Revisiting the inferior supports of Chopart joint complex

an anatomical study

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Aims
The Chopart joint complex is a joint between the midfoot and hindfoot. The static and dynamic support system of the joint is critical for maintaining the medial longitudinal arch of the foot. Any dysfunction leads to progressive collapsing flatfoot deformity (PCFD). Often, the tibialis posterior is the primary cause; however, contrary views have also been expressed. The present investigation intends to explore the comprehensive anatomy of the support system of the Chopart joint complex to gain insight into the cause of PCFD.

Methods
The study was conducted on 40 adult embalmed cadaveric lower limbs. Chopart joint complexes were dissected, and the structures supporting the joint inferiorly were observed and noted.

Results
The articulating bones exhibit features like a cuboid shelf and navicular beak, which appear to offer inferior support to the joint. The expanse of the spring ligament complex is more medial than inferior, while the superomedial part is more extensive than the intermediate and inferoplantar parts. The spring ligament is reinforced by the tendons in the superomedial part (the main tendon of tibialis posterior), the inferomedial part (the plantar slip of tibialis posterior), and the master knot of Henry positioned just inferior to the gap between the inferomedial and inferoplantar bundles.

Conclusion
This study highlights that the medial aspect of the talonavicular articulation has more extensive reinforcement in the form of superomedial part of spring ligament and tibialis posterior tendon. The findings are expected to prompt further research in weightbearing settings on the pathogenesis of flatfoot.

Take home message
- The anatomical arrangement of the Chopart joint complex indicates a combination of pliability and strong reinforcement medially.
- It questions the primacy of posterior tibial tendon dysfunction in the causation of progressive collapsing flatfoot deformity (PFCD) and provides an alternative hypothesis of altered force transmission dynamics of the foot as a result of assumption of erect posture as a primary cause of PCFD.

Bone & Joint Open

Introduction
The Chopart joint complex is located between the hindfoot and midfoot and is known as the midtarsal or transverse tarsal joint. It consists of the talonavicular and calcaneocuboid joints. The joint complex locks on heel eversion, stabilizing the midfoot during the push-off phase of gait cycle.[1,2]

The spring ligament complex is a major ligamentous support described to have load-bearing capabilities. Davis et al[3] described that the ligament had two parts, namely superomedial and inferior calcaneonavicular. Taniguchi et al[4] described an additional third part of spring ligament, namely the inferoplantar part.

Progressive collapsing foot deformity (PCFD), previously known as adult acquired flatfoot deformity (AAFD), is a "complex 3D deformity with varying degrees of hindfoot valgus, forefoot abduction, and midfoot varus."[5] The acquired flatfoot leads to progressive loss of whole foot function and subsequent disability. It is a common condition, and the prevalence of flexible flatfoot is reported in up to one-quarter of the adult population.[6]

There is an ongoing debate regarding the primary cause of this deformity. While posterior tibial tendon dysfunction (PTTD) was most commonly involved previously,[7] recent literature emphasizes the role of other supporting structures, like spring ligament complex, short and long plantar ligaments, and joint capsules.[8-11] The treatment is based on specific deformity; however, there is no unanimity in the choice and time of the intervention.[12,13]

The present work aimed to explore the comprehensive anatomy of the support system of the Chopart joint complex to aid in understanding the pathoanatomy of PCFD.

Methods

The study was conducted on 40 embalmed cadaveric lower limbs available in the department of anatomy at the All India Institute of Medical Sciences, Bhopal, India. The age and sex of the limbs were not known. Limbs with any apparent evidence of congenital/acquired anatomical abnormalities or deformity on external examination of the foot were excluded.

To dissect the Chopart joint complex, the limb was placed in a prone position. Horizontal incision was made from the base of first digit to the base of the fifth digit, and midline incision was made extending from heel to the base of second digit. The incision was further extended to expose the medial aspect of foot and medial side of lower part of leg to expose the medial malleolus and the flexor retinaculum. The plantar aponeurosis was reflected distally. The muscle of the first layer of the sole was identified and removed. The flexor digitorum accessorius muscle present in the second layer of sole was delineated and removed to better visualize the long tendons of the second layer (i.e. flexor hallucis longus (FHL) and flexor digitorum longus (FDL)).

The flexor retinaculum was cut to expose the tendons of tibialis posterior (TP), FDL, and FHL lying deep to it. The relationship of these tendons with regard to the talonavicular joint was noted. The location of the master knot of Henry (MKH) was determined by using the available surface landmarks. The structures supporting the joint were observed and noted.

