Asymmetry of the Pedal Bone and the Reliability of Using the Apex of the Frog as Landmark

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The French chemist and microbiologist Louis Pasteur (1822–1895) said:
'The universe is asymmetric and I am persuaded that life, as it is known to us, is a direct result of the asymmetry of the universe or of its indirect consequences.'

Figure 1: The universe makes beautiful, but not always symmetric, shapes.

The ancients believed that the moon revolved around the earth in a perfect circle. It was considered heresy when early astronomers suggested that the shape of the orbit was an ellipse rather than circle. It was believed in the culture of those times that anything in the heavens had to be perfect. A circle has perfect symmetry whereas an ellipse has partial symmetry (figure 1). It is not just for cultural reasons that humans prefer symmetry, it is also easier for the human brain to perceive and understand symmetry. Asymmetric things are just a little more complicated – as you add more asymmetry, more numbers are required to describe the shape.

The problem with the hoof, is that it is 'nearly symmetric' but not quite symmetric – and this 'not quite' can make a significant difference in how one approaches trimming and shoeing.

Asymmetry of the P3 Bone

The following paragraphs focus on the asymmetry of the third phalange as seen from the palmar aspect (that is, from the 'underside'.) A more lengthy discussion of the hoof asymmetry is presented in a recent publication [1].

Mathematics can be used to provide a quantitative analysis of form, in a field of study called morphometric analysis. Trying to keep the analysis of the pedal bone shape as simple as possible leads to the consideration of simple geometric shapes. What constitutes a simple shape? A circle is a very simple shape because it is completely defined by one single number – namely its diameter. Circles are somewhat too simple to define the palmar aspect of a pedal bone. The next simplest shape is the ellipse which requires two numbers to define it – sometimes called the major and minor diameters. However this is still too primitive to describe the periphery of the palmar aspect of the pedal bone. It seems that a shape requiring three numbers might be the simplest possible shape which can adequately describe the pedal bone. If the minor diameter of an ellipse is allowed to take on two different values on each side of the major diameter then it becomes a simple shape requiring three numbers to describe the pedal bone. Figure shows this progression of simple shapes from one to two to three parameters.

