Surg Radiol Anat (2012) 34:929–933
DOI 10.1007/s00276-012-0982-3

ORIGINAL ARTICLE

Compartments of the foot: topographic anatomy

C. Faymonville · J. Andermahr · U. Seidel · L. P. Müller · E. Skouras · P. Eysel · G. Stein

Received: 7 November 2011 / Accepted: 11 May 2012 / Published online: 26 May 2012

Abstract Recent publications have renewed the debate regarding the number of foot compartments. There is also no consensus regarding allocation of individual muscles and communication between compartments. The current study examines the anatomic topography of the foot compartments anew using 32 injections of epoxy-resin and subsequent sheet plastination in 12 cadaveric foot specimens. Six compartments were identified: dorsal, medial, lateral, superficial central, deep forefoot, and deep hindfoot compartments. Communication was evident between the deep hindfoot compartment and the superficial central and deep central forefoot compartments. In the hindfoot, the neurovascular bundles were located in separate tissue sheaths between the central hindfoot compartment and the medial compartment. In the forefoot, the medial and lateral bundles entered the deep central forefoot compartment. The deep central hindfoot compartment housed the quadratus plantae muscle, and after calcaneus fracture could develop an isolated compartment syndrome.

Keywords Compartment foot · Anatomy · Compartment syndrome

Introduction

The topography of the compartments of the foot, into which the muscles and tendons should be grouped, has been debated in the literature. Most recently in 2008, Ling [10] identified three compartments, and described a modified medial incision for decompression. In 1990, Manoli and Weber [12] renewed the scientific discussion of the topic. Earlier studies did not differentiate themselves substantially from the essentials published by Grodinsky [7] (Fig. 1).

There is disagreement regarding the number of compartments as well as allocation of individual structures. In the literature, there are varying approaches to the evaluation of compartment syndromes, and therefore numerous alternatives for decompression are recommended [1, 3, 9, 11–13, 16].

This study aims to clarify the sometimes confusing diversity of opinions regarding the topography of foot compartments and to account for the resulting recommendations regarding fasciotomy (Fig. 2).

Materials and methods

12 fresh cadaveric feet were injected with multi-colored Biodur mixtures (epoxy-resin synthetic) of low viscosity (a blood plasma analog) and examined using sheet plastination at the Anatomic Institute of the University of Cologne. Injections were done through the muscular structures beneath the fascia under constant monitoring of the compartment pressures (3-way stop clock and pressure measure; Stryker Inc.). The specimens were then repeatedly turned

C. Faymonville (✉) · L. P. Müller · E. Skouras · P. Eysel · G. Stein
Department of Orthopaedic and Trauma Surgery, University Hospital of Cologne, Kerpener Str. 62, 50924 Cologne, Germany
e-mail: christoph@faymonville.de

