Immediate and long-term effects of hoof trimming on the equine phalangeal alignment

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Introduction The study aimed to compare the effect of trimming methods on the equine phalangeal alignment.

Methods Seventy warmblood horses were allocated to three groups and their hooves were trimmed according to three different methods. Dorsopalmar and lateromedial radiographs of the foot were assessed to evaluate the effect of trimming on the phalangeal alignment before and after trimming at the beginning of the study (immediate changes) and after ten months (long-term changes). Hooves in group A were trimmed according to a method which aims to improve the mediolateral balance of the hoof. The method used in group B considers natural references on the hoof. In group C the hooves were trimmed towards straight toe and pastern axes.

Results Significant short-term effects of trimming occurred only for the palmar angle of the distal phalanx, particularly in group C. The sagittal alignment of the proximal phalanges was not significantly influenced. In all groups there was only a long-term effect on the mediolateral alignment of the proximal and middle phalanx, with the greatest impact in group C.

Conclusions and clinical significance The palmar angle of the distal phalanx can be immediately affected by specific trimming. Limited effects were observed on the alignment of the proximal phalanges. A long-term effect on these parameters only occurred in group C, when aiming to achieve a straight toe axis. Apparently phalangeal alignment is affected by factors additional to the hoof capsule morphology. The study showed that different trimming methods have a variable impact on the phalangeal alignment.

Keywords horse, equine hoof capsule, morphology, hoof trimming

Abbreviations API, angle of the proximal phalanx to the ground; APII, angle of the middle phalanx to the ground; APIII, angle of the proximal phalanx to the ground; DIPS, distal interphalangeal joint space symmetry; DWA, dorsal wall angle; PA, palmar angle; PI, angle of the proximal phalanges to the ground; PII, angle of the middle phalanx to the ground; WAlat, lateral wall angle; WAmad, medial wall angle. Immediate and long-term effects of hoof trimming on the equine phalangeal alignment
This biomechanical background is the fundament of different trimming methods. One of the most popular references for trimming the equine hoof is the toe or pastern axis theory, aiming to create a straight axis of the three phalanges and the hoof.\textsuperscript{1,4,11}

The references for this theory are hard to assess objectively. Routinely performed trimming, based on this theory, often has a subjective character, depending on the experience and perspective of the respective farrier. As a result various other trimming methods, using dynamic-functional or natural-individual references, have been developed.\textsuperscript{2} Little scientific evidence is available as to how trimming the equine hoof according to different methods affects the phalangeal alignment.\textsuperscript{12–14} Most prior studies examining the alteration of the phalangeal alignment were carried out under experimental conditions in the laboratory, or examined forced changes of the hoof angle using wedges.\textsuperscript{7,8} No study has yet examined the effects of different routinely performed trimming methods on the phalangeal alignment under practical conditions. The aim of the present study was to test the following hypotheses:

1. Different hoof trimming methods have specific short-term effects on the alignment of the distal phalanx.

2. A changed alignment of the distal phalanx affects the alignment of the middle and distal phalanx.

3. Hoof trimming methods have specific long-term effects on the alignment of the three phalanges.

The objective was to evaluate the effect of routinely performed hoof trim to shed light on the impact of trimming on the phalangeal alignment of the equine distal limb.

\textbf{Methods}

\textit{Horses}

Seventy adult warmblood horses were included in this study. The horses were housed in three stables located in the same area to ensure similar environmental conditions. The animals were divided into three groups according to their stable (A: n = 24, B: n = 24, C: n = 22). Detailed information about selection of the horses, their housing, management and health status, as well as group characteristics are given in previously published papers.\textsuperscript{15,16}

This study was approved as an animal experiment by the Ethics Committee of the Thuringian state authority (Landesdirektion Thüringen, Office Langensalza) (Permit No: 15-102/12). Client-owned horses were included with informed consent.

\textit{Trimming}

The status of the hoof soundness, former hoof care and a detailed description of the examined hoof trimming methods have been given previously.\textsuperscript{15,16} The barefoot trim was performed by a different professional farrier allocated to each group (A, B, C) who performed the specific trim on all the horses belonging to that group. The three different trims were performed in a standardised manner, strictly based on the corresponding guidelines of the given method.

The trimming method employed in group A used natural marks as references and considered the longitudinal flexibility of the hoof capsule.\textsuperscript{17} This dynamic-functional approach focused on improving the mediolateral balance of the foot. This trim was performed every eight weeks.

In group B the horses were trimmed based on a natural-individual method that considers the management and the individual conformation of the horse.\textsuperscript{18} The primary goal is to regulate the abrasion of the hoof horn in specific regions of the weight bearing margin to achieve a slow and individual alteration of the hoof and limb conformation. Because this method removes the overgrown hoof horn in a limited way and directs the specific abrasion pattern of the hoof horn, the trim needed to be performed every four weeks.