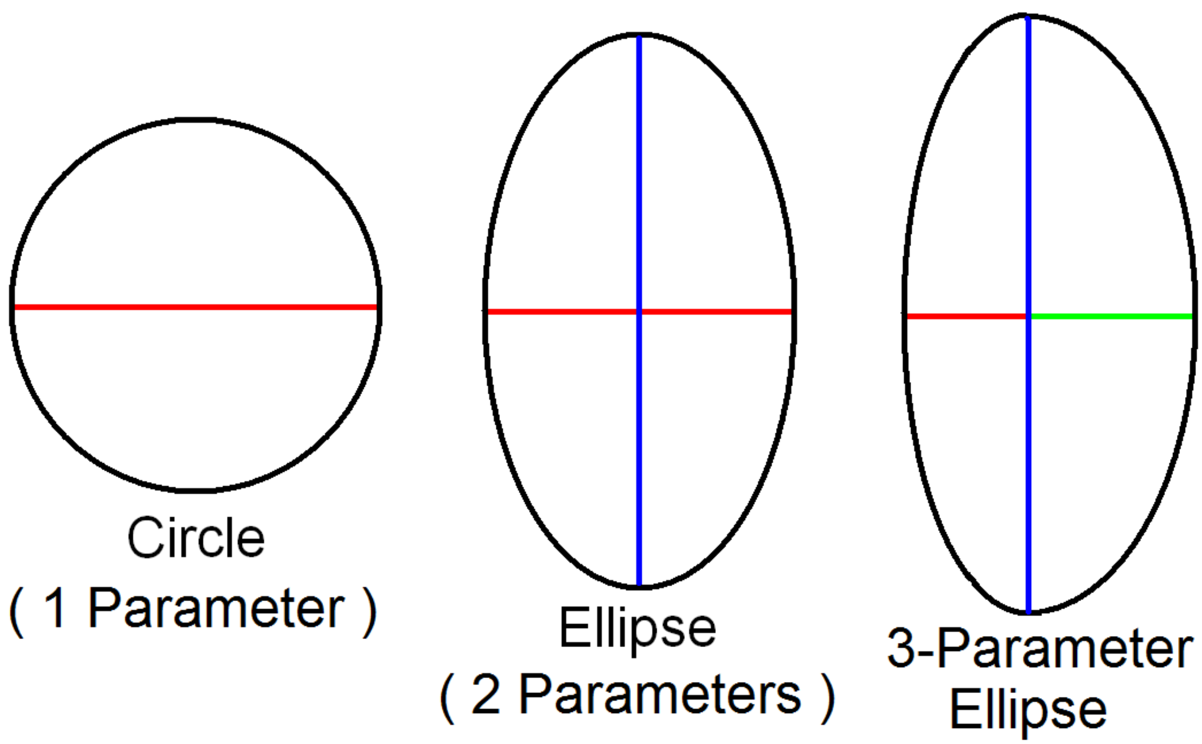

Figure 2: Three simple shapes. The circle is defined by one parameter namely the diameter (shown in red.) The ellipse is defined by two parameters namely a major (blue) and minor (red) axis or diameter. To anticipate the asymmetry of the pedal bone a shape called a 'three parameter ellipse' will be used in this paper. The three parameter ellipse has a major axis (blue) but its minor axis has a narrow side (red) and a wide side (green.) Using the three parameter ellipse will allow the data that is analyzed to display a degree of asymmetry whenever present.

To describe the shape of the periphery of the solar aspect of the pedal bone, only the lower half of these candidate shapes would be used (figure 3.) We purposely wish to ignore the shape of the most caudal (rearmost) portion of the bone's periphery, called the palmar processes, because their shape can vary and distort in many ways and for reasons unrelated to the theme of this paper.

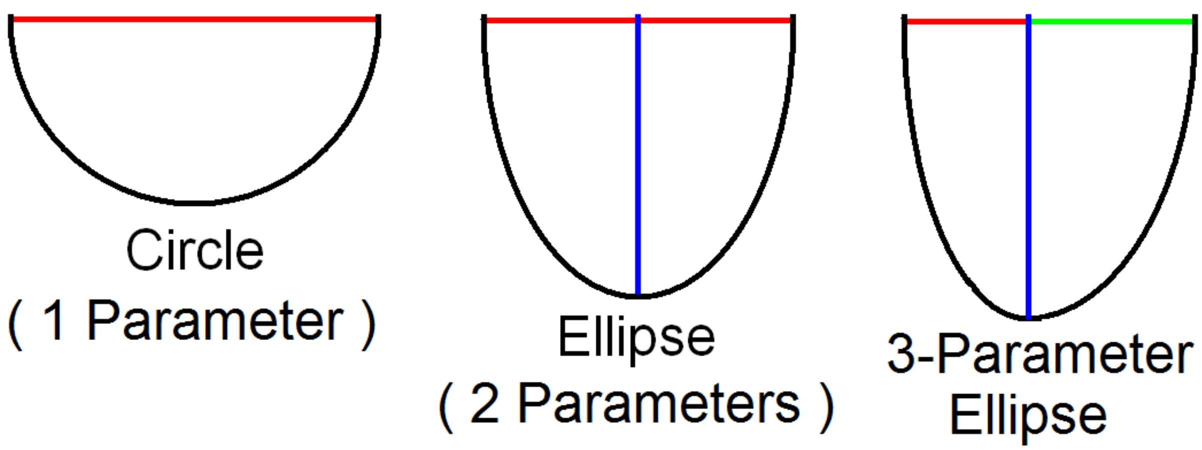

Figure 3. Of course, to describe the shape of the pedal bone's periphery, only the lower portion of these shapes would be used. If the one or two parameter shape is used, it would force a symmetric result. By using the three-parameter ellipse, we allow the data to show asymmetry if present.

The geometry on the palmar aspect of the pedal bone was established by means of a mathematical fit of a "3-parameter ellipse" (an ellipse which is allowed to be 'lop-sided' with two differing values for either side of its minor-axis.) Using this method, it appears that this geometric shape fits the pedal bone quite well, and most pedal bones show a similar asymmetry: they are generally narrower to the medial side than to the lateral side.

