Does osteochondrosis affect the toe-heel and medio-lateral hoof balance in growing Warmblood foals?

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Abstract

Introduction: Osteochondrosis (OC) is a frequently observed developmental disease in young horses. It has been diagnosed in foals as young as several days of age and can result in (subclinical) lameness.
Aim of the study: To investigate whether the presence of osteochondrosis at a young age affects the toe-heel and medio-lateral hoof balance, measured with the asymmetry index of the peak vertical forces and coefficient of variation.
Materials and methods: Pressure plate measurements at walk and trot of eleven Dutch Warmblood foals during their first 24 weeks of life were used to determine toe-heel and medio-lateral hoof balance of the peak vertical force as described by Oosterlinck et al. (2013). Radiographic evaluation for the presence of osteochondrosis of tarsocrural and femoropatellar joints was performed at 4–6 weeks and after 6 months.
Results: Foals with osteochondrosis showed several small differences in hoof balance curve patterns, mainly at 4-6 and 12-16 weeks of age. The coefficients of variation of medio-lateral balance of the positive group were different in week 6, while the ASI of toe-heel balance was affected mostly during week 12 and 16, both in the hind limbs at trot. Foals with osteochondrosis presented with a different variation pattern medio-laterally and a quicker shift towards loading of the toe during the stance phase.
Conclusion: Gorissen et al. (2016) found that foals with osteochondrosis show a lower peak vertical force in the OC-affected hind limbs during week 4 and 6. This study demonstrates these foals also present with a different distribution of pressures in toe-heel and medio-lateral hoof balance compared to unaffected foals. It should be noted that this is not limited to the 4-6 week time period. Foals with persistent lesions show multiple significant differences at later ages than 4-6 weeks as well, compared to foals with no or regressed lesions. This possibly indicates that regressing lesions have little effect besides a slight subclinical lameness, but that foals with persistent lesions - even if not clinically lame - will load their feet differently during this important growth period. This may affect their development and performance later in life.

Introduction

Osteochondrosis

Concerning Developmental Orthopedic Disease (DOD) in warmblood foals osteochondrosis (OC) is currently the most diagnosed developmental disease of young horses. OC has several stages of development, in which osteochondrosis dissecans (OCD) is the last and most frequently clinically manifested stage. Lesions arise because a focal delay occurs in endochondral ossification. According to current scientific opinions, this focal delay is most likely caused by a localised failure of vascularisation and consequently chondronecrosis. Two proposed mechanisms by which this failure of vascularisation occurs are injury to cartilage canal vessels and an altered collagen metabolism. Subsequent repair and regression of lesions or their progression to OCD is influenced by several factors, which makes the disease process of osteochondrosis extremely dynamic. Energy and nutritional imbalances, different exercise and housing regimes and genetic predisposition all have some effect on the pathogenesis, regression and progression of lesions.[8]

Young foals under the age of six months rarely show clinical lameness, while they can be affected by osteochondrosis from birth, evidenced by radiological findings.[8]

Adaptation strategies of lame horses

Weishaupt (2008) investigated all current data on adaptation strategies of lame horses. At the walk it was found that mainly the loading (vertical impulse) of the lame limb would decrease, which is compensated by the contralateral limb and at a smaller extent by the other two limbs.
At the trot, there are four different strategies to decrease the loading of the lame limb, which do not have to be present simultaneously. The first strategy is for the horse to increase the frequency of steps or decrease the velocity of movement. In contrast, for the second strategy the horse can increase the duration of the stance phase in the lame limb as well as the contralateral limb, relative to the swing phase. For another strategy the horse decreases the diagonal vertical impulse (the lame limb and the contralateral diagonal limb) by using less suspension and switching to the other diagonal pair quicker, causing a visible asymmetry in the vertical oscillation of the trunk. The final option is for the fore limb lame horse to shift its weight to the diagonal hind limb while loading that diagonal, then to the other fore limb when loading the sound diagonal. In hind limb lameness, the horse shifts its weight mainly to the other hind limb. Therefore, both front and hind limb lameness are a cause for disparity between the loading of each hind limb.
These weight shifting mechanisms increase vertical impulse in the sound limbs, but the peak ground reaction force in the sound limbs was not increased at all, while the horse does succeed in a significant decrease of ground reaction force in the lame limb (by 4-24%). This decrease of peak force can be measured with force or pressure plate data and with inertial sensors.

