Pferdeheilkunde 22 (2006) 5 (September/Oktober) 592-596

# Ground surface and poly-urethane (PU) filling alter the pressure distribution pattern in square standing horses

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**Summary**

This study was conducted to evaluate the effects of Pour-In, Poly-Urethane (PIPU) products on pressure distribution underneath the hoof and shoe, as many farriers report the successful use of these products in cases where horses suffer from a reduced bearing surface. The tested hypotheses were that shoes filled with PU would increase the bearing surface and thus provide lower mean pressures and that these effects would be the same despite the deformability capacities of the surface the horses stood on. Data were collected from 6 clinically sound Warmblood horses while standing on top of a pressure/force measuring device. The horses had been shod at random with regular steel shoes and the same shoes filled with PU. Data were collected on 2 different ground surfaces, a firm, rubber surface, and a deformable, sand surface. With PU filling the bearing surface underneath the shoe did not increase significantly, nor did the mean pressure decrease. On a firm surface the pressure distribution pattern is similar in both shoeing conditions. On a deformable surface the shoe filled with PU has a significantly different ($p<0.05$) pressure distribution pattern and mainly the sole and the frog became loaded. With the use of PIPU the pressure distribution pattern underneath the shoe and hoof , is altered. These findings will aid to explain why so many farriers use PU products successfully in horses with a defect in their hoof wall or loss of bearing surface. On the other hand there seems no reason to shoe sound horses without problems in their feet with PIPU to provide 'total foot support'. It might even have negative effects on horses with normal healthy feet which are trained on a deformable, sand surface, since normal loading of the hoof should occur mainly on the hoof wall instead of the frog and sole being the only weight bearing structures.

**Keywords**: frog, sole support, hoofwall defect, orthopedic shoeing, pressure distribution.

**Bodenbeschaffenheit und Polyurethane (PU)-Hufpolster verändern das Druckverteilungsmuster am stehenden Pferd**

Viele Hufschmiede berichten über den erfolgreichen Einsatz von Polyurethan (PU)-Hufpolstern bei Pferden, die an unzureichender Tragfläche leiden. Ziel der Studie war die Untersuchung der Auswirkungen dieser Produkte auf die Druckverteilung unter Huf und Eisen. Die Hypothese war, dass Beschläge, die mit Polyurethan aufgefüllt wurden, die Tragfläche vergrößern und so zu geringeren mittleren Drücken führen, und dass dieser Effekt vergelichbar dem von verformbarem Boden ist, auf dem das Pferd steht. Für die Untersuchung standen 6 gesunde Warmblutpferde zur Verfügung, die während der Messung auf einer Druckmessplatte standen. Die Pferde waren zufallsverteilt mit einem normalen Stahleisen mit und ohne PU-Einlage beschlagen. Die Messungen wurden sowohl auf harten Gummiboden als auch auf verformbarem Sandboden durchgeführt. Die PU-Füllung des Beschlag erhöhte die Tragfläche unter dem Huf nicht significant. Auch verminderte sich der mittlere Druck nicht. Auf harter Bodenfläche ist die Druckverteilung bei beiden Beschlägen gleich. Auf Sand zeigte der Beschlag mit PU-Füllung ein signifikant ($p>o,05$) abweichendes Druckverteilungsmuster, wobei Sohle und Strahl mehr belastet wurden. Durch die Anwendung von PU-Füllungen wird das Druckverteilungsmuster unter Huf und Eisen demnach verändert. Das Ergebnis hilft bei der Erklärung, warum so viele Hufschmiede diese Produkte bei Pferden mit Horndefekten und mangelhafter Tragfläche erfolgreich einsetzen. Andererseits gibt es keinen grund, gesunde Pferde ohne Hufprobleme mit Polyurethan-Einlagen zu beschlagen, um Ihnen eine "bestmögliche Unterstützung zu gewähren". Für Pferde mit gesunden Hufen, die auf Sandboden trainiert werden, könnten PU-Einlagen möglicherweise von Nachteil sein, weil die beim Fußen die Hufwand den Druck aufnehmen sollsein soll und nicht Sohle und Strahl, wenn diese die allein belasteten Strukturen sind.