The tendons of TP, FDL, and FHL were cut from musculotendinous junction in the lower leg and these tendons were reflected distally to expose the ligaments of the talocalcaneonavicular and calcaneocuboid joints. The different parts of the spring ligament were identified based on their attachments and direction of fibres. The disposition of long and short plantar ligament was observed. The distally reflected tendons were reposited again, and their relationship with the different parts of the spring ligament was noted. In five limbs, the ankle joint was disarticulated to separate the foot. The talus was removed by disarticulating the subtalar joint to observe the superior surface of spring ligament. All the dissections were performed by a team of senior anatomists (SAA, SK, RL).

The comprehensive anatomy of Chopart joint Complex was studied to gain an insight in the supportive role played by the surrounding structures. This was also documented pictorially.

Ethical review statement

This paper had institutional ethical approval (AIIMS Bhopal, no. IHEC-LOP/2019/IM0229).

Results

The anatomical arrangement of structures and their inter-relationships, as observed in the present study, are described in three tiers: bones, ligaments, and tendons.

Osseous arrangement

The joint cavity was in the shape of a sinuous 'S'-shaped curve in a transverse plane, which was convex anteriorly on the medial aspect (talonavicular joint) and concave anteriorly laterally (calcaneocuboid joint). The articular areas of the calcaneus and cuboid are in close approximation, whereas a triangular gap persists between the calcaneus and navicular, which widens as we move medially (Figure 1).

A shelf-like process of cuboid snuggly fitted into the coronoid fossa of the calcaneus on the inferior aspect of calcaneocuboid joint (Figure 2).

The medial end of the concave articular facet close to the tuberosity projected proximally, creating a shelf inferiorly (Figure 2). A small beak-like process emerged from the middle of the inferior margin of the articular area of the navicular, and pointed towards the constricted part between the anterior and middle calcaneal facets of the sustentaculum tali (Figure 2). This beak was variably developed but was present in all the limbs studied.

Ligamentous arrangement

Three ligaments were observed inferiorly, the spring ligament complex medially and short and long plantar ligaments laterally (Figure 3).

Spring ligament complex was a triangular structure with three parts – superomedial, inferomedial, and inferoplantar.

The superomedial part of the ligament was the largest and was placed on the medial aspect of the talonavicular articulation; this part thus had a medial and a lateral surface (Figure 3). Both surfaces of this part were entirely covered with cartilage. Proximally, this part of the spring ligament was attached to the inferior margin of the medial part of sustentaculum tali and distally to the under-surface of the medial aspect of the navicular tuberosity. The superomedial part was confluent with inferomedial part towards the surface facing the joint cavity, but could be delineated separately from the inferior aspect (Figure 3 and Figure 4).

The inferomedial part had similar proximodistal attachments (lateral to the attachments of the superomedial

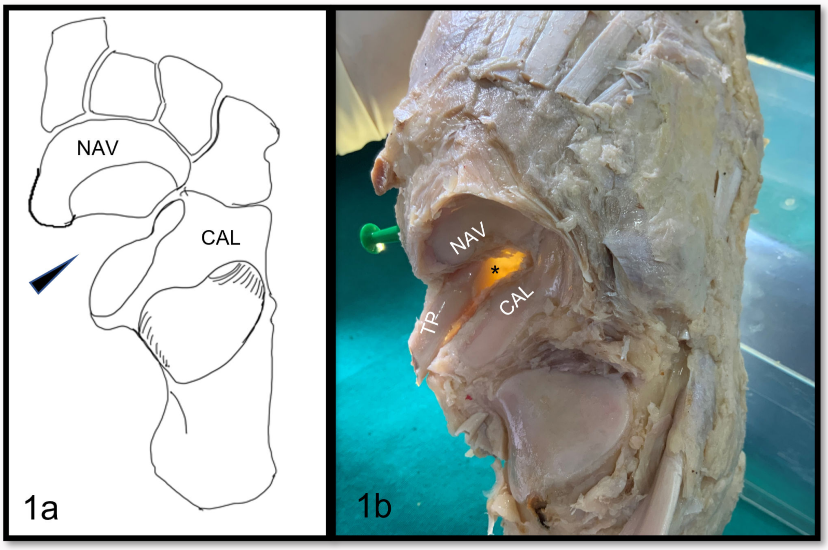

Fig. 1

a) Schematic line diagram, and b) photograph of the socket of the talocalcaneonavicular joint after removing the talus. A triangular gap (solid arrow head) between the calcaneus and the navicular bone is seen, which narrows laterally and widens medially; it is also the highest in location. CAL, calcaneocuboid; NAV, navicular, TP, tendon of tibialis posterior.