Osteochondrosis-related lameness in foals

Gorissen et al. (2016) observed the same foals as used in this study. None were visibly lame during measurement periods, but Gorissen et al. (2016) showed that the OC-positive limbs did have a decreased ground reaction force at 4 and 6 weeks of age. Therefore, despite the absence of clinical lameness, it is likely these foals were experiencing some discomfort at this point in time. Knowing this, this study attempts to discern whether this assumed discomfort also causes an alteration in the medio-lateral and toe-heel hoof balance, and whether this affects the foals' development. Mild favoring of the medial or lateral side is expected, as well as heel-landing and a quicker shift to toe loading in the OC-positive limbs.

Materials and methods

The data set used in this study was collected previously and is described in detail in Gorissen et al. (2016). A short summary of the subjects, data collection and analysis can be found below.

Animals

The animals used in this study were eleven privately owned Royal Dutch Sport Horse (KWPN) foals (five mares, six stallions), bred for showjumping. Their daily management was very similar and the foals were raised following usual standards in the Dutch horse breeding industry.
Before each measurement session all animals were clinically examined for soundness and visible signs of injury. Subjects were only included in that session if they were considered healthy.

Data collection

For data collection a portable pressure plate with a surface of 1.95 x 0.32 m was used, equipped with 16,384 sensors (Footscan 3D, 2 m system). The pressure plate was installed in an empty hallway on the stud farm, protected by a thick rubber mat and encased in a wooden frame with ramps to create one smooth surface. The pressure plate was connected to a laptop with the Gait Scientific software from RsScan International (Footscan Scientific Gait 7 gait 2nd generation, RSscan International, Paal, Belgium).

Before each measurement session the plate was calibrated. Next, the foals were each led over the pressure plate by an experienced handler, following their dams. After weaning they were led alone or following a pasture mate. Runs where the foals changed speed, did not move in a straight line or mainly walked besides the pressure plate were discarded. Runs were repeated until five valid measurements per limb were collected.

The first two measurement sessions took place at a few days and 7 days after birth at a walk. Then data was collected every two weeks at both a walk and trot until 12 weeks of age. After that foals were measured every 4 weeks until 24 weeks of age, with a total of 11 measurement sessions per foal. All runs were recorded with a digital video camera for later visual identification of footprints.

Using the computer software of RsScan International, footprints were manually selected out of the raw data and assigned to left fore (LF), right fore (RF), left hind (LH) or right hind (RH), based on the video images. These footprints were divided into four quadrants, with the horizontal axis placed at the widest part of the foot and the vertical axis approximately through the middle of the toe and between the two heel bulbs, as in Oosterlinck et al. (2013). Symmetry of hoof loading was assessed separately for toe-heel and medio-lateral hoof balance by calculating asymmetry indices (ASIs) of the peak vertical force (medio-lateral ASI = (medial-lateral)/(0.5*(medial+lateral))*100 [3]). The resulting value is a number between -200 and 200, with 0 meaning perfect symmetry, a positive number indicating more toe or medial loading and a negative number indicating heel or lateral loading. The resulting five ASIs for toe-heel and medio-lateral balance were averaged to create one value representative for that limb at that time.
For analysis five representative time points in the stance phase were chosen, which were 1% (approximately landing), 25% (braking), 50% (maximal vertical loading), 75% (propulsion) and 99% (approximately break-over), as shown in Figure 1.
Variation in hoof loading was quantified by calculating the coefficient of variation (COV = (ASI-mean)/mean[6]), again separately for both toe-heel and medio-lateral balance. Means were calculated by averaging the ASIs for each measuring moment, divided in groups by gait, front or hind limbs, and the five time points in the stance phase.

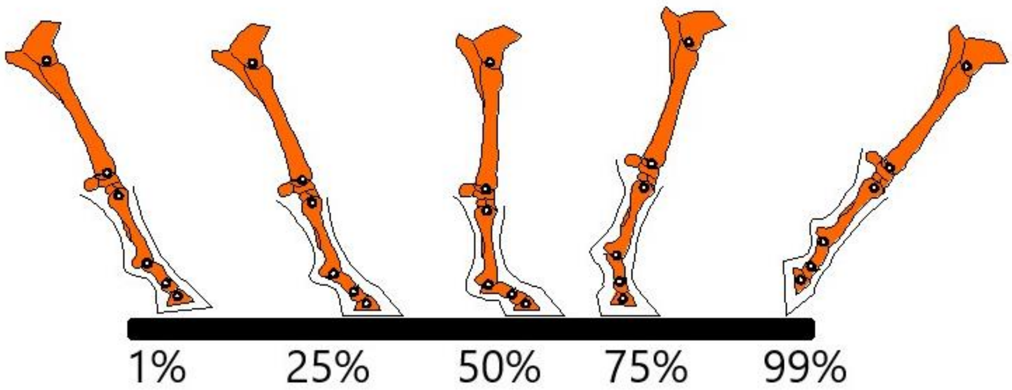

Figure 1: Time points in the stance phase[11]