C. Faymonville · U. Seidel · G. Stein
Department II of Anatomy, University of Cologne, Cologne, Germany

J. Andermahr
Department of Trauma and Orthopaedic Surgery, General Hospital Mechernich, University Bonn, Bonn, Germany

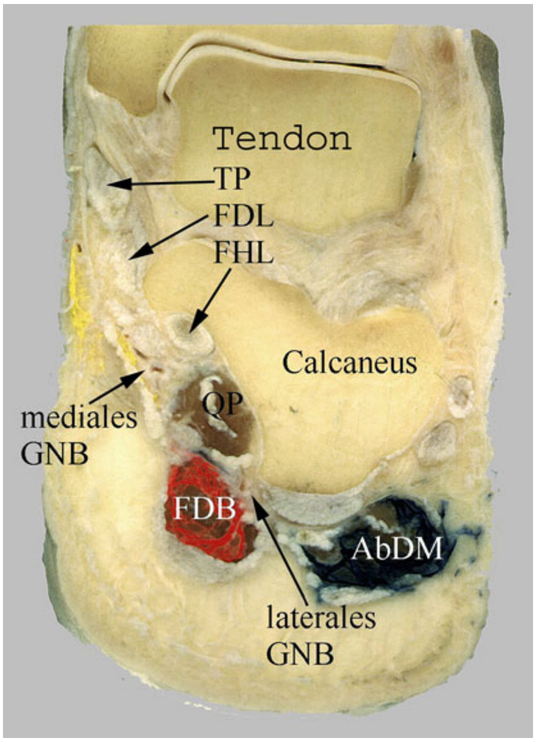

Fig. 1 Coronar slice of the proximal hindfoot, plastination; *FHL* tendon of the M. flexor hallucis longus, *FDL* tendon of the M. flexor digitorum longus, *QP* M. quadratus plantae, *AbDM* M. abductor digiti minimi, *FDB* M. flexor digitorum brevis, *med/lat GNB* medial/lateral nerves and vessels

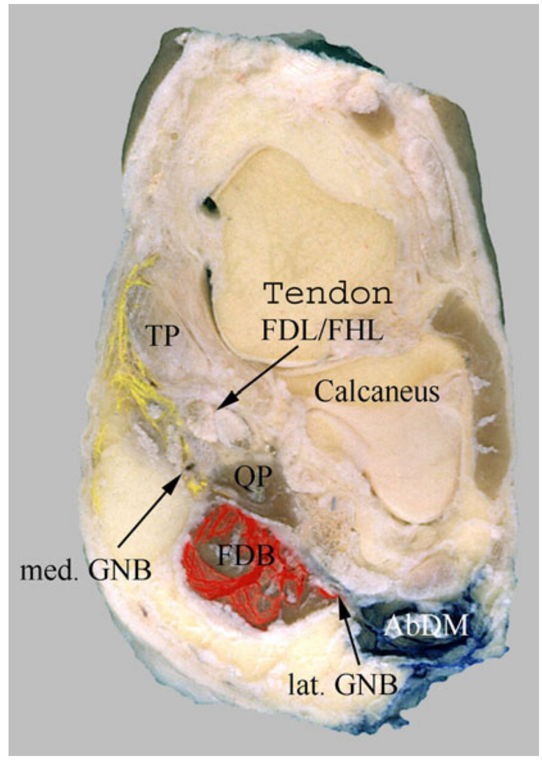

Fig. 2 Coronar slice of the distal hindfoot, plastination; *FHL* tendon of the M. flexor hallucis longus, *FDL* tendon of the M. flexor digitorum longus, *QP* M. quadratus plantae, *AbDM* M. abductor digiti minimi, *FDB* M. flexor digitorum brevis, *TP* tendon of M. tibialis posterior, *med/lat GNB* medial/lateral nerves and vessels

until the synthetic had completely dispersed and set, and finally rinsed and degreased with acetone. At this point, the specimens could be cut and the sheet plastination with epoxy-resin was performed. In total, 32 injections of different dyed synthetics were carried out on the 12 foot specimens. Injections were performed into pre-defined areas. Thereby an identification of appropriate compartments was enabled. The compartments addressed were injected four times each, distributed randomly on all feet and included the following: anterior tibial, posterior tibial, peroneal, quadratus plantae, plantar fascia/abductor hallucis, plantar aponeurosis/flexor digitorum, dorsal fascia/interosseous, and plantar fascia/flexor digitorum. The adjacent compartments can also be obtained from Table 1.

Table 1 Compartments addressed by injections

Compartment injected
Anterior tibial
Posterior tibial
Peroneal
M. quadratus plantae
Plantar fascia/abductor hallucis
Plantar aponeurosis/flexor digitorum
Dorsal fascia/interosseous muscles
Plantar fascia/flexor digitorum

Results

The muscles and neurovascular structures could be allocated to six compartments. These were the dorsal compartment, and in the plantar region a lateral compartment, medial compartment, superficial central compartment, as well as deep central forefoot and deep central hindfoot compartments (Fig. 3).

