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The synovial joints of the human foot[1]

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SUMMARY

The human foot is considered an organ with an assortment of tissues with different morphological characteristics and well defined limits, but effectively has a simple functionality when static that becomes extremely complex when in movement. Its complex structure, comprised of an elastic and resistant skin covering a bone framework, joints, muscles, tendons, veins and nerves, can be compared to an efficient mechanical assembly. After a long and extraordinary evolutive journey, the human foot has undergone numerous changes to perfect its function; it has lost most of its grabbing function whilst gaining new characteristics that have ultimately allowed the modern man to stand upright. The complex articular structure of the human foot consists of thirty four synovial joints, of which eighteen have curved surfaces and sixteen plane surfaces. Following the criteria set by the systematic, radiological and clinical anatomy, the Authors contribute further to the current knowledge on the ankle, tarsal (anatomic subtalar, transverse tarsal, cuneonavicular, intercuneiform and cuneocuboid), tarsometatarsal, intermetatarsal, metatarsophalangeal and interphalangeal joints and dorsal, plantar and interosseous ligaments of the human foot.

The articular lines of the transverse tarsal (Chopart) and tarsometatarsal (Lisfranc) joints are particularly interesting and not only from a surgical point of view; through a straightforward identification of few reference points, it is possible to find the medial and lateral extremities of the Chopart's and Lisfranc's lines, the former pinpoints the boundary between the hindfoot and midfoot and the latter between the midfoot and forefoot.

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1. INTRODUCTION

Among the most widespread transport methods, one in particular stands out. Millions of these wonderful and highly sophisticated machines can be found all over the world. They contain just 28 parts which interact with each other through 34 linkages with the help of 20 transmission belts, are co-ordinated by a complex sensor system and governed by the most advanced computer ever designed, as well as being powered by an ideal fuel which is cheap, non-toxic and ecological (Ridola et al., 2002).

Like a four by four, this perfect machine is able to adjust to any kind of terrain thanks to its capability to modify its structure to adapt for moving on uneven ground; it is also capable of maintaining a constant balance as well as distributing the weight it is carrying evenly.

This machine is the human foot, formed by 28 pieces (the bones), 34 linkages (the synovial joints), 20 transmission belts (the intrinsic muscles), co-ordinated by numerous sensors (the nerves), regulated by an advanced computer (encephalon) and fuelled by a fluid (the blood) through a complex vascular network.

This organ, an assortment of tissues with different morphological characteristics and well defined limits, has a simple functionality when static that becomes extremely complex when in movement (Ridola, 2004).

Keeping in mind that the symmetry between the feet is certainly influenced by the subject being right- or left-handed, a study by Ridola et al. (2001) using the computerized baropodometer (BPE), has shown that in young people of both sexes there is no correspondence in linear measurements such as footprint length (FL), anterior heel width (AHW), isthmus width (IW) and posterior heel width (PHW) between the right and left foot; the non-correspondence percentages were respectively 74% in FL, 58% in AHW, 71% in IW and 73% in PHW. On the other hand the valuation of the plantar footprint showed a correspondence (78%) between right and left foot with normal footprints in 55.5% of the total sample (IW ranging between 1/3 and 2/3 of AHW), hollow feet in 20.5% (IW less than 1/3 of AHW) and flat feet in 2% (IW more than 2/3 of AHW). A correspondence (82%) was also observed studying the digital formula, in particular: 1>2 (egyptian foot): 62%; 1=2 (standard foot): 9%; 1<2 (greek foot): 11%.

The foot is a hard-wearing machine but it nonetheless needs to be protected due to its fragility and complexity. It requires constant maintenance, bearing in mind that the load both of the feet need to withstand is estimated at around 11[illegible] tons/day (Gravante et al., 2005).

However, the foot cannot be regarded as a merely mechanical object; it is one of the most vulnerable parts of the human body as it is exposed to damage or trauma, forced to be in contact with ground, risking lesions or diseases. Famous feet have contributed to moments of great joy; extraordinary goals by footballers such as Luca Toni, David Trezeguet, Andriy Shevchenko and Ronaldinho will be remembered by some of us for decades to come; and in cases when a foot has to be ampu tated, the distress caused by losing a limb which has allowed man to stand upright and become mobile, is evident to all.

After a long and interesting journey evolving through the arboreal ancient primates, brachiating anthropoid and gorilla, in the modern man the foot has lost most of its grabbing function whilst acquiring novel static and dynamic functions (Bruno, 1958) (Fig. 1).

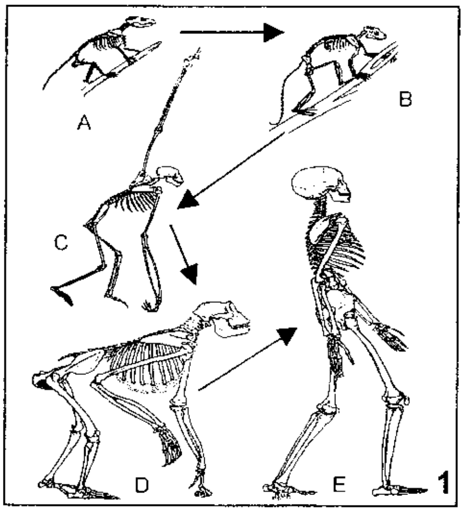

Fig. 1 — The evolution of the foot through marsupials (A), arboreal primates (B), brachiating anthropoid (C), gorilla (D) to orthograde modern man (from Morton D.J, 1948, modified).

At least ten easily noticeable elements have contributed to this alteration (Benninghoff and Goertler, 1975; Williams, 1995):

1. the horizontal position of the foot at a 90 degree angle in relation to the leg in order to increase the support platform;
2. a 180 degrees rotation relatively to the hand;
3. the medial positioning of the first ray, short, rigid and on the same level with the other toes;
4. the loss of opposing function of the first toe;
5. the longitudinal axis of the foot resting on the second toe that is relatively firm;
6. the atrophy of the phalanges due to the modification of their functional role;
7. the morphological disposition of the skeletal structure with the dorsum facing upwards and the plantar vault downwards;
8. the increased mass of talus and calcaneus on which the weight of the body rests;
9. the increased strength of the metatarsal bones;
10. the distal end of the tibia and fibula form a mortise (deep socket) into which the pulled shaped trochlea of the talus fits (Figs. 2, 3, 4).