The outer periphery of the pedal bone (P3) as viewed from the solar aspect was traced from widest part of the bone around the toe end and back to the widest part of the bone on the opposite side. A point at the extreme distal end of the lunar crest structure was indicated for each image. A numerical optimization algorithm was used to "best fit" a 3-parameter ellipse to the periphery of the bone, with the constraint that the major axis pass through the point at the extreme distal end of the lunar crest curve.

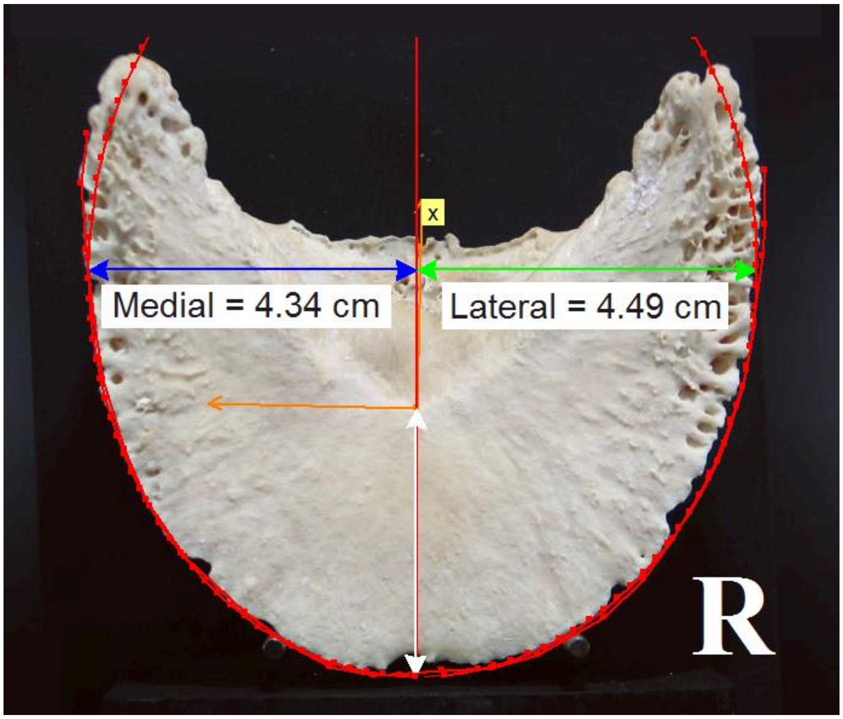

Figure 4: Example of a 3-parameter ellipse fit to the periphery of the P3 bone.

Figure 4 shows the fitting of the lop-sided 3-parameter ellipse, and the resulting measures found from centerline (major axis) of this ellipse out to the medial and lateral edges of the bone.

In the study reported in this portion of the paper, the data is derived from 55 pedal bones --- 32 right feet, 23 left feet.

The results of the data generated can be stated as follows: Using the computer generated results an “asymmetry value” was obtained by forming the ratio of the larger of the two measures (as shown in figure 4) divided by the smaller of the two measures. This ratio is then multiplied by 100 in order to measure the asymmetry in terms of a percentage. In other words, Asymmetry = 100 *(larger distance / smaller distance)

If the bone was symmetric this value would be 100. As asymmetry grows larger, the value grows larger than 100.

For the set of 55 pedal bones, values ranged from 100.0 to 113.5 with the average being 104.57. That is, the average pedal bone showed an asymmetry of about 4.5%. The standard deviation was 6.8%.

Only 7 pedal bones had a value less than 101.0 -- that is, 7 of the 55 were "nearly symmetric" with an asymmetry of less than 1%.

For the other 48 pedal bones which showed more than 1% asymmetry, it was the lateral aspect of the pedal bone which was wider in all but 5 of the pedal bones. That is, 43 of the 48 pedal bones (90 %) showed the expected asymmetry of a broader lateral side as compared to the medial side.

Conclusion: Most of sampled pedal bones are asymmetric and display a broader lateral side compared to the medial side. This experiment was to assess asymmetry of pedal bones via an impartial mathematical method.

Reliability of the Tip of the Frog as a Landmark

In this section, the following question is asked: If a hole is drilled at the apex of the keratinized frog, where would it land on the pedal bone? How well can the apex of the keratinized frog be used to locate the same spot on the pedal bone?

