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BIOMECHANICS OF THE MEDIAL AND LATERAL LONGITUDINAL ARCHES OF THE FOOT

The longitudinal arches have long been recognized by artists and sculptures as an important part of the human foot. Over five centuries ago, Leonardo Da Vinci, the Renaissance painter, sculptor, architect and inventor, called the human foot “a masterpiece of engineering and a work of art”. On analysis of his many drawings, it seems evident that DaVinci appreciated the shapes of the longitudinal arches of the foot and also appreciated their mechanical significance for the bipedal human.

The medial longitudinal arch (MLA) and the lateral longitudinal arch (LLA) are generally considered to be the two main components of the longitudinal arches of the foot. The MLA consists of the calcaneus, talus, navicular, three cuneiforms, and first, second and third metatarsals. The LLA consists of the calcaneus, cuboid, fourth and fifth metatarsals. The MLA has an increased height when compared to the LLA and the MLA is considered to be the more flexible, or more compliant, of the two longitudinal arch structures.

The MLA and LLA receive additional support from the presence of the five digits, all of which serve as stabilizing structures for the longitudinal arches and as important attachment points for the plantar ligaments, tendons, muscles and fibrocartilaginous plantar plates which help to provide both passive and active support to the MLA and LLA. The supportive tension forces arising from the plantar ligaments, the extrinsic muscles within the plantar arches (i.e., posterior tibial, flexor digitorum longus, flexor hallucis longus and peroneus longus muscles), the plantar intrinsic muscles and the plantar fascia, not only allow the MLA and LLA to be flexible enough for the foot to be able to adapt to terrain variances and perform side-to-side athletic activities, but also allow the foot to be rigid enough for efficient propulsion during gait (Kirby KA: Longitudinal arch load-sharing system of the foot. Revista Española de Podología, 28(2), 2017).

One of the most obvious structural differences between the MLA and LLA is that the MLA almost always has a higher arch-shape than does the LLA. Another obvious clinical difference between the MLA and LLA is that the MLA is more flexible and will tend to flatten more during weightbearing activities than does the LLA. In biomechanical terms, the MLA can be said to be more compliant or less stiff than the LLA. Even though podiatrists recognize this difference in compliance (i.e., flexibility) between the MLA and LLA in the feet they examine on a daily basis, it is important to understand the reason behind this difference in MLA and LLA compliance so that foot biomechanics may be better understood and conservative and surgical treatment of foot pathologies can be better appreciated and planned.

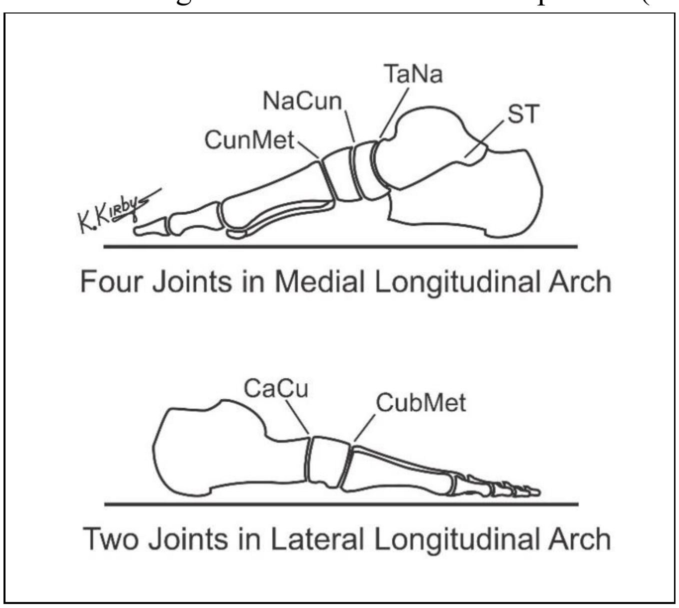

Figure 1. In the medial longitudinal arch (MLA), there are four joints, while in the lateral longitudinal arch (LLA), there are only two joints. The MLA, with double the joints of the LLA, is more compliant than the LLA. In addition, the larger arch span of the MLA increases the bending forces on the MLA which increases arch flattening when compared to the shorter arch-span of the LLA.