The horses in group C were trimmed according to the pastern axis method considering static-geometric references.\textsuperscript{3,11} It is aimed to improve the symmetry of the hoof with the axis of the limb perpendicular to the ground surface viewed laterally, from the front and behind. The trim was performed every eight weeks.

\textit{Data collection}

The study was carried out from June 2011 to April 2012. The radiographic examinations of both front feet were performed directly before and 10–20 min after trimming at the beginning of the study and after ten months, according to the same guidelines and conditions. All radiographs were taken by the same experienced veterinarian according to the guidelines of previous publications.\textsuperscript{19,20} For the radiographic examination, a portable x-ray unit and a digital detector system were used.
For each examination a dorsopalmar and lateromedial radiograph of the toe, including the hoof capsule and the three phalanges, were produced. Initially, the hooves were permanently marked according to prior published guidelines to ensure standardised centring of the radiation beam in each examination. In the dorsopalmar projection, the mark was created by using the following references: a line through the central groove of the frog, the tip of the frog, the centre at the dorsal toe of the hoof, elongated parallel to the horn tubules at the median of the dorsal hoof wall. The main beam of the x-ray generator was focused 2 cm below the coronary band, parallel to the ground and at a right-angle relative to the lateromedial radiographic plane. In the lateromedial projection, the mark for the main beam was defined by determining the widest part of the hoof. This was measured from the medial to the lateral side at the solar surface and at a right angle to the middle of the line between the bulbs of the heel and the dorsal aspect of the hoof wall. The beam was focused 2 cm below the coronary band parallel to the sagittal plane of the limb. The horses were positioned with both front feet parallel on wooden podoblocks to elevate the feet on the same height of 9 cm to examine the equine toe including the complete hoof. The examined foot was placed on a MetronPXTM podoblock (EponaTech LLC, Creston, CA, USA) with embedded reference markers used for later calibration and analysis of the radiographs. The horses had to remain relaxed with a straight body axis in their most natural position. No sedation was necessary. A standardised protocol (60kV, 0.2mAs/s, focus-film distance 75cm) was used to ensure reproducible radiographs for a quantitative radiographic measurement. The radiographs had to fulfil set criteria. In the dorsopalmar projection; the frog’s central groove, the extensor process and half of the distance between both condyles of the middle and proximal phalanx had to be in line. The solar margin of the distal phalanx and the interphalangeal joint spaces had to be clearly definable. Criteria defined by Dyson et al. were used for the lateromedial projection; the condyles of the middle and proximal phalanx were parallel and no more than 5 mm apart at any point, the lateral and medial solar borders of the distal phalanx were superimposed, the palmar aspects of the extensor process of the distal phalanx were superimposed, the interphalangeal joint spaces had to appear clearly.
Data analysis

The DICOM files generated during the radiographic examinations were converted into JPEG files and imported into the software MetronPXHoof® (EponaTech LLC, Creston, CA, USA). After calibration, the parameters of interest were measured by the same person using standardised references. The alignment of the three phalanges to the bearing border in the dorsopalmar projection was marked with positive values for a lateral tilt and negative values for a medial tilt of the bones.

Statistical Analysis

Statistical analysis was carried out with commercial software (R-A language and environment for statistical computing, Vienna, Austria). Descriptive statistics (mean, standard deviation, minimum, maximum) were calculated and data were tested for Gaussian distribution using the Shapiro Wilk test. Significance tests for normally distributed data were performed using the Welch t-test; for non-normally distributed data the Wilcoxon test was used. The significance level was set to alpha = 0.05. Estimation of correlations and slopes was carried out using simple linear regression; significance of the slopes was tested using t-statistics.

Results

Pre-trimming

The results of the radiographic measurements of both front feet of all examined horses (n = 70) at the first examination prior to trimming are shown in Table 1. The analysis of the dorsopalmar radiographs showed a palmar angle (PA) of 6.12° ± 3.09° for the left and 6.10° ± 2.99° for the right hooves. The dorsal wall angle (DWA) was 52.19° ± 3.80° on the left hooves and 52.28° ± 3.82° on the right feet. There was a strong correlation between the PA and the DWA (left hooves: R = 0.70, P < 0.001; right hooves: R = 0.66, P < 0.001). No significant differences occurred for the PA and DWA between both hooves. The angle of the middle phalanx to the ground (PII) was 54.75° ± 6.90° on the left side and 50.31° ± 5.73° on the right side. There was a significant difference of 4.26° between the left and the right feet (P = 0.04). The same results were shown for the angle of the proximal phalanges to the ground (PI). The difference between the left PI (69.89° ± 4.75°) and the right PI (66.18° ± 6.34°) showed a significant lower angle of approximately 3.71° (P = 0.043) on the right side. The correlation between PA and PII (left limbs: R = -0.34, P = 0.15; right limbs: R = -0.40, P = 0.08) or PA and PI (left limbs: R = -0.12, P = 0.62; right limbs: R = -0.17, P = 0.47) was weak. A stronger correlation was observable for the relation between PI and PII (left limbs: R = 0.52, P = 0.02; right limbs: R = -0.67, P = 0.001).

