Pressure plate analysis of the locomotion pattern of Warmblood foals in the first 6 weeks after birth

Research Project Veterinary Medicine University of Utrecht
D.M.E. de Hair
3501736

Abstract
The aim of this study was to analyze the pressure plate data that occur during walking and trotting in foals and how this develops in the first 6 weeks of age. Also the moment when a foal has the same gait pattern and forces like an adult horse has been determined. Nine sound foals were followed for 6 weeks after birth. They had to walk and trot over a pressure plate embedded in a custom-made runway. There is a significant correlation between the front limbs and the hind limbs for the peak vertical force (nPVF), the peak vertical pressure (nPVP) and the vertical impulse (nVI) in trot during the 6 weeks. In walk no significant correlation is found.
The asymmetry indices show different significant correlations and gave every week different values for walking and trotting so during the 6 weeks there wasn't a significant correlation between the asymmetry indices. The data were compared to that of adult horses and there is found that the values of the nPVF are somewhat higher despite the decline that is visible at week 1 in the foals at walk and in trot they start the same but in week 6 they are higher than in adult horses, the nPVP starts higher but at week 6 is almost the same at walk and at trot the nPVP is higher than in adult horses, the nVI increases during the 6 weeks in walk and trot and is at week 6 comparable with that of adult horses.
The conclusion is that foals at 6 weeks are still a little bit unstable and asymmetrical. The nPVF, nPVP and nVI are around 6 weeks the same or almost the same as in adult horses but the distribution between the 4 limbs changes every week.
The fact that the nPVF is higher in week 0 than in week 1 and week 0 is the period in which the foals are the most unstable and uncoordinated, this can be a risk full period to get injuries and develop diseases like OC(D). Also in the weeks after week 1, foals are still unstable and so they are more vulnerable to injuries especially in the pasture were the surface isn't smooth and they run, jump etc.

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Supervisors
Drs. B.M.C. Gorissen
Dr. C.F. Wolschrijn

Introduction

During movement biomechanical stress in the joints occurs. This is one of the factors that can cause osteochondrosis (OC) in foals and which can cause lameness. In OC there is a focal failure in the endochondral ossification. An area of growth does not become converted to bone because of the growth cartilage fails to undergo matrix calcification or vascular invasion.(Ytrehus et al., 2007)

There are two major theories about the development of OC. The first one is that the vascularization went wrong and that the cartilage cannals in the growth cartilage which contains blood vessels shear. The other one is that there is a reduction of type II collagen and due to that the cartilage is more vulnerable to biomechanical stress and shear sooner. (Laverty et al., 2013)

OC lesions can develop in the first few months after birth in the period of intense growth. OC lesions are found in foals 2 till 18 days after birth. (Lecocq et al., 2008)

Predilection sites for OC in the horse are the pastern, tarsus and knee joint. In the pastern the predilection sites are the dorsal aspect of the distal metacarpus and metatarsus, in the tarsus predilection sites are the intermediate ridge of the distal tibia and the lateral trochlear ridge of the talus, and in the knee joint predilection sites are the lateral trochlear ridge of the femur and the medial condyle of the femur. (Ytrehus et al., 2007)

Koning et al., (2012) researched pigs to determine if their conformation and locomotive characteristics played a role in the development of OC. There was discovered that a stiffer and slower gait pattern was significantly associated with OC in the tarsus and lower OC scores were associated with a weak and steep pastern of the hind legs. It was indicated that weak or steep pasterns of the hind limbs protected the tarsocrural joint against the development of OC. Also in earlier studies small to moderate associations of OC in the tarsus have been found in different directions and magnitude between breeds with weak or upright pasterns of the hind legs, stiff gait and swaying hindquarters. (Koning et al., 2012).

Also Koning et al., (2012) discovered that there was an association between front leg conformation and the development of OC in the hind legs. This suggest that a certain leg conformation may influence the distribution of body weight between front legs and hind legs. (Koning et al., 2012)

Several studies have speculated that joint loading can play a role in the development of OC. Also abnormal amount of pressure on certain parts of the joint can result from conformation or locomotive characteristics. This could lead to vascular disruption and therefore necrosis or it can lead to abnormalities in normal chondrocyte functioning in the growth cartilage which can lead to the development of OC. (Koning et al., 2012)

According to Wolff's law, bone adapts to the biomechanical loadings it is exposed to. So the mechanical load which is applied to living bone tissue influences the structure of bone tissue. (Ruff et al., (2006)

Horses are precocial so in a few hours after birth they stand up, walk, trot and gallop without any training and adaptation. There is maturation of the nervous and musculoskeletal systems required for postural control. (Nauwelaerts et al., 2013).

Nauwelaerts et al., (2013) have investigated the postural balance of the foals in stance and found that in the first few hours after birth foals are unstable and have a poor postural control. In the first week of their lives this improves significantly and keeps improving the following until 2-3 months of age as muscular and neuromotor control develops. In the first week foals are stilted and hypermetric but they are getting better coordinated within a few days after birth due to the development of the nervous and musculoskeletal systems. (Nauwelaerts et al., 2013).

In humans it takes a year before children can stand independently. From 4 to 7 years of age children adapt to a more adaptable sensory feedback strategy. (Nauwelaerts et al., 2013)

Back et al., (1995) researched to see if foal kinematics can predict its performance on adult age. There was found that the swing duration, the maximal angle of protraction-retraction and the maximal flexion of the tarsal joint were similar and very well correlated between foals and adults. In the study foals were followed from 4 months to 26 months of age. In this period the kinematic variables hardly changed so it can be concluded that the kinematic variables already mature at young age. At an age of 4 months the adult locomotor variables can be quantitatively predicted. (Back et al., 1995).

Training of foals can influence their coordination. Back et al., (1999) researched training regimes on the development of the coordination of foals. There was found that training could influence the coordination and the foals that were kept at box-rest had a poorer and inefficient coordination in comparison to the trained and pasture group. In the trained group mainly hind limbs were trained and only at gallop, and in the pasture group forelimbs and hind limbs were trained in all gaits. The trained group almost moved the similar as the box-rest group.

The first few months after birth isn't investigated yet dynamically. Nauwelaerts et al., (2013) investigated foals after birth in stance. Back et al., (1995) researched foals from 4 months of age but Lecocq et al., (2008) describes that foals already can have OC lesions 2 days after birth. So it is important to investigate the first weeks after birth, how a foal walks in these first weeks, how long they are unstable and how this develops.