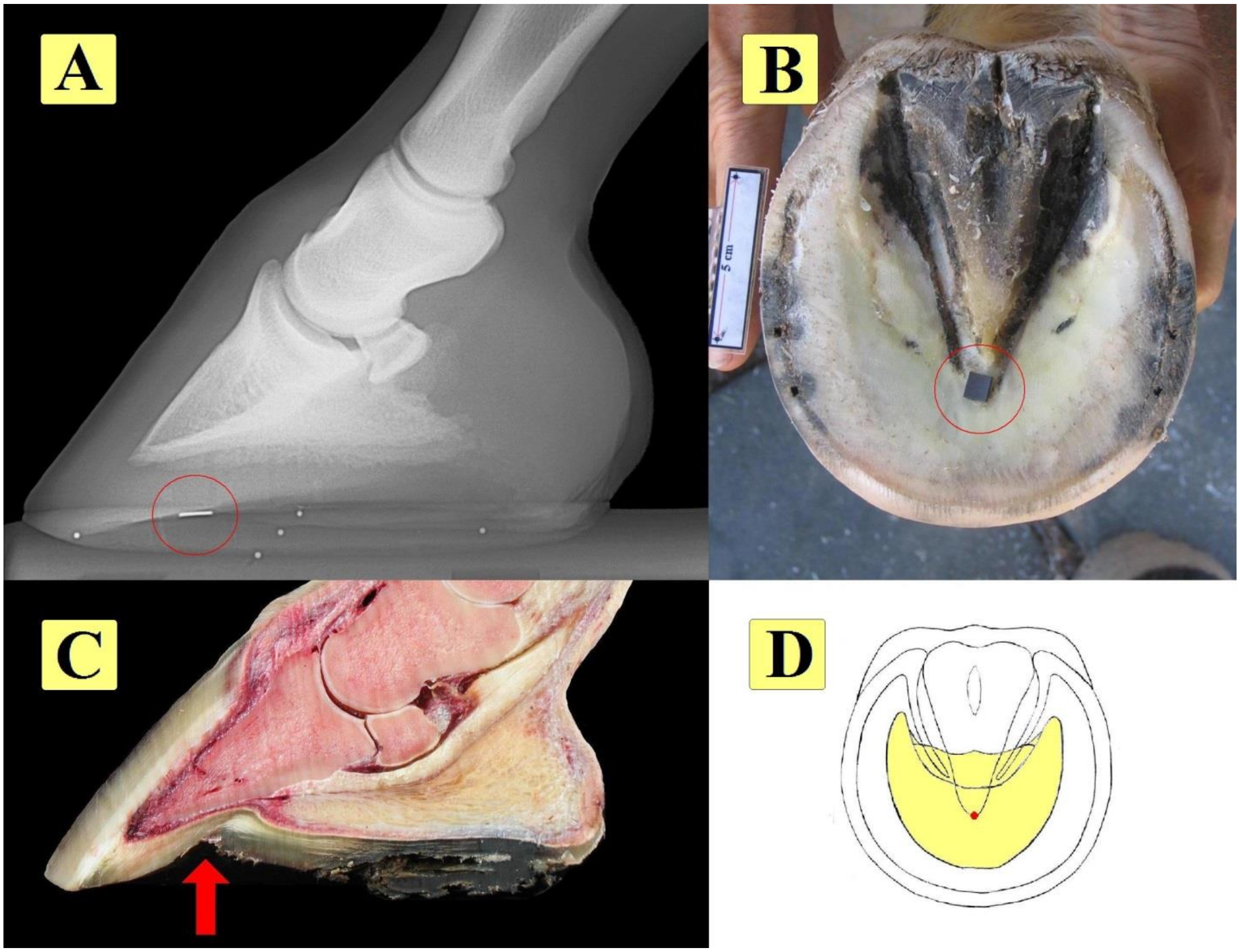

Figure 5: If a hole is drilled at the apex of the keratinized frog, where would it land on the pedal bone? How well can the apex of the frog be used to locate the same spot on the pedal bone? A radio-opaque marker at the apex of the frog (B) is seen in a lateral radiograph (A). It marks the junction of the sole and the apex of the keratinized frog (red arrow in C.)