Data analysis

Statistical analysis was performed using SPSS Statistics 22. Mean ASIs per group (divided by time, gait, limb and stance phase) were compared with the non-parametric Mann-Whitney-Wilcoxon test. The coefficients of variation for these same groups were analysed with ANOVA. Comparisons were made between OC positive and OC negative foals at 6 weeks and OC positive and OC negative hind limbs at 6 weeks. Foals that had persistent OC at 24 weeks were also compared to the rest of the foals. The Benjamini-Hochberg false discovery rate method was used to correct for multiple comparisons. Results with a corrected P value <0.05 were considered significant.

Results

Specific details of the foals' progress over the duration of the study and the radiographs can be found in Gorissen et al. (2016). In brief, the foals grew to a similar and normal rate for Warmblood horses. The OC status at 6 weeks and 24 weeks of age have been recorded in Table 1.

Table 1: Osteochondrosis status of foals

Foal number	*OC at 6 weeks*	*OC at 24 weeks*
1	2	0
2	1	0
3	0	0
4	1	0
5	2	2
6	0	0
7	1	0
8	0	0
9	2	1
10	0	0
11	0	0

Medio-lateral hoof balance

As shown in Figure 2, foals start out loading the entire foot equally throughout the stance phase. As age increases the different time points in the stance phase show different curves. As previously mentioned, a positive ASI indicates increased pressure on the lateral half of the foot, whilst a negative ASI indicates more pressure on the medial half. Looking at the 1% of stance curve, foals land on the lateral side of the foot, with the pressure shifting even more laterally with age. During the stance phase the ASI is closer to zero. At this point the foals are close to equally weighting the entire foot. At break-over, pressure returns to the lateral side, even more so after 8 weeks of age.

