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Pictorial Review

Master knot of Henry revisited: a radiologist's perspective on MRI

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The master knot of Henry refers to a narrow space located between the anatomical crossover of the flexor hallucis longus and flexor digitorum longus tendons. This small space is prone to "intersection syndrome," as a result of tendinosis, tenosynovitis, and tears of the aforementioned tendons at the knot of Henry. The aim of this educational review is to detail the anatomy of the knot of Henry, including common variations in the tendon position and orientation. These complex interconnections can affect the outcome of surgical intervention if not appreciated at the time of treatment. We will also provide an overview of the common and rarer pathologies related to the knot of Henry. The aim of the present review is to make radiologists more aware of pathologies in this region, which are not routinely seen in daily practice.

Introduction

Plantar mid-foot pain is a common complaint, with mid-foot tendon disorders being the most common aetiology for pain in this region. Other underlying causes include trauma, infection (usually diabetes related), benign/malignant soft-tissue or bone-related pathologies.

The master knot of Henry refers to a narrow space in the plantar mid-foot located between the abductor hallucis muscle and anatomical crossover between the flexor hallucis longus (FHL) and flexor digitorum longus (FDL) tendons.[1] This small space is prone to repetitive friction, giving rise to tendinosis, tenosynovitis, and tears of the aforementioned tendons at the knot of Henry. The term "intersection syndrome," refers to a healing response secondary to fibrosis that can occur in these pathologies.[2]

The present article will review the normal anatomy of the knot of Henry and discuss the various interconnections between FHL and FDL. The variations in inter-tendinous anatomy are important to know as FHL/FDL tendon transfer maybe used for surgery in cases of tibialis posterior dysfunction and neglected Achilles tendon rupture.[3] Tibialis posterior dysfunction is one of the most common causes of acquired flat foot in adults, and tendon transfer is normally carried out if more conservative methods have failed.[3] It is clear that knowledge of the anatomical connections plays a valuable role in surgical preparation of tendon grafting, with the aim of reducing tendon harvesting morbidity and understanding how a postoperative functional deficit may have arisen.

The surgical approach to the knot of Henry is also technically challenging due to the close proximity of the medial plantar neurovascular bundle. We will outline the course of the medial plantar nerve as well as highlight the features of neurogenic lesions which may occur. We will also present

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pathologies related to the knot of Henry, namely various cystic and soft-tissue masses including sarcomas. Although not specifically confined to the knot of Henry, this is a rather unusual location hence useful for radiologists to appreciate tumour imaging appearances. The aim of the present review is to make radiologists more aware of common and rarer pathologies in this area, which can be easily overlooked in this small anatomical region.

Anatomy

The FHL muscle originates from the distal fibula posteriorly. It passes through the knot of Henry coursing medially through the fibro-osseous tunnel between the great toe sesamoid bones inserting onto the first distal phalanx base (Fig 1). It acts as the main great toe flexor. Due to its long course, FHL is prone to friction at specific locations. Tendinopathy is most common at the tibiotalar joint as FHL curves posterior to the talus. Distal to the hallux sesamoids is the second most common followed by the intersection with FDL at the knot of Henry. Interestingly, a rare cause of posterior ankle impingement is hypertrophy of the FHL muscle belly at the musculotendinous junction, so called “stopper in bottle” phenomenon.[4]

FDL originates at the distal tibia medial to the FHL origin. In the mid-foot region, FDL receives the quadratus plantae muscle insertion and then splits into four tendons. These give rise to the lumbrical muscles inserting onto the bases of the second to fifth toe distal phalanges. FDL serves to flex the second to fifth toes (Fig 1). Generally one fibrous slip connects FHL and FDL distal to their crossing point. These connecting fibres are collectively termed “chiasma tendinum plantare,” first described by A. K. Henry in 1940.[5] LaRue and Anctil in 2006 formally described three types of anatomical relationship between FHL and FDL from their observation of 24 cadaveric specimens.[6]

Beger and co-workers in 2018 further characterised these connections with newer connections not previously discussed in literature (Fig 2).[7] The exact location of tendon tears in relation to these anatomical crossover slips at the knot of Henry are crucial for surgical planning. If the FHL tendon is cut proximal to the knot of Henry, there will be

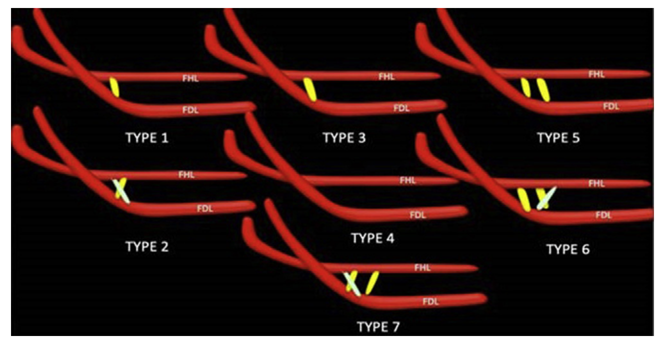

Figure 2 Illustration showing the various connections between the FHL and FDL as classified by Beger *et al.*, 2018.[6] Type 1 (75%): one slip from FHL to FDL; type 2 (10%): bidirectional slips; type 3 (0%): one slip from FDL to FHL; type 4 (0%): no slips; type 5 (5%): two slips from FHL to FDL; type 6 (5%): two slips from FHL, one slip from FDL; type 7 (5%): two slips from FDL, one slip from FHL.