Table 1 Results of radiographic measurements pre-trimming independent of any group (n=70) at the final examination

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Left Mean ± SD</th>
<th>Max</th>
<th>Min</th>
<th>Right Mean ± SD</th>
<th>Max</th>
<th>Min</th>
</tr>
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<tbody>
<tr>
<td>DWA (*)</td>
<td>52.19 ± 3.80</td>
<td>64.07</td>
<td>42.24</td>
<td>52.28 ± 3.82</td>
<td>67.01</td>
<td>44.03</td>
</tr>
<tr>
<td>PA (*)</td>
<td>6.12 ± 3.09</td>
<td>16.52</td>
<td>1.13</td>
<td>6.10 ± 2.99</td>
<td>16.38</td>
<td>0.00</td>
</tr>
<tr>
<td>PII (*)</td>
<td>54.75 ± 6.90</td>
<td>75.72</td>
<td>42.53</td>
<td>50.31 ± 5.73</td>
<td>62.13</td>
<td>40.73</td>
</tr>
<tr>
<td>PI (*)</td>
<td>69.89 ± 4.75</td>
<td>78.88</td>
<td>62.66</td>
<td>66.18 ± 6.34</td>
<td>80.82</td>
<td>53.78</td>
</tr>
<tr>
<td>APIII (*)</td>
<td>1.38 ± 0.91</td>
<td>3.44</td>
<td>-0.88</td>
<td>1.00 ± 0.97</td>
<td>3.51</td>
<td>-1.90</td>
</tr>
<tr>
<td>API (*)</td>
<td>3.19 ± 1.93</td>
<td>7.73</td>
<td>-2.12</td>
<td>2.55 ± 2.50</td>
<td>9.42</td>
<td>-4.61</td>
</tr>
<tr>
<td>DIPS (*)</td>
<td>3.34 ± 2.00</td>
<td>7.59</td>
<td>-2.68</td>
<td>2.75 ± 3.20</td>
<td>10.97</td>
<td>-5.29</td>
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<tr>
<td>WAmed (*)</td>
<td>1.17 ± 1.29</td>
<td>4.51</td>
<td>-1.96</td>
<td>0.72 ± 1.68</td>
<td>5.19</td>
<td>-2.33</td>
</tr>
<tr>
<td>WAlat (*)</td>
<td>75.07 ± 5.71</td>
<td>120.67</td>
<td>94.56</td>
<td>104.27 ± 5.24</td>
<td>119.19</td>
<td>93.48</td>
</tr>
<tr>
<td>WAmed (*)</td>
<td>74.25 ± 5.71</td>
<td>120.16</td>
<td>90.39</td>
<td>105.42 ± 5.75</td>
<td>121.50</td>
<td>94.35</td>
</tr>
</tbody>
</table>