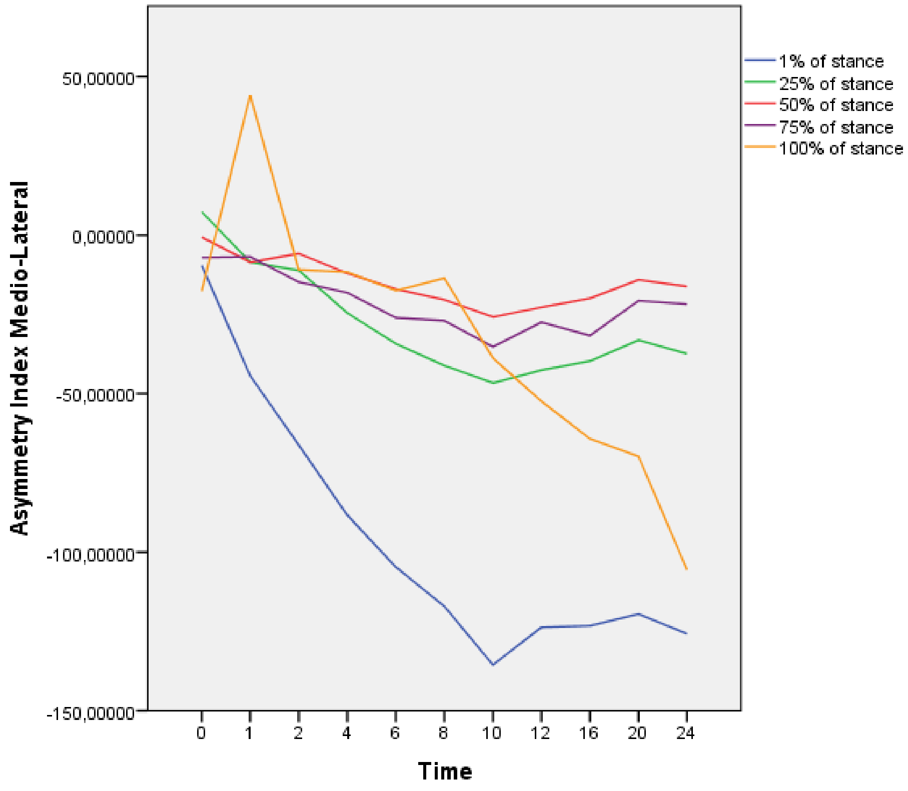

Figure 1: Progression of medio-lateral balance over the study period

The only difference in medio-lateral balance between OC-positive and OC-negative foals was observed in week 4, but only in the forelimbs at 1% and 25% of the stance phase (P<0.05). The COV in the hind limbs showed significant differences while trotting in week 6, when comparing positive and negative foals (P<0.01) as well as hind limbs (P<0.05), both during the support phase of the stance. The COV is higher at 25% and 75% and lower at 50% for foals with OC lesions, as shown in Figures 3-5. In week 1 there was one significant measurement: between foals for the forelimbs at a walk at 75% of the stance phase (P<0.01). The P values can be found in Table 2-4.

Table 2: Results of medio-lateral balance comparing mean ASI of OC+ and OC- foals

Gait	*Limbs*	*Time*	*Stance phase*	*P value*
Trot	Fore	Week 4	1%	0.023
			25%	0.035

Table 3: Results of medio-lateral balance comparing COV of OC+ and OC- foals

Gait	*Limbs*	*Time*	*Stance phase*	*P value*
Walk	Fore	Week 1	75%	0.005
Trot	Hind	Week 6	25%	0.005
			50%	0.003
			75%	0.005