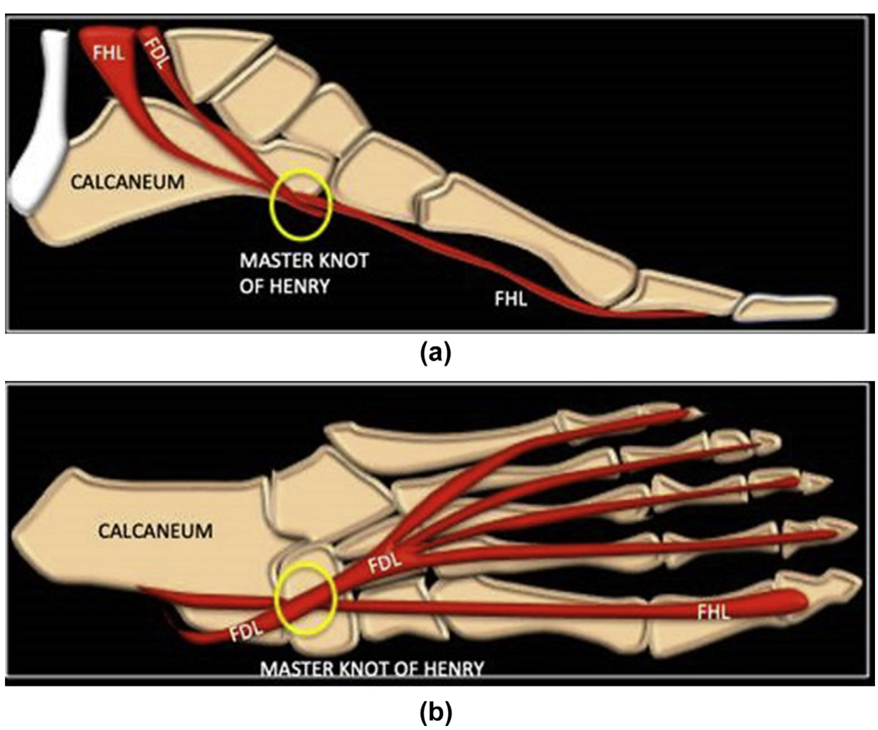

Figure 1 (a) The course of the FDL and FHL tendons. They cross over at the plantar portion of the navicular bone at the knot of Henry. (b) FHL attaches onto the base of the first distal phalanx, while FDL divides into four tendons. Each tendinous FDL slip inserts onto the plantar aspect of the 2nd-5th distal phalanges.

limited symptoms due to the combined action with FDL at the crossover. Toe plantar flexion should be maintained, which is considered an ideal outcome for the patient. Harvesting the tendon at this site proximal to the knot of Henry would therefore be considered safe; however, a ruptured tendon distal to the knot of Henry would result in a complete deficiency of plantar flexion. Hence, repair should be considered.[8]

The tibial nerve has two terminal branches: the larger medial plantar nerve and the smaller lateral plantar nerve. The medial plantar nerve is typically vulnerable to injury distal to the origin of the abductor hallucis muscle. More distally the nerve courses alongside the flexor digitorum brevis, giving off the proper digital plantar nerve. It then divides opposite the bases of the metatarsal bones into three digital plantar nerves.

Normal magnetic resonance imaging appearances

On magnetic resonance imaging (MRI), both the FDL and FHL tendons appear as hypointense structures that descend along the medial ankle before travelling along the plantar aspect of the mid-foot. The described fibrous connections, commonly one slip from FHL to FDL if present, are normally seen as a small linear hypointense slip, and should not be mistaken for a tendon tear (Fig 3).

Clinical symptoms and signs

As both the FHL and FDL tendon sheaths usually communicate at the knot of Henry, isolated tendon injuries are fairly rare. They may occur in the proximal forefoot, and tends to affect FDL more given its superficial location to FHL.

"Intersection syndrome" describes the fibrotic response to trauma sustained at the knot of Henry and represents a healing phase after a tear, tenosynovitis, or other pathology. Most patients are asymptomatic and pain may only be present if there is associated synovitis on imaging.

Repetitive eversion of the foot or pathology spreading from the knot of Henry tendons can affect the medial plantar nerve. This is commonly seen in runners due to increased heel valgus and foot pronation whilst running, and is termed "joggers foot."[9] There is tenderness and sometimes numbness along the entire medial foot arch, heel, and specifically at the navicular tuberosity. This is important as medial plantar nerve denervation is thought to increase secondary osteoarthritis at the first metatarsophalangeal joint. Chronic or severe denervation typically manifests as fatty atrophy of the foot plantar muscles (Fig 4).

The numbness or pain related to the medial plantar nerve can be elicited by the Tinel test.[8] The examiner maximally dorsiflexes the ankle, everts the foot, and extends all of the toes to stretch the tibial nerve and its medial plantar nerve branch. Tinel's test is positive if the patient complains of localised nerve tenderness whilst the examiner taps over the tarsal tunnel.

