

## Origins and Morphological Development of the Hallux Sesamoids: A Literature Review

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### Abstract

Although it may initially appear that there is an infinite variability to each sesamoid's morphometrics, researchers have consistently found that individually, the tibial and fibular sesamoids display significant homogeneity in their dimensions and shape, and when referenced to the distal metatarsal edge, the tibial sesamoid is consistently positioned more distal. An understanding of their embryonic origins, and the relatively subtle but significant differences in their morphometrics, may help understanding first metatarsophalangeal joint functionality.

A systematic review of sesamoid origins may provide some insight into their spatial and structural variabilities and possible function differences.

**Methods:** A literature search was performed to review the histological origins of the sesamoids, their asymmetrical alignment, the sequential time frame for their maturation and ossification, and environmental factors that contribute to their morphometrics. A tibial and fibular sesamoid from a cohort of seven (N = 7) skeletal specimens was selected to compare their morphology to that described in the literature.

**Results:** Fibrous tendon tissue develops into islands of fibrocartilage in tendons that wrap around bony prominences. A cellular response to compressive loads is increased TGF- $\beta$  synthesis, which stimulates synthesis of extracellular matrix proteoglycans, a necessary component in sesamoid development. Sesamoid developmental shape is dependent on local mechanical forces such as sesamoid groove geometry, contractility of the flexor hallucis brevis tendons, ground reactive forces, and epigenesis. Ossification occurs at a different time frame in males and females, with the tibial sesamoid ossifying in females between 8 - 9 years of age, and up to a year later in males. Each sesamoid specimen utilized in this review exhibited different morphometrics, but their differences were consistent with those reported in the literature.

**Conclusion:** The morphology of each sesamoid and its spatial position appear to be dictated by a combination of genetics, joint geometry, and extrinsic and extrinsic mechanical forces.

**Keywords:** *Epigenesis; Hallux Sesamoid; Sesamoid; Sesamoid Origins*

### Introduction

The tibial and fibular sesamoids have been somewhat of an enigma in the history of foot biomechanics and surgery. Antidotal and experimental evidence is clear that they contribute to the most common disorders of the first metatarsophalangeal joint including hallux

valgus and hallux rigidus, but there remains significant uncertainty regarding their contributions to metatarsophalangeal joint functionality and lower extremity biomechanics. When sesamoids are ignored in reconstructive joint procedures, the result can be an unintended iatrogenic issue for the surgeon. A systematic review of the evolution and development of the sesamoids may help in identifying their basic morphometric differences.

### Discussion

The bone morphogenetic protein family of signaling molecules have been active for more than 500 million years [1], and may have provided the intrinsic capability for sesamoid formation [2]. The fossil record indicates that sesamoid bones coincidentally appeared in both reptilian lizards and mammals about 150 - 200 million years ago [3]. Their simultaneous appearance suggests that the capacity for endochondral ossification may have been acquired through the same evolutionary processes [3], and is believed to be similar to the secondary ossification progression found in long bone epiphyses [4]. Robbins and Vogel's research [5] with fetal bovine culture tissue found that compression loading and treatment with transforming growth factor beta (TGF- $\beta$ ) resulted in up regulation of aggrecan and biglycan synthesis, which suggests that the cellular response to compressive loads is increased TGF- $\beta$  synthesis, which in turn stimulates synthesis of extracellular matrix proteoglycans [5]. The result is fibrocartilage formation, which appears to represent an important intermediate step in sesamoid development [5].

Benjamin [6] and Gillard [7] found that fibrous tendon tissue develop into islands of fibrocartilage in tendons that wrap around bony prominences. Sesamoid bones, including those plantar to the metatarsal head, typically develop within these types of tendons [4].

Sesamoid development is also dependent on local mechanical forces associated with skeletal geometry, muscular contraction, ground reactive forces, and epigenesis (the theory that embryonic tissue development proceeds by gradual successive change) [4]. Drachman and Sokolof [8] found that patellae were smaller in paralyzed chick embryos, and plantar tarsal sesamoids failed to form entirely in paralyzed embryos, thus demonstrating the importance of mechanical forces in their development. Congenital hypoplastic sesamoids [9,10] and the absence of one or both sesamoids is well documented in the foot [11-20], but whether this is due to the absence of undifferentiated islands of fibrocartilage in the tendons, or inadequate compressive forces at a critical time in sesamoid development is unknown. Accessory sesamoid presence appears to be dependent on evolutionary development in related species (phylogeny), with the patella and both sesamoids plantar to the metatarsal found consistently in humans [21]. Sesamoids also tend to develop in areas that experience both tensile strain and compressive mechanical stresses [8,21,22] which is consistent with their presence in the foot.

Feldman, *et al.* [23] determined that the sesamoids began as islands of undifferentiated connective tissue by the 8<sup>th</sup> week, became precartilaginous in the 10<sup>th</sup> week, developed chondrification centers by the 12<sup>th</sup> week, and attained their adult shape by the 5<sup>th</sup> month. O'Rahilly, *et al.* [24] and subsequently Brenner, *et al.* [25] corroborated Feldman's findings, examining the prenatal development of the sesamoids and metatarsal in 12 - 38 week old cadaveric specimens; they found that the sesamoids had already developed by the 12<sup>th</sup> week. Brenner, *et al.* research also seemed to indicate that premature sesamoid groove development could result in a loss of the inter-sesamoidal ridge: they attributed early developmental hallux valgus to this [25].