The alignment of the three phalanges to the bearing border in the dorsopalmar projection was marked with positive values for a lateral tilt and negative values for a medial tilt of the bones.
Evaluation of the lateromedial radiographs enabled assessment of the following results. The distal phalanx is not oriented parallel to the ground. The angle of the distal phalanx to the ground (APIII) tilted slightly laterally about 1.38° ± 0.91° on the left hooves and 1.00° ± 0.95° on the right hooves. A significant difference (P = 0.02) could be demonstrated between the left and the right limbs. On the left side in three horses out of the 70 animals and on the right side in four horses the distal phalanx was tilted medially. In 9 left and 17 right hooves the distal phalanx had a level mediolateral position (between -0.5 and +0.5°) in the hoof capsule. The angle of the middle phalanx to the ground (APII) was 3.19° ± 1.92° (left feet) and 2.55° ± 2.5° (right feet) tilted to lateral. Three horses (left side) and 11 horses (right side) showed a tilted APII medially. A straight alignment of APII (-0.5 - +0.5°) was observed in 4 (left feet) or 5 cases (right feet). The angle of the proximal phalanx to the ground (API) showed mean values of 3.34° ± 2.00° for the left and 2.75° ± 3.20° for the right feet. In 3 horses on the left side and 13 horses on the right side the proximal phalanx was tilted medially. API showed values between -0.5 and +0.5° in 5 (left feet) or 7 horses (right feet). For API and APII the difference between the two sides was not significant (API: P=0.09, APII: P=0.19). Calculating the correlation of the alignment of the three phalanges in the 0° projection shows the following relationships. The APIII has a moderate or weak correlation to the APII (left feet: R = 0.34, P = 0.004; right feet: R = 0.36, P = 0.002) and API (left feet: R = 0.21, P = 0.007; right feet: R = 0.22, P = 0.07). The strongest correlation occurred between APII and API with R = 0.81, P < 0.001 (left feet) and R = 0.61, P < 0.001 (right feet). The distal interphalangeal joint space symmetry (DIPS) is slightly narrowed at the lateral side with a value of 1.17° ± 1.29° (left feet) and 1.23° ± 0.20° (right feet). High standard deviations occur. In 11 animals, the DIPS were narrowed to the medial side in the left feet and in 23 horses on the right side. Seven (left feet) or 11 (right feet) showed an almost parallel joint space symmetry with values between -0.2 and +0.2. The difference of the DIPS between the left and the right side was not significant, but showed a P value of 0.08.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Group A</th>
<th>Left Mean ± SD</th>
<th>Immediate effect of trimming</th>
<th>Mean ± SD</th>
<th>Long-term effect of trimming</th>
<th>Mean ± SD</th>
<th>Immediate effect of trimming</th>
<th>Mean ± SD</th>
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<td>1B</td>
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<td>2A</td>
<td>1A:2A</td>
<td>1A</td>
<td>1B</td>
<td>1A:1B (P-value)</td>
<td>2A</td>
</tr>
<tr>
<td>PA (°)</td>
<td>5.25 ± 2.93</td>
<td>0.07</td>
<td>4.56 ± 3.53</td>
<td>0.46</td>
<td>5.11 ± 3.22</td>
<td>0.08</td>
<td>4.11 ± 2.75</td>
<td>0.26</td>
</tr>
<tr>
<td>DWA (°)</td>
<td>50.56 ± 3.85</td>
<td>0.2</td>
<td>51.68 ± 4.66</td>
<td>0.36</td>
<td>50.25 ± 4.39</td>
<td>0.4</td>
<td>50.21 ± 3.40</td>
<td>0.97</td>
</tr>
<tr>
<td>PII (°)</td>
<td>51.82 ± 4.89</td>
<td>0.77</td>
<td>54.19 ± 5.12</td>
<td>0.3</td>
<td>52.11 ± 7.79</td>
<td>0.69</td>
<td>54.11 ± 5.43</td>
<td>0.51</td>
</tr>
<tr>
<td>PI (°)</td>
<td>66.53 ± 4.66</td>
<td>0.46</td>
<td>70.19 ± 4.24</td>
<td>0.08</td>
<td>70.46 ± 4.72</td>
<td>0.12</td>
<td>72.35 ± 2.76</td>
<td>0.29</td>
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<tr>
<td>APIII (°)</td>
<td>1.53 ± 0.88</td>
<td>0.9</td>
<td>1.20 ± 0.81</td>
<td>0.18</td>
<td>1.12 ± 1.21</td>
<td>0.61</td>
<td>1.29 ± 0.98</td>
<td>0.61</td>
</tr>
<tr>
<td>API (°)</td>
<td>3.52 ± 1.98</td>
<td>0.85</td>
<td>2.10 ± 1.50</td>
<td>0.008</td>
<td>1.78 ± 2.39</td>
<td>0.63</td>
<td>2.06 ± 1.37</td>
<td>0.19</td>
</tr>
<tr>
<td>DIPS (°)</td>
<td>1.23 ± 1.77</td>
<td>0.91</td>
<td>0.37 ± 1.17</td>
<td>0.04</td>
<td>0.32 ± 1.12</td>
<td>0.95</td>
<td>0.33 ± 0.77</td>
<td>0.98</td>
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</tbody>
</table>

Table 2: Values of the radiographic measurements in the horses of group A at different time points: 1A = first examination before trimming, 1B = first examination after trimming, 2A = final examination before trimming, 2B = final examination after trimming. Significant differences are described with the p-value and highlighted for immediate (1A:1B) and long-term (1A:2A) changes.
No correlation between the DIPS and the APIII was demonstrated (left feet: R = 0.07, P = 0.57; right feet: R = 0.05, P = 0.69). Stronger correlations occurred between the DIPS and the APII (left feet: R = 0.52, P < 0.001; right feet: R = 0.59, P < 0.001). The correlation between the DIPS and the API was also strong, with R = 0.57, P < 0.001 (left feet) and R = 0.76, P < 0.001 (right feet). No correlations were demonstrated for the relation between the WAlat or WAmed with the APIII or the DIPS (R < 0.1, P > 0.4 for all calculations).

Immediate effects
The analysis of the examination comparing the radiographic parameters directly before and after the first trim are shown in tables 2–4 (1A : 1B).

