Changes in hoof kinetics and kinematics at walk in response to hoof trimming: pressure plate assessment

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Appropriate hoof preparation and symmetry are linked to the well-being of the horse. Previous studies have shown the efficacy of pressure plates (PPs) in delivering objective biomechanical analysis. We aimed to assess the effect of hoof trimming on hoof biomechanics using a PP. Nine clinically sound Arabian horses were walked across a PP while foot strike was recorded by a digital camera. Kinetic and kinematic parameters were recorded before and after trimming. Changes were considered significant when $p < 0.05$. Vertical force ($p = 0.026$) and contact pressure ($p = 0.006$) increased after trimming. Stance-phase duration ($p = 0.006$), swing-phase duration ($p = 0.023$), and gait-cycle duration ($p = 0.007$) decreased significantly post-trimming. The observed changes in kinetic and kinematic parameters were related to hoof trimming. The reported results underline the importance of farriery practice and its effect on hoof biomechanics, which should be considered by both farriers and veterinarians.

Keywords: biomechanics, horses, kinematics, kinetics, pressure plate

Introduction

Maintaining hoof balance is essential for horses’ soundness and performance [2]. Thus far, in daily practice, farriers and trimmers evaluate hoof balance by visual assessment, which is not flawless and, hence, may not provide a perfect assessment of hoof biomechanics. Farriers strive to maintain the optimum hoof balance by performing regular hoof care and trimming. While the trimming techniques and protocols may vary in different disciplines and among breeds, the goal is often the same: to preserve hoof balance. To date, trimming and shoeing techniques mostly rely on empiric craftsmanship rather than on evidence-based scientific approaches [7,38]. Information on the effect of routine farriery on internal structures and biomechanics of the equine foot is also limited [23]. Quantification of normal trimming and/or shoeing requires the use of sensitive measurement equipment [38]. Recent advances in gait and biomechanical analyses have provided several technologies to objectively evaluate hoof biomechanics; among those, pressure plates (PPs) are gaining more popularity in veterinary research and clinical settings [26,27].

PPs have been successfully used in humans [6,8,14,30,31,36], dogs [15,17,20,34], sheep [16], cows [4], cats [1,19,39], and horses [9,12,22,24,25,28,29,32,35,37,38]. A recent study compared the accuracy of force plates (FPs) and PPs, and the authors concluded that a PP was a precise alternative for use in a clinical setting [28]. While FPs have been used as the premiere benchmarks of capturing biometric data of hoof contact with the ground, several limitations apply. Because of the relatively small size of an FP, it can require many attempts to collect clear-cut data. Studies have shown that PPs can yield values similar to those of FPs [29]. The PPs may record data from simultaneous and consecutive hoof strikes as well as from different regions of the hoof [29]. Moreover, PPs are portable and can calculate pressure distribution as well. Our objective was to assess the effect of hoof trimming on hoof biomechanics by using a PP system that provides high resolution with high spatial accuracy. We hypothesized that none of the following parameters would change at midstance in response to routine trimming of the hoof: vertical force, pressure, contact area, peak pressure, stance-phase duration, swing-phase duration, gait-cycle duration, duty factor, and swing-phase.
Materials and Methods

Animals
Nine clinically sound Arabian horses (5 mares and 4 geldings) were used in this study. Their average withers height was 152 ± 5 cm and the average age was 5.9 ± 3.1 years. The horses were housed in stalls, regularly exercised, and received regular hoof trimming and shoeing at 6-week intervals. Their shoes were removed before the experiment; they were again shod by the same farrier at the conclusion of the experiment. The study was approved by the Western University of Health Sciences Animal Care and Use Committee (R 11/ACUC/022), and horse owners provided consent for the use of their animals.

Measurement systems and data collection
The PP used in this study was 2.1 m × 0.8 m in size and utilized approximately 18,000 force-sensitive, bendable resistors (Walkway; Tekscan, USA) and has been successfully used in previous human and veterinary biomechanical studies [5,10, 11,17,21,40]. Using USB connections, the PP was connected to a laptop equipped with Walkway 7.0 software (Tekscan), and data were collected at 100 Hz. To provide adequate grip and protection for the sensors and to avoid slipping, the PP was covered with a thin, soft rubber mat approximately 2.5 m × 1 m in size and 5 mm in thickness, as recommended by the manufacturer (Fig. 1). The PP was calibrated according to the manufacturer’s specifications by placing a person with known weight across the PP and manually inputting that weight into the Walkway software.

Each horse was walked over the PP to warm up and to allow them to familiarize themselves with the equipment. This process was helpful in reducing the horses’ stress and avoiding abnormal gait. An experienced handler guided the horses across the PP at a velocity of 1.3 to 1.5 m/sec. A digital camera was positioned alongside the PP, and foot strike and gait were recorded (Cannon VIX-AF200; Canon, USA). A valid trial consisted of the horse walking in a straight line across the PP at a constant pace without a misstep. At least five valid trials were performed per horse for both the before- and after-trimming experiments. Once the before-trimming trials were completed, the farrier trimmed the hooves of each horse, and the horses were led across the PP a second time to record the after-trimming trial data (Fig. 2). The acclimation period (the time between the before- and after-trimming data collection) was limited to two hours based on results in a previous study [13]. Measurements were saved and analyzed at a later date. The same experienced farrier trimmed the hooves of all horses by applying routine farriery techniques; no corrective or therapeutic trimming was done.

Kinetic measurements
For both right forelimb (RF) and left forelimb (LF), the following kinetic measurements were collected at midstance before and after trimming: vertical force (N), which was normalized to the horses’ body weight; contact area (cm²); contact pressure (kPa); and peak contact pressure (kPa).