The aim of this study was to analyze the pressure plate data that occur during walking and trotting in foals and map the instability of foals after birth.
To do this a portable pressure plate was used. The pressure plate gives information over the pressure distribution in different regions of the hoof during a complete stance period of the hoof. (Oosterlinck et al., 2010)
Meijer et al. (a) (2014) followed growing pigs from 5 weeks of age during 10 weeks and weekly measurements were performed. There was found that a higher speed leads to a higher peak vertical force, a higher load rate and a higher peak vertical pressure. Therefore, it is important that there is speed limit and the foals walks in a steady state. There was also found that there was a significant difference between sessions which was described to the growth and conformation changes of the growing pigs. This means that the forces change when the pig gets older. This may indicate that this will also be the case in this experiment.
Also due to the fact that foals improve their postural control and aren't hypermetric anymore after 1 week it can be expected that after two weeks foals walk and trot more like an adult horse.
The weight distribution of adult horses is 60 percent on the forelimbs (30 percent on the right- and 30 percent on the left forelimb) and 40 percent on the hind limbs (20 percent on the right- and 20 percent on the left hind limb). (Back et al., 2007). When this connection is disturbed than the horse is unstable. So for the foals there can be looked at the weight distribution and also the connections between the peak vertical force, peak vertical pressure and vertical impulse of the different limbs because this should also be well divided.
It is hypothesized that after two weeks foals are more stable because Nauwelaerts et al., (2013) discovered that the stability of foals in stance improved in their first week and according to Back et al., (1995) the 'kinematic fingerprint' of a foal is already there at an age of 4 months.

Material and methods
The study was approved by the Ethical Committee of Utrecht University.

Foals
Twelve foals were studied, all born and raised in 2014 in the Netherlands at a breeding stable. The foals have been followed during 6 weeks from the day they were born. The measurements were performed at the stable. The experimental group (n=12) is based on literature research: Oosterlinck et al. (2010) used 6 foals, Oosterlinck et al. (2011) used 11 ponies, Meijer et al. (a) (2014) used 10 pigs. The experimental group consisted of 5 mares and 7 stallions. The foals are KWPN foals breed for jumping. The foals were sound. Due

to the fact that there wasn't a scale available the weight of the foals was calculated before each measurement session with the formulas of Staniar et al., (2004).
The first measurement session with the pressure plate was taken in the first week after birth. After that there were measurement sessions at 1, 2, 4 and 6 weeks of age.
The foals were born in a stable. The first few days there was access to the pasture during the day depending on the weather and a few days later during the days as well as during the nights. The foals and dams are kept together in the pasture.

Measurement system and data collection
The pressure plate was a Footscan® 3D Gait Scientific 2 m system (RSscan International, Olen, Belgium) with an active sensor surface of 1.95 m × 0.32 m containing 16384 sensors (2.6 sensors per cm^2), with a sensitivity of 0.27-127 n/cm^2 and a measuring frequency of 126 Hz. The pressure plate was connected to a laptop with dedicated software (Footscan Scientific Gait 7 gait 2nd generation, number 799, RSscan International, Olen, Belgium). Calibration of the pressure mat was performed according to the manufacturer's instructions.
The setting was in an empty stable complex so there was no influence from other horses. The pressure plate was laid down on the ground. Next to the pressure plate 2 wooden planks were put with the same height as the pressure plate to broaden the walk way. The cable of the pressure plate was put under the wooden plank at the right in which a space was made for it. At the beginning and end a wooden plank with a slope was put down so the foals wouldn't have to step on a height. These planks were attached to the two wooden planks with tape. The hole walkway was covered with a 5 mm thick rubber mat. The location of the pressure plate under the rubber mat was cleared by put down tape at the rubber mat on the corners of the pressure plate.
The foals were guided by hand. The mare was also guided by hand and walked next to the plate so the foal would follow the mare. If the foals were too unstable or scared to walk by hand they were embraced by front and hind and were guided over the plate.
A trial was considered valid if complete hoof prints of a forelimb, hind limb or both were recorded. Also the foal had to walk in a steady velocity, straight and in a normal way on the plate. If a foal stumbled, was head shaking or was doing something else on the plate which could influence the measurement that trial was considered not valid.
Based on literature research each session 5 valid trials were necessary. Oosterlinck et al. (2011) used 5 valid trails, Meijer et al. (2014) used 3 valid trails and Oosterlinck et al. (2010) used valid 5 trails. Due to the fact that foals are more unstable and more difficult to handle because they aren't trained and handled before 5 valid trails were chosen. To get 5 valid trails in walk and trot sometimes 20 or more runs were necessary. Therefore more valid trails weren't possible due to the fact that foals get tired after some runs and this influence the data. There had to be found a balance between accuracy and repeatability.
A session was taking as long as necessary to have 5 valid trails. So on location there was a selection between the valid trails that were saved and the non-valid trails that weren't saved. Al trials were filmed with a camera for later determination of which print is which hoof and to see of something went wrong during the trail, for example that the foal stumbled just before it steps on the plate.

Data processing
Hoof strikes of 5 valid runs were manually assigned to left fore (LF), right fore (RF), left hind (LH) and right hind (RH) limb. Hoofs were selected based on a few criteria: the hoof has to be completely on the plate, the whole stance phase has to be recorded and the foal had to walk or trot.
Also the video's of each trial were evaluated to see whether a foal stumbled just before it steps on the plate or if it trotted the first step instead of walked or galloped instead of trotted. Such hoofs were excluded. Next to that the video's were analyzed to give a description of the foal's locomotion.
Also pictures were taken from every foal before every measurement session so it was

possible to look back at the conformation of the foals at that moment.

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

After determining the hoofs the results were saved and exported to Microsoft Excel.
From every measurement session the average for each hoof was calculated. With these average the peak vertical force (N) (nPVF), the vertical impulse (Ns) (nVI) and the peak vertical pressure (N/cm^2) (nPVP) were normalized for bodyweight. The peak vertical force and the vertical impulse were also represented as percent of bodyweight. The peak vertical force was used to calculate the bodyweight distribution over the four legs using the formula from Meijer et al.(b) (2014).
Forelimb and hind limb asymmetry indices (ASI) of all variables were calculated using the formula from Meijer et al., (b) (2014). Also the ASI's were calculated using the formula from Oosterlinck et al., (2011) so it is possible to compare them.
Based on literature the nPVF, nPVP and the nVI were used to compare with adult horses in the study of Oosterlinck et al. (2010).
From every measurement the velocity was determined because the velocity influence the nPVF and the nPVP (Meijer et al., (b) 2014).
For every week and for every foal the average velocity was calculated with the RsScan program. To get the velocity one left front limb and one right front limb was assigned and the velocity was calculated by the program.
At the end for all variables the average of all foals was calculated to determine the average KWPN foal.