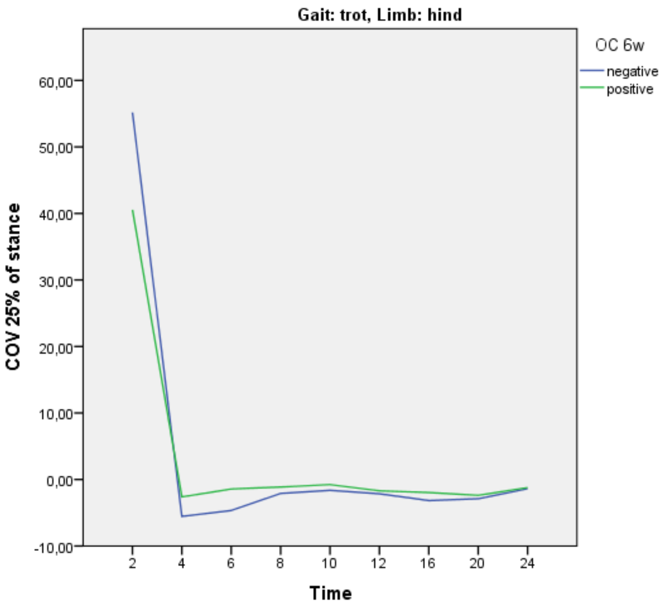

Figure 2: COV curve at 25% of stance of the hind limbs in trot

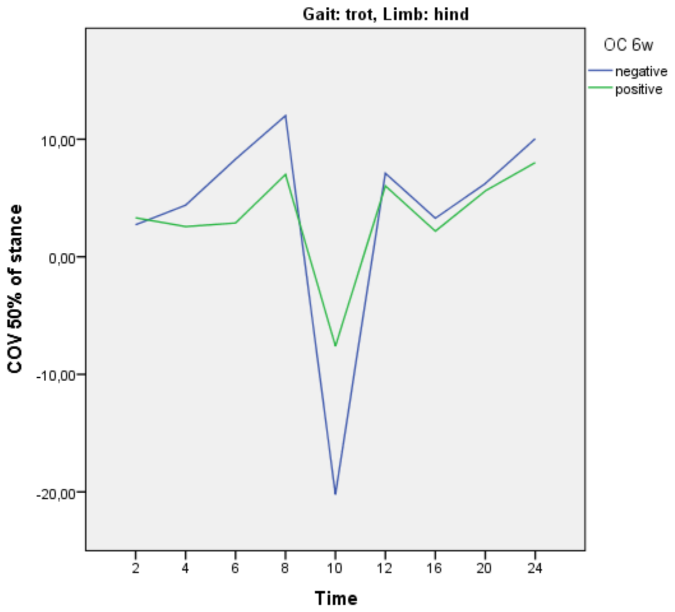

Figure 3: COV curve at 50% of stance of the hind limbs in trot

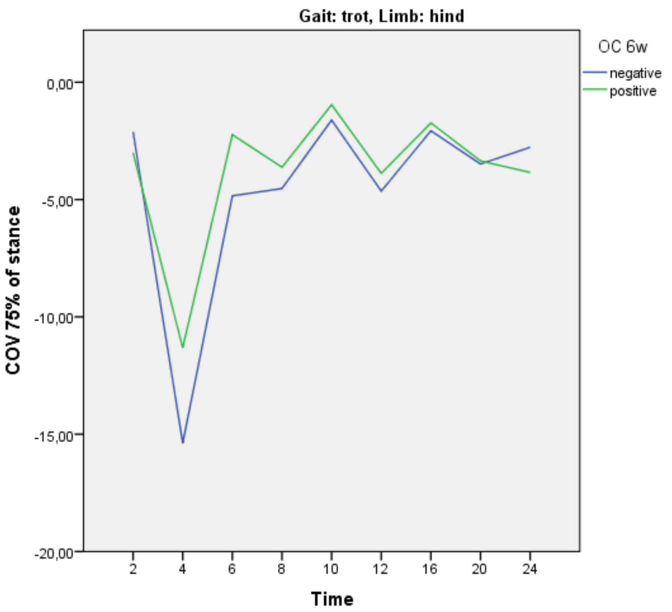

Figure 4: COV curve at 75% of stance of the hind limbs in trot

Table 4: Results of medio-lateral balance comparing COV of OC+ and OC- hind limbs

Gait	*Limbs*	*Time*	*Stance phase*	*P value*
Trot	Hind	Week 6	25%	0.025
			50%	0.025

Toe-heel hoof balance

The toe-heel balance curves show more consistency over time than the curves of the medio-lateral balance do (Figure 5). Landing occurs mainly flat, with a slight shift towards the heel over time. During the stance phase, the heel is loaded maximally at 25%, then weight gradually shifts towards the toe during 50% and 75%, with maximal toe loading at break-over. Little change occurs as age progresses, except for the amount of weight shifting decreasing slightly.

