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The Hoof Capsule: Wood or Skin?

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To the touch, the hoof capsule is very rigid and feels almost like dead wood. The hoof capsule is indeed made up of a dead material - keratin. The keratinous capsule resembles fiber re-enforced plywood. Plywood, like keratin, is also made of dead material, both are structurally very strong but this is where the similarity between these two materials ends. Unlike keratin, plywood is a man made composite based on natural materials. Keratin is found in the outer layer of any skin and is the product of a process called keratinization. This process starts with the production of live cells (basal cells) in the deepest layer of the epidermis (outer layers of the skin) called the stratum basale. The live cells migrate to and die at the surface of the skin to form a protective crust called the stratum corneum.

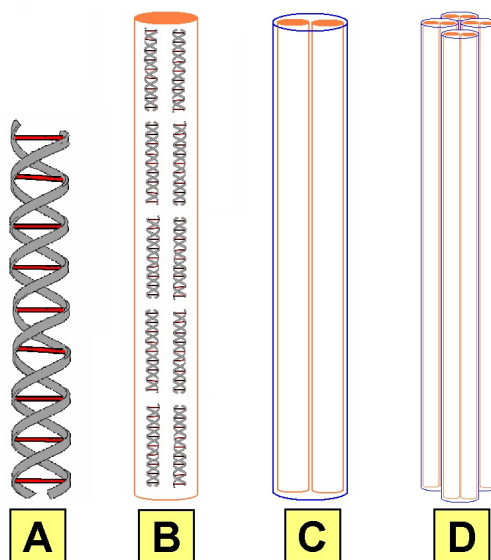


Figure 1. A simplified view of the keratin hierarchy: Keratin proteins form a helix pair (A) with disulfide bonds (shown in red) cross-linking for strength.

Many of these helix pairs combine to make a protofilament (B), which in turn group together to form a microfibril (C), which in turn group together to form a microfibril (D).

Although the dermis (lying beneath the epidermis) is not directly involved in the production of keratin, it plays a role by interacting with the basal cells. Skin is found in all mammals as well as fish, amphibians, reptiles and birds. The general purpose of skin is to provide protection from the elements.

Remember that skin is made up of two main layers, the dermis, and covering it, the epidermis. Note that the epidermis does not contain blood vessels but does contain color pigments – melanin pigments. What makes keratin (found in the last layer of the epidermis) fascinating lies in the fact that it can come in many different structures such hair, fur, claws, hooves, scales and feathers.

The type of keratin found in mammals is referred as alpha keratin. Alpha keratin is a so-called structural fibrous protein that takes the form of a two-strand helix --- think of two telephone cords coiled together. This two-coil form is not in itself structurally strong. In order to re-enforce it, links span between the two cords. These re-enforcement links are referred as disulfide bridges or cross-links. These links add stability and rigidity to the alpha helix (figure 1A.) The number of disulfide bridges can vary depending how the keratin is structurally employed. Flexible keratin (as found in hair and skin) has less disulfide bonds, whereas rigid keratin (as in hooves and horns) has more disulfide bonds.

The alpha keratin proteins join together to form bigger coils, which in turn twist together to form even bigger rope-like structures (figure 1 B-D), which form one keratin fiber. Then the keratin fibers are laid down in a crisscross manner to form a thin film. Think of this film as a fabric that can be used to create different structures such a hair or hooves.

The keratinous hoof capsule owes its structure and replenishment from various parts of the hoof dermis. Dermis is the lower layer of the skin that contains a network of micro blood vessels, sensory nerves, sebaceous glands (oil producing glands) and sweat glands. The blood vessels of the dermis also play an important part in thermoregulation. The amount of blood vessels, nerves and glands vary depending on the function of the dermis and/or the type of animal. For instance, cat and dog dermis is very poor in sweat glands (except at the paws.) In horses, the hoof dermis does not have sweat glands. The structure of the dermis can also vary depending on its function. This will become clear as we examine the different sections of the hoof dermis and how they contribute to the hoof capsule. These regions are

the sole dermis, sensitive frog dermis, sensitive laminae and coronary papillae.