Medial

The one constant structure found in the medial compartment was the abductor hallucis muscle. The fascial chamber extends from the flat base of the abductor hallucis muscle on the medial and underside of the calcaneus along the medial border of the plantar surface, growing ever narrower distally until the first metatarsal head. The borders of the compartment are the superficial plantar fascia on the medial and plantar sides, the medial intermuscular septum laterally, and the first metatarsal, the medial

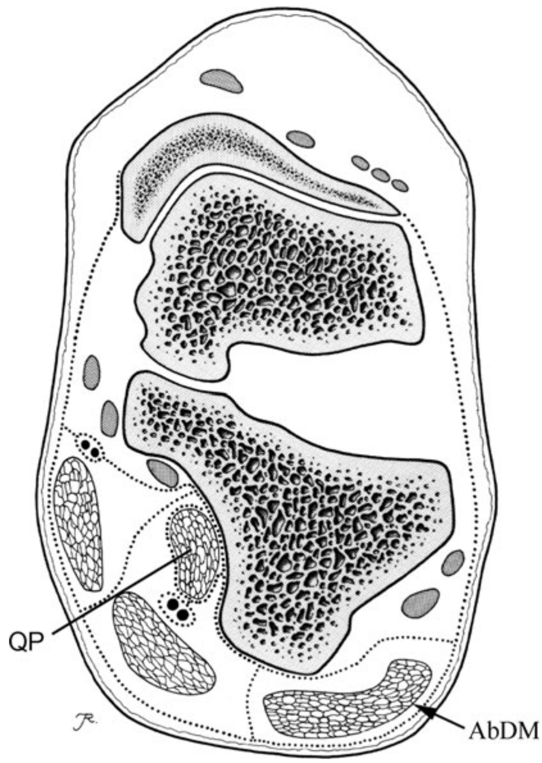

Fig. 3 Coronar slice of the proximal hindfoot; *QP* M. quadratus plantae, *AbDM* M. abductor digiti minimi

cuneiform, navicular, and calcaneus bones dorsally. The flexor hallucis brevis muscle cannot be unequivocally assigned to this compartment. The medial belly was colored with each of four injections (Fig. 4).

Lateral

In the hindfoot, the abductor digiti minimi muscle is a constant structure of the lateral compartment. The lateral neurovascular bundle is within the compartment half of the time. In the other cases, it lies medial to the lateral compartment. In the forefoot, the flexor digiti minimi brevis muscle is sometimes within this compartment, and sometimes separate. From the coloring, it appears that this muscle can belong to either the lateral or the deep central forefoot compartments. Far distally, the tendon of the flexor digitorum longus muscle of the fifth ray slips into the lateral compartment (Fig. 5).

The lateral and plantar borders of the compartment are defined by the superficial plantar fascia, and medially by the lateral intermuscular septum. Dorsally, it is defined by the fifth metatarsal, cuboid, and calcaneus bones.

Superficial central

The flexor digitorum brevis muscle is a constant member of this compartment. In all hindfoot cuts, there is a marked boundary with the quadratus plantae muscle and around both neurovascular bundles, running medially and dorsolaterally.

At the transition to the forefoot at the level of the Lisfranc joint line, the tendon of the flexor digitorum longus muscle fans out to the origin of the quadratus plantae muscle and slips out of the deep hindfoot compartment into the superficial central compartment. There it continues along the lumbrical and flexor digitorum brevis muscles.

The plantar aponeurosis makes up the plantar border, the medial intermuscular septum the medial border, and the lateral intermuscular septum the lateral border. Dorsally, the compartment is defined by the following two compartments.