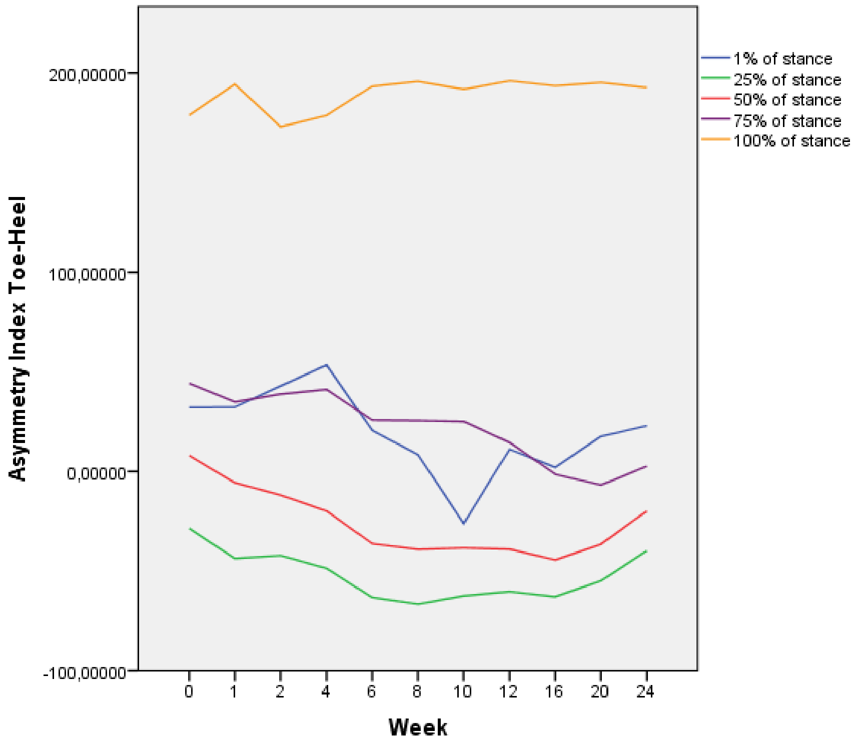

Figure 5: Progression of toe-heel balance over the study period

For the toe-heel hoof balance more significant results were found. Starting with the ASI, when comparing OC-positive and OC-negative foals, differences were observed in the fore limbs at a walk in week 0 and 1 ($P<0.05$). When comparing the hindlimbs, differences were observed only in week 12 at the trot during the support phase of stance ($P<0.05$). In hind limbs with OC lesions pressure was distributed more towards the toe region at every time point, indicating the foot is unloaded quicker, as shown in Figure 6-8. When the foals were split between those with persistent osteochondrosis lesions at 24 weeks and those who never had lesions or those that had regressed lesions by week 24, significant differences were observed in walk in both fore and hind limbs in week 8 and 10 ($P<0.05$), in trot in forelimbs at week 4 ($P<0.05$) and in hindlimbs at week 12 and 16 ($P<0.05$). For the forelimbs most differences occurred at mid to end moment of the stance phase; for the hindlimbs at beginning to mid moment and occassionally at 75% as well. Figure 9 demonstrates that these foals not only unload their hind limbs quicker, but that this persists up until 12 and 16 weeks.
Looking at COV the only significant differences were found when comparing these same groups of OC positive or negative at 24 weeks, in the hind limbs at both gaits in week 12 and 16 ($P<0.05$).

Table 5: Results of toe-heel balance comparing mean ASI of OC+ and OC- foals

Gait	*Limbs*	*Time*	*Stance phase*	*P value*
Walk	Fore	Week 0	50%	0.028
			75%	0.010
		Week 1	75%	0.015

Table 6: Results of toe-heel balance comparing mean ASI of OC+ and OC- hindlimbs

Gait	*Limbs*	*Time*	*Stance phase*	*P value*
Trot	Hind	Week 12	25%	0.028
			50%	0.045
			75%	0.028

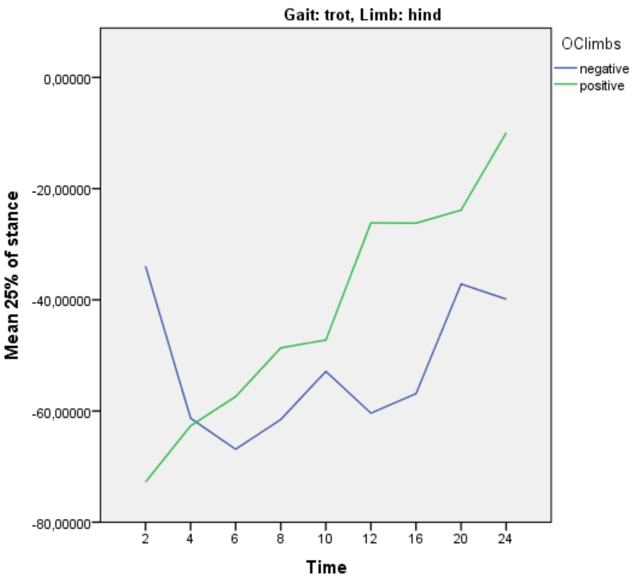

Figure 6: ASI curve at 25% of stance of the hind limbs in trot, comparing hind limbs

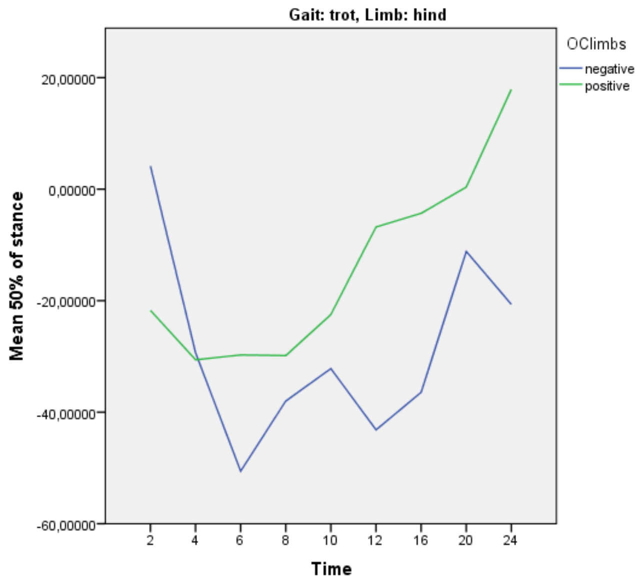

Figure 7: ASI curve at 50% of stance of the hind limbs in trot, comparing hind limbs

