Pressure plate analysis and medio-lateral hoof stability in Warmblood foals and their relation with osteochondrosis

ABSTRACT

The aim of this study was to evaluate the association between right hind (RH) and left hind (LH) limb loading, medio-lateral hoof stability and the osteochondrose (OC(D)) score in foals. Eleven clinical healthy and sound Warmblood foals were walked and trotted over a pressure plate, covered with a rubber mat and handled by a handler while following their mother. The hind limb peak vertical force (PVF) corrected for the weight (nPVF) was found to be not significantly different between RH and LH. At an age of four to eight weeks X-rays of the hock were taken according to the PROK method of the KWPN studbook and scored by two certified equine veterinarians. Comparison of the lateral versus the medial asymmetry-indices (ASI's) of the group with OC(D) and the group without OC(D), revealed a significant difference at walking pace. Comparison of the nPVF of the group with OC(D) and the group without OC(D), revealed a significant difference during trot. The OC(D) score at this age is still dynamic and may change until the age of five months, but an early indication of the OCD score may help in selecting the best rearing method for the foal.

Introduction

Horses are precocial animals (Nauwelaerts *et al.*, 2013), which means that most foals will stand and walk within two hours. Therefore, good coordination and sufficient ossification of the skeleton is necessary. After birth biomechanical forces act on the bone and the bone adapts to these forces. The legs of foals are 60-70% of the adult length (Acworth, 2003). The muscles are not yet fully developed after birth, which is one of the factors responsible for the unstable stance during the first weeks of their lives, like Nauwelaerts *et al.* (2013) revealed (Nauwelaerts *et al.*, 2013). Back *et al.* (1999) researched the influence of exercise on the stability of foals and discovered that the box-rest foals showed an uncoordinated and hypermetric locomotion pattern in contrast to the other groups (Back *et al.*, 1999). In order to get stability, the foals needed exercise, some foals more than others. While exercising, foals play and can make explosive movements. These unexpected explosive movements together with the unstable standing and unsteady gait result in different biomechanical forces, which is one of the factors which can play a role by osteochondrosis (dissicans) OC(D)).

OC(D) is a disorder in the endochondral ossification of the growth-cartilage and is seen in horses, pigs, dogs, cattle, cats, rats and humans (Ytrehus *et al.*, 2007). The etiology of OC(D) is still not fully understood, but it is thought to have a multi-factorial etiology which causes a defect in the process of endochondral ossification (Jeffcott, 1991). At this point there are two main theories about the development of OC(D). The first is the ischemia theory, which states that vessel necrosis will lead to chondrocyte death and these dead chondrocytes cannot respond to the endochondral ossification. The second theory states that a reduction of type II collagen leads to weaker cartilage (Laverty and Girard, 2013). Although the theories differ, the result is the same: the tissue is not strong enough for the biomechanical forces which leads to OC(D).

In horses there are different predilection sites for OC(D). These include the hock and the knee (Sloet van Oldruitenborgh-Oosterbaan *et al.*, 2007). At an age of only three days, OC(D) lesions can already be detected in horses, which shows that the first days are very important. These lesions are dynamic in the first months after birth and later become static at around 5 months of age for lesions in the hock and 8 months of age for lesions in the knee (Dik *et al.*, 1999). By taking X-rays, an OC(D) score can be given by a licensed veterinarian. There are five degrees of OC(D) (Dik *et al.*, 1999; Sloet van Oldruitenborgh-Oosterbaan *et al.*, 2007):

A. Normal: no or minimal flattening
B. Minimal: slight contour change
C. Mild: sound contour defect
D. Moderate: contour defect with corresponding fragment
E. Severe: contour defect with several fragments

A study from de Koning *et al.* (2012) revealed the association between conformation and locomotive characteristics and OC(D) in pigs. They discovered an association between lower OC(D) scores and a steep or weak pasterns of the hind legs and an association between greater OC(D) scores and a slow and stiff gait pattern in the tarsus (de Koning *et al.*, 2012). In contrast to pigs, horses are not even-toed which may cause a different outcome.

