaris muscle to the patella, may have the most clinical significance. It should be noted that, although observed in a small number of the sample population ($n = 5$; 10.9%), the advanced mean age of the sample population (71 ± 12 years) may have influenced the result. More sedentary persons are less likely to habitually load the knee enough to stimulate maintenance of fibrous tissues in distinct patterns. The lack of use of such bands as activity decreases with age and may mask the true incidence of these extensions. Conversely, alteration of gait, habitual loading of the lateral aspect of the knee, or other factors may contribute to the development of such structures. The specimens used in this study showed no signs of recent surgery; yet, older, well-healed surgical procedures may also have contributed to their development. The most likely clinical relevance would be in its possible contribution to PFPS. Common causes of PFPS are asymmetrical balance of the muscles and tendons attaching to the patella that result in medial or lateral displacement (Callaghan and Oldam, 2004). Common treatments for PFPS involve stretching and strengthening particular quadriceps femoris muscles to promote balanced muscular influence over the patella and, less frequently, surgical restoration of patella position and tracking (Ward and Powers, 2004). However, both of these treatments look exclusively at the anterior aspect of the joint. A patient with a fibrous extension from the plantaris muscle, especially an athlete in a jumping sport (where this muscle is likely to be more developed), would have an increased lateral pull on the patella, which may cause displacement. Current rehabilitative and surgical treatments may be ineffective (or likely, less effective) if the connection goes undetected and therefore unaltered. With consideration of the potential presence of such connections, initial physical therapy could focus on passive mobilization of the patella medially, thus lessening the influence of the band. With an initially more mobile patella, the quadriceps femoris muscles could more easily and effectively be balanced.

The variability of the plantaris muscle observed in this study suggests that it may have a more important role in knee dynamics than previously thought and thus a greater role in knee injuries. Further screening of a larger population that utilizes imaging techniques to properly identify each of these variations would allow additional investigation of plantaris muscle mechanics, involvement in rotational knee ligament injuries, and PFPS within an active population. Further study could possibly allow improved training, treatment, and rehabilitation procedures that could be tailored to the patient's individual variation(s). It is hoped that this descriptive study might prompt further investigation into the mechanical and clinical repercussions of this muscle's anatomical involvement with posterior knee structures.

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