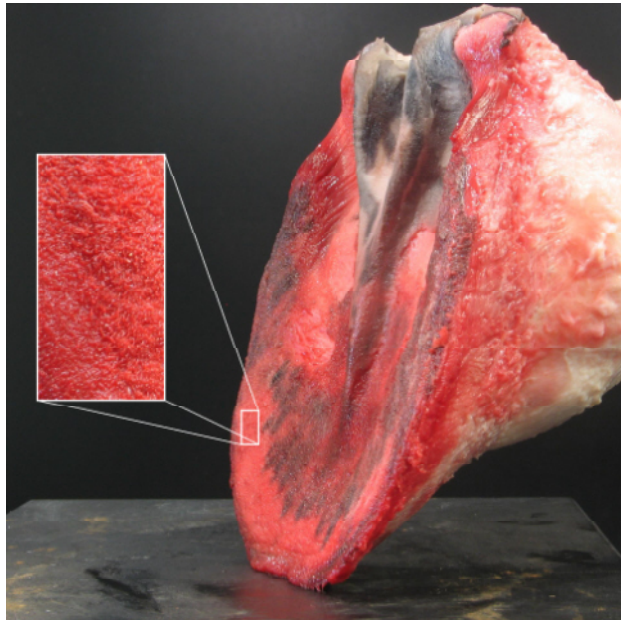


Figure 2. A view of the sole dermis. Note the papilla structures in the enlarged area, which attach to the keratinous sole (not shown).

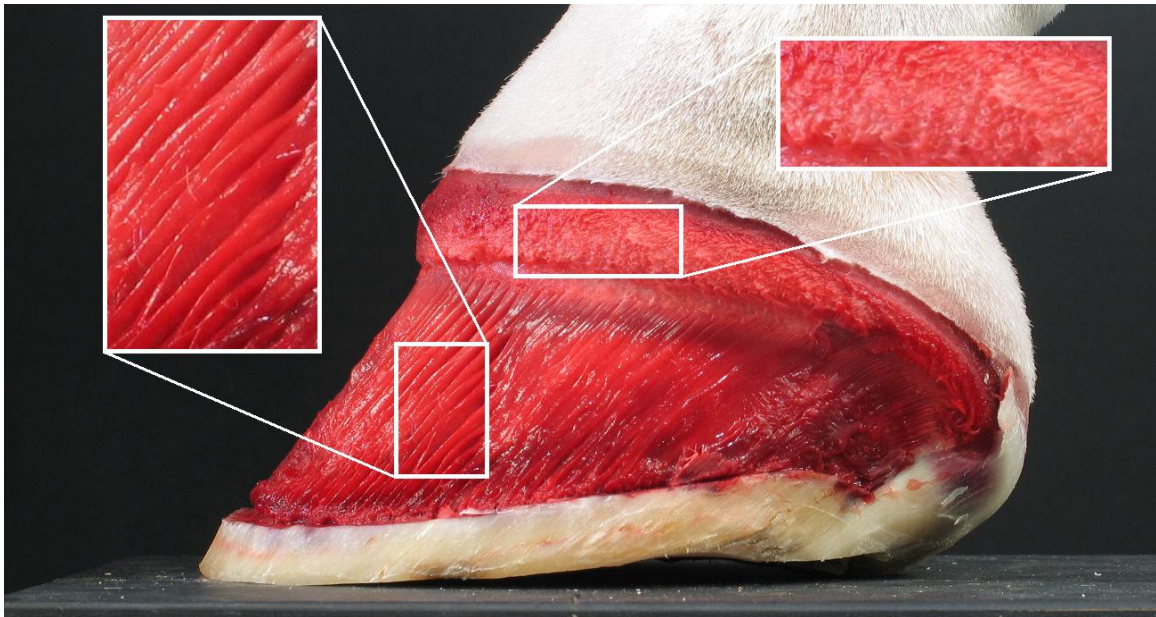


Figure 3. On the left, an enlarged view of the sensitive lamina which attach to the hoof wall, and on the upper right a view of the coronary papilla structures where the hoof wall tubules are generated.

The papillary region of the dermis connects into the epidermis. Visualize plugs (dermis area) and sockets (epidermal area) hooking together. The sole dermis and frog dermis have fairly short papillae, whereas the coronary papillae are quite elongated. The sensitive lamina is another form of dermal papilla. Note that the lamina dermis contains the most complex network of blood vessels among the different regions of the hoof dermis.