For intersection syndrome at the knot of Henry open debridement is recommended if conservative measures fail[9]; however, this often requires extensive soft-tissue dissection quite deep in the plantar mid-foot region. Hence endoscopic debridement maybe performed as it involves less trauma and a lower risk of recurrent fibrosis.[10]

Tenosynovitis

As the FHL tendon communicates with the ankle joint in 20% of individuals, ankle joint fluid can decompress into the FHL tendon sheath and track distally. Thus it can be difficult to differentiate asymptomatic tendon sheath distension from true tenosynovitis. As a rule of thumb, FHL tenosynovitis should only be diagnosed if the amount of

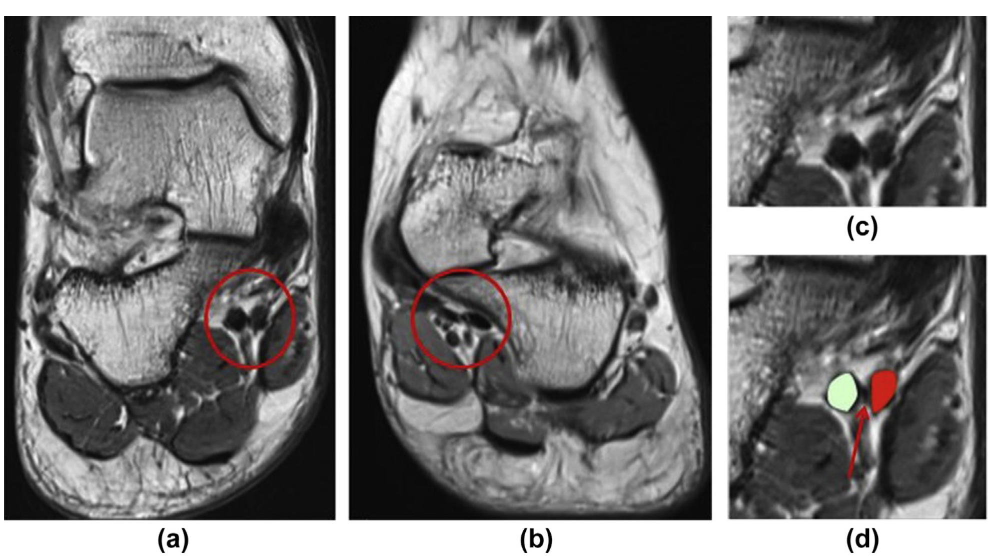

Figure 3 Proton-density weighted (PD) coronal MRI of two different patients (a) and (b) with a magnified view at the master knot of Henry. (c,d) A linear hypointense slip (red arrow) connecting the FHL (green) and FDL (red) tendons. The location and identification of this slip is crucial in knowing where to harvest the FHL tendon for grafting.

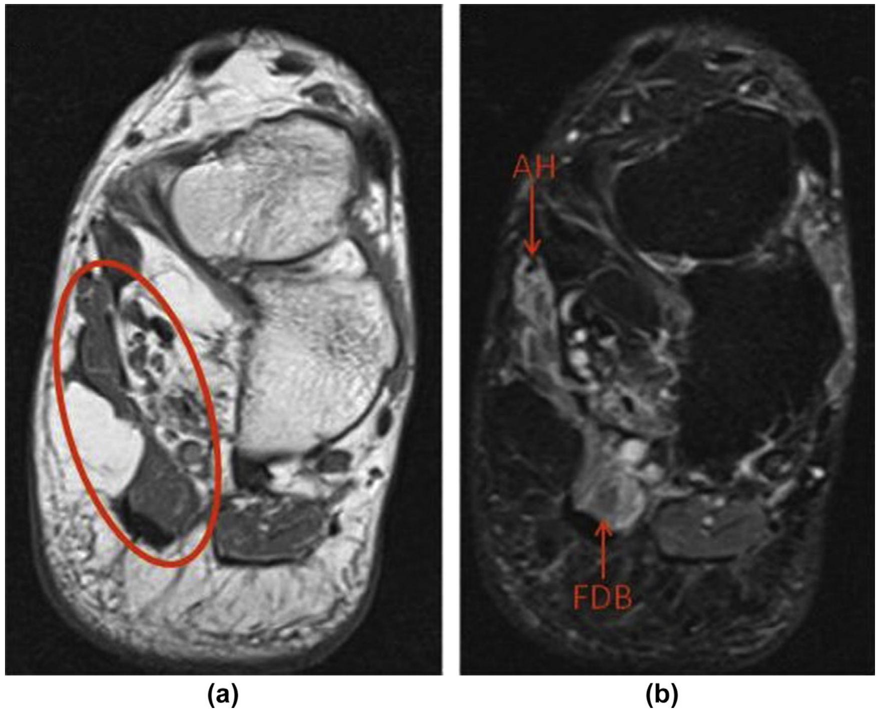

Figure 4 (a) T1-weighted and (b) short-tau inversion recovery (STIR) coronal MRI images show marked oedema and fatty atrophy of the abductor hallucis (AH) and flexor digitorum brevis (FDB) muscles. Although not specifically demonstrated here, tendon disease at the knot of Henry can indirectly cause entrapment of the medial plantar nerve. This may eventually lead to a denervation injury of the plantar foot muscles as shown above.

surrounding fluid is out of proportion to the volume of ankle joint effusion, or when complex internal debri termed "synechiae," is found[11]; however, it is unusual to see fluid track all the way down beyond the knot of Henry, fluid here should be considered pathological (Fig 5).