The human foot can be compared to a complex mechanical assembly. It combines a bone structure supported by joints, muscles, ligaments, veins and nerves, all

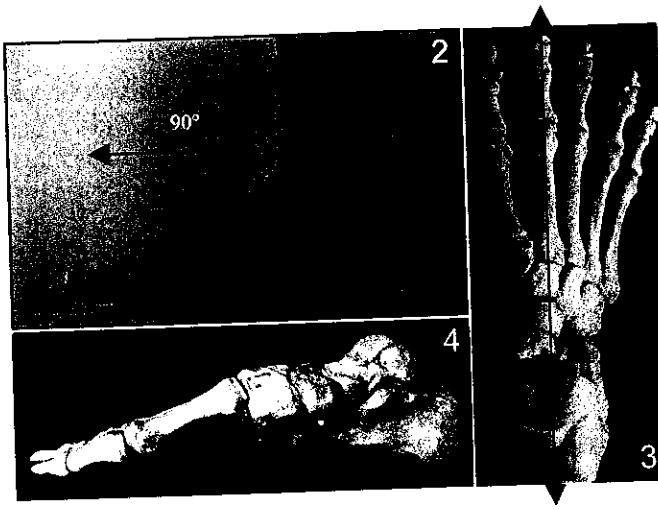

Fig. 2 — The horizontal position of the foot at a 90 degree angle in relation to the leg is one of the morphological characteristics that have contributed to the perfection of its evolution.
Fig. 3 — The dorsum of the foot. Note the 180 degrees rotation relatively to the hand, the morphological changes of the first ray and the longitudinal axis of the foot onto the second toe.
Fig. 4 — Details of the medial margin of the foot; these include the mass of the talus and calcaneus, increased strength of the metatarsal bones, atrophy of the phalanges and the disposition of the skeletal system of the plantar vault.

wrapped up in a flexible and resistant skin layer which is particularly reinforced in the highest strain regions. The prevalent skeletal component determines the formation of an arch-shaped bone structure with a posterior convex dorsum and a concave basis that rests on the ground. The arch conformation contributes to a higher load bearing capacity; at the same time the soft tissues of the sole of the foot are protected from compression. The stability of the plantar arch depends upon: the shape of the skeletal structures arranged like an architectonical vault; the strength and resistance of the ligaments that join the different bones; the stiffness of the plantar ligaments and aponeurosis that constitute the joist that links the extremities of the pillars; the action of the tendons of the intrinsic and particularly extrinsic muscles that suspend the arch from above (Ridola e Palma, 2001) (Fig. 5).

Fig. 5 — Sagittal section of an anatomical preparation of the foot through the medial longitudinal arch showing the calcaneus, talus, navicular, medial cuneiform, first metatarsal bone, proximal and distal phalanges of the first toe. The stability of the plantar vault is determined by the shape of the bones, the strength of the ligaments, the plantar ligaments and aponeurosis that connect the anterior and posterior pillars of the longitudinal arches, and by the tendons of the intrinsic and extrinsic muscles that suspend the arch from above.

2. GENERAL ASPECTS OF THE SKELETAL SYSTEM OF THE FOOT

The human foot is formed by three elements: the bones, the joints and the muscles (Snell, 1995).

The feet of vertebrates have less skeletal segments than those of amphibians and reptiles, lacking the rays of the prehallux on the medial margin and the postminimus on the lateral margin, reducing the number of rays to five; in the tarsum, the os intermedium is fused with the proximal central bone originating the talus; in turn, the fusion of the fourth and fifth tarsal bones originates the cuboid, the fusion of the distal centralia originates the navicular, whilst the calcaneus, located close by, shifts backwards settling under the talus and therefore assuming the role of a fundamental posterior support for the foot (Morton, 1948; Stark, 1955) (Fig. 6).

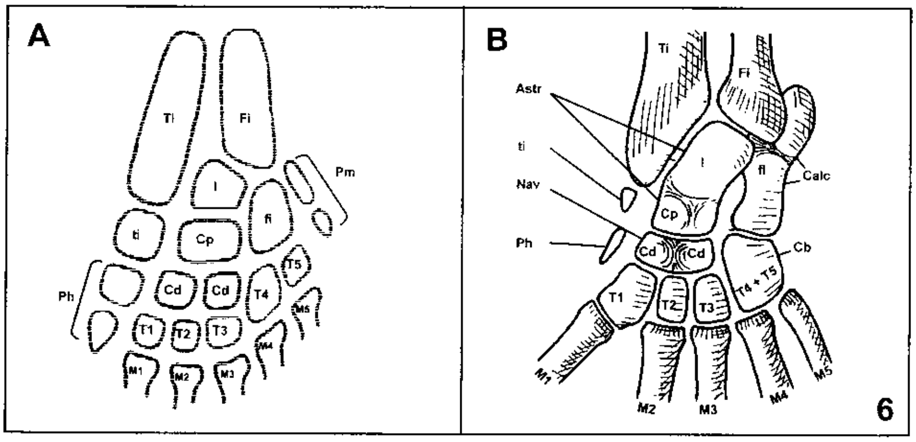

Fig. 6 — The archetype of the skeleton of amphibians (A: from Morton D.J. 1948, modified) and reptiles (B: from Stark D. 1955, modified) Ti = Tibia; Fi = Fibula; ti = tibial; fi = fibular; Calc = Calcaneus; I = Os intermedium; Cp = proximal Central; Cd = distal Centralia; Astr = Talus (I + Cp); Nav = Navicular (Cd + Cd); T = first, second, third, fourth and fifth Tarsals; Cb = Cuboid (T4 + T5); M = first, second, third, fourth and fifth Metatarsals; Ph = Ray of the prehallux; Pm = Ray of the postminimus. The skeleton of the feet of vertebrates has less sections than those of amphibians (A) and reptiles (B), lacking the ray of the prehallux (Ph), the ray of the postminimus (Pm) and tibial (ti); in the tarsum, the os intermedium (I) is fused with the proximal Centralia (Cp) originating the talus (Astr); the fibular element (fi) is repositioned underneath the talus (Astr) forming the calcaneus (Calc); the distal centralia (Cd) are combined originating the navicular bone (Cd + Cd); the fourth and fifth tarsals (T4 + T5) fuse to create the cuboid (Cb), whilst the first, second and third tarsals (T1, T2, T3) form the medial, intermediate and lateral cuneiforms respectively.