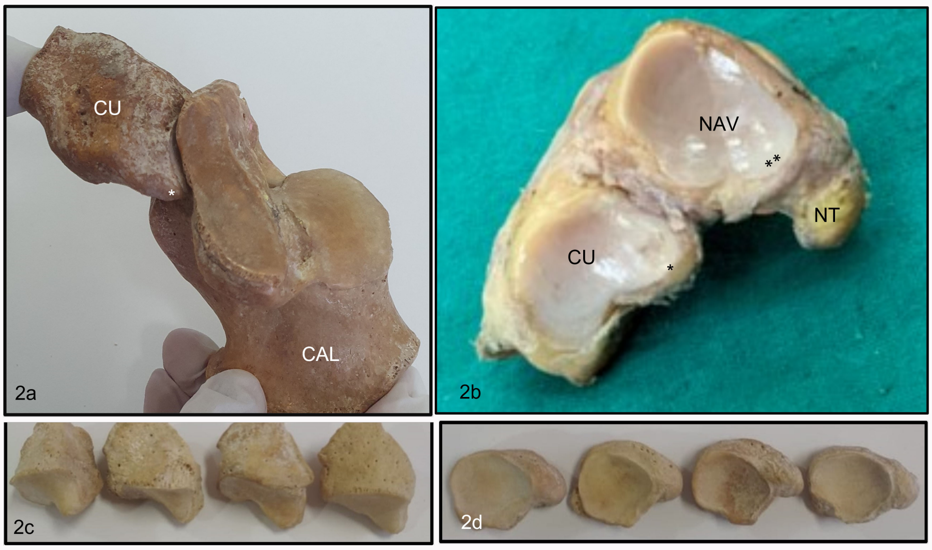

Fig. 2

a) Beak of cuboid fitting into the coronoid fossa of the calcaneus, b) shelf-like inferior supports of the cuboid (*) and navicular (**), c) beaks of the cuboid bone. and d) beaks of the navicular bone. CAL, calcaneus; CU, cuboid; NAV, navicular; NT, navicular tuberosity.

part) onto the sustentaculum and navicular tuberosity, respectively. The fibre direction of the inferomedial part was acutely oblique, directed forwards and medially. The superior surface of the inferomedial part facing the joint cavity was variably covered with cartilage.

The inferoplantar bundle was cord-like and was proximally attached to the coronoid fossa of the calcaneus, and distally to the inferior aspect of the navicular; the fibres were directed obliquely forwards and medially. A triangular gap was observed between the inferoplantar and inferomedial bundles inferior to the head of the talus (Figure 3).

The spring ligament, when visualized from the aspect of the joint cavity, was partially covered with cartilage and partially (towards the apex of the bony gap bridged by spring ligament) with fibrofatty tissue covered by synovium (Figure 4).

A faceted area was seen on the medial surface of the head of the talus corresponding to the superomedial part of the spring ligament. A small triangular area on the head of the talus, between the facet for the spring ligament and the sustentaculum tali, was somewhat depressed and pitted. This corresponded to the fibrofatty tissue filling the lateral part of the gap between the calcaneus and the navicular (Figure 5).

The long and short plantar ligaments were present inferior to the calcaneocuboid joint. The long plantar ligament was a longitudinal bundle extending from the inferior surface of the calcaneus between the anterior and medial tubercles to the cuboid and bases of metatarsals.