Other signs of true tenosynovitis include sheath thickening, circumferential fluid, and heterogeneous signal within the fluid. Isolated tenosynovial fluid around FDL is rare, but has been reported in hammer toe deformities or plantar plate disease.[11]

Ganglion

Ganglia are non-tumoural cystic lesions that arise from a joint or tendon sheath. A part of the ganglia may be adjacent to, or directly communicate with the joint or tendon sheath

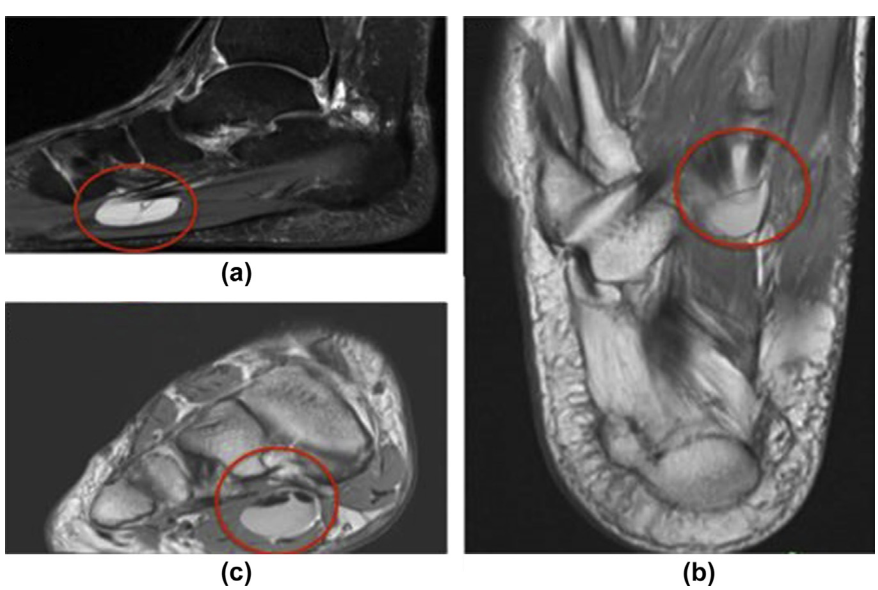

Figure 5 (a) PD FS sagittal, (b) PD axial, (c) PD coronal MRI images show peritendinous fluid signal involving the FHL and FDL tendons at the knot of Henry consistent with tenosynovitis.

on imaging.[12] They maybe uni- or multilocular, have small septa, and can be of variable size.

After the hands and wrists, the dorsum of the foot is the most common place for ganglia to occur. Although larger ganglia usually arise from degenerative joints, it is not uncommon to see them at the knot of Henry with underlying FHL and/or FDL tendinosis or tenosynovitis.

If small, they may disappear over time and are normally asymptomatic. Larger lesions may present with swelling or pain. MRI most frequently demonstrates a multilobulate mass with homogeneous low T1-weighted and high T2-weighted signal intensity. Some ganglia may contain a large proportion of mucinous fluid and hence show a high or intermediate T1 signal (Fig 6).

Myxoma

Myxoid lesions range from benign to malignant lesions all with internal myxoid stroma.[13] Myxomas refer to benign myxoid lesions that are typically intramuscular. The signal characteristics of a pure myxoma are homogeneously increased signal intensity due to high mucin and low collagen content (Fig 7). MRI tends to show a sharply defined low T1 lesion with a homogeneously hyperintense T2/fat-suppressed (FS) signal.[13] On contrast-enhanced sequences, myxomas show only peripheral rim enhancement, but can have varying degrees of internal enhancement, which may pose a diagnostic dilemma. These tumours are characterised by a slowly

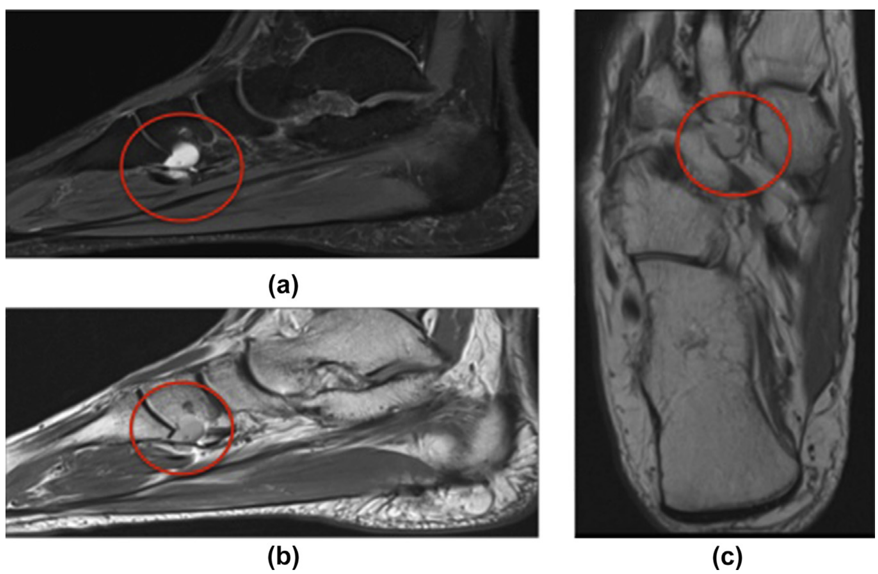

Figure 6 (a) PD FS sagittal, (b) PD sagittal, (c) PD axial MRI images show a small well-defined unilocular cystic lesion in relation to the knot of the Henry, with volar protrusion. It is of cystic signal on FS imaging and intermediate signal on T1 sequences consistent with a ganglion with internal mucinous material.