**Schlüsselwörter**: Strahl, Sohle, Hufpolster, Hufwanddefekt, Hufwand, orthopädischer Beschlag, Druckverteilung

## Introduction

Today´s sport horses are top athletes who have to jump over high fences and dance to music in demanding competitions. With these high expectations of the equine athletes, people try to improve performances and prevent injuries by providing optimal individual guidance in training, housing and feeding but also in shoeing. All these things together make today's performance horse a valuable competitor. Still many injuries occur in the equine athlete, with the highest prevalence of distal front limb injuries such as tendonitis, podotrochleosis and arthritis/ arthrosis with often a poor prognosis and/ or a long period of rehabilitation (*Kaneene* et al. 1997).

Since domestication of the horse, man developed horseshoes to protect the hooves from excessive wear. In contrast to the development of sport shoes for human athletes, where every sport has its specific shoes, many horses still have to wear shoes similar to those made hundreds of years ago. With correct trimming and shoeing it is possible to improve the ease of movement and to lower peak loading during breakover and thus horses can be protected from overload injuries of the distal limb (*van Heel* et al. 2006). All types of alternative shoeing are designed to treat or prevent limb an hoof injuries or optimise performance. However, their use and function are highly subjective and often lack scientific backing. Primary goals in shoeing can be increase of shock absorbance, reduction of excessive strain on the joints, increase of the bearing surface to reduce maximum pressures on the hoofwall or decrease peak pressures. To improve shock absorption and decrease the load on the hoofwall many materials can be used between the hoof and the shoe such as leather, plastic soles and silicones. Although these materials lower the accelerations at hoof wall level, the beneficial effects of these interventions are hardly measurable at the level of the distal joints (*Willemen* et al. 1999).

The hoof wall is the weight bearing structure of the hoof (*Stashak* 2002). When the horse moves the hoofmechanism and the especially the frog is believed to be important to absorb shock and load. Whether or not the frog should be a weight bearing, loaded structure while moving is a matter of dispute, but as a result of shoeing the hoof and the frog are lifted from the ground. In some cases farriers use a poly-urethane (PU) in shod horses to increase contact surface. It has clinically proven its usefulness in horses with hoofwall defects, and other problems where more support or damping seems necessary. Maybe this product can benefit horses without hoof problems as well and provide more support by increasing the bearing surface. Therefore we initiated this study to objectively evaluate the supporting effects of a PU filling on the pressure distribution pattern underneath the shoe. The following three hypotheses were tested:

1. Filling shoes with PU will increase the bearing surface underneath the shoe because not only the shoe, but the frog and the sole will be loaded as well.
2. When the bearing surface is increased the pressure distribution will be more equal and thus the shoes filled with PU will have lower mean and peak pressures.
3. The supporting effect of a PU filling is similar on different ground surfaces.

## Materials and methods

This study was performed in 6 clinically sound, adult Dutch Warmblood horses (5 mares, 1 gelding), with an average age of 10 ± 2.4 years. Four different interventions were performed to test the effect of a PU filling on the bearing surface, the mean pressures, the peak pressures and the pressure distribution pattern underneath the hoof.

The horses were shod with a 22/8 LB (Mustad) shoe. To fill the shoe Pour-In, Poly-Urethane (PIPU) hoofpad (Equibuild®, Vettec) was used. This product provides, when hardened, a firm supportive structure. To apply the PU the foot was lifted and held horizontal and the ground surface of the shoe was covered with a plastic pad. The hoof was filled and placed back at the ground to harden. After a few minutes the plastic pad was removed and the hoof was completely filled, up to 2-3 millimeters from ground level (Fig. 1). Tests were performed at random with or without PU filling. Both shoeing conditions were tested on a firm, rubber surface and on a deformable, sand surface. The firm surface existed of a rubber mat covering the measurement equipment, the deformable surface existed of the same rubber mat covered with a 2.5 – 3 cm thick layer of loose sand. After each measurement the sand layer was straightened, and the height of the layer was chekked with a marked pole. Data were captured using a combination of measuring systems, containing a Kistler® force plate and an RSfootscan® plate. The Rsfootscan (RsScan International) is a pressure measurement plate which contains pressure sensitive polymer sensors (0.39 $cm^2$). The measuring surface is 976 mm ¥ 325 mm containing 8192 conductive

