The equine foot is composed of a hard external hoof capsule that contains the distal phalanx and related soft tissue structures. Primary epidermal laminae and SELs interdigitate with corresponding dermal structures to form the complex architecture of the laminar junction. Primary epidermal laminae line the entire inner surface of the hoof capsule from the coronet to the ground surface around the circumference of the hoof. Distal to the third phalanx, the laminar junction forms a connection between the hoof wall and sole that is visible at the ground surface as the white line. The white line is clinically important in hoof wall diseases such as white line disease and laminitis.  

The white line is believed to serve as a marker of the integrity of the more proximal portions of the laminar junction inside the hoof wall. The basic anatomic features of the laminar junction have been described, as have the material properties of the laminar junction and the relationship between internal and external features of the hoof wall.  

A better understanding of the form and function of the laminar junction may aid practitioners in diagnosing and treating hoof disease. The objectives of the present study were to further elucidate the functional morphology of the laminar junction by determining PEL number, density, and structure in hooves of healthy horses; assess the relationship between variations in regional density and morphology of the hoof capsule solar surface; and histologically evaluate morphologic features of the primary and secondary laminae.

**Materials and Methods**  

**Data collection**—Both forefeet from nine 3-year-old Quarter Horses that had died of catastrophic racing injury unrelated to the feet were obtained at necropsy. Feet were removed proximal to the coronet and frozen.

Hoof symmetry and gross morphologic features—With the hoof viewed in the dorsopalmar plane, grossly...
visible differences between the medial and lateral hoof wall angles, from coronet to ground surface, were recorded (Figure 1). Symmetry of the solar surface was quantified by comparing the distances from midline (ie, from a line bisecting the frog) to medial wall and midline to lateral wall, measured at the widest part of the foot. An asymmetry index was established as the ratio of solar surface lateral width to medial width.

Solar surface asymmetry was further assessed by use of a semiquantitative scale of localized areas of flare. Flare is an area of hoof wall that deviates abaxially from the normal straight edge when the hoof wall is viewed from coronet to ground surface. Flare can also be viewed on the solar surface as an area where the wall deviates from an otherwise smoothly arched perimeter. Flare in the dorsal portion of the hoof wall (toe) is often referred to as a dished wall. Viewed from the solar surface, toe flare often appears as a bulge in the hoof wall perimeter and may be associated with elongated PELs in the white line. Flare in the quarter of the hoof is usually seen in the distal third of the hoof wall. On the solar surface, flare in the hoof quarter appears as separation between hoof wall and sole horn in the white line. Axial deviation of the hoof wall causes a rolled-under or crushed appearance. A rolled-under area of hoof wall is most commonly seen in the heels.

A scale was created to quantify flare on the basis of those descriptions. Rolled-under hoof wall horn was assigned a negative number, and abaxial hoof wall deviation was assigned a positive number. The scale used to describe the degree of flare was none, mild, moderate, or severe. A grade of 0 (no visible flare) was assigned when the foot was symmetric with no flare. A grade of 1 (mild) was assigned when wall perimeter asymmetry was just detectable. A grade of 2 (moderate) was assigned when asymmetry was easily detectable. A grade of 3 (severe) was assigned when distortion was observed with obvious deviation from normal hoof wall configuration. For each hoof, localized solar surface flaring was recorded by region by use of the anatomic terms toe, quarter, or heel. For example, if a foot had a rolled-under heel on 1 side and lateral toe flare on the contralateral side and both changes were obvious, assigned scores would be −2 for the heel axial flare and 2 for the lateral toe abaxial flare.

**Counting PELs**—Feet were sectioned with a bandsaw in 5-mm-thick slices in a plane parallel to the ground. The proximal cut surface of the most distal section was examined under a dissecting microscope (magnification, 7X to 20X). Primary epidermal laminae were counted on the cut surface of the distal section around the perimeter of the hoof wall, including the bars (Figure 2). The bars are the area of the foot where the wall at the heels deflects inward. Because bar laminae are continuous with wall laminae at the heels, a reproducible method for counting bar laminae was created. The lamina at the palmar tip of the heel was counted as the last wall lamina. This last wall lamina was identified as being oriented in a palmar-dorsal direction with the laminae on both sides oriented obliquely.