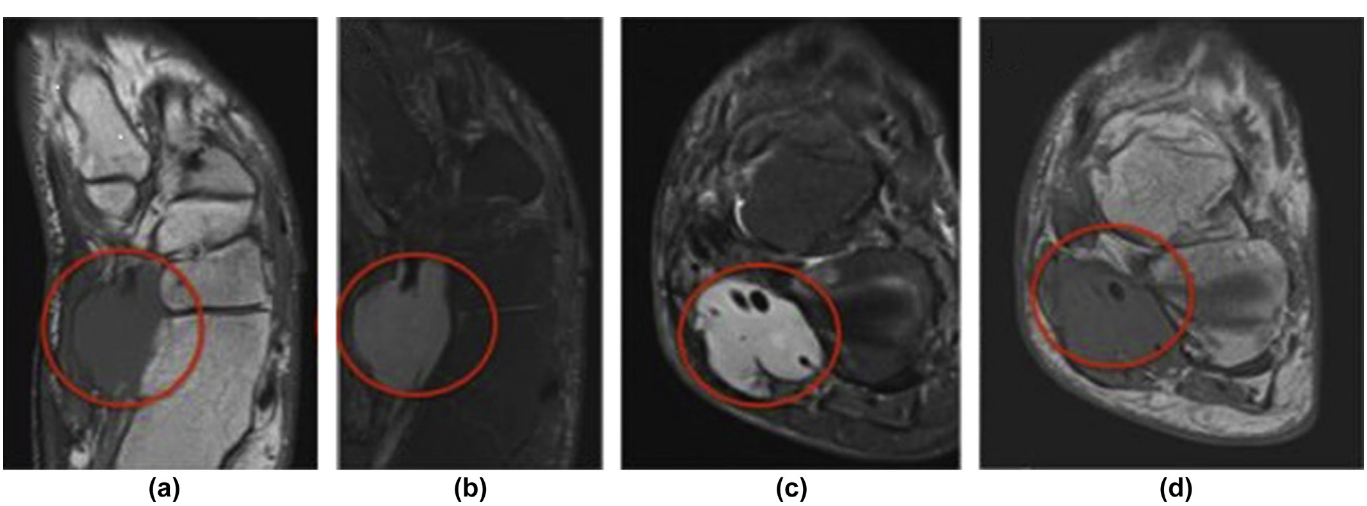

Figure 7 (a) T1 axial, (b) STIR axial, (c) STIR coronal, (d) T1 coronal MRI images show an area of low T1 signal isointense to muscle and high cystic FS signal at the knot of Henry. This is replacing the normal fat between the abductor hallucis brevis and flexor digitorum brevis muscles. It is well defined and shows no adjacent bony erosion. Given its sharply defined contour and cystic appearance on unenhanced sequences, MRI signal characteristics are typical of a histologically confirmed myxoma.

expanding cystic mass without forming distant metastases.

The differential diagnosis for high water content soft-tissue masses mimicking a cyst include bursa, ganglion, synovial cyst, neurogenic tumours, myxoid liposarcomas, and myxofibrosarcoma (previously known as myxoid malignant fibrous histiocytoma-MFH).[13] Most bursae, ganglia, and synovial cysts occur in the typical expected locations, e.g., joints, whereas most myxoid lesions are intramuscular. These joint-related lesions are also truly cystic, so will have an anechoic appearance with no internal enhancement on ultrasound. Myxoid liposarcoma often contains a small amount of intrinsic fat. Myxofibrosarcoma, like soft-tissue myxoma, is typically an intramuscular lesion but has a far more heterogeneous imaging appearance, with areas of haemorrhage and solid nodular regions that can exhibit strong contrast enhancement.[13]

As myxomas have no metastatic potential and the chance of local recurrence is under 10%, resection if symptomatic is normally recommended.[13]

Myxofibrosarcoma

Myxofibrosarcoma was formerly known as the variant of MFH.[13] It presents within older adults and commonly involves the extremities. Unlike most soft-tissue sarcomas, it is less well defined with a propensity to spread through fascial planes. This makes complete resection difficult with high local recurrence rates.

MRI typically shows a lesion of low T1 and high T2 heterogeneous signal. Mild T1 iso-intensity or increased signal has also been reported. As they are infiltrative, enhancing curvilinear projections, so called “tail sign,” maybe seen extending from the lesion to the surrounding soft tissues with perilesional oedema.[14] Commonly, curvilinear fibrous septa are seen within the lesion presenting as areas of low signal (Fig 8). In advanced cases, local bone destruction can also be seen.

