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NOTE

Surgery

Toe white line separation associated with the notch (*crena marginalis*) on the distal phalanges in Thoroughbred yearling horses

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ABSTRACT. The shape of the white line of the hoof is closely related to the shape of the notch on the dorsal distal bearing border of the distal phalanx (P3). In this study, a radiographic survey of the P3 of both forelimbs of 163 Thoroughbred yearling horses was conducted. The correlation of the depth and width of the notch were analyzed with the toe white line separation grades (0 to 3). As a result, the toe white line separation grade increased, the depth and the width of the notch also increased significantly. Radiographic examination of the P3 of the forelimbs might be useful for deciding whether to implement hoof care to prevent onset of toe white line separation.

KEY WORDS: distal phalanx, notch, radiographic examination, Thoroughbred, white line

The hoof wall of the horse comprises three layers: the *stratum externum* (external layer), *stratum medium* (middle layer), and *stratum internum* (inner layer) [8, 9, 13]. The nonpigmented zone of the *stratum medium* combined with the dermal lamellae is responsible for attaching the hoof wall to the distal phalanx (P3). Distally at the sole-hoof wall junction, the white zone (white line) consists of intertubular horns and terminal tubules surrounded by intertubular horns, and has hard and elastic characteristics [12]. It contributes effective connection to the *st. medium* with the sole by its unique morphology and physiology. Even though it confers flexibility of the hoof capsule in motion, it is relatively weaker than other horns in the case of excessive mechanical stress, moisture and infections, then occasionally progresses to white line separation and finally develops to hoof wall separation [2–4, 7–9]. Some veterinarians and farriers use the term "white line disease" (WLD) [8, 9, 13] as a synonym for hoof wall separation in which the horny structures between the *st. medium* and the *st. internum* are progressively broken and separated from each other. This lesion can widen and extend upward into the white line tissue to eventually develop into a "gidoh" in Japanese [6]. A focal separation that occurs in the center toe of the hoof wall is also called "seedy toe" [9]. Though the terminology is confusing, WLD, gidoh, and seedy toe usually start from white line separation. In the clinical field of equine veterinary medicine, both white line separation and hoof wall separation are troublesome hoof diseases that require rest and hoof therapy over a long period of time. Meanwhile, toe white line separation lies directly perpendicular to the notch of the dorsal distal bearing border of the P3 called the *crena marginalis* or *crena marginis solearis* [8, 10, 14, 18]. It was hypothesized that a local laminar wedge (distinct histological aberration) in the organization of the laminar architecture at the crena (notch) might be made because of a weakened bond between the hoof capsule and the P3 [18]. This locally forming laminar wedge is not a good structure to resist mechanical stress and is probably susceptible to traumatic injury. Anecdotally speaking, the shape of the notch is closely related to the shape of the white line. In a previous radiographic study, the notch was easily detectable as a normal finding (96.8% of fore-hooves and 48.4% of hind-hooves) in several breeds of horses (from 2 to over 7 years old) without present or previous lameness related to a foot disease [16]. Furthermore, the notch was reported to be first observed in young horses ranging from 4 to 22 weeks old [15]. However, there are only a few reports examining the details of the relationship between the notch shape and the occurrence of the toe white line separation [1, 17].

Usually, a young Thoroughbred horse's first shoeing is performed after starting ridden exercise training because the hooves of the fore feet especially wear down with the start of the exercise training. However, the hooves of Thoroughbred horses after they start exercise training or become racehorses are not suitable for investigating the relationship between notch shape and toe white line separation because they have already been trimmed or shoed. On the other hand, in yearling horses whose breaking has just begun, toe white line separation may already be present at the center of toe area. If the possibility of, or susceptibility to, toe white line separation can be predicted, this knowledge may be useful for preventing progression to toe area of WLD or seedy toe and

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gidoh. We at the Hidaka Training and Research Center always check the condition of the bearing surface of the hoof in young racehorses.

Then, we postulated that the morphological characteristics of this notch of the P3 are related to the existence of the local laminar wedge and finally cause white line separation on the toe area. In this study, we investigated the relationship between the shape of the notch on the dorsal distal bearing border of the P3 of each of the forelimbs and the clinical condition of white line separation in the toe area of the hooves of Thoroughbred yearling horses.

