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The Effect of Reducing the Bone to Cast Distance in an Equine Transfixation Pin Cast: An Ex Vivo Biomechanical Study

Inaugural-Dissertation

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1 Abstract

Objective: The aim of this study was to evaluate the effect of reducing the bone to cast distance on the resistance of the pin to cyclic loading in equine transfixation pin casts.

Study Design: Eleven pairs of cadaveric equine third metacarpal bones were prepared and one 6.3/8.0 mm transfixation pin was placed in standard fashion 10 mm proximal to the distal physeal scar into each bone. One metacarpus of each pair was tested with a distance of 10 mm (10 mm group) and the contralateral metacarpus with a distance of 20 mm (20 mm group) between the outer cortex of the bone and the fixation of the pin. Eight pairs were tested using a simplified test set-up in which the pins were fastened at both ends to polyoxymethylene-copolymer sleeves. The pins of the remaining three pairs of bones were incorporated into a fibreglass cast. All specimens were tested under cyclic loading until failure of the pin in axial compression.

Results: All pins failed uni- or bilaterally at clinically relevant load levels. Pins of the 10 mm group endured significantly ($p < 0.05$) higher load levels and total number of cycles until failure compared with the pins of the 20 mm group.

Conclusion: The distance between the bone surface and the cast at the location of pin insertion has a significant effect on resistance of the pins to cyclic loading. Therefore, the amount of padding applied underneath an equine transfixation pin cast can have an influence on the overall stability and durability of the construct.

Key Words:
Horses
Transfixation Pin Cast
Pin Breakage
Cyclic Loading
Padding

2 Zusammenfassung

Das Ziel dieser Arbeit war es, den Einfluss der Reduktion der Distanz zwischen Knochen und Cast in einem Transfixations-Pin-Cast beim Pferd auf die Widerstandskraft des Pins gegen zyklische Belastung zu untersuchen.

Elf Paar Röhrbein-Knochen wurden entnommen und jeweils ein 6.3/8.0 mm Transfixations-Pin wurde 10 mm proximal der distalen Epiphysenfuge implantiert. Jeweils ein Knochen jedes Paars wurde mit einer Distanz von 10 mm (10 mm Gruppe) und der kontralaterale Knochen mit einer Distanz von 20 mm (20 mm Gruppe) zwischen der Knochenoberfläche und der Fixierung des Pins getestet. Acht Paar Knochen wurden in einem vereinfachten Versuchsaufbau getestet, wobei die Enden der Pins jeweils in einer Polyoxymethylen-Hülse befestigt wurden. Die Pins der restlichen drei Knochenpaare wurden in einen Cast inkorporiert. Alle Proben wurden unter zyklischer Belastung in axialer Kompression bis zum Versagen des Pins getestet.

Alle Pins versagten uni- oder bilateral bei klinisch relevanten Lasten. Die Pins der 10 mm Gruppe hielten hierbei signifikant ($p < 0.05$) höheren Lasten und Anzahl Zyklen bis zum Versagen stand als Pins der 20 mm Gruppe.

Die Distanz zwischen der Knochenoberfläche und dem Cast im Bereich des implantierten Pins hat einen signifikanten Einfluss auf die Widerstandskraft des Pins gegen zyklische Belastung. Daher kann die Menge an Polsterung, welche unter einen Transfixations-Pin-Cast angebracht wird, einen Einfluss auf die Stabilität und Lebensdauer des Konstrukts haben.

Stichworte:
Pferd
Transfixation-Pin-Cast
Pinbruch
Zyklische Belastung
Polsterung

3 Introduction

Transfixation pin casting is indicated for the treatment of comminuted fractures of the proximal or middle phalanx in horses.[1-3] It is recommended to place two or three pins with a diameter of 4 to 6.3 mm in the distal metaphyseal region of the third metacarpus/metatarsus. The pins are to be separated vertically by 2 to 4 cm and should be divergent by a total of 30 degrees in the frontal plane.[1, 2, 4, 5] Complications reported include pin loosening, pin hole sequestrum formation, secondary fractures through a pin hole and pin breakage.[1-3, 6-8] Pin breakage is reported sporadically in the literature, as pins may be removed or replaced, and its incidence is probably underestimated.[7-10]

The overall stability of any external fixator depends on its weakest component, which is reported as the pin-bone interface.[3, 11] Stresses arising inside the pin at the pin-bone interface originate from the bending moment (M_0) of the pin and pin deformation, where 92 % of the total stresses are attributable to the bending moment[12] (Fig. 1).