A pressure plate has been used to study the gait of different animals quantitatively, for example by Meijer *et al.* (2014) with pigs and Oosterlinck *et al.* (2013) with horses. Meijer *et al.* (2014) revealed that there was a low degree of asymmetry in sound pigs between the nPVF (Peak Vertical Force corrected for weight) right hind (RH) and left hind (LH) (Meijer *et al.*, 2014). Pigs are between altricial and precocial, so they are semi-precocial, in contrast to horses who are precocial. Oosterlinck *et al.* (2013) researched the medio-lateral hoof stability in seven Royal Dutch Sport Horses by letting them walk and trot over a pressure plate. All the horses were sound, based on visual evaluation. No significant differences were found between left and right limbs, but the lateral part of both hoofs present higher loading at walk compared to the medial part. However, during trot the horses land more on the left hoof than the right. In the left hoof, the medial zone had a higher loading, in contrast to the right hoof, where the lateral zone presented higher loading, so the horses showed a landing pattern (Oosterlinck *et al.*, 2013). To conclude, multiple studies have used the pressure plate to identify differences in pressure on the limbs and to evaluate gait patterns. The pressure plate has thus proven to be a valuable device in increasing our understanding in limb pressures and gait patterns.

The distribution of forces between the legs and medio-lateral hoof stability can reveal locomotive characteristics, which could possibly be linked to a certain OC(D) score. A study with foals has never been performed. The unsteady stand, gait and coordination are not ideal, even as the unexpected moves they can make. In addition, it has never been investigated at which age foals have a steady walk and a similar pattern in the way they land in the medio-lateral stability as adult horses. However, the OC(D) lesions in foals can already be seen at three days of age which may indicate that the first unsteady attempts to stand and the unsteady walks can influence the development of OC(D) lesions (Lecocq *et al.*, 2008).

The aim of this study is to see if there is a correlation between the aspect of the medio-lateral hoof stability and the OC(D) scores of the knee and the hock at 4 till 8 weeks of age. In order to investigate the medio-lateral hoof stability a pressure plate will be used. To see if there is any form of stability, the nPVF and the asymmetry indices (ASI's) of lateral and medial will be evaluated and a possible link with OC(D) will be studied. The foals will probably not be stable at 4 till 8 weeks of age, because Nauwelaerts *et al.* (2013) found a static stability at 2 till 3 months of age and a dynamic stability would be more difficult for the foals (Nauwelaerts *et al.*, 2013). Yet some foals may have a more medio-lateral stability than other foals. Oosterlinck *et al.* (2013) found a specific landing pattern in adult horses and possibly foals will also have a preference for a specific landing pattern and there is a possibility that this may influence the development of OC(D). The hypothesis is that foals with a more stable and even medio-lateral landing pattern will have a lower OC(D) score.

Material and Methods

Ethical note

This study was approved by the Ethical Committee of Utrecht University.

Horses

Eleven Dutch Warmblood (KWPN) foals (5 mares, 6 stallions) were used for this study. The foals were born between May and August 2014 at the same breeding stable in The Netherlands. All measurements were performed at the same stable and prior to the measurements each foal was adjudged healthy and not lame. The foals that were used for this experiment were born in a stable. The foals and their dams had access to a pasture (weather-permitting).

Measurement system and data collection

Gait stability was measured on location with a portable pressure plate from RsScan International, Paal, Belgium, which consists of 16384 sensors with an active sensor surface of 1.95 m × 0.32 m (2.6 sensors per cm^2), with a sensitivity of 0.27-127 n/cm^2 and a measures frequency of 126 Hz. The pressure plate was connected to a laptop with the Gait Scientific software from RsScan International (Footscan Scientific Gait 7 gait 2^{nd} generation, RSscan International, Paal, Belgium). This measuring system is similar to the one Meijer *et al.* (2014) and Oosterlinck et at. (2011, 2013) used (Meijer *et al*, 2014; Oosterlinck *et al.*, 2011; 2013).

Calibration was performed with a 85 kg weighing person walking over the pressure plate, following the manufacturer's instructions.

The measurements took place in an empty stable to make sure that the foals were not easily distracted by other horses. The pressure plate was placed on an equal surface on the ground with wooden planks at both sides and slopes on the start and the end of the plate (shore value 65° ± 5) (figure 1). Then the plate and wooden planks were covered with the 5 mm thick rubber mat of 10x1,5 meter, same as Meijer *et al.* (2014) and Oosterlinck *et al.* (2011; 2013) used. The place of the pressure plate was marked with small pieces of tape on the rubber mat at each place of the corner of the pressure plate (figure 2).

Every measurement was filmed with a Philips full HD 1080p camcorder to determine which hoof print was made by which hoof and for the validation of the trail.

Figure 1. *The setting of the pressure plate without the rubber mat.*

Data collection

The measurements were performed 2-3 days after birth (week 0), at one week of age (week 1), two weeks of age (week 2), four weeks of age (week 4), six weeks of age (week 6) and eight weeks of age (week 8). At week 0 and week 1 the foals only needed to walk over the plate. At week 2 and further, the foals had to walk and trot over the plate.