Metastases to the lungs are common in higher-grade tumours. These may have a more nodular soft-tissue component with diffuse infiltration through the fascial planes. The mentioned tail sign if present can differentiate this from other myxoid tumours.[13] Given their metastatic potential, wide surgical excision is the preferred treatment choice. Local recurrence occurs in 50–60% of cases.[13]

Neurogenic tumour

The incidence of neurogenic tumours localised to the plantar foot surface are very rare. Most reported cases of plantar neurogenic tumours have been found at the tarsal tunnel rather than the knot of Henry. Neurogenic tumours at the knot of Henry are related to the medial plantar nerve. The tibial nerve enters the tarsal tunnel and divides into the

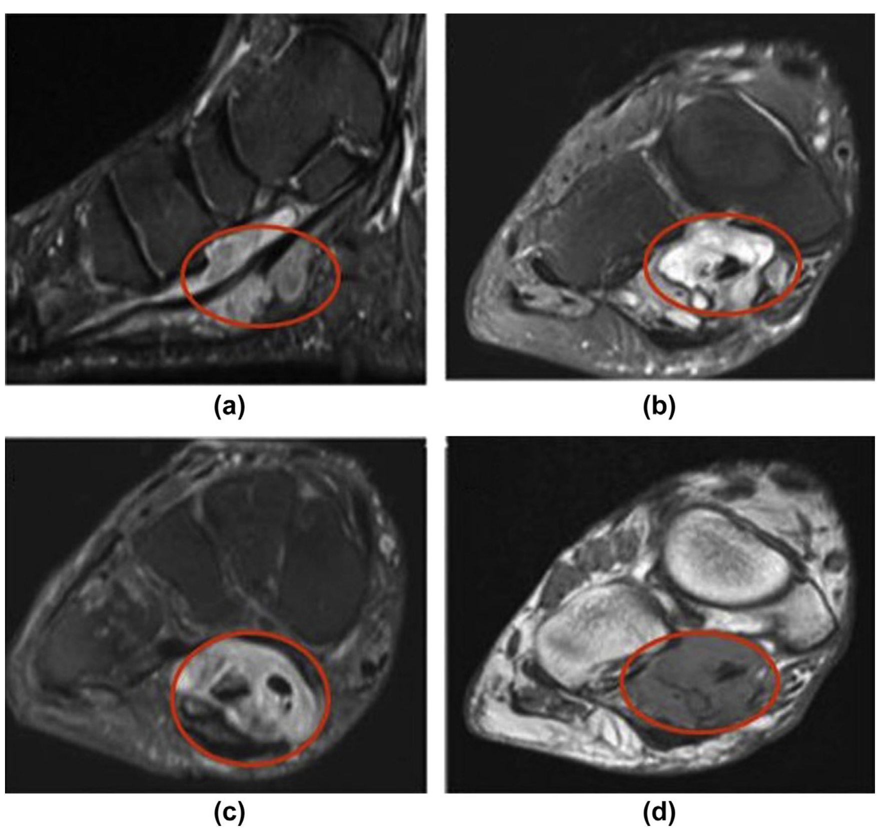

Figure 8 (a) STIR sagittal, (b) STIR coronal, (c) STIR coronal, (d) T1 coronal MRI images show a lobulate lesion with low T1 and high heterogeneous FS signal within the knot of Henry. Curvilinear projections are seen within the lesion. Note that the FS signal is not as homogeneous as in the previous simple myxoid lesion and the borders are slightly less well defined. Pathology from wide surgical excision revealed myxofibrosarcoma.

medial and plantar nerve branches. The medial branch crosses below the talus and navicular bone, sitting between the abductor hallucis brevis and flexor digitorum brevis, at the knot of Henry (Fig 9). In cases of late presentation, there can be associated fatty atrophy of the mentioned muscles. The most common neurogenic tumours at the ankle are schwannomas and neurofibromas; differentiating both on imaging is usually not possible.

As the lesion grows, schwannomas tend to displace the nerve fibres eccentrically. This has been reported as the most specific sign of a schwannoma, but is rarely seen on MRI.[15] Schwannomas, unlike neurofibromas, do not traverse the course of the nerve but remain in the sheath lying on top or bottom of the nerve, possibly displacing it if large.[15] Neurogenic tumours are typically homogeneously isointense to skeletal muscle on T1 sequences and hyperintense on FS imaging. The rim of the lesion appears bright with central low signal, termed the “target sign,” characteristic of schwannoma and neurofibroma, but more commonly reported in the latter.[15] Both lesions are typically benign encapsulated slow-growing tumours with a low likelihood of metastasising.

Intermuscular neurogenic tumours also can display the “split fat sign.” This refers to the presence of fat at both poles of the lesion on T1 imaging. Malignant nerve sheath tumours tend to be more heterogeneous on all imaging sequences and usually have more perilesional oedema.

Operative findings are usually of a smooth, oval, well-defined lesion, which typically has a grey or yellow surface colour.[15] As schwannomas are located eccentric to the parent nerve trunk, en-block excision of the entire nerve is rarely necessary unlike neurofibromas, which course the entire nerve length; however, careful dissection is required to remove the lesion from intact functioning nerve elements.