Deep central hindfoot

When infiltrating the medial compartment, we found that the tendon of the flexor hallucis longus did not lie within. After defining the superficial central compartment, we found that

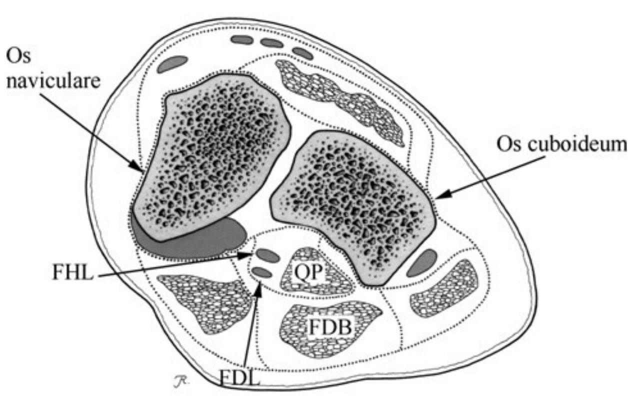

Fig. 4 Coronar slice of the distal hindfoot; *QP* M. quadratus plantae, *FDB* M. flexor digitorum brevis, *FHL* tendon of the M. flexor hallucis longus, *FDL* tendon of the M. flexor digitorum longus

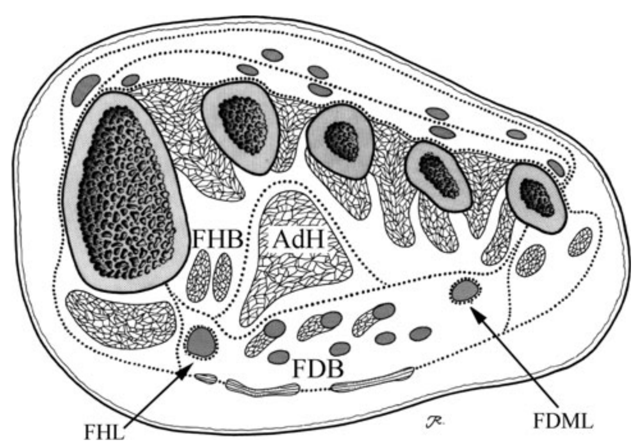

Fig. 5 Coronar slice of the forefoot; *FHL* tendon of the M. flexor hallucis longus, *FHB* M. flexor hallucis brevis, *FDB* M. flexor digitorum brevis, *AdH* M. adductor hallucis, *FDML* tendon of the M. flexor digitorum longus (little toe)

the tendon did not belong there either. With new infiltration placed further proximally, dye reached the compartment surrounding the quadratus plantae, flexor hallucis longus, and flexor digitorum longus muscles. Moving distally, the fascial borders enclosing the tendons of the flexor hallucis longus and flexor digitorum brevis (5th toe) muscles were colored as well. Further distally, the tendon of the flexor digitorum brevis moves into the lateral compartment (see above).

Both neurovascular bundles lie outside the deep hindfoot compartment. The adductor hallucis muscle is not within the same compartment as the flexor digitorum longus muscle. The deep hindfoot compartment is generated from the doubling of the deep plantar fascia. The superficial sheet borders the long plantar ligament, and the deeper sheet the superficial central compartment. The tendons of the flexor digitorum longus and hallucis longus muscles are everted glove-like distally. The compartment is bordered medially and laterally by the respective intermuscular septa.

Deep central forefoot

In the deep central compartment, there are the bellies of both adductor hallucis muscles, the flexor hallucis brevis muscle and the interosseus muscles. The lateral neurovascular bundle enters the compartment at the Lisfranc joint line and merges into the deep plantar arch. Borders of the compartment are the metatarsal bones and the plantar ligament dorsally. The lateral and medial intermuscular septa define the sides of the compartment. On the plantar side, the space is limited by the deep plantar fascia, the distinct sheets of which arise from the coalescence of the quadratus plantae muscle. There is no delineation between the individual interosseus muscles or across the short, centrally located forefoot muscles. Thus, the entire musculature of the forefoot excluding the flexor digiti minimi brevis is contained in the lateral compartment.