Statistical analysis
A linear Mixed Effects Model with foals as random component was used to evaluate associations (1) between gait, left and right forelimb and hind limb and PVF, PVP and VI, (2) gait, forelimb and hind limb PVF, PVP and VI symmetry ratios. To achieve a normal distribution of the outcome variables, a logarithmic transformation of PVF, PVP and VI data was performed.
For further statistical analysis the absolute value of the symmetry ratios was used, thereby removing the distinction between left- or right-sided asymmetry. To achieve a normal distribution of the outcome variables, a square root transformation of the symmetry ratios of PVF, PVP and VI data was performed.
Data were collected and prepared for statistical analysis using Microsoft Excel software. Statistical analysis was performed using SPSS statistics 22.
Also a Bonferroni correction was performed.

Results
One foal died of septic arthritis and therefore was excluded from the research. Another foal had short tendons and due to that had a steep stand. Because this foal doesn't represent the average KWPN foal it was excluded from the research. Another foal was less cooperative and due to that was embraced until the 6 weeks. Because the foal wasn't walking on its own and so didn't represent the average KWPN foal this foal was also excluded from the results.
The average foal was calculated with nine foals, 4 mares and 5 stallions.
In the case of foal 1 and 2 the first week measurement went wrong because the pressure plate was giving off values. These 2 foals are kept out of the result of the first week measurement. In all the other weeks they are included in the results.

Hoof print development

The development of the hoof prints is shown in figure 3. At week 0 and week 1 almost the whole hoof touches the ground but just a little part exactly bares the foal which is visible due to the fact that the most of the hoof is green, which means there is just a little pressure and a small part is orange till red which means there is a lot of pressure.

During the weeks the wall of the hoof is more visible as the orange-red zone and the hoof print at week 6 starts more to look like of that of an adult horse. (Oosterlinck et al., 2013)

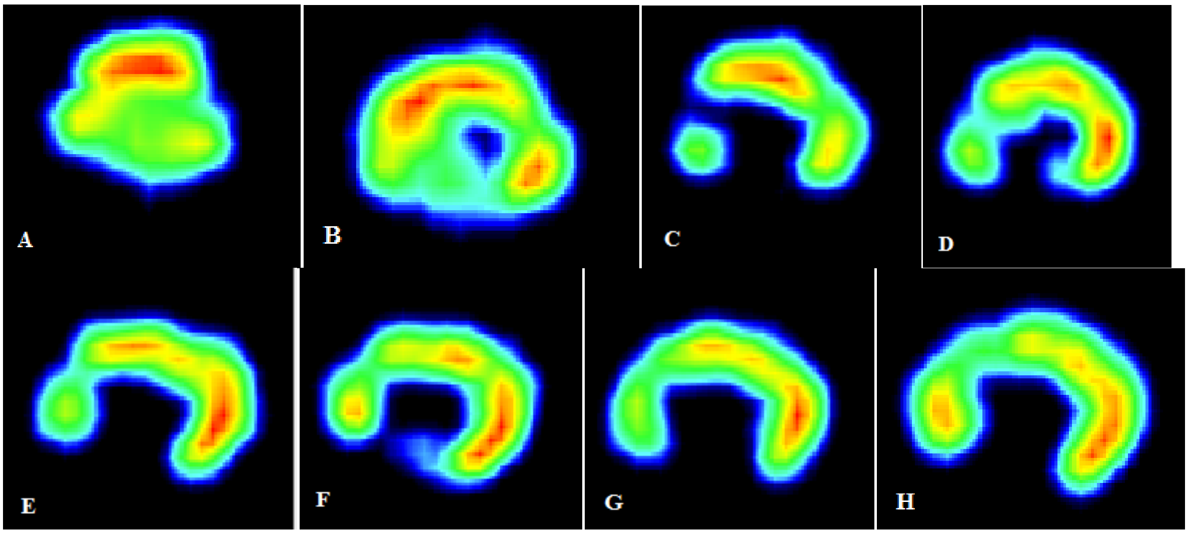

Figure 2: Development of the hoof prints during the 6 weeks of the right front limb of one foal. A: Week 0, walk. B: Week 1, walk. C: Week 2, walk. D: Week 2, trot. E: Week 4, walk. F: Week 4, trot. G: Week 6, walk. H: Week 6, trot. At week 2 there is visible that the foal had a shear in the hoof wall.

Asymmetry indices

In figure 3, 4 and 5 the development of the ASI from the nPVF, nPVP and nVI during walk and trot during 6 weeks is visible. As is visible there is no connection between weeks. The nPVF and nPVP during walk are connected and show the same line. Fore and hind are compared for the nPVF, nPVP and nVI and also fore and hind between nPVF, nPVP and nVI are compared. Sometimes significant correlation could be found but the week after or during trot instead of during walk this significant correlation couldn't be found. There is no connection visible weather a comparison is significant correlated or not.

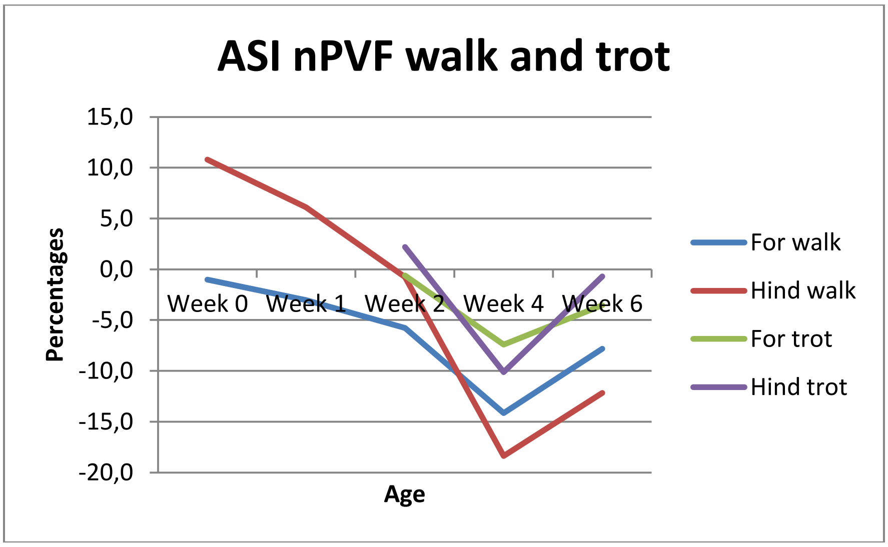

Figure 3: The development of the ASI nPVF during walk and trot during 6 weeks.

