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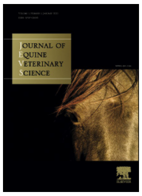

Review Article

Morphological and Biomechanical Properties of Equine Laminar Junction

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ABSTRACT

The interlocking of dermis and epidermis is called the laminar junction or interface. Laminae provide a sturdy junction in between the distal phalanx and the keratinized hoof wall transferring the forces between those structures. Although the horse's weight is imposed on the distal phalanx and the hoof capsule, the laminar junction plays a crucial role in absorbing and dissipating the applied forces both from the weight of the animal and the ground reaction forces. Understanding the morphologic and mechanical properties of the laminar junction is a key to recognizing influencing factors and is paramount to understanding performance and health in horses. This article will present a review of the significance of the morphological and biomechanical properties of the equine laminar junction.

1. Introduction

In horses, the distal phalanx is embedded within and protected by a modified fingernail called the hoof capsule. During peak loading, the hoof wall and the distal phalanx move in concert and separate only when pathologic changes interfere with laminar architecture. It is essential that the hoof wall epidermis, the basement membrane at the dermo–epidermal junction, the connective tissue of the laminar dermis, and the periosteum of the parietal surface of the distal phalanx all remain unified. If a disruption occurs in the junction between these elements, the hoof–distal phalanx bond fails, with serious pathologic consequences within the hoof capsule. Such disruption does occur in pathologic cases such as laminitis. Although discussion of the pathophysiology of laminitis, a devastating catastrophic disease of the laminae, is beyond the scope of this article, knowledge of laminar anatomy and physiology is a prerequisite to understanding laminar pathology. The relationship between morphologic and mechanical behavior of laminar junction needs further elucidation [1]. The goal of this article is to review the significance of morphologic characteristics of the laminar junction and its association with biomechanical behavior.

2. Morphologic Properties of the Dermo–epidermal Junction

The innermost layers of the hoof wall and the bars are named the *stratum internum* or *lamellatum* (layer of leaves) after the 550–600 primary epidermal laminae (PELs), which extend from the coronary groove to the ground surface (Fig. 1). Each keratinized PEL bears 100–150 nonkeratinized secondary epidermal laminae (SELs) that interlock with secondary dermal laminae [2,3]. The laminar junction serves to enlarge the contact surface between the inner hoof wall and the perimeter of the distal phalanx as well as supporting the nourishment of epidermal cells [4]. The surface area of the equine inner hoof wall has been calculated to average 2.4 sm^2 [5]. A recent study using 25 samples from three hooves reported that length of the laminar junction basement membrane was 0.024 μm

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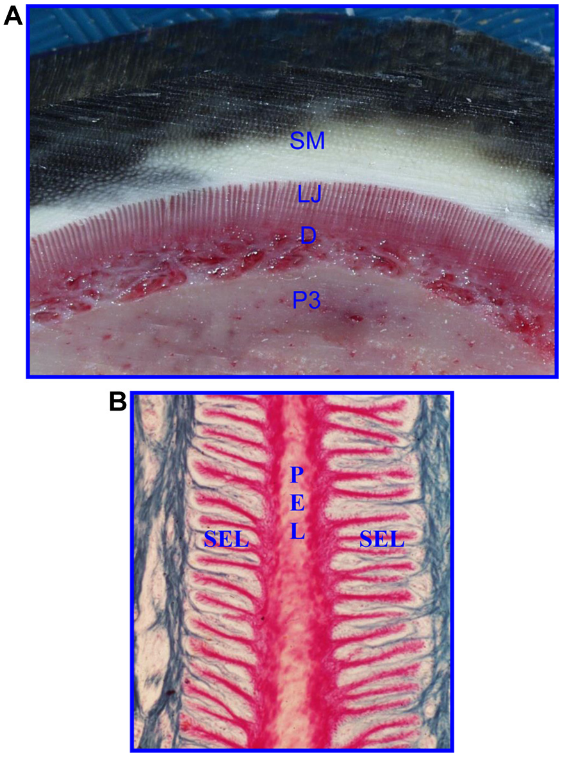

Fig. 1. (**A**) Transverse section of the inner hoof wall; approximately midway between the coronary band and the bearing surface of the hoof wall at the dorsum. Pigmented (outer) and nonpigmented (inner) stratum medium (SM), laminar junction (LJ), dermis (D), and third phalanx (P3). (**B**) Microscopic view of one primary epidermal lamina (PEL) with secondary epidermal laminae (SELs) at each side, stained with hematoxylin–eosin.