**PEL density**—The perimeter of the hoof wall was divided into zones for quantifying the number of PELs (Figure 2). The toe of the foot was designated zone 1. A pin (30-gauge needle) was placed at the midpoint of the toe, which was identified with a line bisecting the foot through the central sulcus of the frog. Twenty-five PELs were counted on the medial and lateral sides of that midpoint. Four additional zones per side were designated and zones were composed of 50 laminae each. Beyond the last zone containing 50 laminae, the remaining PELs (<50) were counted and recorded. Pins were placed to indicate the boundaries of each zone.

Use of zones containing a set number of laminae facilitated detection and quantification of density patterns around the perimeter of the hoof. The numbering system corresponded roughly with the anatomic regions of toe, quarter, and heel. Zone 1 was centered on the midpoint of the dorsal part of the hoof wall; that midpoint was determined by a line from a line bisecting the frog to the widest part of the foot. An asymmetry index was established as the ratio of solar surface lateral width to medial width.
bisectiong the foot through the frog axis and therefore corresponded to the anatomic area called toe in all feet. Zones 2, 4, 6, and 8 were on the medial side; zone 2 corresponded roughly with the medial portion of the toe region, zones 4 and 6 with the quarter region, and zone 8 with the heel region. Zones 3, 5, 7, and 9 were on the lateral side; zone 3 corresponded roughly with the lateral portion of the toe region, zones 5 and 7 with the quarter region, and zone 9 with the heel region.

Calipers were used to measure the distance between pins. Each PEL zone was measured to the nearest 0.10 mm. Laminar density (ie, No. of PELs per centimeter) was calculated by dividing the number of laminae counted by the distance between pins.

Crena—The crena is a notch in the white line at the middle of the toe where the coherent architecture of the PELs is disrupted (Figure 1). After the hoof underwent sectioning with a band saw, a crena score was assigned to each foot on the basis of the depth the crena extended in the proximodistal direction. A score of 0 was assigned if no crena was visible at the solar surface. A score of 1 was assigned if the crena was visible only at the solar surface (ie, in the distal 5 mm of hoof wall). A score of 2 was assigned if the crena was visible on the proximal surface of the distal section, regardless of appearance on the distal side of the second section (a depth from 5 to 9 mm). A score of 3 was assigned if the crena was visible on the proximal surface of the second section, regardless of its appearance on the third section (depth from 10 to 14 mm).

Laminar junction histologic features—After the PEL counts were recorded, samples from 6 feet (each from a different horse) were excised at the level of the middle third of the hoof for histologic evaluation. From 1 specimen, a sample of the crena was obtained from the proximal cut edge of the distal section. Rectangular full-thickness sections of wall horn measuring 1 X 2 cm were removed from the toe and the medial and lateral quarters, placed in buffered formalin (pH, 7.4 to 7.8), and processed for paraffin embedding and staining with H&E and Masson trichrome stains. Slides were examined histologically with bright-field microscopy for assessment of laminar morphology in sections from the toe and quarter.

Statistical analysis—Analyses were performed by use of commercial statistical software. Values of P ≤ 0.05 were considered significant. Morphology scores (for flare and crena) and symmetry ratios were recorded for each hoof. Summary statistics were computed for PEL count (at the perimeter and bars) and density (at the perimeter, medial and lateral portions of the hoof, and zones; Table 1). The Shapiro-Wilk test was used to assess data for normality. Linear correlations were calculated to identify associations between morphologic measurements and symmetry scores. A nested ANOVA (hoof nested within horse) was conducted to compare hoof symmetry variables and zone comparisons of PEL density.