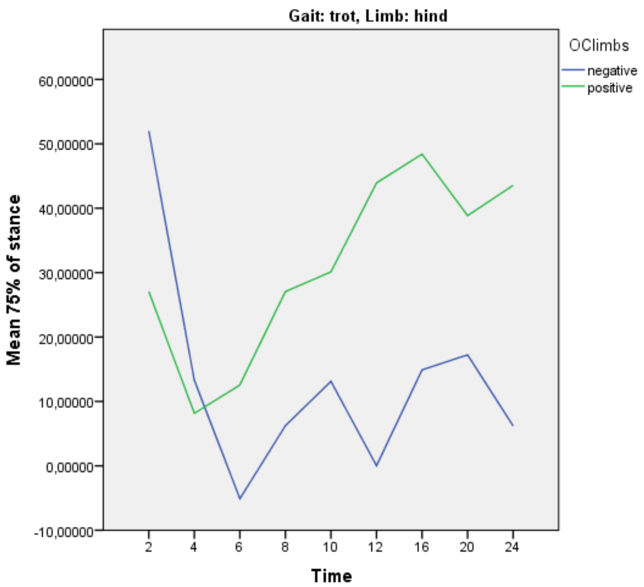

Figure 8: ASI curve at 75% of stance of the hind limbs in trot, comparing hind limbs

Table 7: Results of toe-heel balance comparing mean ASI of foals that were still OC+ at 24 weeks and those with either no or regressed OC lesions

Gait	*Limbs*	*Time*	*Stance phase*	*P value*
Walk	Fore	Week 8	75%	0.025
		Week 10	50%	0.008
			75%	0.005
	Hind	Week 10	25%	0.013
			50%	0.015
Trot	Fore	Week 4	75%	0.013
			99%	0.005
	Hind	Week 12	25%	0.005
			50%	0.008
			75%	0.023
		Week 16	25%	0.035
			50%	0.050

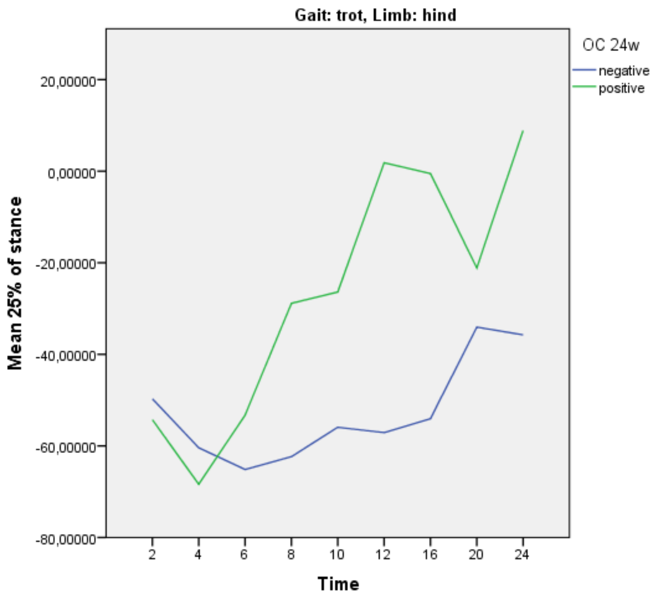

Figure 9: ASI curve at 75% of stance of the hind limbs in trot, OC 24w

Table 8: Results of toe-heel balance comparing COV of foals that were still OC+ at 24 weeks and those with either no or regressed OC lesions

Gait	*Limbs*	*Time*	*Stance phase*	*P value*
Walk	Hind	Week 16	1%	0.025
			25%	0.035
			50%	0.048
Trot	Hind	Week 12	25%	0.045
			50%	0.043

Discussion

In this study the handling and leading of a few days old untrained foals obviously presented some difficulties. Most foals learned to follow their dam over the plate quickly, with minimal guidance, but in some instances steering and coaxing was needed. When foals were halter trained and led with their dam close by or by themselves at a later age, runs were more consistent and behavior was easier to correct with less interference. Van de Water et al. (2016) demonstrated that pressure plate measurements with adult horses are not influenced by handler position, but this requires the horse to be trained to lead.