Chronic intersection syndrome

Synovial osteochondromatosis has been previously reported in tendon sheaths but it is rare to see osseous bodies at the knot of Henry. Typically a stenosing type of tenosynovitis is presumed to have caused this. Due to repeated friction and microtrauma there is synovial proliferation and fibrosis around the tendons, which may calcify over time (Fig 10).[16] The calcification, depending on location and chronicity, can surround the knot of Henry tendons causing entrapment and possibly even rupture.

Another plausible but less likely explanation is that the loose body may have originated from a degenerative ankle joint and traverse the length of the FHL tendon sheath to finally sit at the knot of Henry, causing a surrounding stenosing tenosynovitis.[16]

The onset of pain is most likely secondary to the loose bodies gradually tracking more distally to the mid-foot during weight bearing. The osseous bodies, if smooth and of a small enough calibre may track down the tendon sheath to points of narrowing like the knot of Henry. Movement of these bodies along the tendon sheath are dependent on the varying pressures generated during the

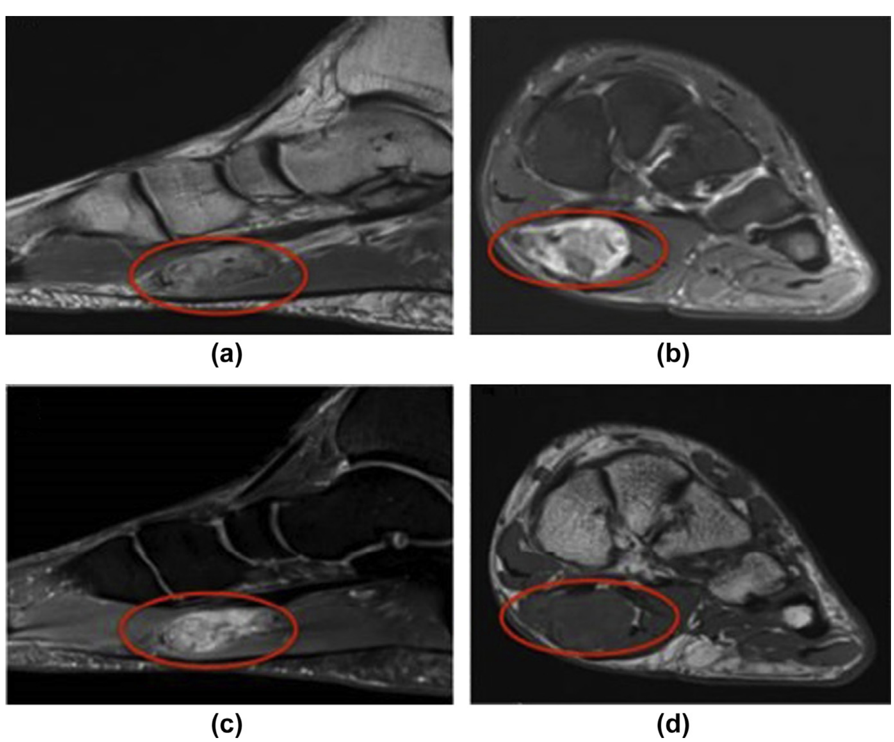

Figure 9 (a) T1 Sagittal, (b) STIR coronal, (c) STIR sagittal, (d) T1 coronal MRI images shows a round, encapsulated mass isointense-increased signal intensity to the surrounding muscles, located at the knot of henry. FS images show a high intensity peripheral rim lesion with central intermediate signal intensity. This is typical of a “target sign,” seen in peripheral nerve sheath tumours such as schwannoma or neurofibroma.