In a research project done jointly with Michael Savoldi in 2005 [2], the apex of the keratinized frog on cadaver limbs was cleaned, and a hole was carefully drilled perpendicularly to the sole at the apex of the keratinized frog or 'keratinized frog junction'. The sole was then removed from the capsule, revealing the 'live frog' or dermal frog underneath. A second hole was drilled perpendicularly at the apex of the 'live frog' or 'dermal frog junction'. Finally, the pedal bone was dissected out and cleaned – an example is seen in figure 6. This experiment was repeated on a total of 27 bones – 14 from right feet, and 13 from left feet. These 27 bones are a subset of the 55 bones used in the previous portion of this paper.

Figure 6: Example of a bone with two holes drilled: the more caudal hole was at the apex of the live frog; the more distal hole was at the apex of the keratinized frog. The apex of the keratinized frog is the normal exterior frog that farriers sometimes use as a landmark.

The goal of this study was to assess to what extent the apex of the frog relates to a constant location on the pedal bone.

My interest in this stems from my belief that it is the bones and the interconnecting joints that define the kinematics of the leg. Trimming and shoeing should be ideally referenced to bony landmarks rather than solely to the keratinized part of the hoof capsule. If the apex of the keratinized frog marks a constant point on the pedal bone, it would be a superior landmark.

The widths of the 27 bone sample ranged from 2.46 inches (62.6 mm) up to 3.74 inches (94.9 mm) with an average width of 3.20 inches (81.2 mm) and a standard deviation (SD) of 0.31 inches (7.8 mm).

Gathered measurements were scaled by the width of the associated pedal bone at its widest point. The measurements are stated as a percentage. For example, in a pedal bone which is 75 mm wide, a distance of 7.5 mm will be stated as 10%. In this way, the locations of the drilled holes are defined as a “percentage of width”. This makes the results independent of the sizes of the various pedal bones.

The results of the data generated can be stated as follows: the ‘scatter’ of the points can be described by bounding boxes that contain all the holes. A bounding box is the smallest rectangle aligned with the major axis of the 3-parameter ellipse that contains all the drilled holes. For the hole at the apex of the dermal frog, the size of the bounding box was 11.6% by 6.7%. For the hole at the apex of the keratinized frog, the size of the box was 18.9% by 11.4%. In both cases, the longer dimension was in the distal-caudal direction, and the shorter dimension was in the medial-lateral direction. Another description of the scatter is to say that the standard deviations for the live frog point were 3.0% distal-caudally, and 1.6% medial-laterally. For the apex of keratinized frog, these values increase to 4.7% distal-caudally, and 2.9% medial-laterally. This suggests that these landmarks tend to have a wider dispersion as we move away from the bone. These results are qualitatively visualized in figure 7.