The hoof capsule is made up of different regions reflecting the architecture of the dermis and the function for which it was designed. The keratinous sole and frog are not very complex structures compared to that of the walls. The main function of the keratinous sole and frog is to lend support to the pedal bone. Their architecture resembles that of fiber (plywood like) sheets.

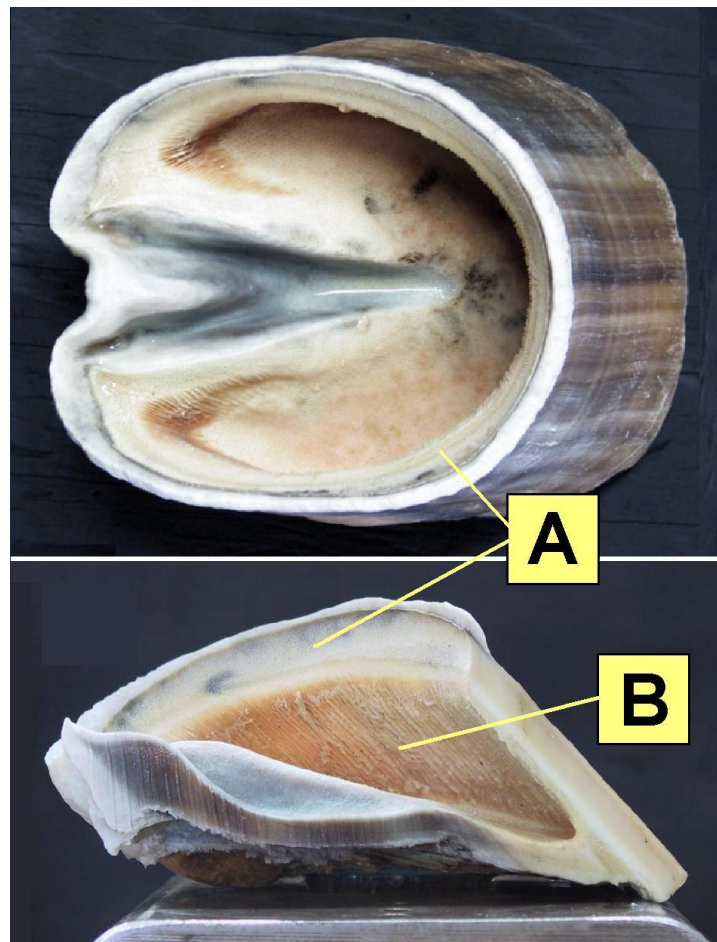


Figure 4. Region A shows the top of the hoof wall that interfaces to the coronary papilla structures. Region B shows the insensitive lamina of the hoof wall. Figures 2, 3, and 4 courtesy of Michael Savoldi.

The insensitive lamina is designed to provide structural strength from shear forces applied to the hoof. This structure mirrors the shape of the sensitive lamina (a primary lamina surrounded by secondary laminae.) The keratinous walls have the most complex architecture of the entire capsule.