When investigating the pressure patterns to determine hoof balance, hoof conformation and hoof care play a vital role. The hooves of foals start out at a very small size with a sharp toe region and very little sole-ground contact. The result is a small area of pressure and a hard to distinguish landing phase and breakover phase by pressure patterns alone. Additionally, some foals have a very steep angle to the phalanges of the foot and some are affected by minimal to severe tendon laxity. This causes the pressure distribution over the stance phase to shift more cranially or more caudally. Hoof care or lack thereof during the study period has the possibility of influencing results to a fairly large extent, especially when these result in a higher medial or lateral hoof wall. According to Hagen et al. (2016) side wedge shoes significantly increased impact and pressure as well as decreased distal interphalangeal joint space on the higher side. Asymmetry in hoof trimming or hoof erosion in absence of trimming could potentially simulate side wedge shoes and therefore produce the same results. Likewise the commonly seen asymmetric forefeet that can appear during development of foals can influence results. For example as in Wiggers et al (2015), where flatter feet showed more pressure during the braking phase and more upright feet shifted into the propulsion phase quicker.

Furthermore, young foals lack postural balance and stability, especially during the first two weeks of life, as shown in Nauwelaerts et al. (2013). Neonatal foals stand with their limbs splayed out to increase their base of support and have a distinctive postural sway, mainly in the craniocaudal plane. Logically their movement in the first two weeks is likewise affected. This was reflected in the mainly crooked (with hooves turned in or out) and inconsistent measurements taken during the first two weeks of this study. In view of this finding it may be possible that the results at week 0 and 1 in the forelimbs are due to normal variation. Because none of the foals, whether affected by OC or not, present with consistent craniocaudal postural balance and thus toe-heel hoof balance in the first two weeks of life, true comparison between groups is difficult.

It is important to note that foals were not clinically lame at any point during the study. Since the alteration in their movement is too small to detect visually, this logically also decreases the sensitivity of detection with the pressure plate. This is especially the case when investigating dynamic processes such as hoof balance, where the pressure pattern shows many minute differences between individuals. It is likely that the factors explained above (such as handling, hoof conformation and postural stability) play a part in explaining the inconsistency of our findings.

The findings at week 4 and 6 reflect the findings of Gorissen et al. (2016) based on the same data set. Interestingly, at week 4, only the ASIs of the forelimbs present with significant measurements and at week 6 we can find only significant differences in the COV of the hindlimbs, both when comparing positive and negative foals and positive and negative hind limbs. The differences in COV indicate that foals do not just redistribute pressure but also attempt to decrease the medio-lateral movement in the limb during mid-stance. This causes an increased COV during the braking and propulsion phase.

Results from comparing the toe-heel balance of the hind limbs at week 12 at a trot come out as significant as well. Comparing OC-positive and OC-negative hindlimbs is further complicated by some foals being affected unilaterally (n = 3) and some foals bilaterally (n = 3). Horses have less possibilities for adaptation in movement when they have bilateral painful conditions.[9]

The remaining significant results were all found when comparing the two foals with persistent osteochondrosis lesions to the rest of the group. Because of the small number of subjects and other complicating factors these results may also be coincidental. However, it is noteworthy that the hindlimbs at week 12 and 16 are different between OC-positive (24 weeks) and OC-negative foals in ASIs as well as COV, similar to the findings at week 4 and 6. Since the means of ASIs were tested, these two foals with persistent lesions may also have unfairly influenced the number of significant results at week 8 and 10.

Main differences were detected at time points 25% (braking), 50% (maximal vertical loading) and 75% (propulsion) of the stance phase. This indicates that any movement alteration happens during the support phase and usually not landing or break-over. As the support phase is the period in which pressures on the weight bearing structures and joints peak, it is more likely for foals to make changes during this phase to redistribute loading away from painful areas.

Another question is the validity of using mean values of asymmetry indices to run statistics on. The asymmetry index is calculated to reflect asymmetrical pressures with one value ranging between -200 and 200. However, the mean of -200 and 200 (extremes) is still zero. The COV were calculated with these averaged ASI numbers, and might therefore not be an accurate representation of variability. This was done because of time constraints of the present study.

Conclusion

Gorissen et al. (2016) found that foals with osteochondrosis show a lower peak vertical force in the OC-affected hind limbs during week 4 and 6. This study demonstrates these foals also present with a different distribution of pressures in toe-heel and medio-lateral hoof balance compared to unaffected foals. It should be noted that this is not limited to the 4-6 week time period. Foals with persistent lesions show multiple significant differences at later ages than 4-6 weeks as well, compared to foals with no or regressed lesions. This possibly indicates that regressing lesions have little effect besides a slight subclinical lameness, but that foals with persistent lesions - even if not clinically lame - will load their feet differently during this important growth period. This may affect their development and performance later in life.

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