This study was performed in accordance with the Ethical Principles in Animal Experimentation and approved by the Ethics Committee of the Institutional Animal Welfare and Experiment Management Committee of the Hidaka Training and Research Center (#2011-5). All procedures were conducted in compliance with the ethical principles of good practice of animal experimentation.

A total of 163 Thoroughbred yearling horses (87 colts and 76 fillies; 17–21 months old) without present or previous lameness related to a hoof disease were investigated. These horses belonged to the Hidaka Training and Research Center, Japan Racing Association. They were purchased at yearling Thoroughbred sales held in Japan from July to September, and were all healthy horses with no particular abnormalities in the hoof or lower limb as determined by veterinarians' physical examination and clinical repository inspection. After stabling at the Hidaka Training and Research Center, they were grazed on pasture day and night until October, when breaking training began. After that, they were kept in individual stalls and grazed in a small paddock. Before shoeing, radiographic examinations of the P3 were conducted in both forelimbs of all 163 Thoroughbred yearling horses in December when they had not started extensive exercise training after breaking. A handmade stand was used to position the fore-hoof with respect to the radiographic generator (Atomscope 20SH; Tec Mikasa Corp., Osaka, Japan) such that it could shoot from a 70-cm focal distance and get a D65PrPaDiO (dorsal 65-degree proximal to palmarodistal oblique projection) shot of the P3 (Fig. 1). The width was measured between the lateral and medial end points of the notch, and the depth was measured between the width line and the deepest point of the notch (Fig. 2) using DICOM viewer software (ExaVision; Zoisoft Inc., Tokyo, Japan). The grading of toe white line separation was carried out at the same time as the radiographic examination using the four grades listed in Fig. 3. The depth of the crack or hole was evaluated by inserting a hoof nail and was measured after scraping the white line with a thin loop knife. The mean values of the width and the depth of the notch within each of the toe white line separation grades were subjected to statistical analyses by using JMP statistical software, version

Fig. 1. Handmade stand for placing the fore hoof in the correct position with respect to the radiographic X-ray generator.

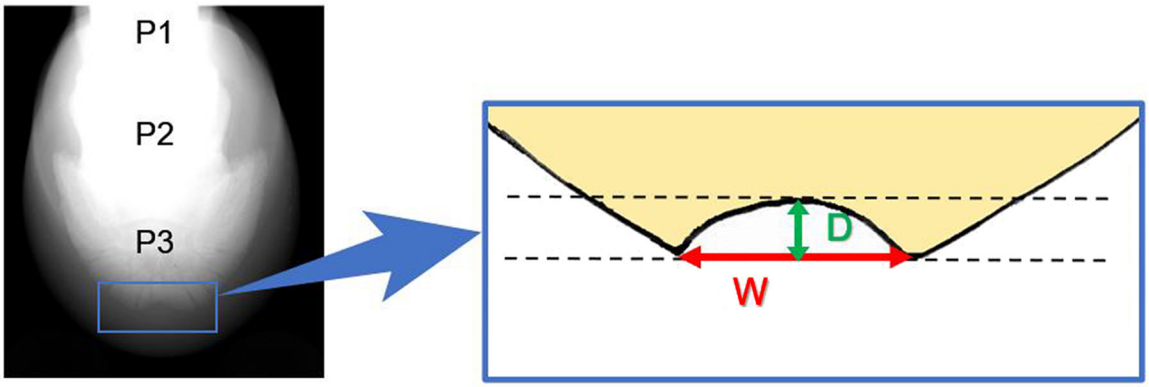

Fig. 2. The measuring points of the notch with the P3 radiographic image. The width (W) is measured between the lateral and medial end points of the notch, and the depth (D) is between the width line and the deepest point of the notch. P1, proximal phalanx; P2, middle phalanx; P3, distal phalanx.

14.0 (SAS Institute Japan Co., Tokyo, Japan). The Shapiro-Wilk normality test found the data of some groups were not normally distributed, so the Kruskal-Wallis test (nonparametric test) was used to test for differences between the groups. Multiple comparisons were performed using the Steel-Dwass test for significant differences found. The level of significance was set at $P<0.05$.

Of the 326 hooves of both forelimbs in 163 yearling Thoroughbred horses, 160 hooves were of the toe white line separation Grade 0, 131 hooves were of Grade 1, 31 hooves were of Grade 2, and 4 hooves were of Grade 3. Photographs of typical cases of each grade are presented in Fig. 4.