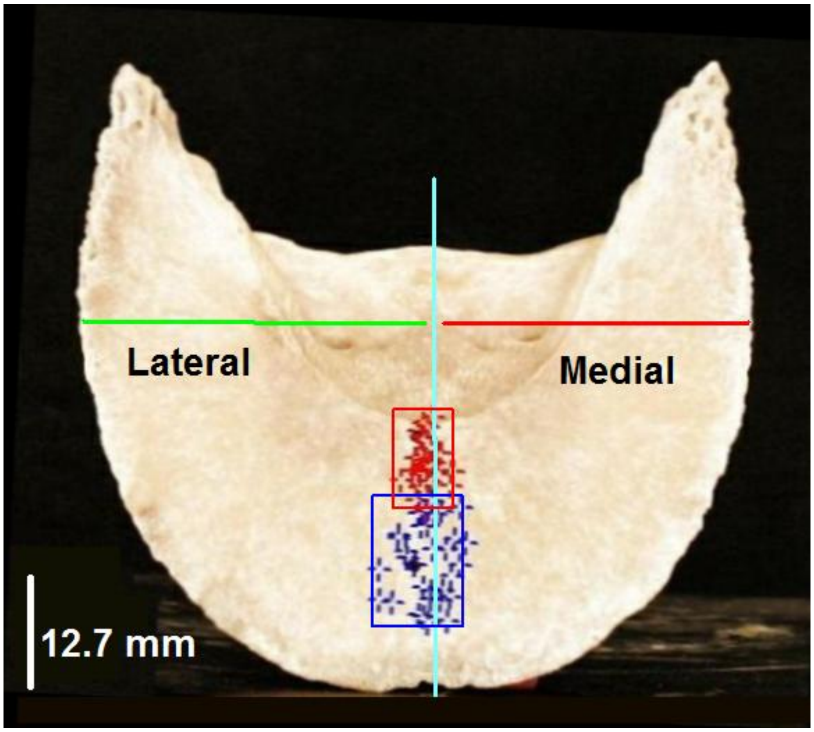

Figure 7: This is a qualitative visualization in which holes from a left pedal bone are plotted ratio-metrically on a single left pedal bone to help visualize what are results are indicating. The red marks correspond to the apex of the live frog, and the blue marks correspond to the apex of the keratinized frog. There is a broader scatter to the keratinized frog apex, and there is an offset to the lateral side.

It is interesting to note the average location of the landmarks in the medial-lateral sense in relation to right and left feet. The apex of dermal frog was on average 1.07% to the lateral side of the centerline for right feet (with standard deviation of 1.34%), and was on average 0.71% to the lateral side of the centerline for left feet (with standard deviation of 1.37%). For the apex of the keratinized frog, these values increase to 2.07% for right feet (SD. of 1.20%) and 1.37% for left feet (SD of 2.77%). This seems to indicate that the apex of the keratinized frog tends to lie somewhat to the lateral side of the centerline (the major axis of the 3-parameter ellipse best approximating the periphery of the bone.)

The results for all 27 bones show that the apex of the keratinized frog was on average 1.76% to the lateral side, with a standard deviation of 1.52%. These results are summarized in Table 1.

	Live Frog Ave	Live Frog SD	Ker. Frog Ave	Ker. Frog SD
Right	1.07	1.34	2.07	1.20
Left	0.71	1.37	1.37	2.77
All	0.91	1.11	1.76	1.52

Table 1: Locations of the apex of the dermal frog and of the keratinized frog as a percentage of width of the pedal bone, relative to the major axis of the 3-parameter ellipse. A positive value indicates a position to the lateral side of this axis.

One interpretation of the above results: the pedal bone is broader to lateral side by an average of 4.5%, and the apex of the keratinized frog is on average 1.76% to lateral side of the axis of the pedal bone. Therefore the apex of the keratinized frog is 4.5% – 1.76% = 2.74% to the lateral of the axis of the pedal bone.

Conclusion: The position of the apex of the keratinized frog relative to the pedal bone varies from bone to bone – hence the scatter as shown in figure 7. Further, this scatter displays a bias to the lateral side of the axis of the pedal bone. The axis of the pedal bone is referring to the major axis of the 3 parameter ellipse which describes the periphery. Any method for trimming making reference to the apex of the frog, has some built-in uncertainty relative to the pedal bone.

In 2014 Mike Savoldi and Dr. Brian Hampson conducted a related experiment on the frog tip junction [3]. Their approach was somewhat different – the asymmetry of the pedal bone was not tested but assumed for this experiment. However very similar outcomes resulted from their experiment: there is a scatter pattern between the keratinized frog junction and the live frog junction when related to position on the pedal bone.

Asymmetry of the Hoof Capsule

In previous publications [1, 2, 4, 5] I have commented on the asymmetry of the hoof capsule itself. That is, using the centerline of the frog as a reference, the width of the capsule to the outer edge of the lateral wall is generally a longer measure as compared to the medial side. This seems to be a reflection of the asymmetry of the P3 bone within. It should not come as a surprise – I have recently measured the sketches from veterinary textbooks of at least 50 years in age [7], and find that these authors have noted the subtle asymmetry in their drawings (figure 8).

