Abstract

We propose a new quantitative measurement that can be made using a lateral radiograph of the equine digit. This measurement can be used to quantify an aspect of bone remodeling of the distal phalange, and hence can be used as a ‘quality metric’ for judging the current health of the distal phalange in a living animal. We find that for any given horse, this metric decreases over it’s lifetime as the distal phalange undergoes (often minor) remodeling. Our ability to make this measurement has benefited from the availability of superior diagnostic images due to the introduction of digital radiography systems into veterinary usage.

Introduction

The details of the shape of the equine distal phalange (or “P3” bone) vary widely from animal to animal. One can think of these variations as having two sources: first, there are differences in P3 shape due to the particular animal’s genetics; second, there are morphological changes during the animal’s lifetime. These morphological changes are thought to be influenced by how the animal is shod (or not), as well as the environment and lifestyle that the animal experiences over it’s lifetime ( differences in terrain, the amount of locomotion and load carried, etc. )

The P3 bone, once the animal is mature, will be prone to decalcification over the animal’s lifetime as a consequence of the stresses of biomechanical loading, and possibly local inflammatory processes (e.g. pedal osteitis). At the risk of over-simplifying, one might say that the P3 bone in a 2 or 3 year old horse is as ‘good as it will ever be’, and its ‘all downhill from there’.

It is believed that proper hoof care and other environmental and nutritional factors make a difference in the longevity of the animal in general and in the quality of the P3 bone in particular. Hence, it would be extremely useful, when presented with an animal for evaluation, to be able to make an objective measurement of the ‘quality’ of the P3 bone. This ‘quality metric’ would ideally reflect the quality of the P3 bone in the living animal at the current point in time, and could be used to judge if the hoof care (and other factors) have been beneficial for the particular animal.
Method

In a high quality lateral radiograph of the equine digit, one can see a contour which lies along the center of the palmar surface of the P3 bone. This contour is visible due to the increased density of the bone along that aspect due to mechanical needs of the DDFT which inserts there. In this paper we will refer to this curve as the palmar curve. Figure 1 shows an example of this curve in a living animal, and figure 2 shows that the same curve can be identified in a radiograph of a cadaver bone.

Figure 1: The “palmar curve” of the equine distal phalanx.

Our method is to view the palmar curve as a mathematical function described relative to a coordinate system located at the distal tip of P3. To be precise, the origin of the reference system is located at the most distal point of the palmar curve. The Y-axis is oriented upwards, and the X-axis points back towards the caudal portion of the P3 bone. In the study presented in this paper, conventional lateral radiographs are used, but those for right feet are flipped horizontally so that in all cases the palmar curve that we study is generally rising as you move along the X-axis. Hence we can analyze the shape of the palmar curve from a set of bones by making a mathematical analysis of a set of curves, each of which can be thought of as a function: \( y = f(x) \). Defined in this way, these functions generally display a positive slope (“up and to the right”) over much, if not all, of their extent.
Figure 2: Figure A is the original radiograph of the cadaver bone. In B we have traced the palmar curve. Figure C shows a radiograph of the same bone after placing a radio-opaque strip of material along the centerline of the palmar surface of the bone and conforming to the surface of the bone (shown in inset photo). In Figure D we have traced the upper side of this radio-opaque strip yielding a very similar curve to that shown in B. Hence, we feel that we can indeed identify the shape of the centerline curve of the palmar surface of P3 from a high-quality lateral radiograph.

We also pick the highest point on the extensor process and drop a line down vertically from that point. Hence, to perform this analysis, one needs the notion of “vertical” and we define this as follows. For a cadaver bone, we simply use its orientation when rested on a flat surface to define “vertical”. For in-vivo bones, one must make an estimation of the “P3 palmar angle” and then use it to define vertical. The “palmar angle” is a popular measure currently in use by veterinarians when describing the foot radiographically. Hence, one can consider the estimation of the palmar angle to be synonymous with estimating how the P3 bone, if it were out of the foot, would sit on a level surface. Figure shows how these constructions are made on a cadaver bone (3A) and an in-vivo bone (3B).