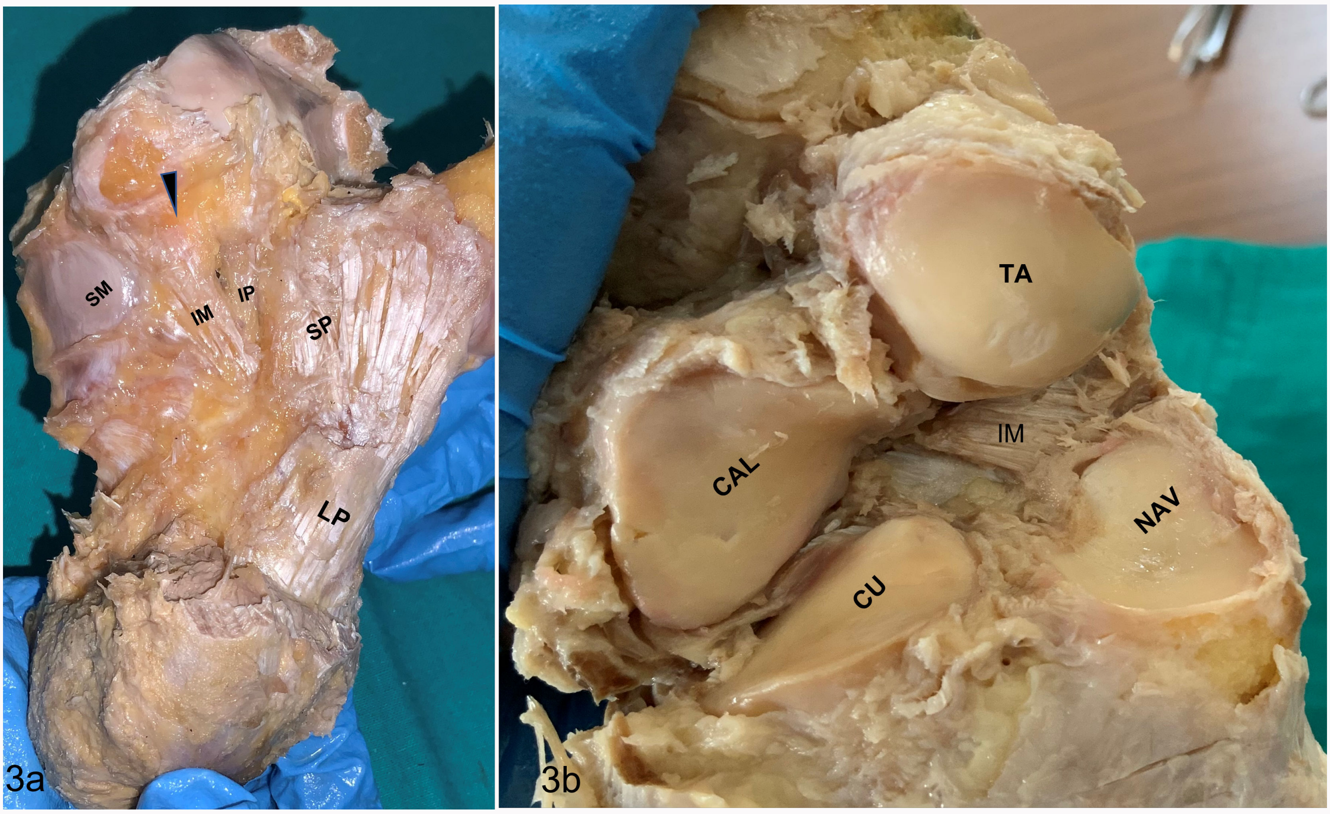

Fig. 3

a) Inferior static supports of the Chopart joint. Arrowhead shows the gap between the inferomedial and inferoplanter bundles of the spring ligament. Note the extent of the superomedial bundle of the spring ligament. b) Direction of fibres of inferoplantar bundle when observed from within the joint cavity. CAL, calcaneocuboid; CU, cuboid; IM, inferomedial; IP, inferoplanter; LP, long plantar ligament; NAV, navicular; SM, superomedial; SP, short plantar ligament.

The short plantar ligament was attached to the anterior tubercle of calcaneus proximally, fanned out anteromedially to be attached to the inferior surface of the cuboid. The relative disposition of short and long plantar ligaments with regard to the inferior surface of calcaneocuboid joint was medial and lateral, respectively (Figure 3).

Tendinous arrangement

The TP tendon, close to its termination, trifurcated in a superficial slip that coursed towards medial cuneiform, a deep slip towards navicular tuberosity, and a plantar slip that coursed towards the sole; the plantar slip was either equal in size or thicker than the superficial slip and the deep slip. Directionally, it appeared to be the continuation of the main TP tendon. This slip passed through a notched area just medial to the navicular tuberosity and coursed distally towards the tarsals and metatarsals for attachment (Figure 6).

The three parts of the spring ligament were buttressed by a peculiar arrangement of tendons of TP, FDL, and FHL: 1) the main tendon of TP, proximal to its trifurcation, was positioned just medial to the superomedial part (Figures 1 and 7); 2) the plantar slip was positioned just inferior to the inferomedial part of the spring ligament (Figure 7); and 3) the crossing of tendons of FDL and FHL forming the MKH was positioned exactly inferior to the gap between the inferoplantar and inferomedial bundles of the spring ligament, so at this position, the MKH was separated from the head of the talus by the synovial membrane only (Figures 7 and 8).