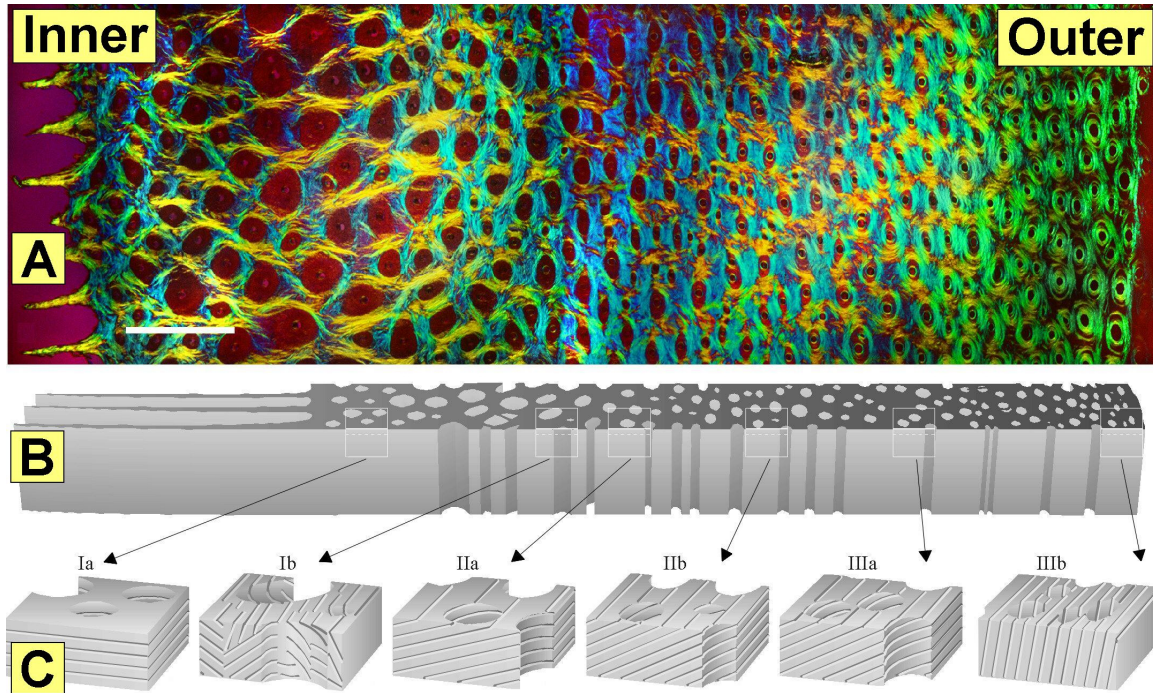


Figure 5. A cross sectional view of the hoof wall is shown in A. The round structures are the tubules, and one can see how their shape changes throughout different regions of the wall. The intermediate structure that contains the tubules is represented in B and C. The various orientations that the keratin takes on within the wall are shown in C.

The hoof walls are not only designed to dissipate tremendous energy from impact but also have to show structural strength against mechanical failure, such as cracks. A crack, forming along the grain of one plane of keratin, will be resisted by a neighboring plane whose fibers have a different orientation (figure 5C.)