Results

Hoof symmetry and gross morphologic features—The feet of all horses had been shod within 1 month of death. In this sample of racehorse feet, gross features suggested that all feet were well-conformed and balanced, and shoe wear was even. Hairlines at the coronet were free of distortion. The frogs in all feet were wide and large and appeared healthy. Soles had been trimmed beyond the level of exfoliating horn and were smooth with no
cracks. Four of 18 feet from 4 horses had mild stretching of the white line at the toe and white line separation in the quarters in the area of the nail holes. Wall horn was solid and smooth, and no growth rings, areas of bruising, or other distortions were detected.

From a dorsopalmar view, slight mediolateral differences were evident in most of the feet, with the hoof wall in 16 of 18 feet being more sloping on the lateral side than on the medial side (Figure 1). No obvious flaring of the walls was seen from the dorsopalmar view. Medial (5.68 ± 0.32 cm) and lateral (5.83 ± 0.22 cm) ground surface widths, as measured across the solar surface at the widest part of the foot, were significantly (P = 0.03) different.

On the solar hoof surfaces, slight regional flares were detectible in most feet. Hoof wall flare was qualitatively determined to be symmetric (grade 0) in 3 of the 18 feet. A single grade 1 (ie, barely detectable) unilateral flare in the lateral portion of the toe was observed in 5 of the 18 feet. Ten feet had a flare with a grade of 2 or 3 (including positive and negative scores). Of those 10 feet, 4 had a diagonal flare pattern (ie, crushed heel [region of axial flare in the heel] with flare at the contralateral toe) and 6 had only unilateral toe flare. No significant associations between flare and the qualitatively measured variables were detected.