As mentioned in the section on statistical analysis methods, because only four horses were classified as Grade 3, statistical analyses were performed with those horses grouped together with the 31 horses of Grade 2. Radiographic images of the P3 showing notches close to the average measurements for each grade are presented in Fig. 5.

The depths of the notch in each toe white line separation grade are presented in Fig. 6. As the toe white line separation grade increased, the depth of the notch also significantly increased ($P<0.001$, Steel-Dwass test). Further, outlier values were found above the upper whiskers of the box plots in each group: three outliers in Grade 0, two outliers in Grade 1, and one outlier in Grade ≥2. Those six outlier values occurred in five horses (with one horse having an outlier value in each forelimb).

The widths of the notch in each toe white line separation grade are presented in Fig. 7. In the Steel-Dwass test, significant differences were found between the toe white line separation groups of Grades 0 and 1 ($P=0.009$), Grades 0 and ≥2 ($P<0.001$), and Grades 1 and 2 ≤ ($P<0.001$). In Grade 0, two outlier values were found outside of the upper whiskers. Those two outlier values occurred in two horses. Furthermore, 14 outlier values were found under the whiskers in

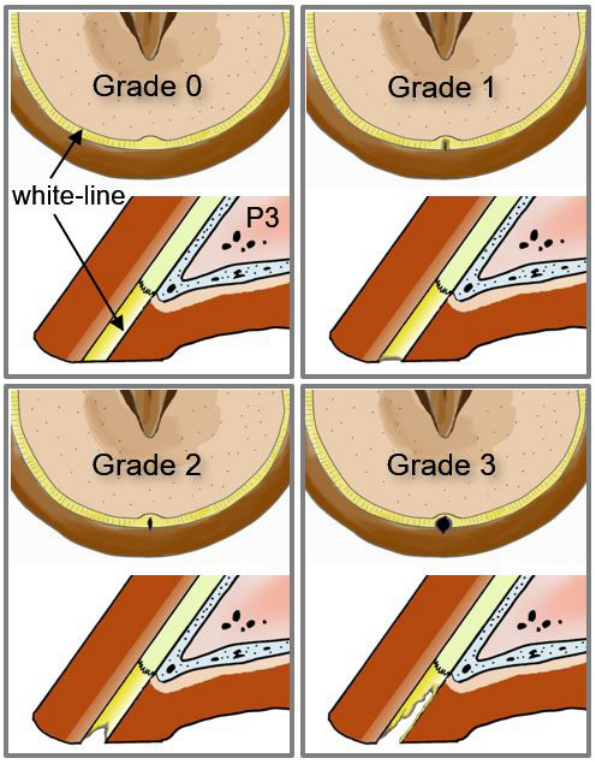

Fig. 3. The white line separation grades in the toe area of the fore-hoof. Grade 0, No abnormality in the white line of the solar surface. Grade 1, Discoloration of the surface layer (dark gray to black) and/or thin crack. Grade 2, Cracks and holes <5 mm in depth. Grade 3, Holes ≥5 mm in depth.

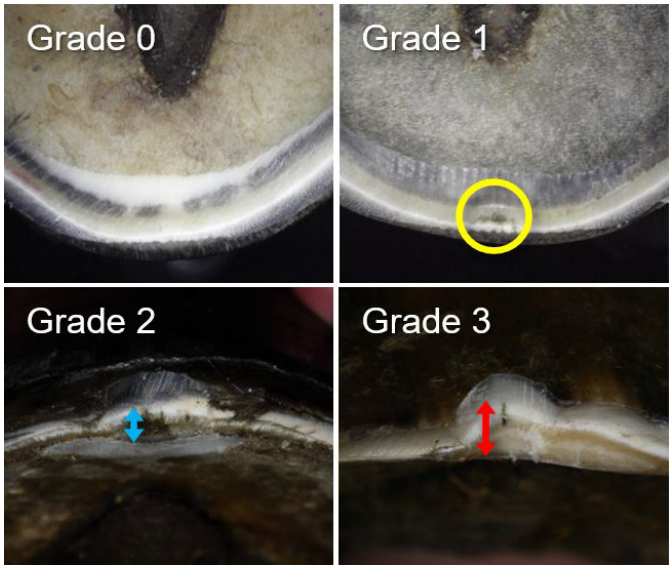

Fig. 4. Typical case of each grade in the toe area of the fore-hoof. Grade 0, No abnormality in the white line of the solar surface. Grade 1, Discoloration of the surface layer and crack. Grade 2, Cranial-caudal view of a hole <5 mm in depth (after trimming with a hoof knife). Grade 3, Cranial-caudal view of a hole ≥5 mm in depth (after trimming with a hoof knife).