At every measurement, pictures were taken of the front, of both sides and of the back of the foal, so it was possible to study how the foals stand on their legs at each point in time. There was not a scale available on location, so their weight was calculated with the formulas of Stanair *et al.* (2004) (Stanair *et al.*, 2004). The height of the foals was measured at withers. The foals walked over the rubber mat with the pressure plate below. They did not receive any prior training to walk over the pressure plate but learned along the way. The foals were guided over the plate by a handler. Until the age of weaning the foals did not only have a handler, but also followed their mother. The mother was also guided by a handler and walked next to the plate. Every walk over the pressure plate was recorded to enable qualitative screening of the trials. A trial was valid if the foal walked in a straight line over the pressure plate, in the correct gait for that moment and looked straight ahead (figure 2). For each session 5 valid trails per hoof were necessary. Measurements take as long as needed to get 5 valid runs.

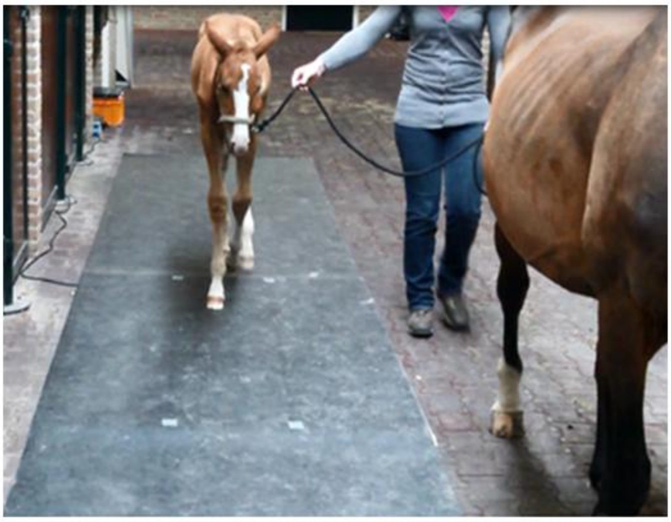

Figure 2. *The pressure plate with the rubber mat and an example of a valid run.*

X-rays

The foals were clustered for the X-ray pictures, most foals were 4 weeks of age and were measured till week 4, one foals was 6 weeks of age and measured till week 6 and two foals were 8 weeks of age and measured till week 8. The X-rays were taken on location by Edigit using the Gierth 400 and FDR D-EVO plus C24i cassettes. These X-rays were taken according to the PROK method of the KWNP studbook, so three X-rays from the hock and knee were taken (Sloet van Oldruitenborgh-Oosterbaan *et al.*, 2007). Of the hock an anterior-posterior, latero-medial and a dorsomedial-palmarolateral oblique direction were taken. Pictures of the knee were taken in a Lateral-Palmaromedial oblique and a latero-medial direction. The foals were lightly sedated with Domesedan ® (Detomidine, α_2-agonist) in order to guaranty the safety for both foal and handler. An OC(D) score will be given following the same method Dik *et al.* (1999) used (Dik *et al.*, 1999).

Data analysis

Using RSscan, the hoof prints were manually assigned to right front (RF), left front (LF), right hind (RH) and left hind (LH). The hoof prints were also divided in a medial and lateral zone by a line through middle of the hoof (figure 3). Only the data from 5 valid trials per hoof from RH and LH were analyzed. Results were saved and exported to Excel. The Peak Vertical Force (PVF) (N) was normalized to body weight (nPVF) using the following formula:

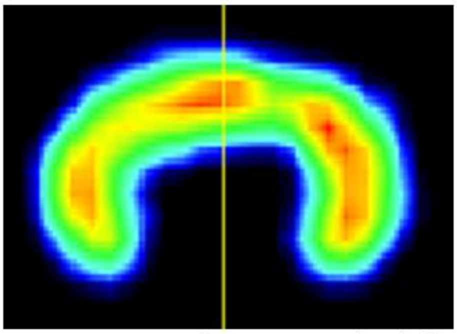

Figure 3. *Hoof prints were divided in a medial and lateral zone by a line through the middle of the hoof.*

$$nPVF = \frac{\text{PVF}}{\text{Body weight}}$$

For each run, the mean nPVF of 5 valid runs was used to calculate the mean distribution between right hind (RH) and left hind (LH) using the following formula:

$$\%\ \text{RH} = \frac{\text{mean nPVF RH}}{\text{mean nPVF RH+mean nPVF LH}} * 100\% \quad \textit{and}\ \%\ \text{LH} = \frac{\text{mean nPVF LH}}{\text{mean nPVF RH+mean nPVF LH}} * 100\%$$