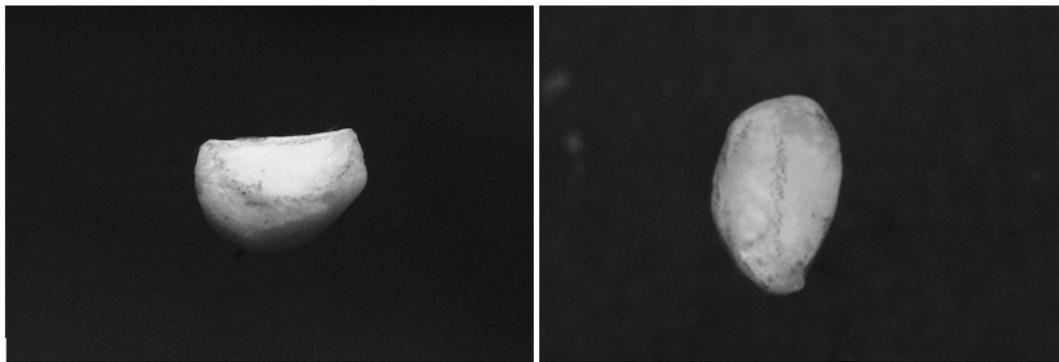
Jahss [18] and Dharap, *et al.* [26] found that tibial sesamoids began to ossify in females between 8 - 9 years of age, and up to a year later in males; this delay in sesamoid maturation may contribute to the reduced risk for metatarsophalangeal joint instability and deformity that seems inherent in males.

Sarin and Carter's research [4] suggest that osteogenic stimuli affect sesamoid ossification differently if there is incongruency between the sesamoid cartilage and its articulating surface as opposed to conforming surfaces - incongruency appears to result in thicker sesamoid articular cartilage [4]. Since each sesamoid groove exhibits its own saggital and frontal plane geometric morphology, depending on where

the reference point is in the groove, a failure of each sesamoid to maintain anatomically correct positions in their respective groove can result in incongruity and cartilaginous changes that alters every affected bony surface.

**Morphological characteristics of tibial and fibular sesamoid**

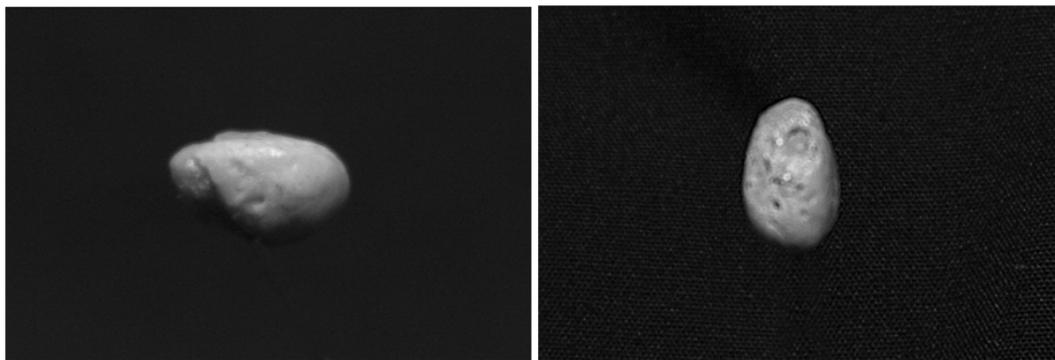
Kewenter and Sarrafian were the first individuals to describe and quantify each sesamoids bones morphometrics, noting the tibial sesamoid as being larger, more elongated, oval, with a longitudinal concave crest [15,27]. Our skeletal specimens in the figures below are consistent with their descriptions, including their sizes. The tibial sesamoid in figures 1A and 1B, measured 10 x 6 x 8 mm, has a dorsal concavity, is crest like, and when viewed from dorsal in 1B, exhibits two cartilaginous surfaces. Since the illustrated sesamoid was lost long ago, the author is unsure of the tibial sesamoids distal or proximal orientation. The fibular sesamoid (Figure 2A and 2B) measured 9 x 6 x 6 mm, is dorsally flat and exhibits less width distally.



**Figure 1A**

**Figure 1B**

**Figure 1:** Tibial sesamoid viewed from medial? (1A) and dorsal (1B). This randomly selected tibial sesamoid’s morphology is consistent with their description in the literature; it is elongated with a concave dorsal surface.



**Figure 2A**

**Figure 2B**

**Figure 2:** Fibular sesamoid viewed from medial (2A) and dorsal (2B). When viewed from medial in figure 2A, the sesamoids flat dorsal surface can be visualized. In figure 2B, the sesamoids most distal edge is oriented to the top.

### Conclusion

Consistent with the literature, each of our sample sesamoid specimens appears to exhibit its own morphometric homogeneity, which attests to the role of epigenesis, tensile forces from the flexor hallucis brevis tendons, and each sesamoids developmental response to ground reactive forces from plantar. This variability is consistent with David, *et al.* [28] analysis that the sesamoids appear to have shared but also uniquely separate functions.

### Conflict of Interest

The author has not received any financial consideration for this manuscript.

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