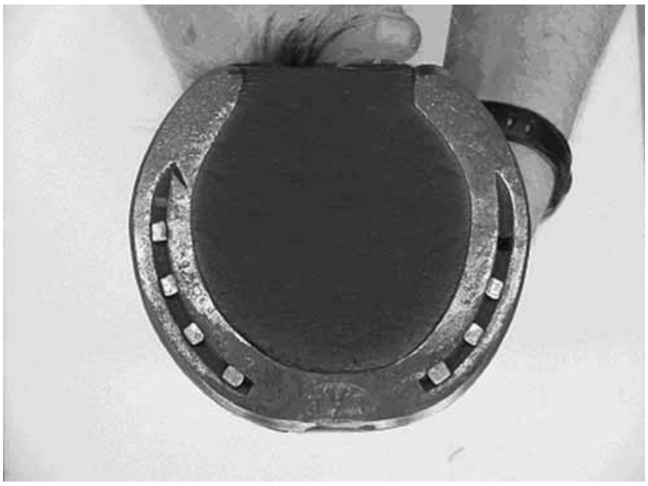

**Fig 1** A left front foot shod with a standard shoe a filled with polyurethane (PU).
*Linker Vorderhuf mit Standardeisen und Polyurethan-Einlage (PU).*

sensors. The Footscan plate was imbedded in an aluminum plate on top of a Kistler Forceplate which dynamically calibrated the RSfootscan plate (*van Heel* et al. 2004). The sum of the vertical forces applied to all loaded sensors of the pressure plate was adjusted to the vertical component of the ground reaction force of the force plate. The threshold level of the Rsfootscan was 3 $N/cm^2$ to discard noise-related information. Pressures above 3 $N/cm^2$ were registered and colorcoded with one of the 256 available colors between blue (threshold) and red (maximum). The measurement frequency was 240 Hz and a total of 500 samples were collected. The mean values of 500 samples were used.

The horses were placed on top of the pressure/ force measuring device with both their front limbs. All Measurements were taken in a standing position; a measurement was valid when the horse stood square, loaded all four limbs and looked forward (Fig. 2). Between measurements the horses had to step off the measurement system. Five valid measurements of both front limbs were collected with both shoeing types and on both ground surfaces.

The data were analysed in the RsFootscan software and in Microsoft Excel. The bearing surface ($cm^2$), the mean pressures ($N/cm^2$) and the peak pressures (N) were determined for both feet in each measurement. The mean value from 5 valid measurements was used to further analyse the data. Data were tested for significance with analysis of variance (ANOVA). A General linear model (GLM) repeated measurements test with if applicable a least significance difference (LSD) post-hoc test were performed. The pressure distribution pattern was classified into three categories:

1 = only pressure on the hoof wall
2 = only pressure distribution over the sole and frog
3 = a combination of both. The classification was made in

the RsScan software, where one operator scored each measurement as 1, 2 or 3. All measurements were used in this analysis, in each measurement cycle there was a frequency of 60 (12 feet measured 5 times). The load distribution pattern was tested with a chi-square test. An outcome with $p<0.05$ was considered significant.

**Fig 2** Picture of a valid measurement of both front feet on the firm surface. The horse is standing square and looking straight forward.
*Messung beider Vorderhufe auf harten Untergrund. Das Pferd steht rechtwinklig und richtet den Kopf geradeaus.*

## Results

*Bearing surface*

There is a significant increase in bearing surface when the horse is measured on a deformable surface compared to the firm surface, relatively seen there is an increase of 46.8% in shoes and 29,5% in the shoes filled with the PU. There is also a significant difference in bearing surface between the shoeing conditions on a sand surface; the shoe had a larger bearing surface compared to the shoe filled with PU (Table 1).