Medio-lateral hoof stability per hoof was calculated with the asymmetry indices (ASI) by the formula:

$$ASI = \frac{\text{PVF medial} - \text{PVF lateral}}{0{,}5\ * (\text{PVF medial} - \text{PVF lateral})} * 100\%$$

A value of 0% indicates a perfect stability between lateral and medial ground reaction forces between the zones. A negative value indicates that the foal had a higher loading on the lateral zone and a positive value indicates that the foal had a higher loading on the medial zone. Possible values range from -200% to 200% (Meijer *et al.*, 2014; Oosterlinck *et al.*, 2013).

The velocity of every measurement was calculated using RSscan software. Therefore, the LF and RF were assigned and then RSscan calculated the velocity in meter per seconds. For every week and every foal the mean velocity was calculated using the velocities of all used runs.

Statistical analysis

A log transformation of the nPVF and the ASI of the nPVF was performed to achieve a normal distribution. A paired T-test was used to evaluate the difference between the nPVF RH and the nPVF LH per foal per week and to determine if there was a significant difference between the ASI of the nPVF RH and the ASI of the nPVF LH per foal per week. To compare the legs with OC(D) with the legs without OC(D), two groups, without OC(D) (0) and with OC(D) (1), with the nPVF and the ASI of the nPVF were made and compared. Therefore, a independent T-test was used. The OC(D)-score was compared with the height and with the weight by using a invariable correlation. Statistical analysis was performed using IBM SPSS Statistics 21, with statistical significance set at $P < 0.05$.

Results

The measurements of foal 1 and 2 did not succeed at week 1, so those foals are excluded from the results of the first week. Pictures and results per foal can be found in appendix 1.

Pictures and videos

The videos showed that in the first week after birth (week 0) the foals were hypermetric. The foals were only hypermetric at week 0 and were not hypermetric anymore at week 1. The videos also showed that the foals were very easily distracted and not well coordinated; they found in difficult to walk in a straight line. There were differences regarding the distraction between the foals, but these differences were not consistent and did not lead to abnormal measurements. Foal 1 and 2 for example were very easy to handle and walked confidently over the plate, in contrast to foal 6 and 7, who were mischievous and foal 8 who needed to be embraced till week 8.

The pictures showed the stance of the foals during the measurements and during the time of taking X-rays. The pictures showed that foal 4 had a stiff stance during the first weeks.

Body weights and heights

Body weights and heights increased during the study (figure 4 and 5). The mean weight in kilograms at week 0 was 58,1±4,6, at week 1 it was 69,3±6,1, at week 2 it was 78,2±6,4 and at week 4 it was 96,1±9,1. The mean weight gain of the foals over the first 4 weeks was 38,0±5,2 kilograms. The mean height in centimeters at week 0 was 102,8±2,6, at week 1 106,1±2,0, at week 2 109,4±2,2 and at week 4 it was 113,5±2,7.The mean gain in heights of the foals over the first 4 weeks was 10,7±2,1 centimeters. The weight of the foals increased faster than the height of the foals.

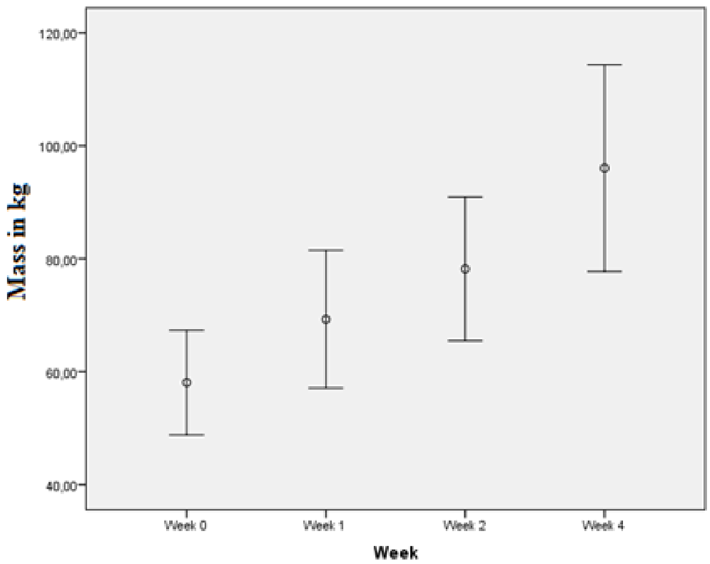

Figure 4. *Mean ± standard deviation of body weight of foals (n=11) during the first four weeks of age.*