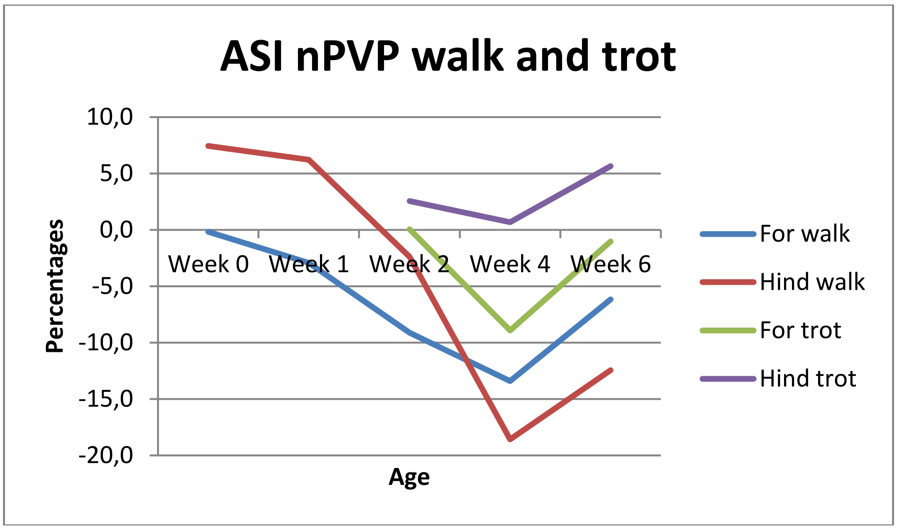

Figure 4: The development of the ASI nPVP during walk and trot during 6 weeks.

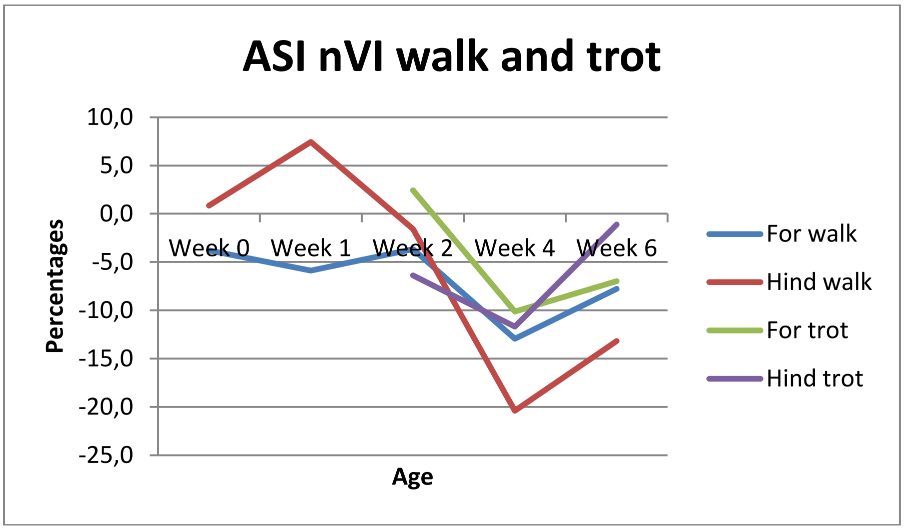

Figure 5: The development of the ASI nVI during walk and trot during 6 weeks.

Peak vertical force

In figure 6 the development of the nPVF during walk is visible. In attachment 3 the mean ±SD is given for al weeks for the forelimbs and hind limbs during walk and trot. The nPVF is higher in the forelimbs than in the hind limbs during walk and trot. During walk there is a little decline visible in week 1 in the forelimbs, after that the nPVF increases. By comparison of all 4 limbs sometimes a significant correlation could be found but in other weeks this significant correlation could not be present. During trot the most comparisons are significant correlated during the weeks. There is no connection visible weather a comparison is significant correlated or not during walk.

Peak vertical pressure

In figure 7 the development of the nPVP during walk is visible. In attachment 3 the mean ±SD is given for al weeks for the forelimbs and hind limbs during walk and trot. The nPVP is higher in the forelimbs than in the hind limbs during walk and trot. During walk the nPVP declines during the 6 weeks. During trot the nPVP remain the same. By comparison of all 4 limbs sometimes a significant correlation could be found but in other weeks this significant correlation could not be present. During trot the most comparisons are significant correlated during the weeks There is no connection visible weather a comparison is significant correlated or not.

Vertical impulse

In figure 8 the development of the nVI during walk is visible. In attachment 3 the mean ±SD is given for al weeks for the forelimbs and hind limbs during walk and trot.

The nVI is higher in the forelimbs than in the hind limbs during walk and trot. During walk there is a little decline visible in week 1 in the forelimbs, after that the nVI increases. During trot the nVI increases over during the 6 weeks. By comparison of all 4 limbs sometimes a significant correlation could be found but in other weeks this significant correlation could not be present. During trot the most comparisons are significant correlated during the weeks There is no connection visible weather a comparison is significant correlated or not.

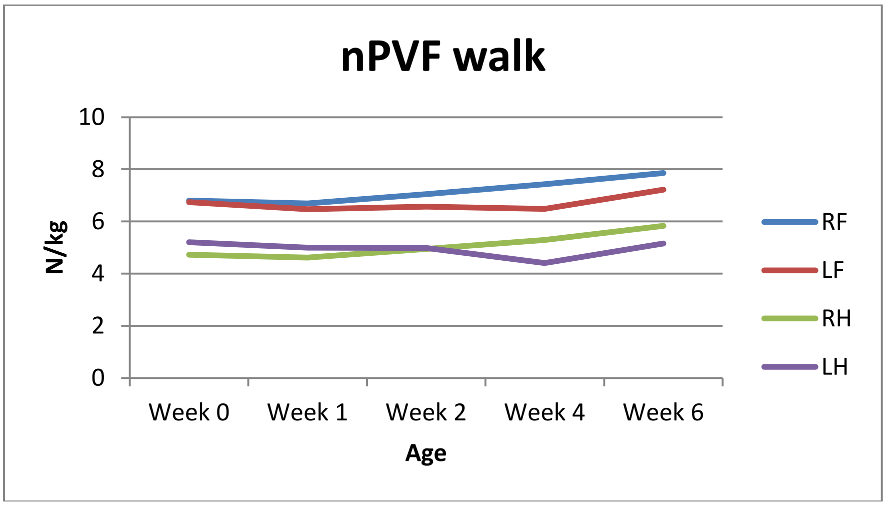

Figure 6: The development of the nPVF during walk during 6 weeks.

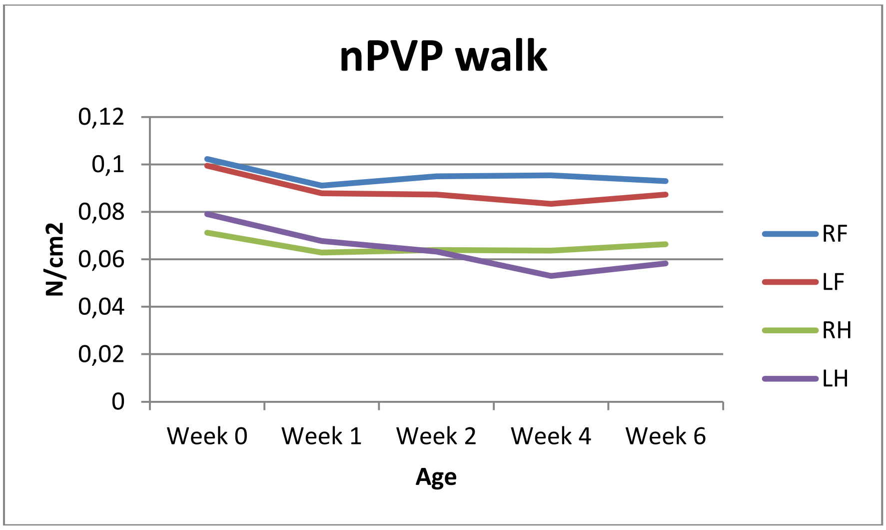

Figure 7: The development of the nPVP during walk during 6 weeks.