Localization of master knot of Henry

The MKH was located in the same horizontal and coronal plane as that of the lower margin of the navicular tuberosity. This point is located at more than one-third but less than two-thirds of the total distance between the tip of the medial malleolus and the navicular tuberosity in the same plane in all the feet studied (Figure 8).

The medial plantar nerve extends forwards in the foot, running superficial to MKH. A slight gap between the MKH laterally, and plantar slip of TP medially, is devoid of any neurovascular structure. The flexor digitorum accessorius muscle lay inferior to the calcaneocuboid joint.

Discussion

The anatomical arrangement of the structures present inferior to the Chopart joint complex was three-tiered: osseous, ligamentous, and tendinous. Specific geometry and inter-relationship of the structures that might enhance support were observed.

Osseous support

These have been explored piecemeal in the available literature, but have not been observed comprehensively as possible supports to the TCN joint. The joint cavity of the Chopart joint complex is sinus in shape. This geometry might

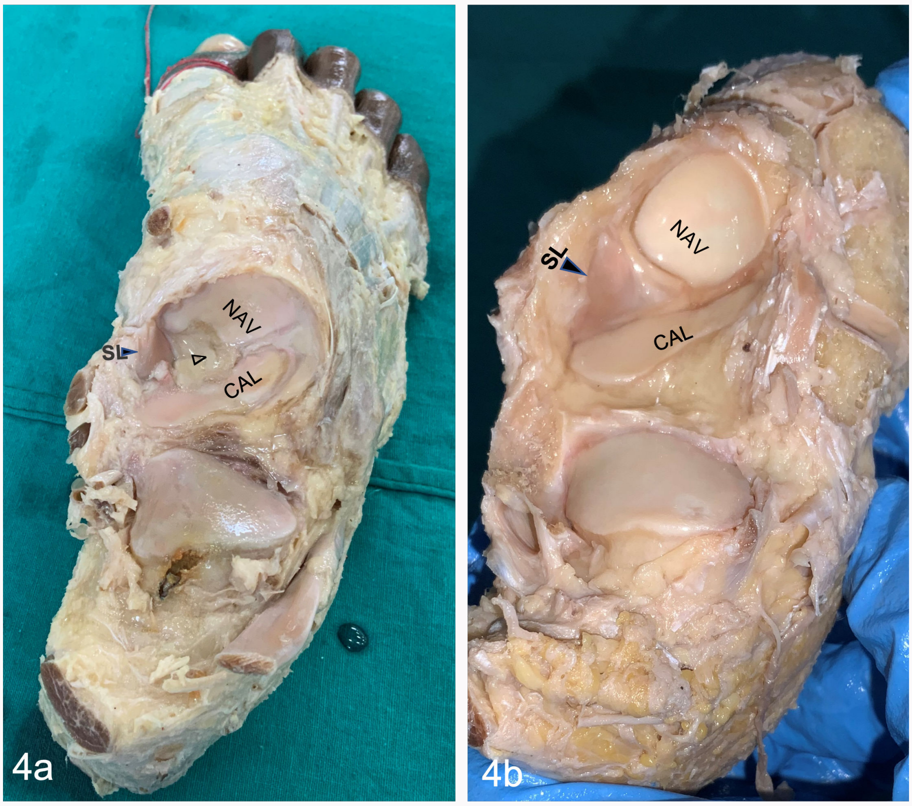

Fig. 4
a) Lesser cartilage coverage and more fibrofatty tissue as compared by b) variability in the extent of the cartilage covering the spring ligament and the variable amount of fibrofatty tissue (empty arrowhead) present. The solid arrowhead shows the highest extent of the spring ligament. CAL, calcaneocuboid; NAV, navicular; SL, spring ligament.