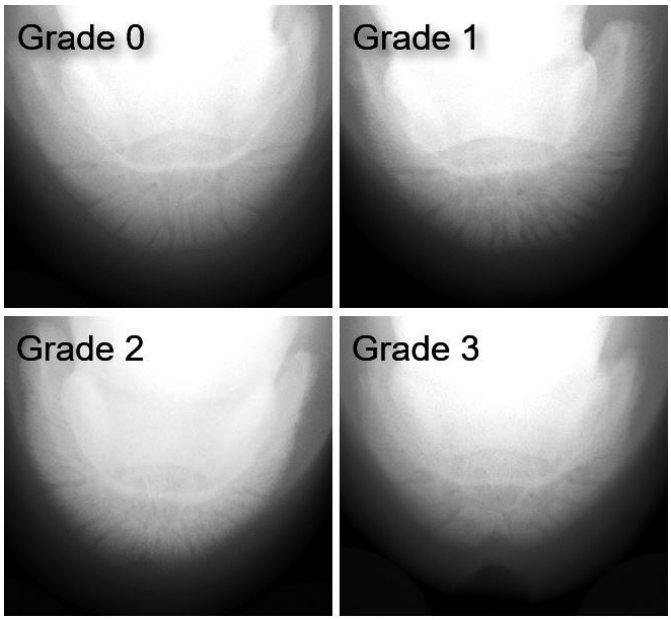

Fig. 5. Radiographic images of the P3 showing notches close to the average measurements for each grade. The width (W) and the depth (D) of the notch in each grade shown here are as follows. Grade 0, W 10.7 mm, D 1.2 mm. Grade 1, W 11.7 mm, D 1.9 mm. Grade 2, W 15.1 mm, D 3.7 mm. Grade 3, W 15.8 mm, D 6.2 mm.

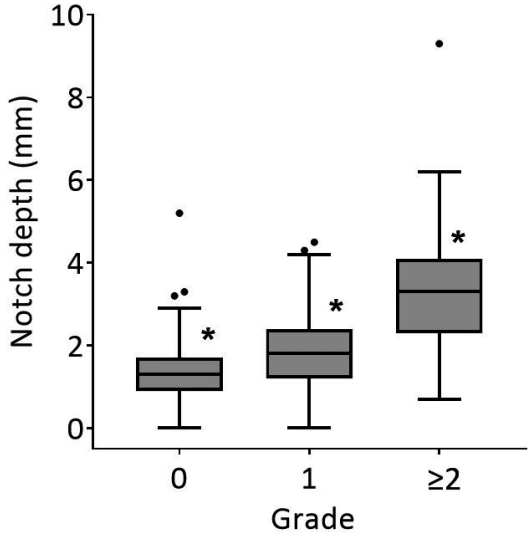

Fig. 6. The depth of the notch in each white line separation grade. The box plot represents the 25th–75th percentile, with the horizontal line inside the box indicating the median. The upper and lower whiskers indicate maximum and minimum values within 1.5 times the interquartile range, respectively. Outliers (●) are values outside of the range of the whiskers. Columns surmounted by an asterisk (*) are significantly different from each other at $P<0.001$.

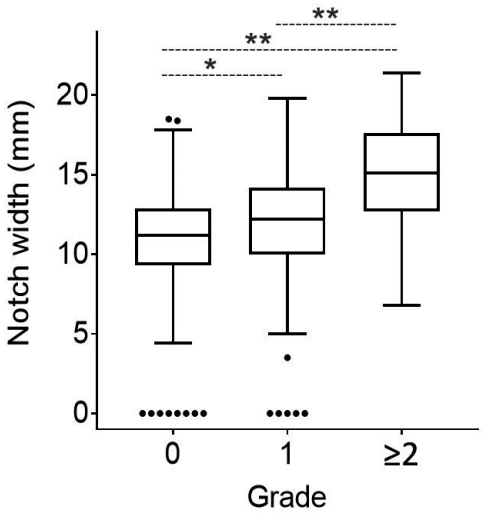

Fig. 7. The width of the notch in each white line separation grade. The box plot represents the 25th–75th percentile, with the horizontal line inside the box indicating the median. The upper and lower whiskers indicate maximum and minimum values within 1.5 times the interquartile range, respectively. Outliers (●) are values outside of the range of the whiskers. The superscript asterisks of each bar indicate significant differences, *P=0.009 and **$P<0.001$.