Kinematic measurements
The following parameters were measured for both forelimbs before and after trimming: stance-phase duration was measured in seconds (sec) and defined as the time duration from impact to toe-off; swing-phase duration (sec) was measured as the time duration between break-over and impact of the next step of the same hoof; gait-cycle duration (sec) was calculated as stance-phase duration plus swing-phase duration; duty factor was defined as the percentage of stance-phase duration divided by gait-cycle duration; and swing phase was calculated as the percentage of swing-phase divided by gait-cycle duration.

Statistical analysis
Data preparation and descriptive statistic derivation were performed by using spreadsheet software (Microsoft Excel 2010; Microsoft, USA). Initially, the statistical difference
between the left and right feet data was investigated by using the independent $t$-test. Kinetic parameters were examined by using the Wilcoxon signed-rank test. Kinematic data were normally distributed; a paired sample $t$-test was used to compare before-and after-trimming data. Statistical analyses were performed by using SAS software for Windows (ver. 9.3; SAS Institute, USA), and $p$ values of $\leq 0.05$ were considered significant.

**Results**

No statistically significant difference in kinematic and kinetic parameters between left and right hooves was detected; thus, a composite outcome was created by averaging both left and right hoof measures. Changes in measured kinetic parameters before and after trimming are shown in Fig. 3. Among the kinetic parameters, vertical force and contact pressure changed significantly after trimming: vertical force increased by 13\% ($p = 0.026$), and contact pressure increased by 14\% ($p = 0.006$). Contact area ($p = 0.958$) and peak contact pressure ($p = 0.376$) did not vary significantly. The changes in kinematic parameters before and after trimming are shown in Fig. 4. Stance-phase duration ($p = 0.006$), swing-phase duration ($p = 0.023$), and consequently, gait-cycle duration ($p = 0.007$) decreased significantly (by approximately 12\%) after trimming. Duty factor and swing-phase after trimming did not change significantly ($p = 0.77$ and $p = 1.00$, respectively).

![Fig. 3](image-url) Mean and SD of kinetic variables: force (A), contact area (B), contact pressure (C), and peak contact pressure (D) before and after hoof trimming. The asterisks indicate statistically significant changes in force and contact pressure.

![Fig. 4](image-url) Mean and SD of kinematic variables: stance-phase duration (A), swing-phase duration (B), gait-cycle duration (C), duty factor (D), and swing-phase (E) before and after hoof trimming. The asterisks indicate statistically significant changes in stance-phase, swing-phase, and gait-cycle durations.
Discussion

The data showed significant changes in kinetic and kinematic parameters following hoof trimming; namely, vertical force and contact pressure increased, whereas the kinematic parameters of stance-phase, swing-phase, and gait-cycle duration decreased following trimming. To ensure consistency of data collection, each horse was tested several times, and data from a minimum of five valid trials were recorded. To avoid any immediate influence on horses’ gaits, none of the horses were sedated for trimming. The hooves were trimmed by applying a routine farriery technique performed by the same farrier with no additional manipulations or excessive trimming. Discussing the different styles of hoof trimming is beyond the scope of this paper; however, the effect, or lack thereof, of inter-farrier trimming techniques on hoof biomechanical responses has yet to be investigated [7,33]. It has been shown that trimming may result in significant changes in hoof conformation [18,38]. The changes in force and contact pressure reported in this study are likely to be related to changes in post-trimming hoof conformation. In addition, it has been stated that trimming may affect the sensory perception of tactile or proprioceptive sensations [3]. Our results showed a significant increase in vertical force and contact pressure in response to trimming. In general, hoof trimming aims to level and balance the solar surface of the hoof; this can potentially alter the sensory perception of the hoof contact with the soft substrate mat. By using Doppler ultrasound technology, it has been shown that proper contact with the surface may improve foot vascular perfusion [3]. It is possible that changes in hoof conformation after trimming improved the force and pressure distribution.

Stride length was not measured in this study; however, since velocities were comparable, and gait-cycle duration decreased after trimming, it can be concluded that stride length might have been decreased after trimming as well. A previous study also found a decrease in duration of landing after trimming [38].

The results of this study provide an insight into kinetic and kinematic responses to routine hoof trimming. The horses used in this study were client-owned, from one farm, and trained by the same trainer under a similar training regimen and, therefore, may be a better representation of routine living condition of the general horse population than that of academic herds. However, the study had some limitations; for example, weighing the horses in a farm setting to record body mass and the addition of a control group were not feasible. Moreover, the horses were selected from one breed and one discipline; whether the results may vary in different breeds or in horses from different disciplines has yet to be investigated. To protect the PP, it was covered with a thin rubber mat; it is possible that the rubber mat had some dampening effect and caused the measured force or contact pressure to decrease slightly. However, since the same protocol was used for both the before- and after-trimming data collection, such dampening effect of the rubber mat on the comparison of the data, if any, would be trivial. The horses were examined within two hours of trimming, and whether a longer acclimation period or different or more aggressive trimming may result in different outcomes warrants further research. A previous study reported a difference in gait pattern between male and female cats and concluded that the difference was largely attributed to the larger size of the male cats [39]. Despite such differences in other species, the size of male and female horses are not significantly different, so a gender effect is less likely; regardless, more investigation is needed.

Previous scientific reports on the detailed effects of trimming on hoof kinetics and kinematics are scarce. This study used PP measurements to examine the kinetic and kinematic responses to routine hoof trimming in horses and provides an inchoate dataset for consideration in future studies. Our results showed significant changes in several biomechanical parameters following hoof trimming and specified the effect of hoof trimming on hoof biomechanics.

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Conflict of Interest

The authors declare no conflicts of interest.

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