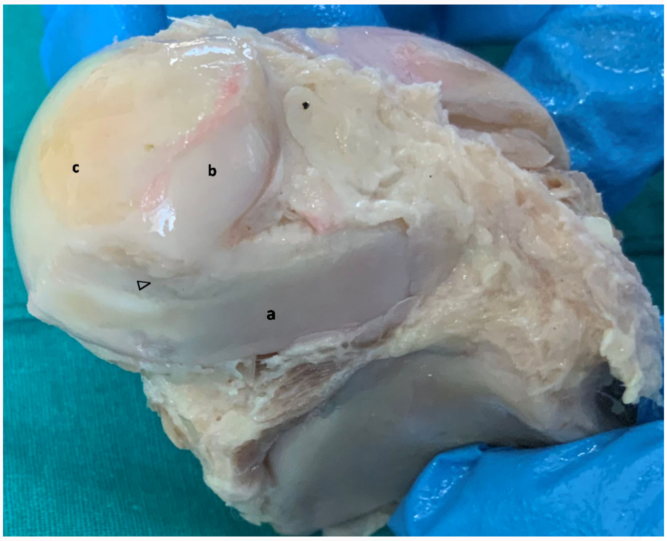

Fig. 5
Faceted area on the head of the talus for the superomedial part of the spring ligament. A rough depressed area (Δ) is also seen between the particular areas for the a) calcaneocuboid, b) spring ligament, and c) navicular.

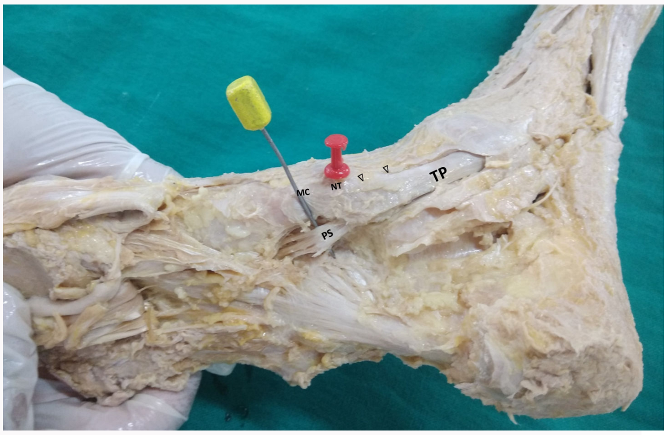

Fig. 6
Thick plantar slip (PS) of the tendon of the tibialis posterior coursing into the sole. Arrowheads indicate the other slips of the tibialis posterior, going towards a) navicular and b) medial cuneiform. LP, long plantar ligament; SP, short plantar ligament; TP, tendon of tibialis posterior.

accord stability to the foot in the stance phase when the foot moves from the first, second, and third rockers, where the hindfoot, midfoot, and forefoot become rigid successively, while the other portions are mobile.[14] The joint cavity not being in a single plane may help in stabilizing the joint during the movements between the forefoot and midfoot.

The medial end of the articular surface of the navicular extends medioplantar, thus creating a shelf-like surface for the head of the talus. This fact has not been highlighted in the available literature. A beak of navicular has been described by Golano et al[15] and Espinosa et al.[16] A similar beak was observed in all the specimens studied. The beak was developed to a