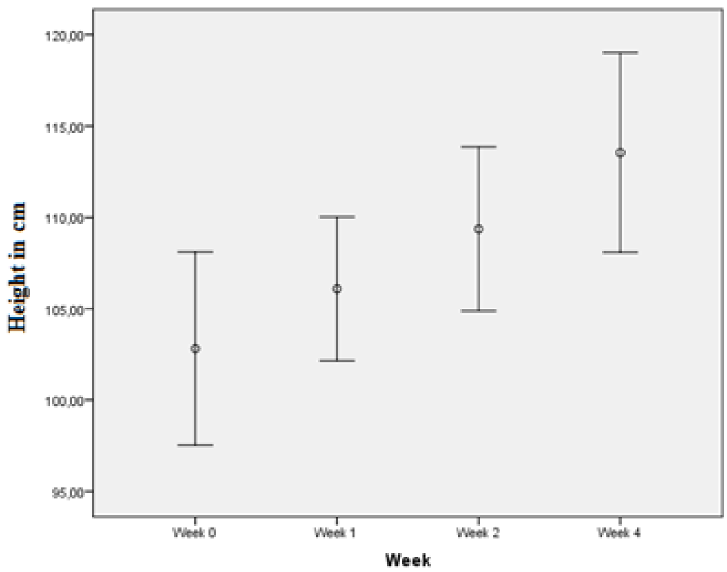

Figure 5. *Mean ± standard deviation of heights of foals (n=11) during the first four weeks of age.*

Velocity

The foals walked and trotted at their own comfortable speed. The mean velocity in meter per second at walk of the foals at week 0 was 1,03±0,1, at week 1 1,1±0,1, at week

2 1,1±0,2 and at week 4 1,1±0,1. So the velocity at walk did not increase much over the course of time. During trot the mean velocity at week 2 was 2,5±0,3 and at week 4 was 2,6±0,4. Thus, at trot the velocity also increased minimally.

nPVF

In table 1 the mean nPVF at walk per week and the distribution of forces over the hind legs are presented. Remarkable is that at walk the distribution of the forces between the hind legs is nearly 50 % RH and 50% LH, except at week 4. However, when the results of the individual foals are studied it becomes clear that the distribution between the hind legs is not equally divided. Appendix 2 shows the box plots of the nPVF RH and LH per foal per week at walk and trot.

WALK	*Right hind*		*Left hind*				
	Mean nPVF	*SD*	*Mean nPVF*	*SD*	*Total nPVF*	*% Right hind*	*% Left hind*
Week 0	5,2	1,2	5,1	1,3	*10,3*	*50,5*	*49,5*
Week 1	4,8	0,9	5,1	1,2	*9,9*	*48,5*	*51,5*
Week 2	5,1	0,8	5,0	0,9	*10,1*	*50,5*	*49,5*
Week 4	5,3	0,6	4,5	0,7	*9,8*	*54,1*	*45,9*

TROT	*Right hind*		*Left hind*				
	Mean nPVF	*SD*	*Mean nPVF*	*SD*	*Total nPVF*	*% Right hind*	*% Left hind*
Week 2	*9,1*	*1,9*	*9,3*	*1,9*	*18,4*	*49,6*	*50,4*
Week 4	*9,4*	*1,9*	*8,3*	*1,5*	*17,7*	*53,0*	*47,0*

Table 1. *The mean nPVF of all the foals per week, the total nPVF and the distribution in percent of the forces between the hind legs.*

The foals walked hypermetrically during the first measurement. Foal 2, 3, 5, 8, 9 and 11 showed at week 0 higher nPVF's than at the other weeks. This is not the case in the other foals. The foals which walked confidently over the plate did not show a different pattern from the more mischievous foals. At walking speed, foal number 3 has a lower nPVF in comparison with the other foals while foal number 8, 9 and 11 has a higher nPVF than the 'average' foals.

ASI

Box plots of the ASI from the nPVF per foal at walking speed and during trot were made and those box plots are shown in appendix 3. The mean ASI is even out because of the changing balance, but may be of value to detect constant lameness. Most foals show the same ASI for the right hind leg and left hind leg over the weeks, but some weeks there are differences between the hind legs. Foal 2 and 5 showed a small distribution in the ASI of the nPVF, while foal 3, 4, 7, 8 and 9 showed a large distribution in the ASI of the nPVF. The videos did not showed this instability.