The skeleton of the human foot is comprised of 28 canonical bones: 7 tarsal bones disposed in a proximal row (talus and calcaneus), a central bone (navicular) and a distal row composed of the medial, intermediate and lateral cuneiform and the cuboid; 5 metatarsals (I-V); 14 bones for the toes, 3 phalanges (proximal, middle and distal) for each toe from the second to the fifth, two phalanges for the first toe (proximal and distal); 2 sesamoid bones resting under the plantar portion of the head of the first metatarsal bone (Balboni et al., 1990; Rosse and Gaddum Rosse, 1997).

Talus and calcaneus constitute the hindfoot; navicular, cuboid and cuneiforms form the midfoot; metatarsal bones and phalanges the forefoot (Figs. 7, 8).

Fig. 7 — Sagittal section of an anatomical preparation of the human foot passing through the medial longitudinal arch and the first toe where it is clear that the skeletal component prevails on the other structural components. 1. Talus; 2. Calcaneus; 3. Navicular; 4. Medial cuneiform; 5. First metatarsal; 6. Proximal phalanx and 7. Distal phalanx of the first toe; 8. Medial sesamoid located plantarly on the head of the first metatarsal.

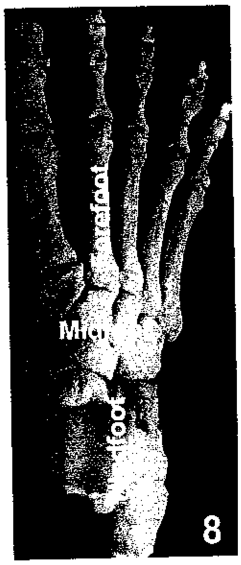

Fig. 8 — The skeletal structure of the human foot. The talus and calcaneus make up the hindfoot, the navicular, cuboid and cuneiforms form the midfoot, whereas the forefoot consists of the metatarsals, the two sesamoids of the first toe and the phalanges.

Structurally the foot is exclusively comprised of short and long bones. The tarsal bones are short bones, with spongy bone covered by a cortical; metatarsal bones and phalanges are long bones with a central compact bone core and two extremities, proximal (base) and distal (head) structurally conformed like in the long bones (Fig. 9).

In the foot there are 34 synovial joints, of which 17 with complementary curved articular surfaces and 17 with plane articular surfaces (plane joint). Moreover, numerous ligaments are disposed dorsally, plantarly and in between the bones. Finally, the foot contains 20 intrinsic muscles, 18 of which are in the plantar region and 2 in the dorsal region; the insertions of 11 tendons out of the 12 muscles of the leg are also located in the foot (Platzer, 1985 and 2000).

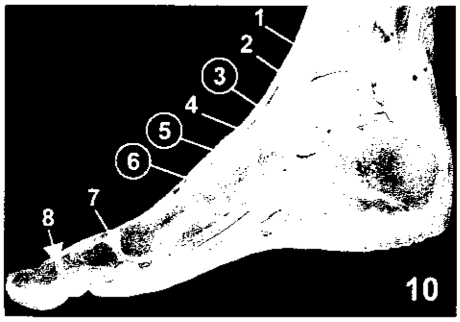

Fig. 10 — Sagittal section of an anatomical preparation of the human foot passing through the medial longitudinal arch and the first ray where some synovial joints with curved articular surfaces can be seen: 1. Ankle (talocrural) joint; 2. Anatomical subtalar joint; 4. talonavicular (transversal tarsal) joint; 7. First metatarsophalangeal joint; and finally, 8. Interphalangeal joint of the first toe. This anatomical preparation of the foot also contains the following synovial joints with plane articular surfaces: 3. Anterior talocalcaneal (transverse tarsal) joint; 5. Medial part of the compound cuneonavicular joint; 6. First tarsometatarsal joint.

pound joints with more than two articular surfaces (i.e. the talocalcaneonavicular and cuneonavicular); moreover, not all of the synovial joints of the foot have independent and single articular cavities (apart from the metatarsophalangeal and interphalangeal joints) whereas the anterior tarsal joints contain interconnected articular cavities; in the tarsometatarsal joint there are only three articular cavities, with the medial one being situated between the base of the first metarsal and the medial cuneiform bone, the intermediate laying between the base of the second and third metarsal and the cuneiform bones and the lateral one between the base of the fourth and fifth metatarsal and the cuboid; finally, some of the synovial joints of the foot (intercuneiform and cuneocuboidal joints) contain interosseous ligaments effectively including them in the amphiarthrosis (Hochschild, 2005).

For the taxonomic classification of the synovial joints of the foot we have considered the presence of the articular surfaces with their cartilaginous layer as a fundamental feature.

The foot joints permit the movement of the foot on three axes:

1. the transverse axis, situated between the lateral and medial malleolus and corresponding to the rotation axis of the ankle joint, consents movements of dorsal flexion (20-30 degrees angle) and plantar flexion (30-50 degrees angle)
2. the longitudinal axis of the leg around which 35-45 degrees angle abduction and adduction movements are permitted
3. the longitudinal axis of the foot, along the second toe, around which is possible to have medial rotation or supination (50 degrees) and lateral rotation or pronation (20-25 degrees angle).