**PEL count**—Mean ± SD number of PELs around the perimeter of the hoof, including the bars, was 551 ± 0.22 cm)

<table>
<thead>
<tr>
<th>Variable</th>
<th>No. of feet</th>
<th>Mean ± SD</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Overall laminar density (zones 1–9)</td>
<td>18</td>
<td>20.63 ± 1.40</td>
<td>18.54–23.49</td>
</tr>
<tr>
<td>Zone 1 (toe region)</td>
<td>18</td>
<td>26.67 ± 2.73</td>
<td>22.68–32.94</td>
</tr>
<tr>
<td>Medial zone 1 (medial half of toe)</td>
<td>18</td>
<td>26.09 ± 2.97</td>
<td>21.21–33.71</td>
</tr>
<tr>
<td>Lateral zone 1 (lateral half of toe)</td>
<td>18</td>
<td>27.36 ± 2.82</td>
<td>23.10–34.18</td>
</tr>
<tr>
<td>Laminar density in medial zones</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Zone 2</td>
<td>18</td>
<td>22.94 ± 1.50</td>
<td>20.42–25.04</td>
</tr>
<tr>
<td>Zone 4</td>
<td>18</td>
<td>20.09 ± 2.28</td>
<td>16.56–24.73</td>
</tr>
<tr>
<td>Zone 6</td>
<td>18</td>
<td>18.30 ± 1.84</td>
<td>15.85–21.70</td>
</tr>
<tr>
<td>Zone 8</td>
<td>18</td>
<td>16.44 ± 1.89</td>
<td>14.21–21.58</td>
</tr>
<tr>
<td>Zone 10</td>
<td>1</td>
<td>15.04</td>
<td>NA</td>
</tr>
<tr>
<td>Mean density (medial)*</td>
<td>18</td>
<td>20.77 ± 1.60</td>
<td>18.94–24.32</td>
</tr>
<tr>
<td>Laminar density in lateral zones</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Zone 3</td>
<td>18</td>
<td>21.44 ± 2.27</td>
<td>21.26–28.49</td>
</tr>
<tr>
<td>Zone 5</td>
<td>18</td>
<td>23.67 ± 1.89</td>
<td>17.53–24.76</td>
</tr>
<tr>
<td>Zone 7</td>
<td>18</td>
<td>19.19 ± 1.65</td>
<td>17.12–22.02</td>
</tr>
<tr>
<td>Zone 9</td>
<td>18</td>
<td>15.95 ± 1.61</td>
<td>12.68–18.45</td>
</tr>
<tr>
<td>Zone 11</td>
<td>2</td>
<td>16.20 ± 2.84</td>
<td>14.19–18.21</td>
</tr>
<tr>
<td>Mean density (lateral)†</td>
<td>18</td>
<td>21.72 ± 1.50</td>
<td>19.14–24.74</td>
</tr>
<tr>
<td>Laminar counts</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total No. of laminae</td>
<td>18</td>
<td>551.72 ± 30.21</td>
<td>499–601</td>
</tr>
<tr>
<td>Total laminae—no bars</td>
<td>18</td>
<td>499.06 ± 28.96</td>
<td>450–554</td>
</tr>
<tr>
<td>Medial laminae</td>
<td>18</td>
<td>278.00 ± 19.25</td>
<td>252–312</td>
</tr>
<tr>
<td>Lateral laminae</td>
<td>18</td>
<td>276.72 ± 18.47</td>
<td>247–309</td>
</tr>
<tr>
<td>Medial laminae—no bars</td>
<td>18</td>
<td>247.89 ± 15.48</td>
<td>225–285</td>
</tr>
<tr>
<td>Lateral laminae—no bars</td>
<td>18</td>
<td>251.17 ± 17.36</td>
<td>225–286</td>
</tr>
<tr>
<td>Medial bar laminae</td>
<td>18</td>
<td>26.44 ± 5.67</td>
<td>12–25</td>
</tr>
<tr>
<td>Lateral bar laminae</td>
<td>18</td>
<td>25.56 ± 5.62</td>
<td>13–36</td>
</tr>
<tr>
<td>Extra laminae (medial)</td>
<td>15</td>
<td>24.13 ± 9.5</td>
<td>9–40</td>
</tr>
<tr>
<td>Extra laminae (lateral)</td>
<td>13</td>
<td>28.53 ± 10.85</td>
<td>5–44</td>
</tr>
<tr>
<td>Hoof symmetry</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Medial ground surface width (cm)</td>
<td>18</td>
<td>5.68 ± 0.32</td>
<td>5.13–6.26</td>
</tr>
<tr>
<td>Lateral ground surface width (cm)</td>
<td>18</td>
<td>5.83 ± 0.22</td>
<td>5.50–6.27</td>
</tr>
<tr>
<td>Asymmetry index (L cm/M cm)</td>
<td>18</td>
<td>1.03 ± 0.05</td>
<td>0.95–1.15</td>
</tr>
<tr>
<td>LM difference (cm)</td>
<td>18</td>
<td>0.14 ± 0.25</td>
<td>0–0.30–0.77</td>
</tr>
</tbody>
</table>

*Includes medial zone 1. †Includes lateral zone 1. L = Lateral half of the hoof. M = Medial half of the hoof. NA = Not applicable.

**Table 2**—Differences in laminar density between selected locations in the left and right forefeet of the same 9 horses as in Table 1.

<table>
<thead>
<tr>
<th>Locations compared</th>
<th>Difference*</th>
<th>P value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Left and right hoof</td>
<td>−0.24 ± 0.32</td>
<td>0.46</td>
</tr>
<tr>
<td>Medial and lateral portions of hoof</td>
<td>−0.04 ± 0.17</td>
<td>0.01</td>
</tr>
<tr>
<td>Zones 1 and 2</td>
<td>3.73 ± 0.88</td>
<td>&lt; 0.001</td>
</tr>
<tr>
<td>Zones 1 and 3</td>
<td>2.23 ± 0.88</td>
<td>0.001</td>
</tr>
<tr>
<td>Zones 2 and 3</td>
<td>−1.51 ± 0.88</td>
<td>0.03</td>
</tr>
<tr>
<td>Zones 4 and 5</td>
<td>−1.58 ± 0.88</td>
<td>0.02</td>
</tr>
<tr>
<td>Zones 6 and 7</td>
<td>−0.39 ± 0.88</td>
<td>0.19</td>
</tr>
<tr>
<td>Zones 8 and 9</td>
<td>0.50 ± 0.88</td>
<td>0.47</td>
</tr>
<tr>
<td>Zones 2 and 4</td>
<td>2.85 ± 0.88</td>
<td>&lt; 0.001</td>
</tr>
<tr>
<td>Zones 4 and 6</td>
<td>1.79 ± 0.88</td>
<td>0.01</td>
</tr>
<tr>
<td>Zones 6 and 8</td>
<td>1.86 ± 0.88</td>
<td>0.01</td>
</tr>
<tr>
<td>Zones 3 and 5</td>
<td>2.79 ± 0.88</td>
<td>&lt; 0.001</td>
</tr>
<tr>
<td>Zones 5 and 7</td>
<td>2.48 ± 0.88</td>
<td>&lt; 0.001</td>
</tr>
<tr>
<td>Zones 7 and 9</td>
<td>3.24 ± 0.88</td>
<td>&lt; 0.001</td>
</tr>
</tbody>
</table>