In the dorsopalmar projection, the main effects occurred in group A and C. The changes of the PA before and after trimming reached no significant level in group A, but were still noticeable with a decreased angle of -1.29° in the left hooves (P = 0.07) and -1.26° in the right hooves (P = 0.08) (Figure 2). No significant differences in the PA occurred in the horses of group B (left hooves: P = 0.94, right hooves: P = 0.84) (Figure 3).

In group C the PA in both front feet decreased significantly, approximately -1.74° in the left (P = 0.05) and -2.12° in the right feet (P = 0.005) (Figure 4). The DWA was not significantly influenced by trimming in any of the groups. Additionally, no significant influence on the PII and PI related to one of the trimming methods was proven. Very heterogeneous data were observed for the sagittal alignment of the middle and proximal phalanx by trimming.

In the lateromedial radiographs no significant short-term changes of the AP III, APII, API or DIPS occurred in any of the groups.

The evaluation of the values assessed before and after trimming in the last examination after ten months showed that very slight changes had occurred. After performing the different trimming methods over ten months, no changes of the phalangeal alignment occurred. Only the PA in group A still decreased significantly (left hooves: -1.56°, P = 0.05; right hooves: -1.62°, P = 0.03). Further significant short-term changes (before and after

<table>
<thead>
<tr>
<th>Group B</th>
<th>Left</th>
<th>Immediate effect of trimming</th>
<th>Mean ± SD</th>
<th>Long-term effect of trimming</th>
<th>Mean ± SD</th>
<th>Immediate effect of trimming</th>
<th>Mean ± SD</th>
<th>Long-term effect of trimming</th>
<th>Mean ± SD</th>
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<tr>
<td>1A</td>
<td>1A:1B (P-value)</td>
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<td>1A:2A</td>
<td>2B</td>
<td>1A</td>
<td>1A:1B (P-value)</td>
<td>2A</td>
<td>1A:2A</td>
<td>2B</td>
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<tr>
<td>PA (*)</td>
<td>5.13 ± 2.93</td>
<td>0.94</td>
<td>5.65 ± 2.48</td>
<td>0.48</td>
<td>5.41 ± 2.47</td>
<td>0.84</td>
<td>6.28 ± 2.21</td>
<td>0.21</td>
<td>5.18 ± 2.43</td>
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<tr>
<td>DWA (*)</td>
<td>52.76 ± 3.17</td>
<td>0.8</td>
<td>54.02 ± 4.34</td>
<td>0.3</td>
<td>53.63 ± 3.17</td>
<td>0.44</td>
<td>54.46 ± 3.78</td>
<td>0.43</td>
<td>53.03 ± 3.77</td>
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<tr>
<td>PII (*)</td>
<td>51.31 ± 7.00</td>
<td>0.69</td>
<td>50.28 ± 5.86</td>
<td>0.73</td>
<td>51.65 ± 5.29</td>
<td>0.99</td>
<td>51.25 ± 5.32</td>
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<td>50.23 ± 4.81</td>
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<td>PI (*)</td>
<td>69.97 ± 8.30</td>
<td>0.41</td>
<td>68.75 ± 4.91</td>
<td>0.77</td>
<td>68.41 ± 6.77</td>
<td>0.84</td>
<td>68.14 ± 5.20</td>
<td>0.93</td>
<td>67.15 ± 6.24</td>
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<td>APIII (*)</td>
<td>0.86 ± 0.87</td>
<td>0.48</td>
<td>1.10 ± 0.69</td>
<td>0.33</td>
<td>0.63 ± 0.80</td>
<td>0.55</td>
<td>0.98 ± 0.70</td>
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<td>1.03 ± 0.72</td>
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<td>APII (*)</td>
<td>2.73 ± 1.93</td>
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<td>1.56 ± 1.77</td>
<td>0.04</td>
<td>2.91 ± 2.02</td>
<td>0.78</td>
<td>1.71 ± 1.71</td>
<td>0.04</td>
<td>2.57 ± 1.65</td>
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<tr>
<td>API (*)</td>
<td>2.86 ± 2.34</td>
<td>0.83</td>
<td>1.68 ± 2.59</td>
<td>0.11</td>
<td>3.56 ± 2.71</td>
<td>0.63</td>
<td>2.50 ± 2.20</td>
<td>0.16</td>
<td>2.73 ± 1.84</td>
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<tr>
<td>DIPS (*)</td>
<td>1.20 ± 1.03</td>
<td>0.46</td>
<td>0.10 ± 1.26</td>
<td>&lt;0.001</td>
<td>1.13 ± 1.27</td>
<td>0.31</td>
<td>0.32 ± 0.83</td>
<td>&lt;0.001</td>
<td>0.97 ± 1.10</td>
</tr>
</tbody>
</table>