Adduction, abduction, medial rotation and lateral rotation movements are permitted by the subtalar, transverse tarsal and tarsometatarsal joints. On the other hand, the dorsal and plantar flexions of the toes are permitted by the metatarsophalangeal and interphalangeal joints.

4. ANKLE JOINT

The articular surfaces are represented proximally by the tibiofibular complex and distally by the trochlea of talus (Inman, 1976).

and more superficial ones that reach the tuberosity of the navicular bone (tibionavicular pars); other fibres, vertically orientated, reach the medial margin of the plantar calcaneonavicular ligament and the sustentaculum tali (tibiocalcanear pars); other fibres, diagonally orientated, are inserted into the medial tubercle of the posterior process of talus (posterior tibiotalar pars) and constitute the broader pars of the medial ligament (Fig. 12).

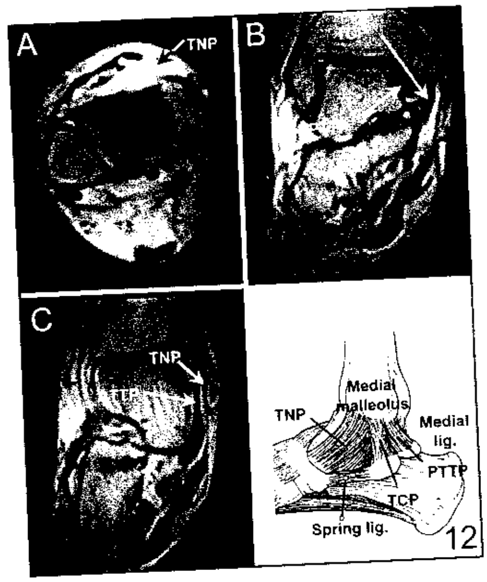

Fig. 12 — Picture and MRI scan image (A, B, C) of the medial ligament. A: On the surface, tibionavicular part (TNP); B: Tibiocalcaneal part (TCP) and posterior tibiotalar part (PTTP); C: Anterior tibiotalar part (ATTP) which is located underneath the tibionavicular part (TNP).

The lateral ligament originates from the lateral malleolus and is inserted into the talus and calcaneus bones. In comparison with the medial ligament it represents a weaker support for the ankle joint and it contains three ligaments: the anterior talofibular ligament, structurally weak, reaches the talus neck laterally; the calcaneofibular ligament that diagonally reaches the calcaneus stabilising the subtalar joint; the posterior talofibular ligament, stronger and more resistant, that is inserted into the lateral tubercle of posterior process of the talus (Fig. 13).

The ankle joint determines plantar (30-50 degrees angle) and dorsal flexion (20-30 degrees angle) movements of the foot; when the foot if flexed plantarly there is also the possibility for minute adduction, abduction and rotation movements (Palastanga et al., 2004).

5. TARSAL JOINTS

The tarsal joints consist of a complex of extremely stable joints; these joints can be divided in a posterior group formed by the talocalcaneal joint; a middle group, the transverse tarsal joint, that can be divided in a medial portion, the talocalcane-

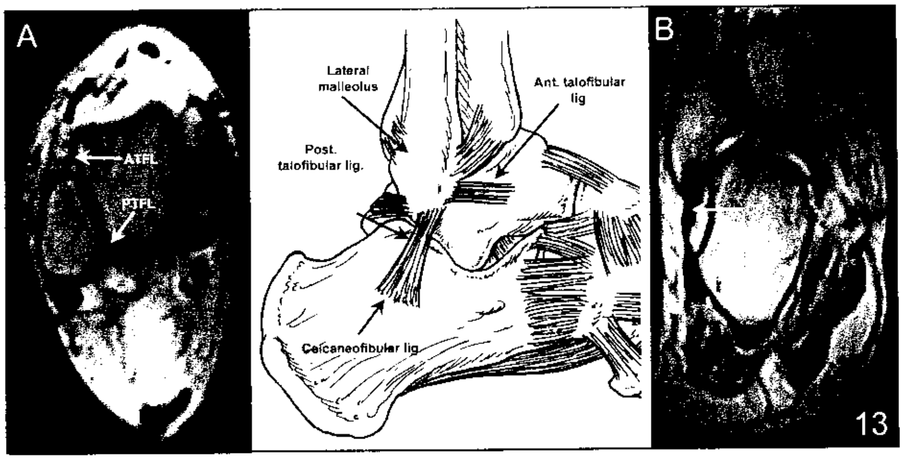

Fig. 13 — Picture and MRI scan image (A, B) of the lateral ligament. A: Anterior talofibular ligament (ATFL) and posterior talofibular ligament (PTFL); B: Calcaneofibular ligament (CFL).

onavicular joint, and a lateral portion, the calcaneocuboid joint; and an anterior group that comprises all the joints between the navicular, cuneiform and cuboid bones (Fig. 14).

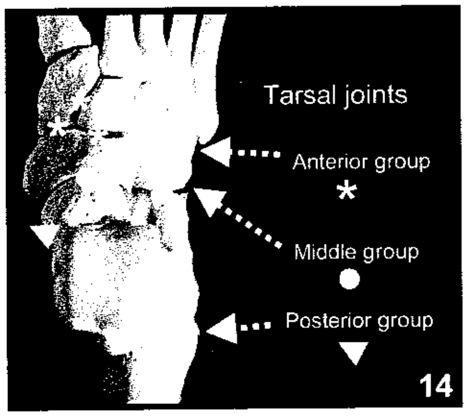

Fig. 14 — The tarsal joints. The posterior group: Posterior talocalcaneal (subtalar) and anterior talocalcaneal joints; The middle group: Transverse tarsal joint made up medially by the talocalcaneonavicular joint and laterally by the calcaneonavicular joint; The anterior group: Compound cuneonavicular, intercuneiform and cuneocuboid joints.