(0.020–0.027 μm) [1]. This large surface area of suspension of the distal phalanx and the great compliance of the interdigitating laminar architecture is likely to reduce stress and ensures even energy transfer during peak loading of the equine foot [6].

In common with all epidermal structures, the epidermal laminae of the inner hoof wall are avascular and depend on capillaries in the microcirculation of the adjacent dermis for oxygen and nutrients. The laminar interface contributes to the nourishment of the epidermal cells through diffusion from the underlying dermis [4]. The dermal cells are connected to the basement membrane through hemidesmosomes. The basement membrane plays a crucial role in physiologic regulations and behavior of the dermo–epidermal junction [7].

Circumferentially, the laminar morphology is uniform in newborn foals whereas it deforms in adult horses; imposed regional stresses are associated with those changes [8,9]. In adults, the laminae are fairly straight at the toe and the curvature increases as they move toward the heels. Dorsal laminae are positioned dorsopalmarly and are approximately 50 mm long and 7 mm wide; they become shorter and wider toward the heels [5,10]. Secondary epidermal laminae follow a similar pattern: the toe laminae are tightly bunched and the spacing increases toward the heels [1]. The laminae are more erratic at the sides of the hoof (i.e., quarters and heels); a greater number of laminae are curved, oriented dorsally or palmarly (plantarly in the hindlimbs). The curvature of these laminae has a unique pattern: at the quarters, they mostly curve palmarly (toward the heels), but at the heels their curvature varies proximodistally. At the proximal parts, most of the laminae curve palmarly, but at the distal parts (close to the distal border of the distal phalanx), they curve dorsally [11]. The reason for such abrupt variation is not clear, although it could be related to the position of the distal phalanx within the hoof capsule and/or be associated with abaxial movement of the distal heels.

Laminae may branch and give rise to new laminae [12,13]. Bowker [12] suggested that this represents a mechanism for increasing the number of PELs. In a study on 47 Thoroughbred cadaver feet, the authors counted the number of bifurcations in a sample of 25 central PELs at the toe, quarters, and heels [10]. They reported a range of 0–7 branched PELs per sample of 25, with the highest number of branching at the toe and the quarters. More branched laminae were noted at the lateral side of the left hooves and at the medial side of the right hooves compared with the other side. This disparity could be related to the asymmetrical loading in response to counter-clockwise racing tracks in North America; however, the exact etiology is unknown. Sarratt and Hood [14] reported the number of branching SELs on one PEL at the toe in six Quarter Horses. They found a significant increase in the branching SELs about 8 mm distal to the coronary band but a decrease toward the distal parts. They also found a similar pattern in density of the SEL. We previously showed differences in laminar morphology between Thoroughbred and Standardbred horses, which presumably are related to the differences in exercise regimen of those horses [15]. It has been suggested that variations in laminar morphology occur in relation to the applied stresses on the hoof [8,10,14,16–19]. Further evidence is provided by comparing stress variation around the laminar junction with that of laminar morphology, calculated by a finite element analysis, and several laminar measurements correlated with calculated stress level [19].

3. Biomechanical Properties of Laminar Junction

With each footfall, the hoof wall distorts: the dorsal hoof wall moves caudally, whereas the quarters and heels move abaxially [20,21]. Laminar junction has a central function in transferring the forces and coordinating the movements of the hoof wall and distal phalanx; however, the impact of diverse laminar architecture is not well known. It is reported that the distal phalanx pulls the laminae inward causing a radial tension parallel to the direction of the laminae at the toe [16]; this is consistent with the relatively uniform and straight orientation of the laminae at the toe. At the sides, laminae are subjected to axial tension as well, resulting in shear forces [16]. The applied forces (e.g. weight of the animal, tensile, and radial forces) and abaxial movement of the wall are associated with increased versatility in laminar morphology at the sides. Larger laminar spacing at the quarters and heels is coupled with greater amount of dermis (i.e. dermal laminae). The dermis contains large amounts of vasculature and is associated