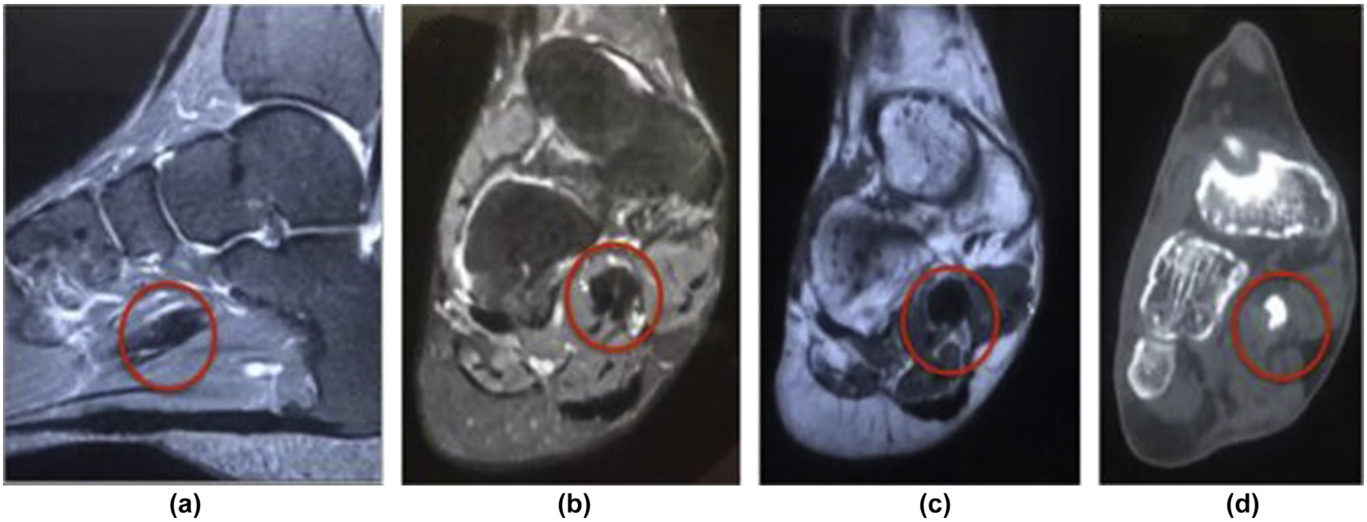

Figure 10 (a) STIR sagittal, (b) STIR coronal, (c) T1 coronal MRI, (d) coronal MPR computed tomography (CT) images show an example of chronic intersection syndrome with a large calcified loose body at the knot of Henry on both CT and MRI. Synovial osteochondromatosis within the knot of Henry tendon sheath is likely to have resulted from a chronic stenosing tenosynovitis.

gait cycle. This can cause a waxing and waning phenomenon of symptoms.[16]

MRI typically shows fibrosis associated with the knot of Henry. The loose body and extent of calcification or ossification can be best characterised on CT. For chronic intersection syndrome open or endoscopic debridement is recommended if conservative measures fail.

Conclusion

We have given a detailed anatomical roadmap of the knot of Henry and its various components. This area is often overlooked by radiologists as most ankle pathology relates to the stabilising ligaments and flexor and extensor tendons rather than the plantar mid-foot region.

Recent literature has outlined new connections between FHL and FDL. This is important to appreciate and will have a role in reducing postoperative functional loss following tendon transfer. We have also presented a range of common pathologies at the knot of Henry, as well as a few rare soft-tissue sarcomas among other tumours. Through this pictorial review, we aim to make radiologists more aware of pathologies in this region, which are not routinely seen in daily practice.

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Conflict of interest

The authors declare no conflict of interest.

References

1. Donovan A, Rosenberg ZS, Bencardino JT, *et al.* Plantar tendons of the foot: MR imaging and US. *RadioGraphics* 2013;**33**(7):2065–85.
2. Lui TH, Chow FY. "Intersection syndrome" of the foot: treated by endoscopic release of master knot of Henry. *Knee Surg Sports Traumatol Arthrosoc* 2011;**19**:850–2.
3. Narvaez J, Narvaez JA, Sanchez-Marquez A, *et al.* Posterior tibial tendon dysfunction as a cause of acquired flatfoot in the adult: value of magnetic resonance imaging. *Br J Rheumatol* 1997;**36**(1):136–9.
4. Rodriguez D, Bernhard BD, Maldague PF, *et al.* Tarsal Tunnel syndrome and flexor hallucis longus tendon hypertrophy. *Orthop Traumatol Surg Res* 2010;**96**(7):829–31.
5. Henry AK. *Extensile exposure*. 2nd edn. Edinburgh: Churchill Livingstone; 1970.
6. LaRue BG, Anctil EP. Distal anatomical relationship of the flexor hallucis longus and flexor digitorum longus tendons. *Foot Ankle Int* 2006;**27**(7):528–32.
7. Beger O, Elvan O, Keskinbora M, *et al.* Anatomy of master knot of Henry: a morphometric study on cadavers. *Acta Orthop Traumatol Turc* 2018;**52**(2):134–42.
8. Gillott E, Pinak R. Repair of iatrogenic rupture of the flexor hallucis longus tendon following an akin osteotomy: a case report and review of literature. *Foot Ankle Online J* 2012;**5**:1. https://doi.org/10.3827/faoj.2012.0505.0001.
9. Brown MN, Pearce BS, Trescot AM, *et al.* Medial plantar nerve entrapment. In: Trescot AM, editor. *Peripheral nerve entrapments*. Cham: Springer; 2016.
10. Lui TH. Endoscopic release of master knot of Henry. *Arthrosc Tech* 2015;**4**:e847–50.
11. Rosenberg ZS, Beltran J, Bencardino JT. MR imaging of the ankle and foot. *RadioGraphics* 2000;**20**(Spec No):S153–79.
12. Lee JW, Joo MW, Sung JK, *et al.* Origin of satellite ganglion cysts with effusion in the flexor hallucis longus tendon sheath around the hallux. *Clin Orthop Surg* 2018;**10**(1):94–8.
13. Baheti AD, Tirumani SH, Rosenthal MH, *et al.* Myxoid soft-tissue neoplasms: comprehensive update of the taxonomy and MRI features. *AJR Am J Roentgenol* 2015;**2204**(2):374–85. https://doi.org/10.2214/ajr.14.12888.
14. Yoo HJ, Hong SH, Kang Y, *et al.* MR imaging of myxofibrosarcoma and undifferentiated sarcoma with emphasis on tail sign; diagnostic and prognostic value. *Eur Radiol* 2014;**24**:1749–57.
15. Kwon JH, Yoon JR, Kim TS, *et al.* Peripheral nerve sheath tumour of the medial plantar nerve with tarsal tunnel syndrome: a case report. *J Foot Ankle Surg* 2009;**48**(4):477–82.
16. Shah A, Botchu R, Rennie WJ. Flexor hallucis longus loose bodies—an unusual cause of plantar mid-foot pain. *OMICS J Radiol* 2013;**2**:152. https://doi.org/10.4172/2167-7964.1000152.