X-rays

At 4-8 weeks of age accurate OCD scoring of the knee joints was not possible due to the physiological irregular contour and granular subchondral bone opacity of the femoral trochlear ridges that may persist in foals until the age of 3-5 months. The OC(D) score of the hock of all the foals are presented in table 2, the scores are converted to a binary score based on what is acceptable according to insurance companies (score A and score B are immediately acceptable for the insurance companies and therefore scored as a 0. Score C, D and E are scored as an 1). In figure 6, as an example, the X-ray pictures of the right hock of two foals are shown, one of a foal with only A scores (foal 3) and one of a foal with C scores at the intermediate ridge of the tibia and the lateral trochlear ridge and A scores at the other locations (foal 5).

	Right hind						*Left hind*					
Location	*1*	*2*	*3*	*4*	*5*	*Binary*	*1*	*2*	*3*	*4*	*5*	*Binary*
Foal 1	B	B	C	A	A	1	B	C	A	A	A	1
Foal 2	A	C	A	A	A	1	B	A	A	A	A	0
Foal 3	A	A	A	A	A	0	A	A	A	A	A	0
Foal 4	B	B	A	A	A	0	C	B	A	A	A	1
Foal 5	C	C	A	A	A	1	A	B	E	A	A	1
Foal 6	A	B	A	A	A	0	A	A	A	A	NTB	0
Foal 7	C	A	A	A	NTB	1	A	A	A	A	NTB	0
Foal 8	A	A	A	A	A	0	A	A	A	A	B	0
Foal 9	C	A	A	A	NTB	1	C	A	A	A	A	1
Foal 10	A	A	A	A	NTB	0	A	A	A	A	A	0
Foal 11	A	B	A	A	A	0	B	B	A	A	A	0

Table 2. *Osteochondrose score of the tarsus of the foals. Location 1 is the intermediate ridge of the tibia, location 2 is the lateral trochlear ridge, location 3 is the medial trochlear ridge, location 4 is the lateral malleolus and location 5 is the medial malleolus.*

Figure 6. *Some X-rays of the hock to illustrate the difference between a hock without OC(D) and a hock with OC(D). On the Left hand the pictures of foal 3 which scored at all the five locations a A and on the right hand the pictures of foal 5 with C scores at the intermediate ridge of the tibia and the lateral trochlear ridge and A scores at the other locations.*

Statistical analysis

With the paired T-test no significant difference between the nPVF RH and the nPVF LH at walk and trot was found. Also, no significant difference between the ASI of the nPVF RH and the ASI of the nPVF LH at walk and trot was found. In addition, no correlation between the OC(D) score and the height of the weight was found.

Comparing the OC(D) group with the without OC(D) group revealed that at walking speed there is no significant difference between the nPVF of the group with OC(D) and the nPVF of the group without OC(D). However, between the ASI of the nPVF RH and the ASI of the nPVF LH at walking speed, a significant difference was found. At trot, there is a significant difference between the nPVF of the group with OC(D) and the nPVF of the group without OC(D). No significant difference between the ASI of the nPVF of the group with OC(D) and the ASI of the nPVF without OC(D) at trot was found (table 3).

	OCD-score	Average	SD	Range	
nPVF at walk	*0*	*5,20*	*1,48*	*2,31*	*11,96*
	1	*4,85*	*1,30*	*2,02*	*8,37*
*ASI nPVF LM at walk**	*0*	*7,30*	*70,92*	*-136,54*	*160,8*
	1	*10,55*	*58,96*	*-115,07*	*160,66*
*nPVF at trot**	*0*	*9,62*	*2,27*	*6,00*	*18,2*
	1	*8,54*	*2,29*	*4,93*	*18,48*
ASI nPVF LM at trot	*0*	*5,00*	*61,22*	*-184,70*	*197,34*
	1	*-5,55*	*49,45*	*-127,22*	*129,58*

Table 3. *The average, SD and range of the nPVF at walk, the ASI of the nPVF at walk, the nPVF at trot and the ASI of the nPVF at trot. An * indicates a significant difference.*

Discussion

This study is the first study to evaluate the stability of the hind limbs of foals with a pressure plate and the OC(D) score of the hock from the foals at a young age. A pressure plate study of the stability of horses was only performed with adult horses and ponies. A study about the OC(D) score was only performed in pigs and not yet with horses.