Table 3 Values of the radiographic measurements in the horses of group B at different time points: 1A = first examination before trimming, 1B = first examination after trimming, 2A = final examination before trimming, 2B = final examination after trimming. Significant differences are described with the p-value and highlighted for immediate (1A:1B) and long-term (1A:2A) changes.
Table 4 Values of the radiographic measurements in the horses of group C at different time points: 1A = first examination before trimming, 1B = first examination after trimming, 2A = final examination before trimming, 2B = final examination after trimming. Significant differences are described with the p-value and highlighted for immediate (1A:1B) and long-term (1A:2A) changes.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Left</th>
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<tbody>
<tr>
<td></td>
<td>Mean ± SD</td>
<td>Immediate effect of trimming</td>
<td>Mean ± SD</td>
<td>Immediate effect of trimming</td>
</tr>
<tr>
<td>PA (°)</td>
<td>8.14 ± 3.06 (P-value) 0.05</td>
<td>6.61 ± 2.83 0.11</td>
<td>7.93 ± 2.50 0.005</td>
<td>6.89 ± 2.63 0.21</td>
</tr>
<tr>
<td>DWA (°)</td>
<td>53.35 ± 3.60 (P-value) 0.24</td>
<td>51.93 ± 3.43 0.21</td>
<td>53.02 ± 2.89 0.07</td>
<td>51.74 ± 3.60 0.21</td>
</tr>
<tr>
<td>PII (°)</td>
<td>52.67 ± 5.45 (P-value) 0.53</td>
<td>52.85 ± 4.21 0.43</td>
<td>50.65 ± 5.66 0.24</td>
<td>52.96 ± 4.49 0.36</td>
</tr>
<tr>
<td>PI (°)</td>
<td>69.78 ± 5.47 (P-value) 0.87</td>
<td>68.26 ± 3.11 0.62</td>
<td>68.43 ± 5.63 0.31</td>
<td>72.15 ± 3.80 0.33</td>
</tr>
<tr>
<td>APIII (°)</td>
<td>1.77 ± 0.76 (P-value) 0.69</td>
<td>1.53 ± 0.81 0.34</td>
<td>1.27 ± 0.76 0.88</td>
<td>0.78 ± 0.94 0.07</td>
</tr>
<tr>
<td>API (°)</td>
<td>3.32 ± 1.84 (P-value) 0.59</td>
<td>2.50 ± 1.53 0.05</td>
<td>2.99 ± 2.97 0.81</td>
<td>1.73 ± 1.89 0.04</td>
</tr>
<tr>
<td>API (°)</td>
<td>3.72 ± 1.70 (P-value) 0.8</td>
<td>2.63 ± 1.93 0.05</td>
<td>4.07 ± 3.04 0.82</td>
<td>1.91 ± 2.28 0.02</td>
</tr>
<tr>
<td>DIPS (°)</td>
<td>1.07 ± 0.94 (P-value) 0.79</td>
<td>0.58 ± 1.40 0.04</td>
<td>1.41 ± 2.04 0.75</td>
<td>0.13 ± 1.29 0.03</td>
</tr>
</tbody>
</table>

trimming) for any other parameter were not proven in the final radiographic examination.

**Long-term effects**

To evaluate the long-term effects of each trimming method, the radiographic parameters between the first examination and the examination after ten months before trimming were compared (Table 2–4, A1: A2).

None of the parameters assessed in the dorsopalmar projection showed significant changes over the ten-month period. No sustainable alterations of the PA or the DWA were proven (Figure 2–4). Inhomogeneous values occurred for the PI and PII. No significant differences in the alignment of the proximal phalanges could be proven.

In the lateromedial projection more changes were demonstrated. However, the data show different results within the groups and between the left and right feet. The APIII was not significantly affected by any of the trimming methods over the ten months. In group A the APII and the API were affected significantly in the left feet only by changing towards a straighter alignment (APII: P = 0.008, API: P = 0.01). In group B the APII was altered significantly towards a straighter alignment in both front feet (APII in both feet: P = 0.04).