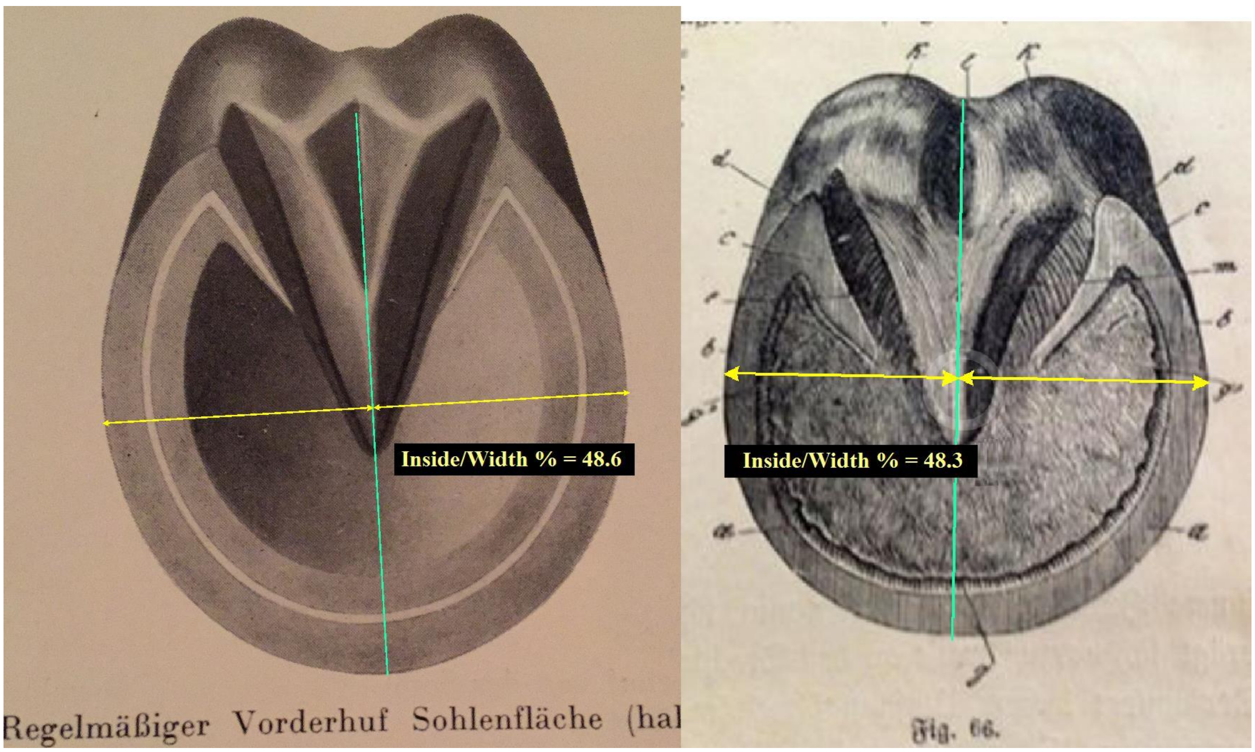

Figure 8: On the left side, apparently a left hoof with the medial side comprising 48.6% of the total width from one publication. On the right side, apparently a right foot with 48.3% of the total foot width to the medial side, from a second publication. Measurements made by Metron software [6].

It is interesting when I first presented my research on the asymmetry of the hoof, I was approached by very seasoned farriers. These farriers already knew that hooves were asymmetric. I am surprised that many publications seem to imply that hooves are symmetric or should be made symmetric by trimming.

References

[1] Craig, Monique, "A Modern Look at… The Hoof", Outskirts Press, 2015.

[2] Craig, John, and Craig, Monique, "Hoof and Bone Morphology of the Equine Digit: Challenges to some Common Beliefs" in The Farrier's Journal, Number 114, 2005.

[3] Hampson, Brian, and Savoldi, Michael, "Can the frog tip-sole junction accurately predict the position of the distal phalanx within the hoof capsule?", in The Farrier's Journal, Number 167, April, 2014.

[4] Craig, John, and Craig, Monique, "Hoof and Bone Morphology of the Equine Digit: Challenges to Some Common Beliefs." presented at the International Hoof Summit, Cincinnati, Ohio, February, 2005.

[5] Craig, Monique, "Die Morphologie Des Hufes." presented in German, at the Luwex Symposium, Germany, 2009.

[6] Eponatech, "Metron-DVM User Manual", 2014.

[7] Images provided by Ray Knightley, farrier. E-mail = ray@knightley.de