Foals

The number of animals used for this study is more than usually used for pressure plate studies. For example: Oosterlinck at al. (2014) used five ponies, Oosterlinck at al. (2013) used seven Royal Dutch Sport Horses and Meijer *et al.* (2014) used ten pigs (Meijer *et al.*, 2014; Oosterlinck *et al.* 2011;2013). The foals did not receive any prior training to walk over the pressure plate but learned it along the way. Most foals were easy to handle and were guided easily over the plate. Some foals were a bit more difficult to handle and some foals found it difficult to walk by hand and needed to be embraced to get valid measurements. The runs during which the foals were very difficult and mischievous were excluded. Also tiredness played a role, some foals found it very difficult to trot and instead of trotting they galloped, so more measurements were needed and the foals got more tired. Therefore, and also because the foals were too small, it was decided to let the foals trot over the plate starting at week 2, so the foals did not trot over the plate at week 0 and week 1. Measurements took as long as needed to get 5 valid runs. The number of valid runs is based on previous research: Oosterlinck *et al.* (2011 and 2013) used also 5 valid trails and Meijer *et al.* (2014) used 3 correct runs (Meijer *et al.*, 2014; Oosterlinck *et al*, 2011, 2013).

Foal number 4 had a stiff stance due to short tendons. Yet this foal is included in the research because it is representative of the normal population KWPN foals.

Velocity

The velocity influenced the PVF both at walk and trot (Oosterlinck *et al.*, 2010). During walking the velocity increased from 1,03±0,1 m/s to 1,1±0,1 m/s in 4 weeks and at trot the velocity increased from 2,5±0,3 m/s at week 2 to 2,6±0,4 m/s at week 4. The nPVF at walk increased from 5,2±1,2 m/s to 5,3±0,6 m/s and at trot the nPVF increased from 9,1±1,9 N to 9,4±1,9 N. Meijer *et al.* (2014) revealed that at pigs an increase of 1 m/s in speed caused a 0,31 N/kg increase in nPVF (Meijer *et al.*, 2014). When extrapolated to foals, the increase of 0,1 N at walk and 0,3 N at trot cannot only be explained by the increase in velocity. A more confident walk of the foals may explain the increase in forces, but further research is necessary.

Stability of the foals

In order to investigate the stability of the foals, a pressure plate was used. Oosterlinck *et al.* (2010, 2011 and 2013) explored the use of a pressure plate as tool for dynamic limb loading symmetry and for a medio-lateral hoof stability (Oosterlinck *et al.*, 2010; 2011; 2013). A comparison between a pressure plate and a force plate revealed that the pressure plate can measure and analyze simultaneous hoof prints and can determine the pressure of different hoof zones, both in contrast to a force plate. The pressure plate can be used for loading symmetry, but the actual PVF showed a lower maximal value than the force plate. The PVF of the pressure plate is not 100% accurate, but using the average of 5 valid hoofs ensures an averaging, so a visible trend certainly has value. Ideally, both a pressure plate and a force plate would be used, but unfortunately it was not possible to use a force plate because of the costs and the fact that use of a force plate is only possible in a laboratorial setting (which would lead to compromised animal welfare).

A recent study from Nauwelaerts *et al.* (2013) revealed that newborn foals are very unstable during static measurements and this instability fades rapidly during the weeks until 2 to 3 months (Nauwelaerts *et al.*, 2013). For the foals, a dynamic stability would be harder to achieve than a static stability, so it can be suggested that it also takes 2 to 3 months or even longer for the foals to get dynamically stable. In this study no stability was found, as expected.

Foals are similar to adult horses regarding the weight distribution between the front and hind limbs. 60 percent of the total weight is carried on the front limbs (30 percent on the LF and 30 percent on the RF) and 40 percent on the hind limbs (20 percent LH and 20 percent RH) (Hair, 2014). Oosterlinck et al. (2010) found a symmetry in the forelimbs of 97% and it is likely that a same kind of symmetry can be found in the hind legs (Oosterlinck *et al.*, 2010). However, the weight distribution between the hind legs in the foals is not 20 percent on the RH and 20 percent on the LH, which shows the instability of the foals. The instability between RH and LH over the weeks is not significant. The nPVF showed a lower value at week 1 in comparison with week 0 and week 2 and 4, this is the result of the higher nPVF at week 0 caused by the hypermetric walk of the foals that week.