**Table 1** The mean loaded surface (cm2) in each shoeing and surface condition in 12 feet of 6 horses. A different symbol means a significant ($p < 0.05$) difference between interventions.
*Mittlere Tragfläche (cm2) für jeden Beschlag und Bodenbeschaffenheit für 12 Hufe von 6 Pferden. Ein unterschiedliches Symbol weist auf einen signifikanten Unterschied zwischen den Beschlägen hin.*

| | Firm surface mean (sd) | Deformable surface mean (sd) |
|---|---|---|
| Shoe ($cm^2$) | 130.1 (20.5)$^a$ | 191.1 (32.7)$^b$ |
| Poly urethane ($cm^2$) | 133.5 (18.3)$^a$ | 173.0 (22.6)$^c$ |

Mean Pressures

In the mean pressure the difference between a deformable surface and a firm surface is also significant. The relative decrease of the mean pressure is 19.2% is shoes and 12.5% in the shoes filled with PU. The difference between the 2 shoeing conditions was not significant although there was a trend ($p = 0.087$) towards a lower mean pressure in the shoes (Table 2).

**Table 2** Mean pressure under the hoof ($N/cm^2$) measured in 12 feet of 6 horses. A different symbol represents a significant ($p < 0.05$) difference.
*Mittlerer Druck unter dem Huf ($N/cm^2$) gemessen an 12 Hufen von 6 Pferden. Ein unterschiedliches Symbol weist auf einen signifikanten ($p < 0.05$) Unterschied hin.*

| | Firm surface mean (sd) | Deformable surface mean (sd) |
|---|---|---|
| Shoe ($N/cm^2$) | 45.9 (4.0)$^a$ | 37.1 (6.8)$^b$ |
| Poly urethane ($N/cm^2$) | 45.5 (3.9)$^a$ | 39.8 (6.9)$^b$ |

Peak pressure

With PU filling in the shoe there was a significant lower peak pressure on a sand surface, the peak pressure decreases with 22.7% from the firm surface to the sand surface. The peak pressure on a sand surface is 20.8% higher in the shoeing condition without the PU filling (Table 3).

**Table 3** Peak pressures measured in 12 feet of 6 horses. A different letter means a significant ($p < 0.05$) difference between interventions.
*Spitzendrücke gemessen an 12 Hufen von 6 Pferden. Ein unterschiedlicher Buchstabe weist einen signifikanten ($p < 0.05$) Unterschied zwischen den Beschlägen hin.*

| | Firm surface mean (sd) | Deformable surface mean (sd) |
|---|---|---|
| Shoe (N) | 185.6 (22.5)$^a$ | 185.8 (39.2)$^a$ |
| Poly urethane (N) | 198.8 (29.6)$^a$ | 153.6 (19.6)$^b$ |

Pressure distribution pattern

On firm surface there were no differences between the 2 shoeing conditions and both had 100% score on hoof wall loading. In the deformable surface there were significant differences between the shoes filled with and without PU (Fig. 4.). In horses shod with PU, the pressure distribution pattern was altered, often into a pattern with only weight bearing on the sole and on the frog.

## Discussion

The bearing surface was determined by the sum of all loaded cells during the 2.1 sec measurement (500 collected samples, 240 Hz), but was rather large and probably the result of the measurement technique used and the sensitivity of the measurement equipment. The threshold level of the Rsfootscan plate was set at 3 N, so each pressure above this level was detected. The threshold is set to discard noise-related information but 3 N might be too low when measuring horses. At the same time each small movement of the horse with which extra sensors were triggered were added in the calculation. This effect was the same for both shoeing conditions and surface conditions and since this is a systematic error it is improbable this influenced the measured effects.