What then are the mechanical factors which make the MLA more compliant and flatten more during weightbearing activities than the LLA? There are two obvious explanations for the MLA being more easily flattened under weightbearing loads. First of all, the MLA has twice as many joints as does the LLA (Fig. 1). Secondly, the MLA has a significantly greater “arch-span” than does the LLA which increases the flattening of the MLA during weightbearing activities compared to the LLA.

It seems obvious that the MLA, an arched structure which is comprised of four movable joints, will deform more under load than the LLA, an arched structure which is comprised of only two movable joints. Why do more joints in an arched structures allow more arch compliance (i.e., greater flexibility) of that arched structure? The mechanical reason is because the bones which make up the MLA and LLA of the foot possess much greater bending stiffness, than do the joints which make up that longitudinal arch structure. In other words, when a bending force is placed across a bone, such as the calcaneus, cuboid or navicular, the actual bending motion of that bone is minimal when compared to a joint because the bone has far greater bending stiffness than the joints which are held together by stretchable ligaments.

Therefore, the MLA, having four joints (i.e., subtalar, talonavicular, naviculocuneiform and cuneiform-metatarsal joints), has twice as many freely-moving joints in its arch structure as the LLA which has only two joints (i.e., calcaneocuboid and cuboid-metatarsal joints). Since bones have much greater bending stiffness than do joints, then any structural element of the body which has more joints contained within it will have more compliance simply due to the fact that the more joints the structural element has, the more movement will occur in that structural element when subjected to bending forces.

As an example, let's analyze the arch-flattening forces on a foot during the late midstance phase of walking, from the middle of midstance to heel-off. The main forces which occur during this phase of walking which tend to flatten the MLA are the rapidly increasing ground reaction force (GRF) acting on the plantar forefoot and the rapidly increasing Achilles tendon tension force and downward-directed force of the tibia onto the talar dome. These combined forces place an "arch-flattening moment" on both the MLA and LLA which will tend to flatten both the MLA and LLA to different degrees. As the GRF acting on the plantar forefoot rapidly increases during the late midstance phase of walking, it is clear that the MLA, with its four flexible joints, will flatten more than the LLA, with only two flexible joints, when weightbearing forces are applied across the longitudinal arches. Put another way, if each of the joints of the MLA and LLA only dorsiflexes 3^0 on each other during the late midstance phase of walking, then the MLA would flatten by 12^0 (4×3^0) while the LLA would only flatten by 6^0 (2×3^0).

The difference in "arch-span" between and MLA and LLA of the foot is another obvious structural and biomechanical factor which affects the arch compliance or arch stiffness of the MLA and LLA in the human foot. The term "arch span" is defined as "the horizontal space between two supports of a structure." When a greater arch span, or a greater distance between its two supports, is present within an arched structure, there will be greater bending forces at the unsupported middle section of the arch structure and less bending forces at the areas of the arched structure that are supported. This engineering concept can be applied not only to a bridge, but also can be applied to the longitudinal arches of the human foot. Since the span of the MLA extends from the distal weightbearing surface of the calcaneus to the medial three metatarsal heads, and the span of the LLA extends from the distal calcaneus to the styloid process area at the base of the fifth metatarsal, the MLA obviously has a much greater arch span than is present in the LLA in nearly all feet. This greater MLA arch span means that greater bending forces will exist within the MLA which results in greater flattening motion within the longer arch span of the MLA, than with in the relatively shorter arch span of the LLA where the unsupported section of the arch is relatively small.

In conclusion, the combination of double the number of freely-movable joints within the MLA, in addition to the much greater arch span in the MLA compared to the LLA, can easily explains the differences in arch compliance and arch flattening between the MLA and LLA within the human foot. The overall biomechanical effect is that the greater compliance and a longer arch span of the MLA will cause it to flatten significantly more than the LLA, whereas the greater stiffness and reduced arch span of the LLA will cause it to flatten less during weightbearing activities. These differences in longitudinal arch compliance and arch-flattening motions between the MLA and LLA within the foot can have both positive and negative biomechanical effects for the individual, which will be explored in more detail in subsequent newsletters.

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