5.1 Talocalcaneal joint (posterior group)

The talocalcaneal joint, a modified multiaxial joint, is comprised of two separate joints, anterior and posterior, separated by independent synovial cavities (Ridola and Palma, 2004).

In the posterior talocalcaneal joint the two articular surfaces, the posterior calcaneal articular facet of the talus and the posterior talar articular surface of the calcaneus bone, are relatively wide, curved and shaped like a saddle joint. This joint is defined "the anatomical subtalar joint" and is positioned underneath the talus bone, aligned with the ankle joint. The fibrous layer is thin and is inserted on the margins of the articular surfaces, with the exception of the posterior talar articular surface of the calcaneus where it is in lesser proximity; the synovial membrane has a diverticle that is connected with the articular cavity of the ankle joint (Fig. 15).

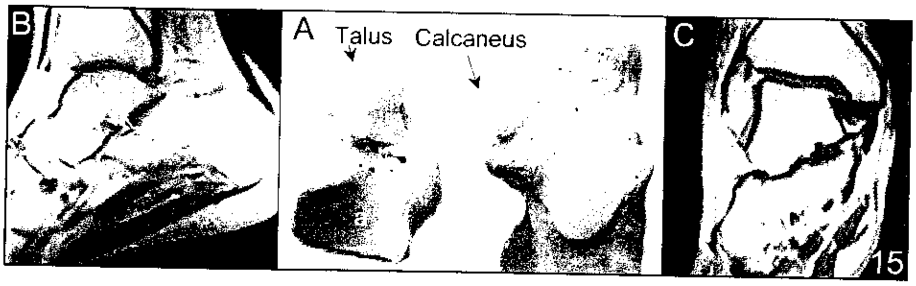

Fig. 15 — The posterior group of the tarsal joints: anatomical preparation (A) and MRI scan image (B, C) A: Articular surfaces of the posterior talocalcaneal (subtalar) and anterior talocalcaneal (transverse tarsal) joints: a. posterior calcaneal articular surface; b. posterior talar articular surface; c. middle facet for calcaneus; d. middle talar articular surface; e. anterior facet for calcaneus; f. anterior talar articular surface. B: Subtalar joint (SJ); talocalcaneal interosseous ligament (TCIL). C: Anterior talocalcaneal joint (ATCJ); SL: spring or plantar calcaneonavicular ligament.

The fibrous layer is reinforced by some ligaments: the lateral talocalcaneal ligament that is located between talus and calcaneus bones inside the calcaneofibular ligament in the ankle joint; the medial talocalcaneal ligament that extends from the medial tubercle of the posterior process of talus to the talar body; the posterior talocalcaneal ligament, quadrilateral and short, disposed between the posterior process of talus and the calcaneus bone; the talocalcaneal interosseous ligament, that is particularly robust and separates the two talocalcaneal joints, being located in the tarsal sinus between the grooves of the talus and calcaneus bones.

According to the Anatomical Terminology (1998) the anterior talocalcaneal joint is part of the transverse tarsal joint.

5.2 *Transverse tarsal or Chopart joint (middle group)*

The transverse tarsal joint consists of two separate components: the compound talocalcaneonavicular joint medially and the calcaneocuboid joint laterally.

The compound talocalcaneonavicular joint is comprised of two portions: the anterior talocalcanear and the talonavicular joint.

The articular surfaces of the anterior talocalcanear joint are the anterior and middle for calcaneus facets of the talus and the anterior and middle talar articular facets of the surface of the calcaneus. Both of these surfaces are plane and therefore this joint is considered to be a plane joint; the articular surfaces of the talonavicular joint instead are the navicular facet of the head of the talus, shaped like a filled sphere segment, and the talar surface of the navicular, shaped like a hollow sphere segment; therefore this joint is classified as a ball and socket joint (Fig. 16).