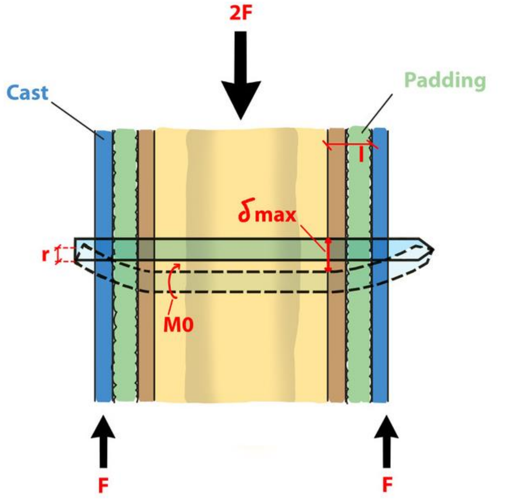

Fig. 1 Simplified model of a transfixation pin cast. The distance between bone and cast (l) is given by the amount of padding and the thickness of soft tissue including the skin. 2F = load applied on bone. r = radius of the pin. M0 = bending moment of the pin. δmax = maximal pin deflection.

The bending moment at the cortex of the bone can be approximated by $F_A \times l_X$ (F = load applied on the metacarpus, l = distance between bone and cast) as depicted in Fig. 2. The maximal bending stress occurs at the pin–bone interface and can be calculated through the bending moment divided by the bending resistance W_B (for a cylinder W_B is proportional to D^3 with D = diameter of the pin). The maximum bending stress is proportional to $\frac{1}{D^3}$. This fundamental mechanical situation explains the correlation between diameter and bending stiffness.

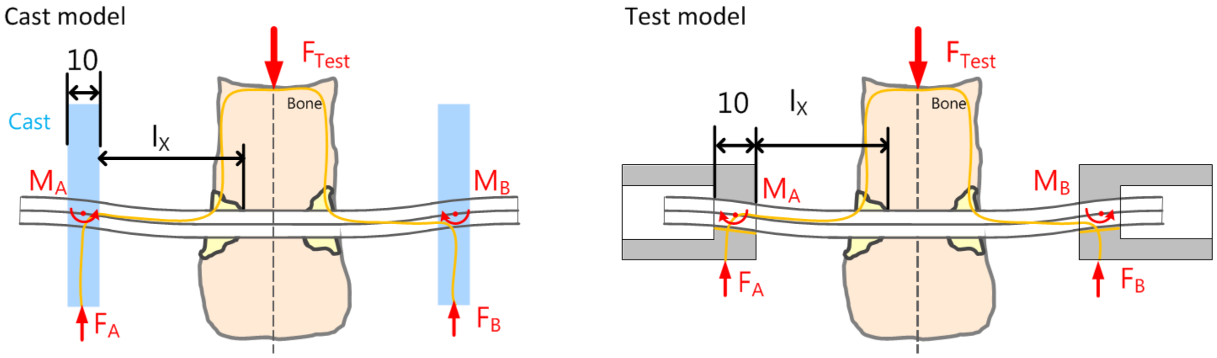

Fig. 2 Mechanical loading configuration of the cast model (left) and test model (right) with the externally applied test load F-test and the resulting reaction forces/moments.

Taking these mechanical properties into account, for maximal transfixation cast stiffness, one would incorporate pins with a maximal diameter, maximal Young's modulus and minimal distance between bone and cast.[13] Pin diameter is limited by the bone diameter, as pins with a diameter of more than 20 % of the dorsopalmar/-plantar bone diameter reduce torsional strength of the bone significantly and increase the risk of secondary fractures through a pin hole.[1, 10, 14] The Young's modulus is defined by the material used and cannot be varied easily. An attempt at reducing the distance between bone and incorporation of the pin in the transfixation device has been made with the development of a tapered-sleeve construct.[13, 15, 16] However, to the authors' knowledge, no studies or reports have been published on the effect of reducing the bone to cast distance by minimizing the amount of padding.

Our hypothesis was that the reduction in the distance between bone and cast would reduce stress on the pin-bone interface and therefore increase the load and number of cycles endured until failure.