However, no significant effect was proven for API. In group C, a significant long-term effect on the APIII and API towards a straighter orientation occurred in both feet (left feet: APIII: P = 0.005, API: P = 0.05; right feet: APIII: 0.02, API: 0.03). The DIPS in all groups were influenced corresponding to the effects on the APII. At the beginning of the study the DIPS were slightly narrowed at the lateral side in each group. In group A the DIPS changed significantly only in the left hooves from 1.23° ± 1.77° before the first trim to 0.37° ± 1.17° before the final trim after ten months (P = 0.05). In group B in both front feet significant change towards an increased symmetry of the DIPS occurred over the ten months (P < 0.001). In group C, the DIPS became significantly more symmetrical in both feet (left feet: P = 0.04, right feet: P = 0.03). However, besides the inhomogeneous behaviour of the data within the groups, high standard deviations were noticeable for the API, APII, and DIPS.
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Quantitative radiographic measurements to evaluate the effect of trimming

Quantitative radiographic measurements of equine feet are useful in assessing the effect of hoof trimming. A standardised protocol should be followed to reduce projection obliquity and image distortion. Although these protocols were used in the current study, it is difficult to ensure high accuracy in repeated examinations. A small deviation in limb positioning or a skewed body axis with shifted load of the limbs can result in images with misleading information. The PI, PII, and DIPS seemed to be distinctly affected by these factors. One must consider that the radiographs present only a snap-shot of a dynamic situation and are a two-dimensional image of a three-dimensional, complex and dynamic object.

Additionally, a standardised measuring protocol and calibration of the radiographs are essential to perform an accurate, comparable analysis.

This study used a precise software which allowed analysis of the parameters. All radiographic measurements were performed by the same person and repeated three times. The measuring failures were smaller than the changes in the values of the assessed parameters. Our results supported quantitative radiographic measurement to evaluate the effects of hoof trimming on the equine phalangeal alignment, but did not substitute for visual judgement of the horse. Radiographs can be used to optimise trimming or shoeing, but it should not be the only basis for a trimming or shoeing recommendation.

Discussion

Figure 2: Impact of the trimming method used in group A on the palmar angle (PA) at different time points: 1A (first examination before trimming) = 4.61°, 1B (first examination after trimming) = 3.47°, 2A (final examination before trimming) = 4.48°, 2B (final examination after trimming) = 3.27°.
Radiographic measurements pre-trimming

The orientation of the distal, middle and proximal phalanx to the ground as well as the conformation of the hoof capsule are important factors associated with the evaluation of the limb conformation and the load on connected structures. Previous studies have examined the link between the shape, morphology and conformation of the hoof or the distal limb as risk factors for catastrophic musculoskeletal injuries or lameness.

In the current study the PA of both front feet was around 6° to the bearing border in the dorsopalmar (sagittal) plane. This is comparable with the results of Rocha et al. In general, different studies have reported the occurrence of a PA between 3° and 6°. It is a parameter strongly associated with orthopaedic disorders and therefore frequently assessed to evaluate the conformation of horses. In the examinations of Dyson et al. 2011 no significant correlation between different injuries and angles of the distal phalanx were demonstrated. Contrary to this, Eliashar et al. 2004 demonstrated a negative correlation between the angle of the distal phalanx and forces applied on the navicular bone, which might have clinical relevance in the pathogenesis of podotrochlosis.

The sagittal alignment of PI I and PI I is related to the load of associated structures, such as the superficial digital flexor tendon or the suspensory apparatus of the fetlock joint. These groups also published a correlation between the orientation of the distal phalanx and the alignment of the proximal phalanges. In the current examinations, there was a weak correlation between the PA and PI I or PI I. A stronger relationship occurred between PI I and PI I. The authors suggest that there are additional factors, such as length of the phalanges, tendon stiffness, body and limb conformation, affecting the alignment of PI I and PI I. Our results reflected those of Linford et al. 1993 finding no uneven DWA or PA between both front feet. However, a significant difference in PI I and PI I between the left and right foot was shown. Other authors published that, in foals, differences between left and right feet may be induced through the development of lateralised behaviour in early life while grazing. Laterised motor behaviour is stated to cause unevenness in front feet. These findings match the general concept of musculoskeletal tissues being moulded through biomechanical loading in the early juvenile period.

In the dorsopalmar projection it could be shown that all phalanges were slightly tilted laterally. Correspondingly, the DIPS were narrowed to the lateral side. This might be related to the posture and limb conformation of horses. The API III showed a weak correlation to the API I or API I. In contrast, the relationship between the API I and API I was strong. This might be related to the specific architecture of the distal (DIPJ) and proximal interphalangeal joint (PIPJ). The complex DIPJ shows a wider range of motion and flexibility to compensate uneven ground conditions and sudden rotational movements.

The PIPJ is a saddle joint with a tight connection between the middle and proximal phalanges and restricted mobility. Moreover, API I and API I are strongly correlated to the DIPS. Additionally, no correlation between the WA I lat/WA med and the DIPS or API III was observed. It seems that the symmetry of the DIPJ is more affected by the alignment of API I and API I and the load or conformation of the proximal locomotor system. This might differ for horses with severe hoof deformities.