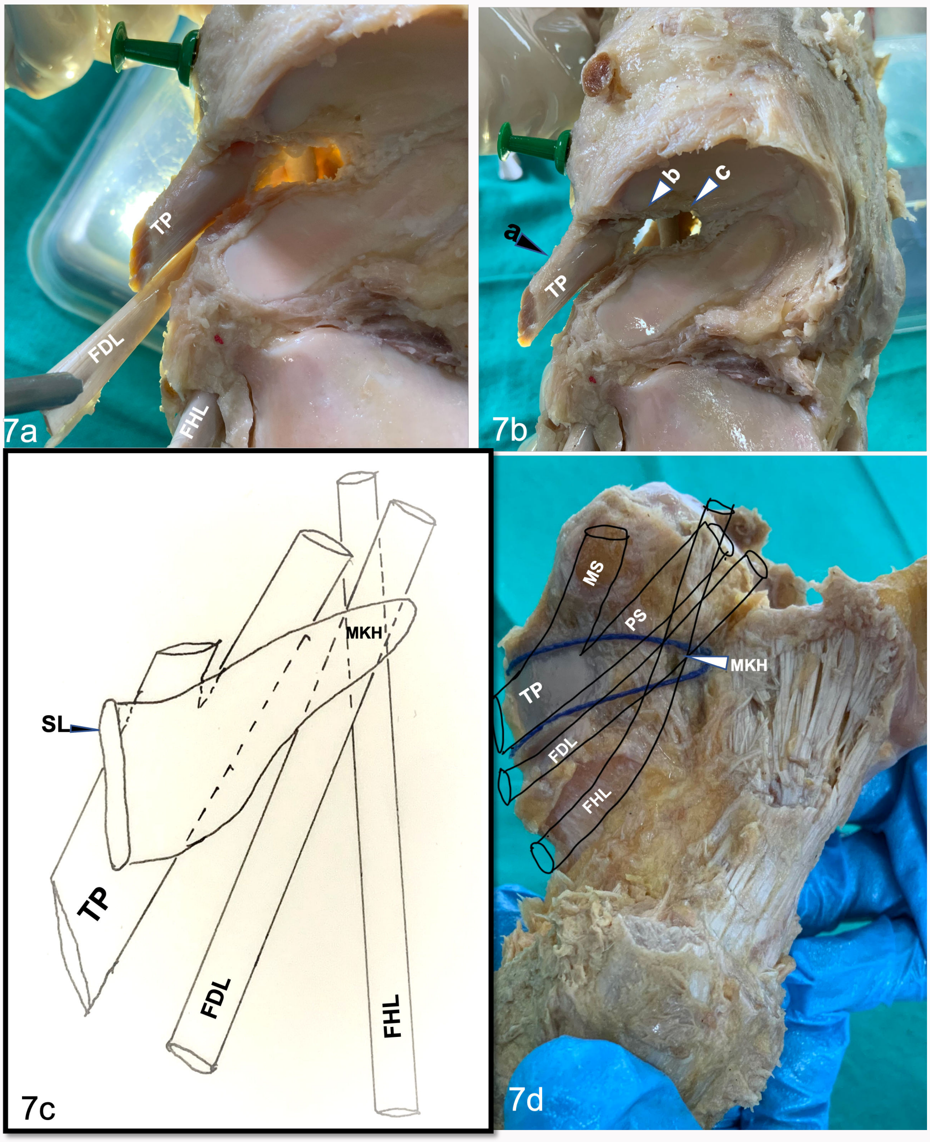

Fig. 7

Schematic of the dynamic support system of the talocalcaneonavicular (TCN) joint. Tendinous reinforcement of TCN joint as seen from above after removing talus and the spring ligament. Note the main tendon of tibialis posterior (TP) buttressing the highest and widest part of the osseous gap. a) TCN joint medially, b) the planter slips of tibialis posterior reinforcing inferomedially, and c) and the master knot of Henry (MKH) reinforcing the joint inferiorly. The schematic representation of the spring ligament with superimposition of dynamic supports reinforcing its different parts: the thread shows the spring ligament, demonstrating various parts of the spring ligament complex seen from the inferior aspect with schematic superimposition of dynamic supports, reinforcing its different parts. FDL, flexor digitorum longus; FHL, flexor hallucis longus; MS, main slip of the tendon of tibialis posterior, PS, planter slip of the tendon of tibialis posterior.

variable extent and was pointing towards the narrow-constricted portion between the middle and anterior talar facets on the sustentaculum tali.

The beak of the cuboid was very well developed and fitted snugly into the coronoid fossa of the calcaneus. The osseous geometry is more congruent in calcaneocuboid joint as compared to the talonavicar joint. Wang et al,[17] while comparing the forces in chimpanzees and human feet, also observed that during evolution, the calcaneocuboid joint of humans has become more stable.

Ligamentous support

The short plantar ligament has not been described as 'fanned out', except for in one study by Melão et al[18] that did not elaborate upon its purpose in the context of its supporting role in calcaneocuboid joint.

The spring ligament having three bundles was also well corroborated in this study.[18,19] Some additional aspects hitherto not highlighted in the available literature were: 1) the major expanse of spring ligament is medial to TCN joint rather than inferior; 2) there is a lack of fibrous capsule inferiorly, as the superomedial and inferomedial part of the spring ligament act as an articular area for the TCN joint and are covered by articular cartilage; 3) the fibrocartilage predominantly covers the superomedial part of the ligament and the inferomedial part to a variable extent, and the lateral part of the triangular gap between talus and navicular is covered by fibrofatty tissue; and 4) the gap between the inferomedial and inferoplantar bundle is a potential weakness inferiorly.