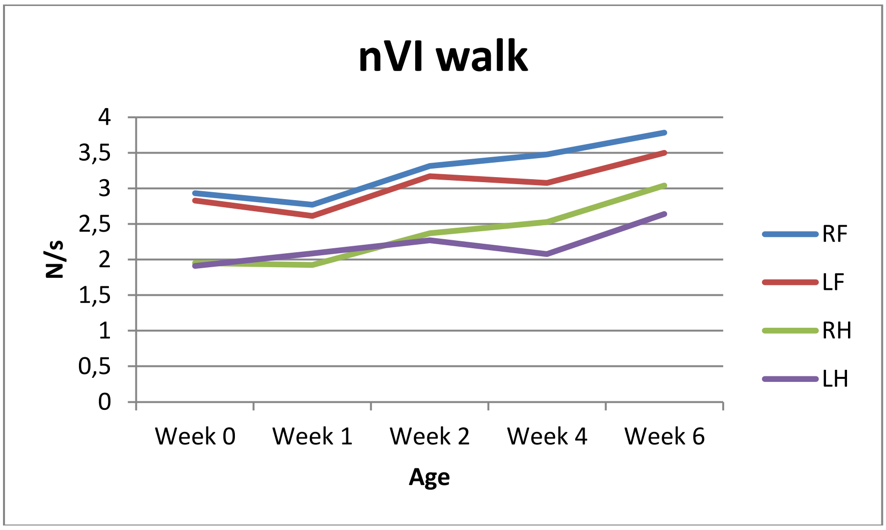

Figure 8: The development of the nVI during walk during 6 weeks.

Growth of the foals
At week 0 the mean weight (SD) was 58,6 kg (4,9) and the mean height at the withers (SD) was 102,9 cm (2,8), at week 1 the mean weight (SD) was 69,7 kg (6,3) and the mean height at the withers (SD) was 106,1 cm (2), at week 2 the mean weight (SD) was 78,1 kg (7) and the mean height at the withers (SD) was 109,4 cm (2,3), at week 4 the mean weight (SD) was 96,6 kg (10,1) and the mean height at the withers (SD) was 114,1 cm (2,5) and at week 6 the mean weight (SD) was 144 kg (12,2) and the mean height at the withers (SD) was 116,3 cm (3).

Videos
The videos show that the foals are hypermetric at the first measurement session at week 0 and that the foals aren't hypermetric anymore at the measurement session at week 1. Furthermore it is visible that some foals have x-legs or a week stand in the hind. Also there is visible that the foals are unstable at the first measurement and are not very coordinated when they are walking. This improves in the first week and after that.

Velocity
From every measurement the velocity was calculated. The average velocity of the walk was 1 m/s during 6 weeks and remained almost the same. The average velocity of the trot increased from 2 weeks until 6 weeks from 2,5m/s till 2,7 m/s. See attachment 1 for the development of the velocity during walk and trot.

Weight distribution
The weight distribution in the foals is around 60 percent in the front and 40 percent in the hind during walk. During the weeks this remains almost the same until 6 weeks of age during walk. Between the limbs there is a difference, one week the left forelimb carried more weight and the other week the right forelimb. See attachment 2 for the development of the weight distribution during walk of the different limbs.

Discussion

Pressure plate
This is the first study that describes the locomotion pattern of foals from birth to 6 weeks of age. To do this a pressure plate was used.
A research has already been done with a pressure plate with young animals. Meijer et al., (a) (2014) has used the pressure plate to determine if it can be used to detect lameness in pigs. There was found that the pressure plate allows recording contra-lateral and consecutive hoof strikes. ASI's of contra-lateral limbs could be excellent replicated over time. The pressure plate can distinguish between simultaneous impacts of different limbs and can measure kinetic and spatiotemporal data of simultaneous and consecutive footfalls. (Meijer et al., (a) 2004). Also the pressure plate can be used to

evaluated temporal variables and kinetic symmetry ratios. With the pressure plate the pressure distribution of the different hoof regions during a complete stand phase can be measured. (Oosterlinkc et al., 2010)
Oosterlinck et al. (2010) compared a pressure plate with a force plate. There was found that the pressure plate gave lower maximal PVF value and that the PVF was later recorded in the stance phase than with the force plate. The differences between the PVF and VI symmetry ratios were relatively small. This means that for the absolute values the pressure plate is less accurate than the force plate but for the symmetry ratios there is no difference between the force plate and the pressure plate. It is possible to dynamically calibrate the pressure plate measurements with simultaneous force plate measurements. But this set-up is only possible in laboratory or clinics. The advantages of the pressure plate are that the pressure plate can analyze simultaneous hoof impacts and the force plate not and the pressure distribution of different hoof regions during a complete stance phase can be determined. With foals it is very difficult to get just one hoof on the plate because the stride length is shorter. So a pressure plate is preferred over a force plate when measuring with foals.(Oosterlinck et al., 2010)
Also in this research not the absolute values were used but the limbs were compared with each other and that outcome was used to determine of the foals stable or not. This comparisons are validated by Oosterlinck et al., (2010).

Foals
The difficulty with the foals was that some foals found it difficult to walk by hand especially the first weeks. To get valid measurement these foals had to be embraced. This influences the data because the foal doesn't walk independently and it can be that it more leans to the side of the handler. Furthermore the foals aren't trained like adult horses so controlling them and guiding them is somewhat difficult. Sometimes it was very difficult to get a foal trotting instead of walking or galloping but generally the walking and trotting with the foals over the pressure plate went very well.
Also the first foals were used as a pilot. After the first measurements with these foals there was more critical looked at runs of they were valid or not and more runs were done for each measurement session and for each foal to get enough valid runs and get 5 valid measurements for each hoof.
Due to these restrictions especially in the first week there were sometimes less than 5 measurements for each hoof.
Also the conformation of the foals has an influence on the results. Some foals were born with weak hind limbs which improved after a few days and some foals have more x-limbs than other foals. All of this influence the results. With adult horses there is less difference in conformation because they are already have grown and things like a weak stance at birth, x-limbs at birth etc. are already gone. So it is easier to have the same results between adult horses.