Immediate and long-term effects of trimming on the phalangeal alignment

In this study the parameters in the sagittal plane seem to be more susceptible to immediate changes than the mediolateral orientation of the phalanges. In Group A and C, the overgrown margin is shortened and the alignment of the distal phalanx was changed significantly towards a decreased PA. The horses trimmed according to the pastern axis method, group C, showed the strongest decrease of the PA. This correlates with the morphometric findings of this study, which shows that the heels of the horses in group C are trimmed more than in group A. In group B, the overgrown weight bearing margin is shortened in a very limited way and no short-term effects were shown for any of the parameters. Other authors have reported a relationship between a changed PA and the sagittal orientation of the middle and proximal phalanx defining the dorsal fetlock joint angle. Moreover, altering the PA influences the strains affecting tendons and ligaments attached to the three phalanges. A decreased PA causes a more upright position of the middle and proximal phalanx resulting in a higher load affecting the deep digital flexor tendon, while relieving the superficial flexor tendon and the suspensory ligament. An increased PA should cause the opposite effect. However, in the current study no relationship between a lower PA and the PI I or PI I occurred in any group. It is questionable if a reorientation of the distal phalanx of approximately less than 2° causes a distinct
alteration of the sagittal alignment of the middle and proximal phalanx.\textsuperscript{13,37} Posture, limb and hoof conformation, muscle elasticity and tendon stiffness should be considered as further factors affecting the alignment of the proximal phalanges or the fetlock joint angle. Practically this is evidenced by the effect of modified horseshoes on the phalangeal alignment.\textsuperscript{19,37}

These results may vary if severe reorientations of the distal phalanx with corrective trimming are performed. Another aspect related to the position of the distal phalanx in the hoof capsule is the pressure exerted from the ground to the bone and the soft tissue of the dermis. Savoldi et al. 2003 showed severe bone remodelling and pathologies at the distal phalanx caused by an adverse hoof conformation.\textsuperscript{38} One should aim for optimal pressure distribution by trimming the hooves.\textsuperscript{36}

No immediate effects were demonstrated for the parameters in the mediolateral plane in any of the groups. Even in group A, using a trimming method affecting the mediolateral plane of the hoof, no significant effects occurred. The flexibility of the hoof capsule probably masks the effect of this specific trim on the mediolateral orientation of the phalanges. This is reflected in other studies where the application of modified horseshoes to alter the mediolateral alignment of the distal phalanx did not produce consistent data for APII or API.\textsuperscript{20}

These results may vary if a severe unilateral shortening of the hoof becomes necessary to perform a corrective trim to treat limb deformities. The mediolateral phalangeal alignment seems to be
most affected by posture (width of the chest or the shoulder) and limb conformation (for instance the angle of the carpal joints).

At the long-term examination, there were no significant changes in any parameters in the sagittal plane. This correlates with the data assessed for the morphology of the hoof capsule. Additionally, no sustainable effects could be proven for the influence of trimming on the heel length or dorsal hoof length determining the PA of the distal phalanx. This study demonstrated a long-term effect on the parameters assessed in the dorsopalmar projection during the ten-month period. In particular, in group C, where the aim was to create a straight toe axis, a significant influence on the APII, API and DIPS towards a straighter alignment was achieved. It is assumed that a straight toe axis viewed frontally is connected to a more even load of the joints and collateral ligaments. It is important to note that the toe axis of each individual horse can be slowly changed towards a straighter alignment, but only to a certain degree. The individual limb and hoof conformation has to be respected to avoid over-correction. In group B, long-term effects included a straighter alignment of APII and a more even DIPS. Although the horn is not substantially shortened, the horn abrasion in this study seemed to be sufficient to reorientate the hooves over time. Nevertheless, this is strongly connected to environmental factors, particularly the ground conditions, to which the horn wear is related.

In conclusion, hypothesis 1 could be partly proven. In group A and C, a significant effect on the palmar angle of the distal phalanx became visible. However, hypothesis 2 could not be proven. The different hoof trimming methods had no specific effect on the alignment of the middle and proximal phalanx.

Figure 4: Impact of the trimming method used in group A on the palmar angle (PA) at different time points: 1A (first examination before trimming) = 7.52°, 1B (first examination after trimming) = 4.03°, 2A (final examination before trimming) = 7.74°, 2B (final examination after trimming) = 7.38°.
Only a long-term effect could be shown for the mediolateral alignment of the middle and proximal phalanx, particularly in group C, where the aim was to achieve a straight toe and pastern axis. Therefore, for specific parameters in the dorsopalmar projection (DIPS, APII, API), hypothesis 3 could be confirmed.

In general, the results may vary for different farriers and are only valid for the examined population and environmental conditions. However, all farriers were right-handed and the consistency of their trim could be proven by the examination of the effect of the trims on the hoof morphology. Several additional factors, such as the environment and posture, affect the morphology of the hoof capsule and the phalangeal alignment.

References