In particular, we wish to study attributes of the front portion (most distal portion) of the palmar curve, and so we will consider the portion of the palmar curve from the tip of P3 up to the point at which it intersects the vertical dropped down from the extensor process.
Figure 3: In figure 3A, a cadaver bone rests on a horizontal surface. A coordinate system has it's origin at the most distal point on the palmar curve. The blue line is constructed as a vertical going through the highest point on the extensor process. In figure 3B, a radiograph of P3 within the hoof is referenced in the same way, except that an estimation of the **palmar angle** must be made, and the coordinate system aligned with it.

In the course of our study, we considered several values which could be computed from the palmar curve, for example, it’s “straightness” ahead of the extensor process, and other measures. However, the measure we found the most useful has to do with the “area under the curve” for the portion of the palmar curve that lies distal to the perpendicular dropped from the extensor process. In general, we believe that in young and/or healthy feet, there will be more area under the curve. This metric gives a notion of how “cuppy” or how “flat” the palmar surface of P3 is.
As shown in figure 4, the area under the palmar curve (shown in green in figure 4A) can be computed as a percentage of the total area of a certain rectangle. This rectangle is defined by two points: the most distal point on the palmar curve, and the highest point on the extensor process. By using percentages defined in this way, an image scale factor is not required -- there is no need for the images to be scaled to any particular units. The bone shown in figure 4 has an area measure of 13.4% which is a relatively high value in our study, indicating a bone with a relatively large palmar concavity. In this paper, we will refer to our metric as the *palmar-metric*.

Figure 4: Our metric is based on computing the “area under the curve” for the portion of the palmar curve that is ahead of the extensor process. We express that area as a percentage of the area given by the rectangle which is specified by the tip of P3 and the highest point on the extensor process. In this way, there is no need for calibrated units. The bone shown in this figure has a palmar curve which is above 13.4% of the area.
What Does the Palmar-Metric Mean?

The palmar-metric gives a way to describe the shape of the palmar side of the pedal bone with a single number. This number gives a measure of how flattened, or how concave the bone is. The lower the value, the flatter the bone. At the risk of over-simplifying, we believe that flatter pedal bones are generally a problem, and are often the result of remodeling and bone loss. Therefore, we generally will imply in this paper that a higher palmar-metric is desirable. Like most things about the equine hoof, this is not quite so simple: for example, the pedal bone from a severe club foot is often highly concave and so has a high palmar-metric, but perhaps this is not a good thing. But with this exception noted, we think ‘the more concave the better’. The palmar-metric gives a way to summarize the pedal bone, and the way it is computed makes it independent of the size of the bone, and also does not require that the radiograph was calibrated. Hence we find it to be a very practical measure.

When the radiograph is calibrated with an accurate length scale, we can use a variation of the palmar-metric to compute an estimate of the physical volume of the concavity of the pedal bone in cubic centimeters. Figure 5 shows a study in which the actual volume of 60 cadaver bones was measured by packing them with putty. We radiographed the bones and showed that we could compute a good estimate of the volume from the lateral radiograph by means of a variant of the palmar-metric.

Results

It is the authors’ opinion that the palmar-metric for a given animal will stay the same or decline over its lifetime, and our data appears to support this. As the P3 bone
demineralizes around it’s periphery, the palmar curve will sink lower, reducing the area under it from a lateral aspect.

In one study we measured the palmar-metric for 266 feet of horses whose age was known at the time of the radiograph. All radiographs for this study were taken with a modern digital radiography system and yielded high quality images in which it was easy to trace the palmar-curve. We show the results in figure 6. The red curve indicates the 3rd-order trend line of the data, and indicates that the palmar-metric, on average, decreases with age. The wide scatter of the data points indicates that many factors other than age must also affect the palmar-metric. Using figure 6, one could determine if a given individual lies above or below the value of the trend line for it’s age as a means of rating the horse as having a below or above average P3 bone. The average palmar-metric for all horses in the study was 6.29%.

Figure 6: Results of our study of 266 feet show that the palmar-metric tends to decrease with the age of the horse, as shown by the trend line shown here in red.

In a second similar study we restricted ourselves only to quarterhorses and measured the palmar-metric for 278 feet of horses of known age. The results, in figure 7, are similar to the mixed-breed study of figure 6.

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Figure 7: Results of our study of 278 quarterhorse feet show that the palmar-metric, on average, decreases with age.