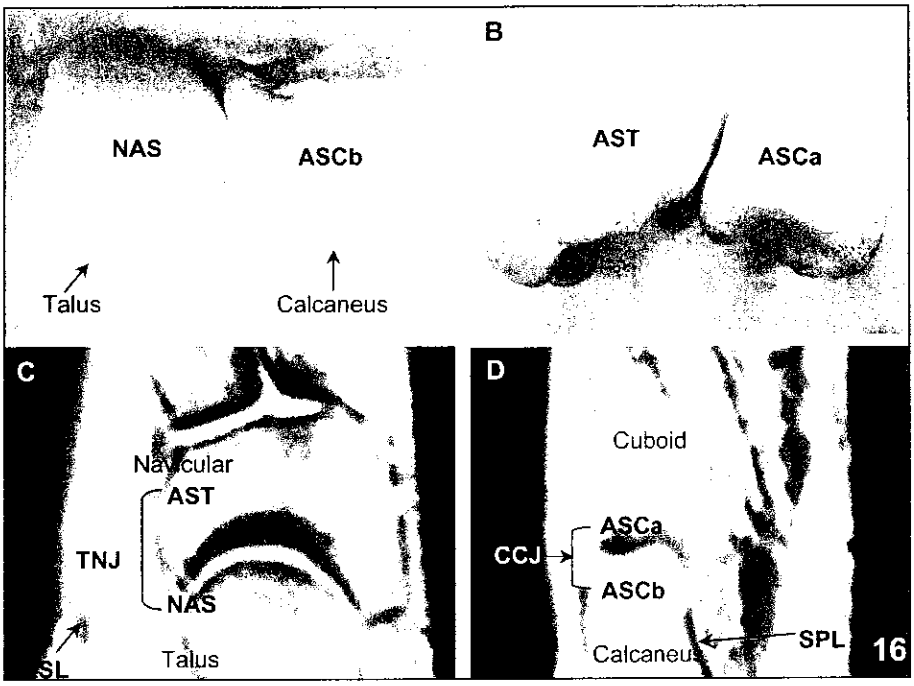

Fig. 16 — The medial group of the tarsal joints: the transverse tarsal joint or Chopart's joint comprises: on the medial portion, the compound talocalcaneonavicular joint (anterior talocalcaneal and talonavicular joints); on the lateral portion, the calcaneocuboid joint. Anatomical preparations (A, B) and MRI scan images (C, D). A: Proximal (talocalcaneal) aspect: navicular articular surface (NAS) and articular surface for cuboid (ASCb). B: Distal (naviculocuboideus) aspect: articular surface for talus (AST) and articular surface for calcaneus (ASCa). C: Talonavicular joint (TNJ); navicular articular surface (NAS); articular surface for talus (AST); spring (plantar calcaneonavicular) ligament (SL). D: Calcaneocuboid joint (CCJ); articular surface for cuboid (ASCb); articular surface for calcaneus (ASCa); short plantar (plantar calcaneocuboid) ligament (SPL). The posterior talocalcaneal ("anatomical" subtalar) and anterior talocalcaneal joints constitute a single entity that is described as "surgical" subtalar joint in clinical anatomy.

The fibrous layer is inserted on the margin of the articular surfaces and is reinforced: dorsally by the bifurcate ligament that originates on the anterior portion of the calcaneus and it then bifurcates in calcaneonavicular (medially) and calcaneocuboid (laterally) ligaments; plantarly, the sustentaculum tali and the navicular are held solidly together by the plantar calcaneonavicular ligament (spring ligament) that represents a strong plantar support completing the articular cavity of the head of the talus along with the navicular and calcaneus. The articular cavity of the talonavicular joint is shared with the anterior talocalcanear joint (Thompson, 2003).

From an anatomo-clinical point of view the posterior talocalcanear joint ("anatomical" subtalar joint) and the talocalcanear component of the talocalcaneonavicular joint, constitute a single entity that is indicated as "surgical" subtalar joint (Moore and Dalley, 1999).

On the lateral side of the transverse tarsal joint, the articular surfaces of the calcaneocuboid joint are represented by the cuboid surface of the calcaneus and the calcanear facet of the cuboid. These surfaces are curved and shaped like a saddle (saddle joint). The fibrous layer is inserted on the margins of the articular surfaces and is reinforced dorsally by the dorsal calcaneocuboid ligament and the lateral portion of the bifurcate ligament (calcaneocuboid ligament); plantarly the plantar calcaneocuboid ligament (short plantar ligament) forms a very strong support for the calcaneocuboid joint.

An additional superficial plantar support is given by the long plantar ligament that joins the calcaneus to the cuboid and third, fourth and fifth metatarsal bone bases.

The Chopart line delineates an italic S shape on the dorsum of the foot that in clinical anatomy is used to delimitate the hindfoot from the midfoot. To trace this line (Fig. 20) the following points must be used: on the medial margin, the tuberosity of the navicular bone easily palpable anteriorly and inferiorly from the medial malleolus apex; on the lateral margin, the medial point of an imaginary line that joins the lateral malleolus apex with the tuberosity of the fifth metatarsal bone base (Tixa, 2002).

The "anatomical" subtalar joint and the transverse tarsal joint allow inversion (more pronounced) and eversion (less pronounced) movements of the foot. The inversion determines a torsion of the foot that causes the medial margin to face upwards (supination) and the plantar surface to face the median plane; in the eversion movement instead the lateral margin of the foot faces upwards (pronation) and the plantar surface is oriented toward the lateral plane.

5.3 Anterior group of the tarsal joints

The anterior group of the tarsal joints are located between the plane articular surfaces of the navicular and the medial, intermediate and lateral cuneiform bones (compound cuneonavicular joint), between the lateral cuneiform and the cuboid (cuneocuboid joint) and between the cuneiform bones (intercuneiform joints). The fibrous layer, common to all these joints, is inserted into the margins of the articular surfaces and is reinforced by the short dorsal, plantar and interosseous ligaments (cuneocuboid and intercuneiform ligaments) that connect opposite articular surfaces. The articular cavities thus created are interconnected between themselves and the cuneometatarsal and intermetatarsal joints.

Their movements are limited but nonetheless very important since they contribute to the flexibility that is necessary for the plantar vault to distribute the weight it is carrying evenly; and also to facilitate the movement of the foot when the tarsal joints are lodged due to joint anchylosis (Fig. 17).

5.4 Tarsal ligaments

The tarsal ligaments include plantar, dorsal and interosseous ligaments.

Fig. 17 — The anterior group of tarsal joints in an anatomical preparation. Note the plane articular surfaces of the compound cuneonavicular (CNJ) and cuneiform (ICJ) joints located between the medial (CM) and intermediate (CI) cuneiforms, and between the latter and the lateral cuneiform (CL) as well as the cuneocuboid joint (CCJ).

The plantar ligaments, that are more robust than the dorsal ones, consist of the long plantar ligament that is located at a superficial level; of the plantar calcaneocuboid and plantar calcaneonavicular ligaments previously mentioned that are situated at a deeper level, and finally of the plantar cuneonavicular, cuboideonavicular, intercuneiform and cuneocuboid ligaments.

The dorsal ligaments comprise the talonavicular, the dorsal intercuneiforms, the dorsal cuneocuboid, the dorsal cuneonavicular, the dorsal calcaneocuboid and the bifurcate ligaments (the latter with its two components, calcaneonavicular and calcaneocuboid, medial and lateral respectively).

The interosseous ligaments include the robust talocalcanear interosseous, cuneocuboid interosseous and intercuneiform interosseous ligaments that have already been described (Fig. 18).

6. THE TARSOMETATARSAL JOINT (LISFRANC)

This joint is constituted by five plane joints that connect the three cuneiform bones and the cuboid to the base of the five metatarsal bones; the first metatarsal joined to the medial cuneiform, the second metatarsal to the three cuneiforms, the third metatarsal to the lateral cuneiform, the fourth and fifth metatarsals to the anterior facet of the cuboid.