Grades 0 and 1. Those 14 outlier values occurred in 13 horses (with one horse having an outlier value in each forelimb).

In this study, we elucidated the relationship between the white line separation grades in the toe area of the forehooves and the shape of the notch (depth and width) within the P3 radiographic images of the forelimbs. Although several studies have examined how the notch of the P3 is involved in the occurrence of white line separation in the toe area of the fore-hooves [1, 5], no previous study has analyzed the relationship between white line separation and the shape of the notch. Empirically, holes deeper than 5 mm are known to evolve into larger white line lesions, if left untreated. Therefore, in this study, the Grade 2 and Grade 3 thresholds were set to be a crack or hole with a depth of 5 mm. It was revealed in our study that the measured values of the notch shapes were closely related to the clinicopathological grades of white line separation in the toe area of the fore-hooves.

In this study, six fore-hooves in five horses had a *crena marginalis* with a depth greater than the upper whiskers in the box plots (outlier values) of Grades 0, 1, and ≥2. Furthermore, two fore-hooves in two horses had a *crena marginalis* with a width greater than the upper whiskers of the box plots of the Grade 0 group. These horses with an extra-deep or -wide *crena marginalis* can be considered horses with hooves that are more likely to develop white line separation in the toe area of the fore-hooves. In contrast, in 14 fore-hooves in 13 horses, the width of the *crena marginalis* was below the lower whiskers of the box plots of the Grades 0 and 1 toe white line separation groups. These horses may be considered to be at low risk of developing WLD in the toe area of the fore-hooves. Furthermore, the horses of Grade 3 in the high grading group had a relatively deeper and wider *crena marginalis* (data not shown). Those horses were purchased at yearling horse sales held from July to September and were 17–21 months old at the time of the radiographic examinations. It is considered that the *crena marginalis* of the P3 continues to develop until those months of age, and that toe white line separation is more likely in occur in horses with a deep or wide *crena marginalis*.

Although WLD does not cause pain unless the lesion extends to the sensitive tissues or there is an occasional abscess, secondary stimulating factors may subsequently cause the lesion to spread over the entire hoof wall. One such secondary factor is the moving mechanism of the hoof. Since the toe area of the hoof where white line separation frequently occurs is the stress point of the hoof during the latter half of the stride, particularly just before breakover [11], if the depth of the notch is deep, the distance between the hoof cusp and the *crena marginalis* of the P3 becomes longer, and it is considered that more stress will be applied to the toe area of the white line. In Thoroughbred horses, hoof trimming usually begins at about 3 weeks of age and is often performed at about 3-week intervals. Although the 35 hooves of Grade ≥2 of the high grade accounted for only 10.7% of the 326 hooves examined, other lower grades (Grades 0 and 1) also contained several hooves with a deep or wide *crena marginalis*. As a potential reason for this, horses with white line separation of high grade might not have had proper hoof care at appropriate intervals, whereas horses without white line separation in the low-grade groups might have had proper hoof care.

The white line separation grade in the toe area of the fore-hooves was related to the depth and width of the notch. It is important to prevent the onset of WLD, gidoh, or seedy toe in the toe area and not let it worsen. Predicting the shape of the *crena marginalis* of the P3 by radiographic examination is considered useful for deciding whether to implement hoof care to prevent the onset of WLD, gidoh, or seedy toe in yearling Thoroughbred horses. Some proper hoof trimming techniques (e.g., rolling or shortening the

long-toe end of the hooves) and correct shoeing (e.g., setting the shoe backward and behind the toe margin, and rolling or rockering the toes of horseshoes) are considered effective.

Radiographic examination of the P3 of the forelimbs might be a useful tool in the prevention of the onset of WLD, gidoh, or seedy toe in yearling Thoroughbred horses. If left without any farriery treatment, secondary infection can occur, and the horse can show mild to severe lameness because of hoof pain resulting in a delay of training. Veterinarians and farriers need to cooperate closely to prevent it. Further investigations of the relationship between the notch of the P3 and white line separation, and the preventive effect of hoof care are needed.

CONFLICT OF INTEREST. The authors declare no conflicts of interest associated with this manuscript.

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