*Data represent difference ± SEM in laminar density (ie, No. of laminae per centimeter).
the toe (zone 1), compared with all other zones, and higher mean density on the lateral side of the hoof, compared with the medial side of the hoof (Figures 3 and 4; Table 2). The PEL density in the medial and lateral zones (containing 25 laminae each) of the toe zone was not significantly ($P = 0.15$) different, so those zones were combined into a single zone of 50 PELs at the toe for purposes of comparison with the other zones, each of which contained 50 PELs. Beginning from the dorsal portion of the hoof wall and moving to palmar zones, significant decreases in PEL density between adjacent zones were identified. When corresponding zones on the medial and lateral sides of the hoof were compared, the dorsal portion of the hoof wall differed significantly from medial to lateral: zones 2 and 3 were significantly ($P = 0.03$) different, and zones 4 and 5 were significantly ($P = 0.02$) different. However, corresponding zones in the palmar region of the foot had no significant medial-to-lateral differences (zones 6 and 7, $P = 0.19$; zones 8 and 9, $P = 0.47$).

Compared with zone 1, the lateral toe zones had higher PEL density than medial toe zones. This difference between zones 2 (medial toe quarter) and 3 (lateral toe quarter) was visible grossly as an area of flare in the lateral toe region in 9 feet. The lateral quarter zones also had a higher PEL density than the medial quarter zones.

**Crena**—A crena was observed at the solar surface in 15 of the 18 hooves (Figure 1). In hooves with no visible crena at the solar surface, no white line defects were detected in the more proximal sections of the toe. Of the 15 feet with a crena at the solar surface, the crena was visible only at the solar surface (ie, to a maximum depth of 5 mm) in 3 feet, from 5 to 9 mm in 7 feet, from 10 to 14 mm in 2 feet, and from 15 to 19 mm in 3 feet. No significant associations between the presence of a crena and the other measured variables were detected.

**Histologic features of the laminar junction**—Histologic examination revealed differing morphologic features of the laminar junction within and between feet (Figures 5 and 6). Compared with sections from the quarters, the toe PELs appeared longer and the dermal surface area appeared smaller. In sections from the toe, the mid-laminar region of most PELs was undulating in all of the feet examined. Similar undulation was observed at the quarters in 4 of the 6 hooves examined.

Although the toe and quarter sections had distinctly different appearances (Figure 5), within a single section, PELs and SELs were uniform in appearance in 2 of 6 feet examined. In 4 of the 6 feet, there was distinct variation in SEL morphology, orientation, and length (Figure 6). Some SELs were stretched to a single cell layer in thickness. The orientation of some SELs was perpendicular to that of the PELs, with short club-shaped tips. Some PELs had few or no SELs at the apical end. Other PELs had longer, more tapered SELs arrayed nearly parallel to the PEL.