The fibrous layers are reinforced by the dorsal, plantar and interosseous ligaments; the Lisfranc ligament, also known as the medial interosseous ligament and located in between of the medial cuneiform and the second metatarsal, being the most important one. Three separate articular cavities can be found in the context of this joint: a medial one connecting the first metatarsal and medial cuneiform, well separated from an intermediate cavity connecting the second and third metatarsals to the cuneiforms and finally a lateral one connecting the fourth and fifth metatarsals to the cuboid (Fig. 19).

The Lisfranc line resembles an oblique broken line that crosses the dorsum of the foot creating an edge between the midfoot and the forefoot (Montis, 1957). To trace this line (Fig. 20) the following points must be found: on the medial margin, the ridge formed by the joint connecting the medial cuneiform and the base of the

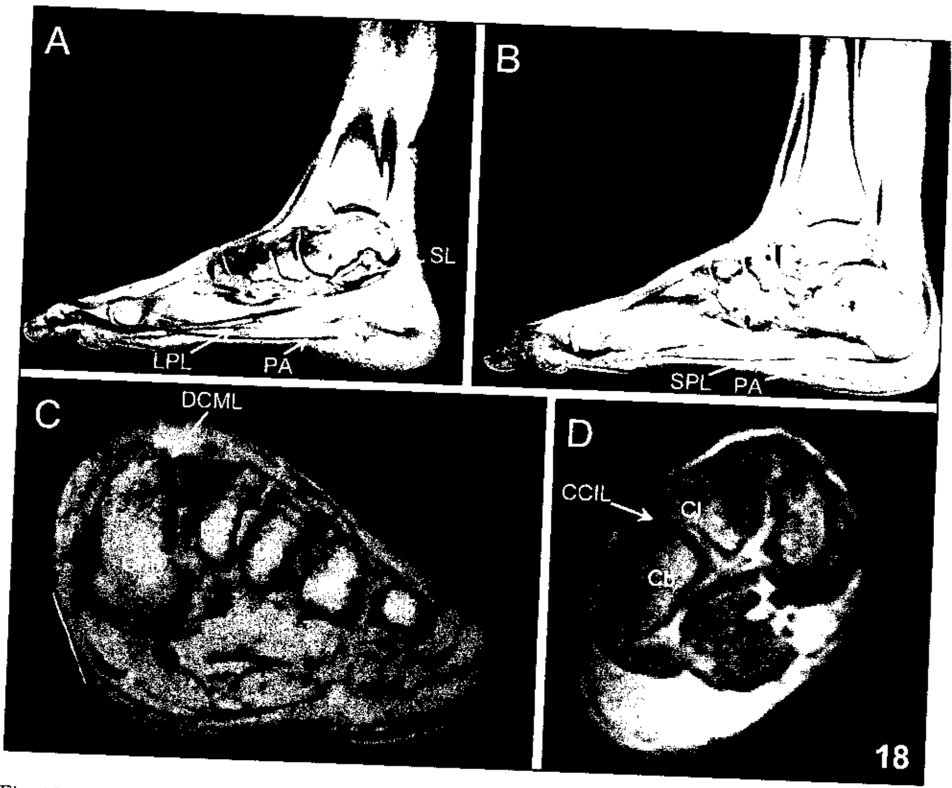

Fig. 18 — Some tarsal ligaments shown in sagittal MRI scans of the foot passing through the medial longitudinal arch and the first (A) and third (B) rays and coronal MRI scan passing through a transversal arch along the Lisfranc's interline (C) or the cuboid and cuneiform bones (D). A, B: Plantar aponeurosis (PA); long plantar ligament (LPL); short plantar or plantar calcaneo-cuboid ligament (SPL); spring or calcaneonavicular ligament (SL). C: Dorsal cuneometatarsal ligament (DCML). D: Cuneocuboid interosseous ligament (CCIL).

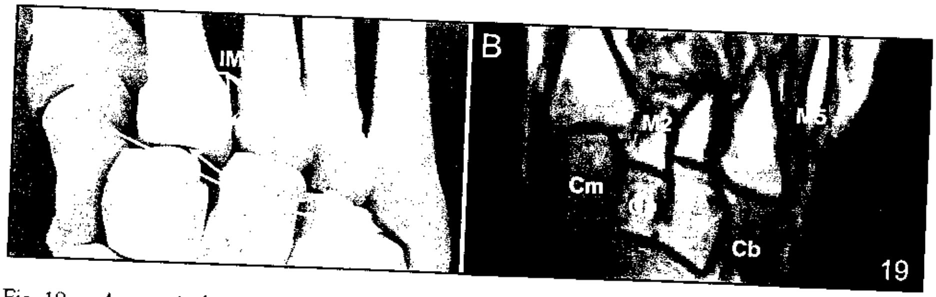

Fig. 19 — Anatomical preparation (A) and MRI scan image (B) of the Lisfranc's tarsometatarsal ligament and intermetatarsal ligaments. A: The plane articular surfaces of the cuneiform bones, cuboid and the bases of the five metatarsal bones. The plane articular surfaces of the intermetatarsal joints located in between of the first-second, second-third, third-fourth and fourth-fifth metatarsal bone bases. B: The geometrically broken line of the articular Lisfranc interline.