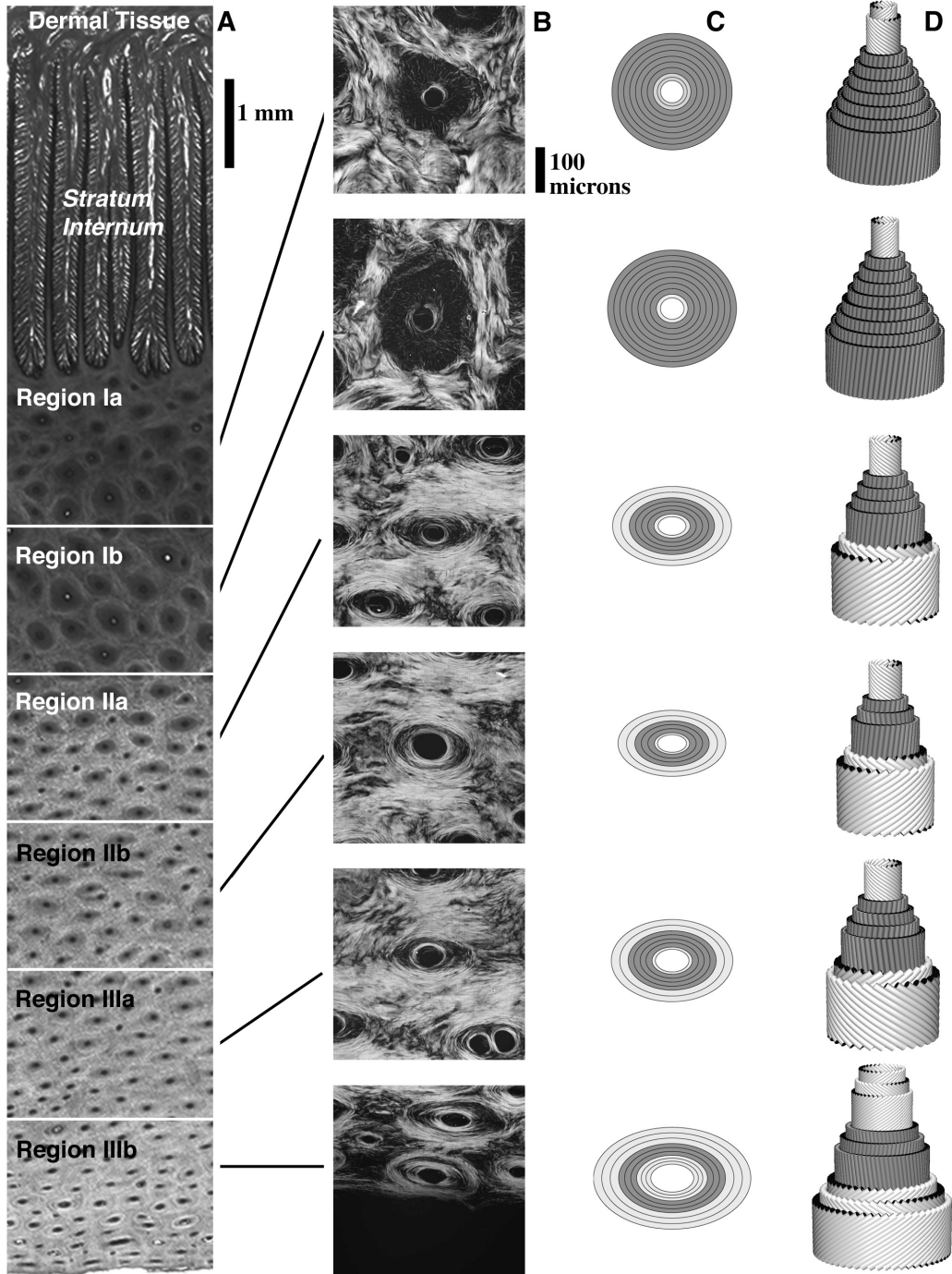


Figure 6. The details of the shape and construction of the tubules varies as one moves from the internal portion of the hoof wall to the external layer of the hoof. The internal structures are more flexible, and there is a gradual stiffening of the structures as we move to the outer wall. The diameter of a typical tubule is only slightly larger than that of a human hair. Figures 5 and 6, courtesy of Mario Kasapi.

The tubules lend some flexibility to the hoof capsule. The tubules can stretch, compress and bow to some extent. The tubules closer to the dermis are more flexible than the outer ones. The inner tubules are also rounder than the outer tubules, which become more elliptical in cross section. The inner tubules being close to sensitive lamina need to match somewhat the mechanical properties of the dermis, meaning these tubules need to flex. The outer tubules are designed to absorb the main brunt of landing concussion and to protect against the elements. This area needs to be very strong and more rigid. The difference in mechanical strength of tubules is largely due to the number of disulfide bridges within the keratin. The keratin of the inner tubules contains fewer bridges, whereas the keratin of the outer tubules contains more bridges. The disulfide bridges provide mechanical strength to keratin but these bridges are not impervious to the outside factors. Moisture plays a role in weakening these bridges. Keratin loses some of its mechanical stiffness and strength when there is moisture involved. You may have noticed that hooves do not behave and look the same during the rainy season. In general, a change in moisture content at the hoof capsule is not a big issue for horses as long as that change is neither sudden nor extreme. Abrupt changes and/or prolonged exposure to moisture may de-stabilize the keratin's structural strength. Genetics also play a role in capsule behavior. Horses bred and living in moist areas have adapted over time to the wet conditions, such as horses in the Camargue region of southern France. I have noticed that thin-skinned horses tend to be more sensitive to moisture changes than 'normal' horses. This probably lies in the fact that thin-skinned horses do not have thick hoof walls and that moisture tends to penetrate further within the capsule.

The dermis of the hoof and the keratinous capsule respond to genes specified in the general blue-print for this form of skin. All of these keratinous structures are related – they are all specialized versions of the same thing -- so, thin-skinned horses often have thin walled hooves. The hoof capsule can be thought of as a highly specialized epidermis, in fact, it is perhaps the most intricate form of epidermis found in mammals. To answer the question posed in the title of this article – it seems the hoof is skin!

Monique Craig is a hoof researcher, farrier, consultant to farriers, rider, trainer, and founder of EponaTech (www.EponaTech.com) and EponaShoe (www.EponaShoe.com).