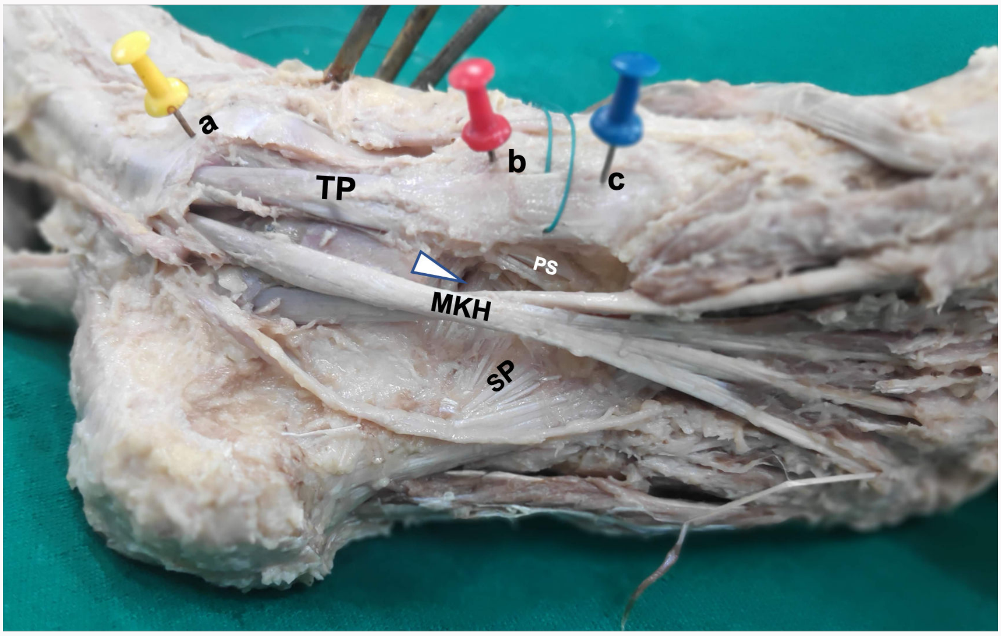

Fig. 8
Surface landmarks for localizing the master knot of Henry (MKH). a) tip of medial malleolus, b) navicular tuberosity, and c) medial cuneiform. The plantar slip of the tibialis posterior is also seen. The MKH is positioned just inferior to the gap between the inferoplanter and inferomedial bundles of spring ligament, indicated by the arrowhead. PS, planter slip of the tendon of tibialis posterior; SP, short plantar ligament; TP, tendon of tibialis posterior.

Tendinous support

It was observed that the TP, along with FDL and FHL (in the form of MKH), are positioned in a manner that might offer sound support to not just the inferior, but also the medial aspect of the talonavicular joint. Though the presence of these tendons is documented in the literature, their precise relation in terms of their reinforcing function of various parts of the spring ligament has not been emphasized enough.

It is noteworthy that the lateral part of the Chopart joint complex has good osseous support, whereas the medial aspect of the joint complex shows weakness in it, which is reinforced by ligamentous and tendinous supports.

Localization of master knot of Henry

The present study also proposed a practical way of localizing the MKH by using proportions of readily palpable landmarks, rather than distance measurements, as proposed by Beger et al,[20] Vasudha et al,[21] and Wan-ae-loh et al.[22] The presence of knot or stratification over the triangular gap between the bundles of spring ligaments reinforces the fact that nature offers dynamic support when needed.

While primarily the tendon of TP has been implicated in the causation of PCFD, Pasapula et al[23] proposed an alternative hypothesis, suggesting involvement of spring ligament as a primary cause, and attenuation of TP tendon as secondary to that.

In the light of observations of this study, the presence of strong reinforcements to the talocalcaneal joint medially indicate a possible mechanism to withstand the forces passing through the talus towards the foot. Persistent impact on the spring ligament and TP medially may result in their inability to offer dynamic support, thus precipitating PCFD.

The authors feel that it would be worthwhile to further explore the role of altered force transmission dynamics in the weightbearing foot, considering that human bipedalism is a recent acquisition in evolutionary history.

In conclusion, the spring ligament complex is more medial in its expanse than inferior. The superomedial part is more extensive than the intermediate and inferoplantar parts and is buttressed by a thick, main tendon of the tibialis posterior.

The thick plantar slip of the tibialis posterior offers inferomedial support to TCN joints and reinforces the inferomedial part of the spring ligament. The MKH is positioned under the gap between the inferomedial and inferoplantar bundles of the spring ligament. An easy approach for locating MKH is also suggested.

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S. Kotgirwar: Formal analysis, Validation.
R. Lalwani: Conceptualization, Methodology, Project administration, Writing – original draft, Writing – review & editing.

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ICMJE COI statement

The authors confirm that they have no conflicts of interest to declare.

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The data supporting this study findings are available to other researchers from the corresponding author upon reasonable request.

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