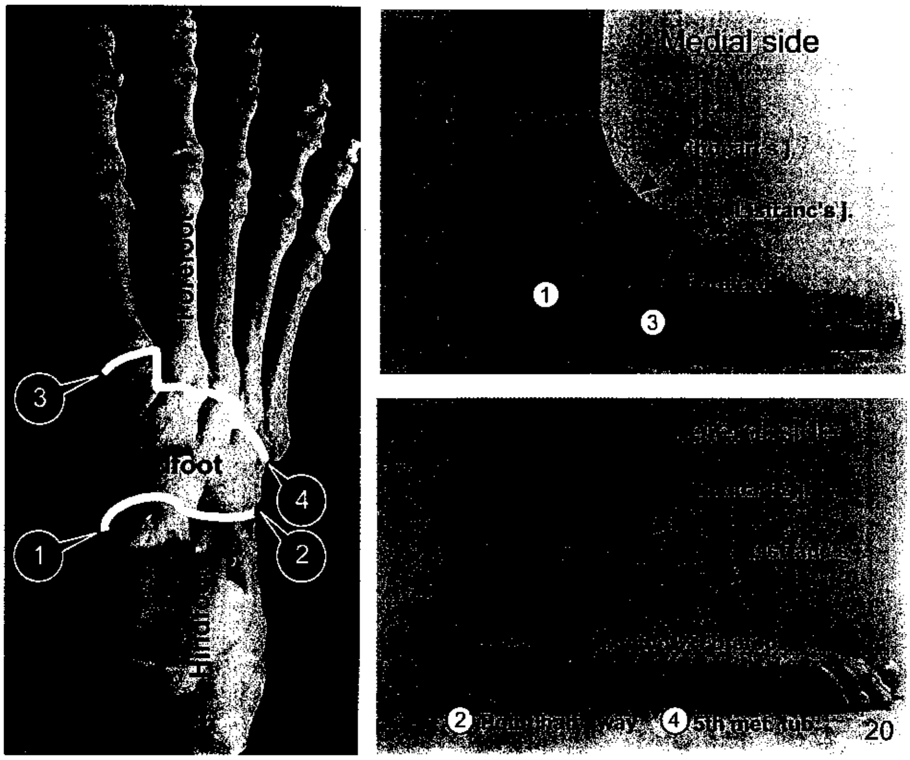

Fig. 20 — In clinical anatomy, the Chopart line represents the border between the hindfoot and midfoot; to trace this line the following reference points must be located and joined: the tuberosity of the navicular (1) on the medial margin of the foot and, on the lateral margin, the medial point of an imaginary line leading from the lateral malleolus apex to the tuberosity of the base of the fifth metatarsal (2). The Lisfranc line represents the border between the midfoot and the forefoot; to trace this line the following reference points must be located and joined: the ridge formed by the first cuneometatarsal joint (3) along the medial margin of the foot and the tuberosity of the base of the fifth metatarsal (4).

first metatarsal, sometimes visible but certainly detectable by holding the aforementioned joint between thumb and index finger and moving it slightly; along the lateral margin, the easily detectable tuberosity of the base of the fifth metatarsal behind of which the lateral extremity of the articular margin is located (Tixa, 2002).

The Lisfranc joint permits slight sliding movements of the articular surfaces.

7. THE INTERMETATARSAL JOINTS

These joints are placed between the bases of the metatarsals and are plane synovial joints; the fibrous layer has reinforcing ligaments that are positioned plantarly, dorsally and at an interosseal level between the second and third, third and fourth as well as fourth and fifth metatarsals, but lacking between the first and second metatarsals

The intermetarsal joints consent very slight sliding movements.

8. METATARSOPHALANGEAL JOINTS

These are synovial joints with ellipsoid articular surfaces (condylar joints) produced by the heads of the five metatarsal bones and the base of the correspondent proximal phalanx to which a fibrocartilagineous lamina is attached with the scope to widen the articular surface. The fibrous layer of this joint is inserted on the margins of the articular surfaces and is reinforced by robust collateral ligaments and by the extensor muscles (Fig. 21).

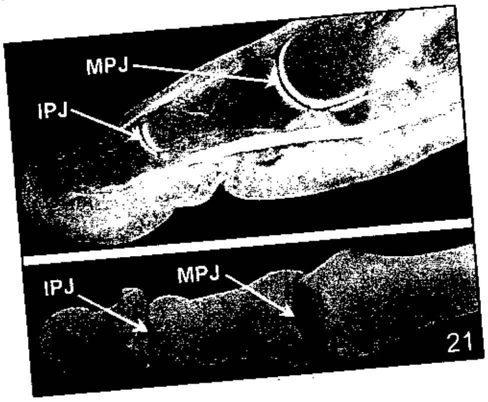

Fig. 21 — The first metatarsophalangeal and first interphalangeal joints in two anatomical preparations (A e B). Note the ellipsoid articular surfaces (condylar joints) of the head of the first metatarsal and the base of the proximal phalanx of the first toe (MPJ), and the cylindrical articular surfaces (hinge joints) of the head of the proximal phalanx and the base of the distal phalanx of the first toe (IPJ).

According to Leliévre (1961), when in a still, upright position and barefoot, the weight of the human body is equally divided between the two feet. Furthermore, in each foot the weight is divided 56.25% and 43.75%, respectively in the hindfoot and the forefoot, therefore creating a slight imbalance in the load sustained by the hind- and forefoot that can be easily corrected by wearing shoes with a 2 cm heel.

Contrastingly, other studies (Woodburne and Burkel, 1994; Moore and Dalley, 1999) have claimed the weight of the body is divided equally between the left and right foot, and furthermore equally divided between the forefoot and hindfoot.

The part of the body weight sustained by the forefoot is unloaded into the ground through the following five points of contact: a large medial one, that includes the two sesamoids associated with the head of the first metatarsal, that bears 16.66% of the weight carried by the forefoot, and additionally four points on the head of the second, third, fourth and fifth metatarsal bones each bearing 8.33% of the weight carried by the forefoot; so the head of the first metatarsal supports a double load.

The metatarsophalangeal joints permit plantar and dorsal flexion movements and tiny adduction and abduction movements on the second toe.

9. INTERPHALANGEAL JOINTS

These are synovial joints that have articular surfaces shaped like cylinder segments (hinge joints) and are made up by the head of the proximal phalanx and the base of the distal phalanx of the first toe, the head of the proximal and middle phalanges, and respectively the base of the middle and distal phalanges of the second, third, fourth and fifth toe. Each articular capsule has reinforcing ligaments and robust collateral ligaments.

These joints consent plantar and dorsal flexion movements by the toes; the middle phalanx can flex at a 90 degrees angle from the proximal phalanx, whilst the dorsal flexion is limited; in the distal phalanx instead the plantar and dorsal flexion movements are similar.

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