The within variation in pressure distribution pattern of a shoe filled with PU on a deformable surface was larger than the variation on a deformable surface. This phenomenon might result of the set-up used in this study. To provide reliable force data, the force plate has to lie free in space and as a result, the sand which was placed on top of the measurement

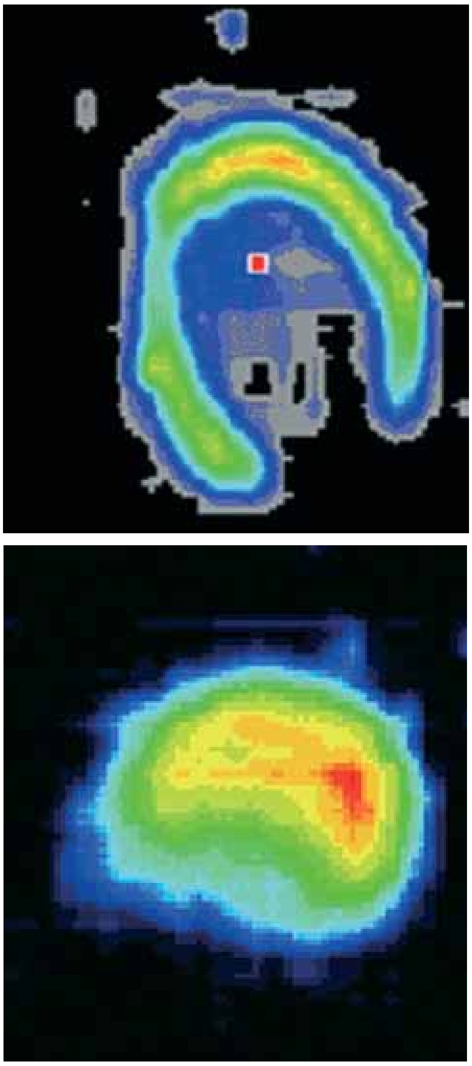

**Fig 3** Typical example of the pressure distribution pattern of (above) a shoe without filling and (below) a shoe with polyurethane (PU) filling, both on a deformable, sand surface. The pressures are colour coded where blue represents the lowest pressures and red the highest pressures.
*Typisches Beispiel eines Druckverteilungsmusters eines Beschlags ohne Einlage (oben) und mit Polyurthan-Einlage (unten), beide auf Sandboden. Die Drücke sind farbcodiert, wobei Blau für den niedersten und Rot für den höchsten Druck steht.*

systems had to have the same surface as the force plate itself. Before every measurement the sand layer was controlled for thickness, but it is possible that in some measurements the horses shifted sand away resulting in a decrease of thickness and thus an altered pressure distribution patterns resembling the pattern of a shoe filled with PU on a firm surface.

Hypothesis / results / interpretation: The following hypotheses were tested:

1 Filling shoes with PU will increase the bearing surface underneath the shoe because not only the shoe, but the frog and the sole will be loaded as well.

2 When the bearing surface is increased the pressure distribution will be more equal and thus the shoes filled with PU will have lower mean and peak pressures.

3 The supporting effect of a PU filling is equal on different ground surfaces.

Ad1. The first testing hypothesis can be rejected. There is no total foot support and no increase in bearing surface or decrease in mean pressures.

Ad 2. The second hypothesis is partly accepted, the peak pressures do decrease but probably as a result of a more equal distribution of the pressure, not of an increase in bearing surface.

Ad 3. The third hypothesis is rejected as well. The supporting effect is completely different on a firm and deformable surface. The mean pressures decrease in the normal shoes and in the shoes filled with PU. The frog and the sole do get loaded but instead of being loaded as well as the hoof wall, they became often the only structures which were loaded on a deformable surface.