Cell nuclei varied from oval to rounded. In SELs with markedly narrow stretched tips, cell nuclei appeared clumped together near the SEL base. The axial portion of the SELs was more densely cellular. In PELs with few or no SEL at the apical end, keratinocytes were still visible at higher magnification (Figure 6). The dermis was composed of a mixture of loose and dense connective tissue, with more dense connective tissue adjacent to the distal phalanx side and more loose connective tissue abaxial to that.

Histologic evaluation of tissue at the crena (obtained at a depth of 15 mm proximal to the ground surface) revealed disruption of the typical architecture of the dermal-epidermal interface. The PELs appeared...
In the present study, the mean medial ground surface width of the hoof was 97% of the mean lateral ground surface width, whereas that value was 93% in previous studies\textsuperscript{11,12} of Thoroughbred racehorses. The smaller magnitude of solar surface asymmetry found in our hooves, compared with existing data on racehorse feet, may be a result of the small sample size in the present study, although the mean ± 2 SD values of our data overlapped with data previously reported.\textsuperscript{12,13} The symmetry differences may be breed specific. Additionally, hoof asymmetry, if related to loading, may develop slowly. The tendency toward greater hoof symmetry in our sample population may have been a result of the feet being obtained from 3-year-old horses, whereas the age range of horses in previous studies\textsuperscript{11,12} was 2 to 6 years.

Total number of PELs has been reported as approximately 500 to 600.\textsuperscript{3,4} The counting methods used in the previous studies was not described, but our mean total PEL count (551 ± 30) is similar to previously reported values.\textsuperscript{3,5} Our study also revealed that the total number of bar laminae did not differ significantly from medial to lateral. The biological importance of the total lamina count, including bar laminae, is presently unknown. For example, it is not known whether there is a genetically predetermined total number of laminae for the mature hoof or if the number is related to environmental factors. Furthermore, little is known about the structure and function of bar laminae.

In a previous study\textsuperscript{14} of laminar morphology, interlaminar spacing, a variable that is related to but distinct from laminar density, was investigated. In our study, the finding of regions of high PEL density in the toe were in accordance with previous findings of decreased interlaminar spacing at the toe compared with that in the palmar portion of the foot.\textsuperscript{11} In previous studies,\textsuperscript{7,14} samples were obtained for evaluation from representative regions around the perimeter of the hoof wall. In the present study, specimens were sectioned parallel to the hoof’s ground surface. Our method was advantageous in enabling visualization and accurate counting of PELs around the hoof perimeter, including the bars. That method facilitates collection of data from live horses in the future because the solar surface of a hoof prepared for shoeing readily yields samples containing laminae around the entire perimeter. However, our sectioning method may have skewed laminar density data in the palmar region of the foot. The method of sectioning used in earlier laminar distribution studies\textsuperscript{7,14} involved sectioning the feet perpendicular to the longitudinal laminar axis. In sample sections in the present study, the relationship between PEL density and interlaminar spacing in the palmar region of the foot would be expected to differ from that at the toe. The angle of obliquity of the hoof wall at the toe is different in 2 previous studies\textsuperscript{11,12} of racehorses that died of musculoskeletal injuries. The absence of association between localized flare and other variables in our study may have been a result of small sample size or flare classification method. Alternatively, there truly may be no relationship between focal areas of hoof wall flare and other measurements of hoof capsule morphology or symmetry.