Dorsal compartment

The infiltration of the synthetic was carried out in three injections through the anterior compartment of the leg, following the muscles of the tibialis anterior, extensor digitorum longus, and extensor hallucis longus distally. The dorsal foot and the anterior leg compartments maintain an uninterrupted communication.

The extensor digitorum brevis and the extensor hallucis brevis muscles maintain an individual compartment, defined by the fascia of the dorsalis pedis.

Intercompartment communication

There are contrasting opinions in the literature regarding communication between the compartments. In our findings, the deep central forefoot compartment was separated from the deep central hindfoot compartment only by a slender sheet of the fascial sheath. This ruptured easily with higher injection pressures. The deep central hindfoot compartment communicated with the superficial central compartment over the tendon of the flexor digitorum longus muscle. In the hindfoot, the two compartments were separated by a deep sheet of the quadratus fascia, which remained intact under high pressure (120 mmHg). The dorsal compartment communicated openly with the anterior leg compartment. Further communication between individual compartments was not evident.

Position of the neurovascular bundle

The position of the neurovascular bundle remained constant in all specimens from proximal to the Chopart joint line. Both conduits lie outside the compartments within a connective tissue sheath. Between the joints of Chopart and Lisfranc, the medial conduit proceeds within the medial compartment. At the level of the Lisfranc joints, it breaches the central deep compartment and forms the deep plantar arch.

The lateral conduit proceeds within the lateral compartment between the Chopart and Lisfranc lines, breaches the deep central compartment distally and forms the deep plantar arch at the level of the interosseus muscles.

Discussion

Using gelatin injections in 1929, Grodinsky [7] classified the sole of the foot into four compartments, from which further studies in the following decades have deviated only in the compartment allocation of individual muscles. A few authors have redivided the central compartment into various subcompartments [9, 11, 15, 17, 19, 23]. Using gelatin injections in 1990, Manoli and Weber [12] identified nine separate compartments, so that the quadratus plantae muscle in the hindfoot and the adductor hallucis muscle in the forefoot were assigned their own discrete compartments. Using MRT, Reach [20] identified ten separate compartments. The communication of the compartments with each other as well as with those of the leg has remained under debate [6, 7, 16, 21]. Connections between the central compartment and deep flexor compartment have been characterized by numerous authors. Grodinsky and Myerson [7, 16] both observed transfer of fluids between subcompartments of the central compartment, as well as between the central compartment and medial, lateral, and interosseus compartments. Saraffian [21] also found communication between the central compartments.

In summary, the plantar region has been divided into three or four compartments, depending on whether or not the interosseus muscle group is given its own discrete compartment. Some authors have subclassified this space into further subcompartments. The allocation of individual muscles to these compartments has been variable.

There are diverse opinions regarding the clinical importance of the foot compartments and thus varying approaches to the evaluation of compartment syndromes [2]. Zwipp and Swoboda [22] find particular risk in cases of tarsal or mid-foot dislocations, where 50 % of evaluated patients develop eventual deformities of the toes or sensory disturbances. Myerson and Manoli [18] concluded that 10 % of all patients with calcaneus fractures develop post-traumatic compartment syndrome of the foot and 50 % develop claw-toe in the long term. There are various opinions in the literature regarding the surgical division of compartments. Grodinsky and Loeffler [7, 11] recommend a longitudinal plantar approach, and Ender [5] uses a short incision of the plantar aponeurosis distal to the heel. Henry [8] describes a medial approach, from which all compartments can be successively decompressed. Mubarak and Hargens [14] suggest a dual-dorsal approach, and Echtermeyer [4] finds a single dorsal incision sufficient. Swoboda and Zwipp [22] conclude that in fracture dislocations, the fascia has already been opened traumatically, and find a single dorsomedial dermatofasciotomy sufficient on a case by case basis. The lateral approach, in combination with other methods, has also been suggested for decompression. The current study identifies six compartments of the foot. For questions of compartment syndrome, pressures should be measured in each of these. In cases of calcaneus fracture, the central deep hindfoot compartment containing the quadratus plantae muscle could develop compartment syndrome in isolation, so in cases of corresponding trauma and symptoms, pressure measurements and fasciotomy, where indicated, should be performed.