Oosterlinck *et al.* (2013) found that adult horses have a higher loading of the lateral part of the hoof at walk and a higher loading of the medial part of the hoof at trot (Oosterlinck *et al.*, 2013). The present study revealed that there is no such pattern in foals, which is plausible considering the instability foals have at this young age.

Osteochondrosis

Over the years the anatomical building plan of the horse changed, for example the legs became longer to be able to meet the high demands made on a good show dressage and jumping course. Therefore, foals are born with long legs and the legs have to grow faster, which is one of the factors which may play a role in the development OC(D). Besides fast growth, anatomical characteristic play a role in the development of OC(D). The bone strength of foals is unknown, but in order to investigate this the foals should be euthanized, which is not possible because of the longitudinal aspect of this study, in addition to compromised animal welfare. It is expected that foals with stronger bone can handle high biomechanical forces better than foals with weaker bone. Anatomically, a higher loading on the medial part of the hoof ensures that the intermedial ridge of the tibia touches the medial trochlear ridge and the lateral malleolus touches the trochlear ridge. A higher load on the lateral part of the hoof causes friction between the lateral trochlear ridge and the intermedial ridge of the tibia and the medial malleolus touches a part of the trochlear ridge. However, it is unlikely that a preference in the medio-lateral zone causes OC(D) because then all horses would then develop OC(D). Only at walking speed, a significant difference between the ASI of the PVF of the group with OC(D) and the ASI of the PVF of the group without OC(D) is found. Only at trot a significant difference was found between the nPVF of the group with OC(D) and the nPVF of the group without OC(D). Notably, at walking speed the average ASI of the nPVF is higher in the group without OC(D) than in the group with OC(D). Same with the nPVF at trot. One explanation may be that a higher instability at walk and a higher nPVF during trot leads to stronger bones and less risk of developing OC(D) and that a normal walk and trot cannot predict OC(D) at a young age. Another explanation may be that OC(D) leads to pain and that less loading leads to less pain. Other parameters which can be used to confirm this are the Vertical Impulse (VI), the Load Rate (LR) and the Peak Vertical Pressure (PVP). In this research these parameters, which are derived from the nPVF, are not used, because the nPVF says more about the stability of the foals.

More obviously, explosive movements while playing may add to the development of OC(D) at one of the predilection sides, depending on the way of landing during those explosive movements. Also, standing up has a great impact on the joint. During a stand up the intermedial ridge of the tibia touches the distal lateral trochlear ridge and the middle of the medial trochlear ridge, these are three predilection sides of OC(D). A normal stand up thus has a great impact on the joint, but especially when the foal cannot stand up smoothly (for example because it is being chased or when it is on a slippery surface), there is a high risk for the development of OC(D).

An OC(D) score at an age of 4-8 weeks is dynamic, so there is a possibility that the score will change. In the hock the OC(D) score will become static around 5 months of age (Dik *et al*., 1999). Nevertheless, scoring the OC(D) at such a young age can be useful for the selection of the type of rearing during the first few weeks with the mare and after weaning. To strengthen the bone, foals need to walk and run in straight lines, so running in a big pasture for example. For foals with an A, B or C score this will probably be the best way of rearing. A foal with a D or E score may be better off when housed in a stable where its movements are more restricted than in a pasture and they can only move in a controlled way. In that way there may be a chance the loose fragment will reattach to the bone. Another option is to perform surgery on the horse, but this can best be delayed until the OC(D) score becomes static, so after 5 months of age (McIlwraith, 2013).

Conclusion

This study provides objective and dynamic data of the Peak Vertical Force and the medio-lateral hoof stability in young KWPN foals. The aim of this study was to evaluate the correlation between the stability of the foal and the OC(D) scores of the hock at 4 to 8 weeks of age. As suggested, the foals are not stable in the first weeks of their life. Surprisingly, the foals do not show a preference for a specific landing pattern like adult horses do, which emphasizes the instability. No significant difference between RH and LH was found. At walking speed, a significant difference between the ASI of the nPVF of the group with OC(D) and the ASI of the nPVF of the group without OCD was found. At trot, a significant difference between the nPVF of the group with OC(D) and the group without OC(D) is found. At walk and trot, the group without OC(D) had a higher mean nPVF than the foals with OC(D). An explanation may be that this leads to stronger bones, but is more likely that OC(D) is not caused by the normal walk and trot, but by the explosive movements and by standing up and that the lower nPVF probably caused by the pain caused by the OC(D).

Future research is necessary to determine at which age the foals are stable and if the OC(D) scores of the foals changes. Also, research should be done to investigate which rearing system is ideal in the dynamic period of OC(D).

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