Velocity
Velocity significantly influences the nPVF and the nPVP. In dogs increased velocity is associated with a higher nPVF and a lower nVI in the hind limbs. In pigs this relationship for velocity and nVI wasn't found. Normally the decrease in stance time is relatively more pronounced with a higher speed than the increase in nPVF, this causes a decrease in nVI. For horses and dogs a higher speed increases the nPVF while the stance time decreases. (Meijer et al., (b) 2014)
The foals weren't always easy to handle the velocity couldn't always be exactly controlled. Therefore the velocity was calculated for every valid run and there was visible that the velocity during walk during the 6 weeks remained the same and during trot it increased when the foals get older as can be expected. The nPVF, nPVP and nVI are corrected for the increase in bodyweight but not for velocity. During walking the velocity remained the same so the increase of the nPVF and the nVI and the decrease of the nPVP can't be explained by a change of velocity.
During trot the velocity increases from 2,5 m/s until 2,7 m/s, both velocity's are comparable

with an adult horse and with an adult pony. (Oomen et al., 2013) (Oosterlinck et al., 2011). So during trot the increase of the nPVF and the nVI can be explained by the higher velocity but because they also increased during walk when there is no change in velocity the change during trot can't be only explained by the increase of velocity and because there is corrected for bodyweight this also doesn't explain the increase of nPVF and nVI. Also the velocity only increased with 0,2 m/s during the 6 weeks. Meijer et al., (b) (2014) found that an increase of 1 m/s in speed caused a increase of 0,31 N/kg nPVF in the pigs. The increase of nPVF during trot is for the right front limb from 10,4 N/kg till 12,6 N/kg so the increase of 0,2 m/s during 6 weeks during trot can't explain the increase of nPVF.

Stability of the foals

To determine of the foals get stable during the first 6 weeks after birth the weight distribution, the nPVF, nPVP, nVI and the ASI's were used.

In foals the weight distribution was 60 percent on the front and 40 percent on the hind. This remained the same during first 6 weeks of their lives. Back et al., (2007) researched the differences in limb loading in Warmblood horses and Quarter horses. There was found that Warmblood horses have a bigger front and have a weight distribution from around 60 percent on the front and 40 percent on the hind, almost the same as the foals. Quarter horses have a bigger hind than Warmblood horses and due to that fact their weight distribution was around 50 percent on the front and 50 percent on the hind.

The foals also have a bigger front, which is similar to an adult horse. Also their weight distribution is after birth the same as in an adult horse. So in that way foals are comparable with adult horses.

But the distribution between right fore and left fore isn't always 30 and 30 percent. This difference every week, one week left fore carried more and another week right fore. This is also the case in the hind limbs. This means that the foals aren't well balanced as adult horses and that they are still looking for a balanced weight distribution.

This is also the case for the nPVF, nPVP and nVI. Also here the right fore and left fore and the right hind and left hind distribution difference between the limbs and the distribution is also different between the weeks. This is the case until 6 weeks. This shows that the foals still aren't stable at week 6.

If there is looked at the development of the nPVF during the 6 weeks period, there is a decline in week 1 and after that an increase until week 6. Nauwelaerts et al., (2013) found that foals are hypermetric in the first days after birth. Also on the videos that were taking during the measurement sessions there is visible that the foals are hypermetric and unstable at week 0 and that they aren't hypermetric anymore at week 1. That the foals are hypermetric at week 0 explains the decline in the nPVF value at week 1. Because of the fact that they are hypermetric they put their hoofs on the ground with more velocity and strength so the nPVF is higher than in week 1 when they aren't hypermetric anymore.

If the nPVF of the foals is compared with adult horses, Oosterlinck et al., (2010) found with the pressure plate a value of 5,1 for the nPVF during walk and 7,8 for the nPVF during trot. The values of the foals are somewhat higher at week 0 and despite the decline at week 1 the values stay higher for the forelimbs during walk. During trot the nPVF is in week 2 higher and stays higher.

If one would calculate the absolute values from the PVF to the nPVF Oomen et al., (2012) found an nPVF of 6,65 during walk and an nPVF of 10,49 during trot for forelimbs for normal shoed hoofs. This is the same as our foals in week 0 and 1 in walk and week 2 in trot. After that the values in the foals are higher in walk and trot.

Compared with the pigs of Meijer et al., (b) (2014) there is the same development of the nPVF for forelimbs and hind limbs. The values are almost the same and in the pigs the values at week 10 are for front and hind higher than at week 1. So in growing animals the nPVF gets higher during the weeks despite it is corrected for bodyweight and in the foals the velocity increases not enough to explain this increase of nPVF. So it is more clear that the

increase of nPVF during the 6 weeks is caused by the change of locomotion pattern of the foals and that the foals put their limbs with more velocity and strength to the ground which than causes the increase of nPVF.
If there is looked at the nPVP, the nPVP declines during the 6 weeks during walk and during trot the nPVP stays the same. The nPVP is higher in the forelimbs than in the hind limbs during the 6 weeks. The decline during walk can be explained by looking at the development of the hoof prints during the 6 weeks. At the beginning there is just a small part that exactly bears and during the 6 weeks this part becomes bigger and the hoof wall becomes visible so there is more contact area and the nPVP declines.
If the nPVP is compared with adult horses and if one would calculate the absolute values from the PVP to the nPVP Oomen et al., (2012) found an nPVP of 0,082 during walk and an nPVF of 0,118 at trot for forelimbs for normal shoed hoofs. In the foals the values are higher during walk and trot but during walk at week 6 it is almost the same as in the adult horses.
In the pigs of Meijer et al., (b) (2014) this decline is also visible but the value is a lot higher than in the foals. This can be explained due to the fact that pigs are smaller animals who have smaller claws in comparison with their body conformation than foals but the development in growing pigs is the same as in growing foals.
In the foals the nVI increases during walk and trot in the 6 weeks. The nVI is higher in the forelimbs than in the hind limbs. The increase can be explained due to the fact that they are more stable and don't stand so long on 1 hoof anymore and during trot the velocity increases a little so the stand shorter on 1 hoof. Also here there is corrected for bodyweight so the increase of bodyweight can't explain the increase of nVI.
If the nVI is compared with that of adult horses, Oosterlinck et al., (2010) found a nVI of 2,9 during walk and 1,5 during trot in the forelimbs with the pressure plate. During walk this is comparable with week 0 and 1. After week 1 the nVI increases in the foals. During trot this is comparable with week 2 and 4 and in week 6 it increases in the foals.
If one would calculate the absolute values from the VI to the nVI Oomen et al., (2012) found an nVI of 3,6 during walk and an nVI of 2,06 during trot for forelimbs for normal shoed hoofs. If this is compared with the foals the nVI during walk and during trot is lower than in adult horses. During walk it is in week 4 and 6 the same as in adult horses and during trot it is almost the same as in week 6. So around week 6 the foals are beginning to look like an adult horse for the nVI.
In the pigs of Meijer et al., (b) (2014) the nVI also show an increase but the values are lower than in our foals. This can be explained due to the fact that the pigs are smaller than the foals and for that their velocity is lower.
The fact that the nPVF, nPVP and the nVI is higher in the forelimbs than in the hind limbs can be explained by the fact that the foals carry more weight on the front than on the hind.
If there is looked at the asymmetry indices all the ASI's didn't shown any linear or particularly development. There wasn't found any connection between weeks, gaits or foals. Also the correlation between the different ASI's changed every week and there wasn't found any connection between if a correlation was present or not. The ASI for the nPVF has as lowest value -18,4 and as highest value 6,1 at the hind during walk during the 6 weeks. The ASI can differ from -200 till 200 so there isn't a really great range between the 2 values but it shows that there is little asymmetry in all the weeks during walk and trot for nPVF, nPVP and nVI asymmetry indices.
During trot more comparisons were significant correlated, also between the weeks. This can be explained by the fact that the trot is a diagonal gait and therefore the limbs are more connected with each other than in walk which is a 4 tact gait.
When compared with the ASI's of Oosterlinck et al., (2011) there is visible that by the ponies the mean ASI's are 89 or above that and that the range isn't quit big during walk and trot. In the foals the mean ASI's change every week and can be as low as 82,8 in week 4 during walk for the nPVF in the hind limbs with a range from 58,7 till 96,3. Compared with the ponies the ASI's between foals differ a lot and also the development between the weeks