In a third study, we computed our palmar-metric for 328 feet of yearling thoroughbred horses. In this case, as all the horses were of the same age, we are not investigating change with age, but rather, we were interested to see the amount of variation in a same breed population of the same age. All yearlings were raised in Australia. Figure 8 shows a histogram of the data. It's interesting to note that some yearlings already display a quite flat pedal bone. Purchasers of expensive racehorses might like to consider this aspect of the pedal bone as part of their purchase considerations.
Figure 8: The distribution of palmar-metric values for a group of yearling thoroughbreds in Australia. A total of 328 feet were measured.

In a fourth study, we looked for the availability of radiographs for the same animal over a large span of years, in hopes of verifying our belief that for an individual horse the palmar-metric decreases with age. In figure 9 we present data for a set of horses for which we obtained radiographs from the past and compared them to radiographs taken recently. The difficulty of obtaining high quality radiographs from the days before digital radiography limited the number of cases we have been able to study in this regard. These cases appear to verify our assertion that the palmar-metric for a given animal should only decrease over time.
In a study of horses for which past radiographs of good quality were available, we found that in all cases, the “palmar area” metric decreased over time. The average rate of decrease for these horses was 0.33% per year.

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<tr>
<td>6</td>
<td>WB / 19</td>
<td>7.3%</td>
<td>5.3%</td>
<td>6.0 years</td>
</tr>
</tbody>
</table>

Figure 9: In a study of horses for which past radiographs of good quality were available, we found that in all cases, the “palmar area” metric decreased over time. The average rate of decrease for these horses was 0.33% per year.

In a fifth and somewhat speculative study, we investigated what might be inferred by plotting palmar-metric versus palmar-angle. In figure 10 we present a scatter plot of palmar-metric versus palmar angle. Palmar angle is a measure of the angulation of the P3 bone as it stands in the hoof (see figure 3B for an example). The red trend line hints at a worsening of our palmar-metric as the palmar angle becomes large or too small. A large palmar angle can cause an increase of weight on the forward portion of P3 which, as a result, leads to more demineralization and hence a smaller palmar-metric over time. One can even imagine that the trend line indicates an optimal palmar angle, appearing to be around 3.75 degrees. There is a high amount of scatter in the data; indeed, just because the palmar angle was at a certain value in the radiograph used in the study, we do not know if that palmar angle was typical for that foot over its lifetime. Hence, we must be cautious in drawing conclusions from these data until further studies can be performed.
Figure 10: Palmar-metric plotted against palmar angle for 266 feet: the red trend line shows that there appears to be a dependence on palmar angle. Does this data imply that the optimum palmar-angle is around 3.75 degrees?

Repeatability of Results

To check the repeatability of our measurement, we used 5 radiographs taken of the same hoof during a single calendar year. Over the course of a single year, we would not expect the palmar-metric to change very much, so we measured these 5 radiographs to see if we would indeed find a constant value. The average of the 5 values was 4.42% with minimum value of 4.22% and a maximum of 4.70%, so the values are all within 0.28% of the average. On a percentage basis, we were within about 6% of the average value.

In a second test of repeatability, we varied the position of the central beam of the x-ray generator on the foot over a 3.25” vertical range vertical (relative to the nominal position of standard practice we were -2.25” to +1.0”). This variation introduced an error of up to about 5% relative to the average value found.

Hence, using modern digital radiographs, we believe we can repeatably measure the palmar-metric within about 6% error, which for an average horse means a maximum
error in palmar-metric of about 0.37%. This value is close to our average yearly decline (from figure 9), so we can effectively measure the palmar-angle to an accuracy equal to the expected change in a year.

**Conclusion**

We have introduced the palmar-metric as a means to assess the quality of the distal phalange in the horse. We believe that for any animal, once the pedal bone is mature, this metric will stay the same or decrease as the animal ages. We believe this metric is a useful means to capture the net effect of how the animal’s lifestyle has impacted the quality of the distal phalange.

The palmar-metric can be directly computed based on a high-quality lateral radiograph of the digit using software developed by two of the authors. Then, given the animal’s age, the trend line (such as in figure 6 or 7) can be used as a guide for what is ‘normal’.

In a follow-on study, we intend to measure many more horses over various time spans in order to develop a better statistical understanding of how our metric changes with age. We would like to correlate the rate of palmar-metric loss with additional factors such as the weight of the animal, the hoof care practices, the amount of work done by the animal, the breed, and other conformational factors.

It is hoped that a better understanding of how and why P3 remodels throughout the animal’s lifetime, along with a way to measure this process from standard radiographs, will yield improvements in hoof care for the horse.