Acknowledgment This work is dedicated to Prof. Dr. J. Koebke, a unique anatomist, who enabled us this research.

Conflict of interest The authors declare that they have no conflict of interest.

References

1. Andermahr J, Helling HJ, Tsironis K, Rehm KE, Koebke J (2001) Compartment syndrome of the foot. Clin Anat 14:184–189
2. Andermahr J, Zähringer M, Helling HJ, Krug KB, Koebke J, Rehm KE (2002) Surgical aspects of the hindfoot MR anatomy. J Foot Ankle Surgery 8:13–19
3. Echtermeyer V (1991) Compartment syndrome of the foot. Orthopade 20:76–79
4. Echtermeyer V (1991) Compartment syndrome. Principles of therapy. Unfallchirurg 94:225–230
5. Ender HG, Moser K (1988) Increased pressure in the compartments of the sole in joint fractures of the calcaneus. Unfallchirurg 91:523–526
6. Goodwin DW, Salonen DC, Yu JS, Brossmann J, Trudell DJ, Resnick DL (1995) Plantar compartments of the foot: MR appearance in cadavers and diabetic patients. Radiology 196:623–630
7. Grodinsky M (1929) A study of facial spaces of the feet. Surg Gynecol Obstet 49:739–751
8. Henry AK (1963) Extile exposure, 2nd edn. Williams & Wilkins, Baltimore, pp 300–308
9. Kamel R, Sakla FB (1961) Anatomical compartments of the sole of the human foot. Anat Rec 140:57–60
10. Ling ZX, Kumar VP (2008) The myofascial compartments of the foot: a cadaver study. J Bone Joint Surg Br 90:1114–1118
11. Loeffler RD, Ballard A (1980) Plantar fascial spaces of the foot and a proposed surgical approach. Foot Ankle 1:11–14
12. Manoli A, Weber TG (1990) Fasciotomy of the foot: an anatomical study with special reference to release of the calcaneal compartment. Foot Ankle 10:267–275
13. Mubarak SJ (1983) A practical approach to compartmental syndromes. Part II. Diagnosis. Instr Course Lect 32:92–102
14. Mubarak SJ, Hargens AR (1983) Acute compartment syndromes. Surg Clin North Am 63:539–565
15. Myerson MS (1987) Acute compartment syndromes of the foot. Bull Hosp Jt Dis Orthop Inst 47:251–261
16. Myerson MS (1988) Experimental decompression of the fascial compartments of the foot—the basis for fasciotomy in acute compartment syndromes. Foot Ankle 8:308–314
17. Myerson MS (1991) Management of compartment syndromes of the foot. Clin Orthop Relat Res 271:239–248
18. Myerson MS, Manoli A (1993) Compartment syndromes of the foot after calcaneal fractures. Clin Orthop Relat Res 290:142–150
19. Rauber A, Kopsch F (1987) Lehrbuch und Atlas der Anatomie des Menschen. Thieme, Leipzig
20. Reach JS, Amrami KK, Felmlee JP, Stanley DW, Alcorn JM, Turner NS, Carmichael SW (2007) Anatomic compartments of the foot: a 3-Tesla magnetic resonance imaging study. Clin Anat 20:201–208
21. Saraffian SK (1983) Anatomy of the foot and ankle. JB Lippincott, Philadelphia
22. Swoboda B, Scola E, Zwipp H (1991) Surgical treatment and late results of foot compartment syndrome. Unfallchirurg 94:262–266
23. Zippel R, Lorenz D, Kocher W, Domagk A (1992) Pressure behavior in muscle compartments of the foot in defined stress, metatarsal and ankle joint fractures. Chirurg 63:310–315