differ much and aren't right the same as in the ponies.
Of course ponies aren't the same as adult horses but Oosterlinck et al., (2011) found that the values of the nPVF, nPVP and nVI in ponies are somewhat higher than in adult horses but with the ASI calculation this difference is not significant.
Meijer et al., (b) (2014) researched pigs from 5 weeks of age and followed them for 10 weeks. These pigs are somewhat older at the beginning of the study but pigs are precocial but they don't have to walk, trot and gallop as much as foals in their first weeks so regardless of the difference in age they are comparable with each other. If there is looked at the nPVF ASI there was the lowest value -15 and the highest value 10 during the 10 weeks. So also here there aren't found really great differences but a little asymmetry is visible. So this is comparable with our foals.
If all those things are put together it is visible that foals aren't stable at week 6. Nauwelaerts et al., (2013) found that foals in stance are after 1 week significantly more stable than right after birth but the improvement continues until 2-3 months of age. So dynamically it can be suggested with that in mind and the fact that the foals in this research aren't stable at week 6, that it also takes 2-3 months or even longer before the foals are stable like an adult horse during walk and trot and that the development of the nervous and musculoskeletal systems takes longer than was thought.

Conclusion
The aim of this study was to analyze the pressure plate data that occur during walk and trot in foals and map the instability of foals after birth.
The ASI's shows us that foals are a lot longer unstable and a little bit asymmetrical than first thought. At 6 weeks of age foals are still unstable which is visible in the ASI changes and the distribution of the nPVF, nPVP and nVI between the limbs and the weight distribution. An explanation for this is that the development and maturation of the nervous and musculoskeletal systems needs more time than always thought. According to Wolff's law bone tissue adapt to the forces that occur on them. (Ruff et al., 2006). But because foals are precocial this adaption didn't found place in the first weeks after birth so the bone tissue isn't adapted to the forces that occur on them. But the nPVF, nPVP and nVI are at week 6 the same or almost the same as in an adult horse. So in 6 weeks of time joints of the foals have to deal with minimum training with forces that are the same in an adult horse. In this research the foals had to walk and trot in a straight line on a smooth surface and there can be expected that the foals are ready for this kind of forces but in the pasture they jump, run, glide out and the surface isn't always smooth so the forces that than occur can be much higher than now was measured with the pressure plate. Because the foals didn't have any training or adaptation to this kind of forces there is a lot more risk to the development of OC especially in the first weeks after birth when the foals are unstable. In week 0 they are hypermetric and the joints have to handle forces in different directions due to the instability, that there is a higher risk to the development of OC in the first week after birth. This can explain that there are OC lesions found as soon as 2 days after birth. (Lecocq et al., 2008). In the weeks after week 0 they are still unstable and so there is more risk to develop OC.
Further research is necessary to determine at what age foals aren't unstable anymore. And also research could be done to investigate if different training regimes like box-rest, only pasture or training by hand influence the age when foals are stable and if this influence the development of OC at a young age so OC can may be prevented by the right training regime.

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Attachment 1

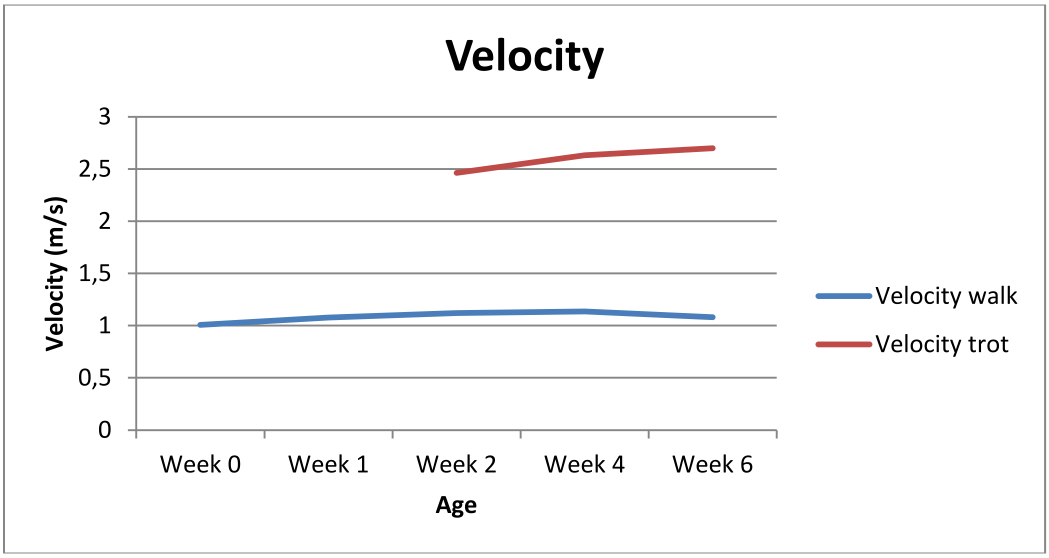

Figure 1: The velocity during walk and trot during the 6 weeks.