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eral side, it might be expected that laminae would be
side) solar surface width, which presumably occurs in
Given the greater lateral (compared with the medial
zonal differences in PEL density warrants investigating.
hoof is insignificant, the finding of significant regional
features of hoof morphology, laminar density may be
predict that in populations with more heterogeneous
mediolateral differences in laminar density as measured
in the present study may have been affected by slight
variation in identification of the center point at the
middle of the toe.
In earlier texts,8,13 PELs around the perimeter of the
hoof wall have been depicted with a homogeneous
distribution between the toe and heels and with simi-
lar morphologic features. In contrast to those findings,
we detected differences in the distribution of laminae
around the perimeter of the hoof despite the fact that
the total numbers of PELs on the medial and lateral
sides of the hoof were not significantly different. One
potential source of these observed zonal differences
between the toe and quarter regions of the hoof is the
change in angle of inclination of the longitudinal lam-
inar axis between the dorsal and palmar regions of the
hoof. Along with PEL density differences from dorsal to
palmar hoof zones, significant PEL density differences
existed between the medial and lateral sides of the hoof.
These differences may be related to solar surface asym-
metry. The higher mean density on the lateral side may
be related to the higher mean solar surface width on the
lateral side (compared with the medial side). Most feet
had the typical conformation of a more sloping lateral
wall. In our sample of 18 front feet from 9 horses, only
2 feet (from 2 different horses) had a lateral wall that
was steeper than the medial wall. One of those 2 feet
had higher PEL density on the medial side, compared
with the lateral side. Laminar density may be related to
the slope of the hoof wall, rather than to the medial or
lateral side of the hoof. However, evidence of a relation-
ship between PEL density and hoof wall slope could
not be determined on the basis of the small sample size
and homogenous population of relatively symmetric
and grossly similar-looking feet in the present study. We
predict that in populations with more heterogeneous
features of hoof morphology, laminar density may be
determined to be related to hoof wall slope, which may
in turn be related to hoof loading.
Because the difference in total number of PELs and
mean density between the medial and lateral sides of the
hoof is insignificant, the finding of significant regional
zonal differences in PEL density warrants investigating.
Given the greater lateral (compared with the medial side)
solar surface width, which presumably occurs in
conjunction with a longer wall perimeter arc on the lat-
eral side, it might be expected that laminae would be
spaced farther apart on the side with the longer arc and
that that area would therefore have a lower PEL density.
It is possible that inert laminae are mechanically pulled
apart, increasing the space between them and decreas-
ing the density. It is also possible that laminar density
is biologically fluid. In other words, regional laminar
density may be a response to hoof loading.
Precise mechanisms of laminar adaptation to load-
ing have not been fully described, although results of
earlier work suggest bifurcation of PELs13 and SELs16
as possible responses. It is also possible that laminae
increase in number in response to stress, much like
epidermal tissue responds to friction by increasing the
number of keratinocytes.17 A common clinical finding
is the so-called stress pattern of diagonal flare in horse
feet: this change is seen grossly as an area of crushed
horn in the medial aspect of the heel with concurrent
abaxial flaring in the lateral toe region. There may be
a mechanism whereby laminae are distributed accord-
ing to the foot’s need for reinforcement and some ideal
level of homeostasis is biologically advantageous. If
this balance becomes disrupted, with laminae being too
numerous or crowded in 1 area and/or too far apart in
another area or both, areas of crushed or flared hoof
wall may result. Evidence that laminar morphology is
associated with hoof loading has been published,18 but
further research is needed to clarify the cause-effect
relationship.
Another question raised by our findings is whether
tissue perfusion is associated with the laminar density
differences around the hoof perimeter. The volume of
dermal vasculature supplying the toe region may be
less than that supplying other areas of the hoof. With
high PEL density in the toe zone, the interdigitating
dermal area is decreased, compared with regions in the
palmar area of the hoof where PELs are spaced farther
apart. Additional research is needed to investigate the
relationship between PEL density and regional blood
volume in the microvasculature.
The physiologic features of blood flow through the
hoof are still poorly understood, but vascular aber-
ration, whether a cause19 or consequence20 of the disease
process, is widely acknowledged to be an important
factor in the development of laminitis. It has also been
hypothesized that blood flow in the hoof is associated
with morphologic features of internal hoof structures
and hoof loading.21 The crena marginis soleae is de-
defined22 as the notch in the middle-to-distal level of the
dorsal aspect of the distal phalanx and is a normal anat-
omic feature of the distal phalanx in some horses. A
similar-sized notch at the solar surface appears as a dis-
ruption in the white line and has been called the crena
by farriers. The crena is frequently observed in horses
and is believed to be a normal finding. Our results re-
vealed that the proximodistal depth to which the crena
extends, and its appearance on the solar surface of the
hoof differed considerably among feet of the horses in
this study. In a previous study,23 it was reported that
32 of 41 (80%) horses had radiographic evidence of a
crena, although the appearance of a crena at the solar
surface was not mentioned. In the present study, 15 of
18 hooves had a crena at the solar surface. However,
because radiography was not used in our study, it is
not known whether the solar surface appearance of the crena was associated with a corresponding notch in the distal phalanx.