The most surprising outcome of this study is the difference in pressure distribution patterns in shoes filled with PU and normal shoes on a deformable surface. The rationale behind shoeing sound horses with a solar filling would be to create a larger weight bearing surface and especially loading of the frog. Because frog contact with the ground may aid normal frog growth and heel expansion (*Balch* et al. 1991). The relation between frog pressure and heel expansion has been stu-

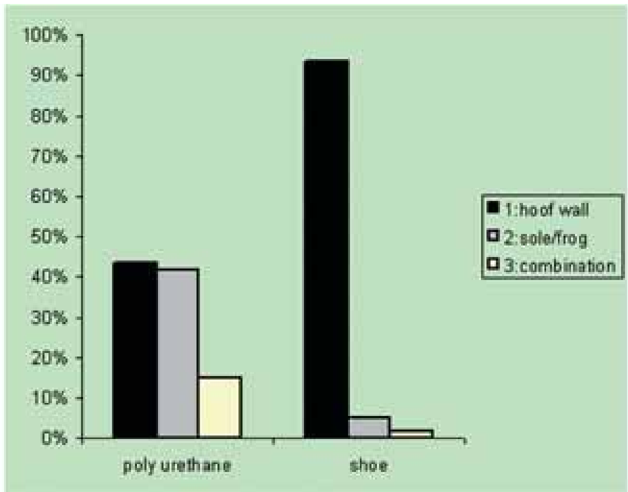


**Fig 4** Relative frequency analysis of the pressure distribution pattern in shoes filled with poly urethane (PU) and shoes without a PU filling on a sand surface. In each measurement cycle there were 60 observations. The pressure distribution pattern was scored into 3 categories and tested for significance with a chi-square test. The distribution pattern in shoes filled with PU on a sand surface is significantly different compared to the shoes without filling.
*Relative Häufigkeitsanalyse der Druckverteilungsmuster von Beschlägen mit und ohne Polyurethan-Einlage auf Sandboden. Jeder Messzyklus umfasst 60 Untersuchungen. Die Druckverteilungsmuster wurden in 3 Kategorien eingeteilt und mit einem Chi-Quadrat-Test auf Signifikanz überprüft. Die Druckverteilungsmuster unter Beschlägen mit PU-Einlage sind gegenüber denen ohne Einlage signifikant verändert.*

died but could not been proven (*Colles* 1989). In a shoe filled with PU it seemed that the shoe cuts through the sand and sand gets captured inside the bars of the shoe where the PU material is located. The PU gets loaded and prevents the shoe to sink further away in the sand. As a result the pressure distribution pattern is opposite to a normal shoe and mainly the sole and the frog get loaded. The same loading pattern was detected in barefoot horses on firm and deformable surfaces. On a firm surface the researchers found loading on the hoof wall and on a sand surface the measured pressure only on the solar surface of the hoof (*Hood* et al. 2001). They concluded that on a deformable surface the solar surface is the primary weight loading surface in horses. Other studies concluded that pressure on the frog and sole can lead to sensitivity and lameness (*Colles* 1989, *Stashak* 2002).

With use of a PU filling it is possible to alter the pressure distribution underneath a shoe. This can explain why so many farriers use the product successfully in horses with problems in their hoof wall, and that it is possible to keep horses working on a deformable ground surface even with a defect in their hoof wall or with 'bad feet'. Because of the above, filling shoes with a PU can be a great aid in a rehabilitation process, because a horse can be kept in a healthy physical condition.

The use of PU in horses with healthy feet which are trained on a deformable surface is arbitrary because normal loading of the healthy hoof should occur mainly on the hoofwall instead of the frog and the sole being the only weight bearing structures. It is possible filling shoes with PU has other beneficial qualities in foot protection, like damping abilities or protection of the sole of horses trained on a firm uneven or rocky surface but this should be studied in further detail.

### Manufacturers addresses:

Footscan scientific version® RsScan international, Olen, Belgium
Kistler Type Z4852/c, 600mm × 900 mm, Kistler corp. Winterthur, Switzerland
SPSS Inc., Chigago, Illinios, USA

### Acknowledgements

The authors would like to thank J. de Zwaan who performed all shoeing interventions during this experiment. Furthermore, we would like to thank A. Klarenbeek and Y. Elte for their help during data capturing. The financial support of Vettec was highly appreciated.

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