Attachment 2

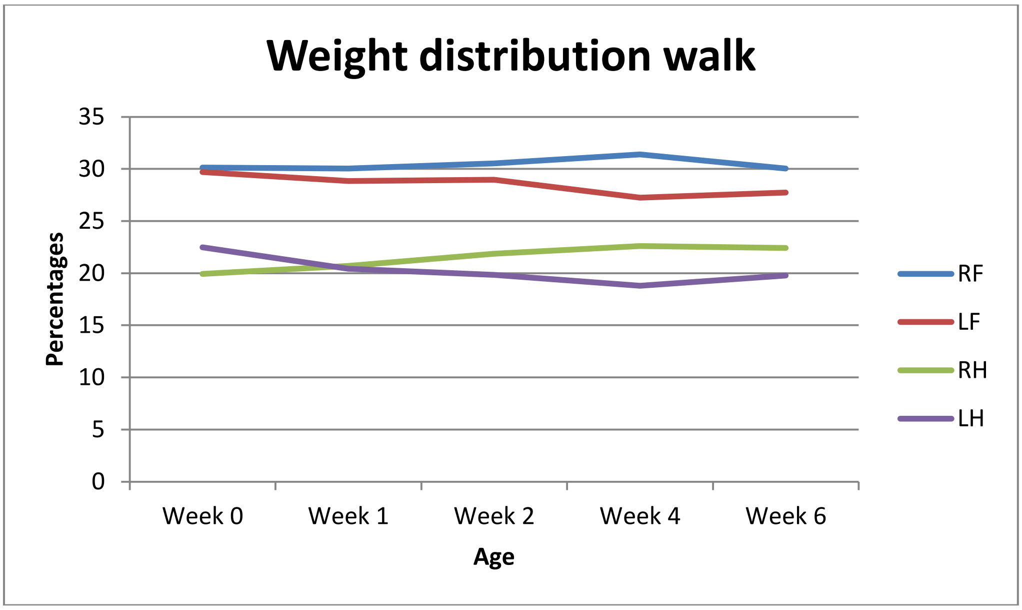

Figure 1: The weight distribution of the foals during walk compared with their age.

Attachment 3

Table 1: Mean ± SD of the Peak Vertical Pressure, the Peak Vertical Force and the Vertical Impulse of left and right for limbs and hind limbs at week 0 of the group of nine foals during walk.

Variables	Walk	
	Left	Right
Fore		
PVP (N/cm^2kg)	0,1 ± 0,02	0,1 ± 0,02
PVF (N/kg)	6,74 ± 1,26	6,8 ± 1,26
VI (Ns/kg)	2,83 ± 0,59	2,93 ± 0,56
Hind		
PVP (N/cm^2kg)	0,08 ± 0,03	0,07 ± 0,02
PVF (N/kg)	5,21 ± 1,28	4,73 ± 1,13
VI (Ns/kg)	1,91 ± 0,27	1,95 ± 0,46

Table 2: Mean ± SD of the Peak Vertical Pressure, the Peak Vertical Force and the Vertical Impulse of left and right for limbs and hind limbs at week 1 of the group of seven foals during walk.

Variables	Walk	
	Left	Right
Fore		
PVP (N/cm^2kg)	0,09 ± 0,03	0,09 ± 0,03
PVF (N/kg)	6,47 ± 1,45	6,69 ± 1,6
VI (Ns/kg)	2,61 ± 0,33	2,77 ± 0,31
Hind		
PVP (N/cm^2kg)	0,07 ± 0,02	0,06 ± 0,01
PVF (N/kg)	5 ± 1,34	4,62 ± 0,78
VI (Ns/kg)	2,09 ± 0,48	1,92 ± 0,34

Table 3: Mean ± SD of the Peak Vertical Pressure, the Peak Vertical Force and the Vertical Impulse of left and right for limbs and hind limbs at week 2 of the group of nine foals during walk and trot.

Variables	Walk		Trot	
	Left	Right	Left	Right
Fore				
PVP (N/cm^2kg)	0,09 ± 0,02	0,1 ± 0,02	0,13 ± 0,03	0,13 ± 0,03
PVF (N/kg)	6,57 ± 1,23	7,05 ± 1,75	10,23 ± 1,6	10,45 ± 2,46
VI (Ns/kg)	3,17 ± 0,79	3,31 ± 0,84	1,52 ± 0,27	1,52 ± 0,23
Hind				
PVP (N/cm^2kg)	0,06 ± 0,01	0,06 ± 0,01	0,11 ± 0,03	0,11 ± 0,02
PVF (N/kg)	4,98 ± 0,85	4,94 ± 0,69	9,02 ± 1,9	8,78 ± 1,65
VI (Ns/kg)	2,27 ± 0,26	2,37 ± 0,37	1,28 ± 0,29	1,35 ± 0,28

Table 4: Mean ± SD of the Peak Vertical Pressure, the Peak Vertical Force and the Vertical Impulse of left and right for limbs and hind limbs at week 4 of the group of nine foals during walk and trot.

Variables	Walk		Trot	
	Left	Right	Left	Right
Fore				
PVP (N/cm^2kg)	0,08 ± 0,02	0,1 ± 0,02	0,12 ± 0,04	0,13 ± 0,05
PVF (N/kg)	6,48 ± 1,4	7,43 ± 1,38	10,31 ± 2,82	11,27 ± 3,78
VI (Ns/kg)	3,07 ± 0,72	3,48 ± 0,66	1,5 ± 0,36	1,71 ± 0,61
Hind				
PVP (N/cm^2kg)	0,05 ± 0,01	0,06 ± 0,01	0,11 ± 0,04	0,1 ± 0,03
PVF (N/kg)	4,41 ± 0,68	5,29 ± 0,63	8,31 ± 1,66	9,22 ± 2,02
VI (Ns/kg)	2,08 ± 0,38	2,53 ± 0,32	1,19 ± 0,26	1,34 ± 0,31

Table 5: Mean ± SD of the Peak Vertical Pressure, the Peak Vertical Force and the Vertical Impulse of left and right for limbs and hind limbs at week 6 of the group of nine foals during walk and trot.

Variables	Walk		Trot	
	Left	Right	Left	Right
Fore				
PVP (N/cm^2kg)	0,09 ± 0,02	0,09 ± 0,03	0,14 ± 0,04	0,14 ± 0,05
PVF (N/kg)	7,21 ± 1,09	7,86 ± 1,59	12,13 ± 3,06	12,64 ± 3,52
VI (Ns/kg)	3,5 ± 0,63	3,78 ± 0,62	1,8 ± 0,44	1,93 ± 0,49
Hind				
PVP (N/cm^2kg)	0,06 ± 0,01	0,06 ± 0,02	0,11 ± 0,03	0,11 ± 0,03
PVF (N/kg)	5,15 ± 0,93	5,84 ± 1,09	10,19 ± 2,48	10,2 ± 2,2
VI (Ns/kg)	2,64 ± 0,4	3,04 ± 0,6	1,47 ± 0,35	1,48 ± 0,32