Because the crena appears as a disruption in the uniformity of PELs at the toe, we hypothesized that it would be associated with variables of asymmetry or changes in laminar density. However, no significant associations were detected between the crena and morphologic measurements. Small sample size and method of data collection may account for the absence of association. Further study is needed to determine whether there is a relationship between the size and appearance of the crena and the depth to which it extends proximally.

The histologic appearance of the crena (examined in 1 specimen) was unexpected. The morphologic features of the laminar junction in the crena resembled the white line rather than the typical dermal-epidermal interface that is observed adjacent to the crena. The white line–like PELs in the crena observed in the present study resembled what authors of a previous study suggested was ectopic white line in horses with chronic laminitis. Histologic evaluation of the crena in a larger sample population is needed to determine whether the features detected in this single specimen characterize the crena region in horse feet in general and whether morphologic features of the crena are a marker of laminar junction integrity.

Despite the homogeneous gross appearance of a uniform population of healthy feet, the histologic portion of this study revealed unexpected variation in the laminar junction in 4 of 6 feet (from 6 different horses). There was no gross evidence of laminitis in specimens used in the present study, but the histologic findings in 4 of the 6 feet examined were consistent in some aspects with previous descriptions of laminar pathologic changes.

Marked alterations were detected in some laminae, even when adjacent laminae had typical morphologic features of uniform SELs with rounded tips. These observations were consistent with architectural features classified by Pollitt as characterizing grade 1 histologic changes of laminitis. Similar variation in the laminar junction has been reported in nonracehorses.

Histologic laminar disease has been detected prior to the onset of lameness in feet of horses with experimentally induced laminitis. Investigators have speculated that repeat episodes of subclinical laminitis with internal remodeling of the laminar interface could account for the gross and radiographic changes typical of chronic laminitis.

The variation in laminar morphology in the feet evaluated in the present study suggests that subclinical tissue damage can exist in isolated PELs. It is unknown whether such variation reflects early stages of pathologic change or is a normal adaptation to the stress of training and racing. In our sample population of racehorses, it is possible that subtle mechanical changes developed at the laminar junction despite the fact that the outer hoof wall had a normal appearance. Although precise mechanisms of laminar adaptation have not yet been identified, it has been suggested that laminar tissue may be similar to bone in its response to stress and that laminar tissue may remodel according to loading patterns. Therefore, the atypical laminar morphology detected in feet in the present study may have been the result of appropriate biological responses to cycles of stress, microdamage, and repair. If this is true, it would be expected that the laminar junction of sound, nonworking horses would have uniform, rather than nonuniform, laminar morphology. Although our histologic observations were consistent in some aspects with previous reports of subclinical laminar damage, it cannot be said whether the changes in the laminar junction in these grossly healthy feet should be considered as normal or diseased. It will be important, therefore, to determine whether these findings represent the normal range of laminar morphology in young racehorses or whether they are manifestations of subclinical disease, given that grossly normal and relatively symmetric feet have been associated with catastrophic injury in racehorses.

In the present study, laminar density was significantly higher in the toe region, compared with that in the quarter and heel regions, and the mean PEL density was higher on the lateral side of the hoof than on the medial side. Further research is needed to establish whether the plane of sectioning affects variation in PEL density at different sites around the hoof wall. Histologic examination revealed various morphologic features of the primary and secondary laminae within and among the feet examined. Further research is needed to evaluate relationships between laminar density, laminar morphology, and gross hoof capsule morphology in different populations of horses. A better understanding of functional morphology in the laminar junction may aid in diagnosis and treatment of foot disease involving the hoof wall.