4 Materials and Methods

4.1 Determination of Conventional Bone to Cast Distance

Dorsopalmar/ -plantar radiographs of four horses that had been treated as patients at the Equine Department of the Vetsuisse Faculty, University of Zurich, Switzerland, before initiation of this study and in which transfixation pin casting was used to treat comminuted fractures of the proximal phalanx were re-evaluated to determine the mean distance from the outer cortex of the bone to the cast at the level of the most distal transfixation pin, which was located ~1 cm proximal to the distal physeal scar of the third metacarpal/ -tarsal bone. The measurements were made using the integrated measurement tool of a commercial DICOM viewer using a reference scale (OsiriX MD; Pixmeo SARL, Bernex, Switzerland).

4.2 Determination of Minimal Bone to Cast Distance

One forelimb of a Warmblood horse slaughtered for reasons unrelated to this study was harvested. A half-limb cast with minimal, but reasonable padding, was applied as thought adequate for clinical application. This consisted of a double layer of stockinette, synthetic padding (Soffban synthetic; BSN medical GmbH, Hamburg, Germany), elastic fixation bandage (Elastomull, BSN medical GmbH, Hamburg, Germany) and fibreglass-polyurethan resin casting tape (Nemoa Cast; AtozBio, Seoul, Republic of Korea). A dorsopalmar radiograph was taken to determine the distance from the outer cortex of the bone to the cast at the level of 1 cm proximal to the distal physeal scar of the third metacarpal bone.

4.3 Specimen Collection and Preparation

Both forelimbs of 11 horses euthanatized or slaughtered for reasons unrelated to this study, were collected. The horses were between 3 and 26 years old with a mean of 16.6 years (standard deviation [SD] = 6.3 years) and weighed between 480 and 640 kg with a mean of 558.6 kg (SD = 55.8 kg). All soft tissues and adjacent bones were removed until only the third metacarpal bones and the attached splint bones remained. The specimens were marked with a tag attached to the lateral splint bone. Wrapped in a moist cloth, the specimens were stored at -20°C until further preparation.

One metacarpus of each pair of limbs was randomly assigned to the 10 mm group and the contralateral metacarpus to the 20 mm group.

One transfixation pin was inserted into the metaphysis of each third metacarpal bone. Prior to pin placement, the specimens were thawed at room temperature over 24 hours. Twenty gauge needles were placed as markers medially and laterally in the periosteum of each third metacarpal bone 1 cm proximal to the distal physeal scar. Dorsopalmar radiographs were taken to verify the correct position of the needle and rule out pathological conditions of the bony specimens. Transfixation pins with a thread-runout design (Duraface Full-pins for Large Animals, 6.3/8.0-mm; IMEX Veterinary, Inc., Longview, Texas, United States) were inserted according to manufacturer's instructions and as recommended in the literature.[1] An aiming device was positioned at the site indicated by the marker needles and sequentially larger drill bits and water cooling were used to prepare a horizontal hole from medially to laterally into each bone. Low-speed power tapping with the corresponding tap (IMEX Veterinary Inc., Longview, Texas, United States) was then followed by pin insertion from medially to laterally. The pins were advanced until the threaded parts protruding medially and laterally were of equal length. The specimens were wrapped in a moist cloth again and stored at -20°C until testing.

4.4 Biomechanical Main Study

Eight pairs of metacarpi prepared as described above were used for the main study. The test set-up was as reported recently.[9] In brief, five markers were attached to each specimen to allow monitoring of the pin position in relation to the bone using a camera (Monochrome 1928×1448 Pixel, GS3-U3–28S4M-C 1/1,8" Grasshopper USB 3.0 camera, mounted with a AF NIKKOR f = 35–105 mm lens Nikon Japan, analysis with MatroxTM Image Design Assistant, St. Regis Blvd. Dorval, Quebec, Canada). The specimens were then mounted to the testing apparatus mimicking a transfixation pin cast model (Fig. 3A, B). The metacarpi were proximally fixed in a hollow stainless steel profile with several screws. This profile was connected to the load cell which was attached to the actuator of the test machine. The pins were fastened at both ends to POM-C (polyoxymethylene-copolymer) sleeves. The distance between the POM-C sleeves and the bones was adjusted according to the previously assigned 10mm or 20mm. The sleeves were then inserted into and supported by the stainless steel sidewalls, which in turn were joined by the ground plate.

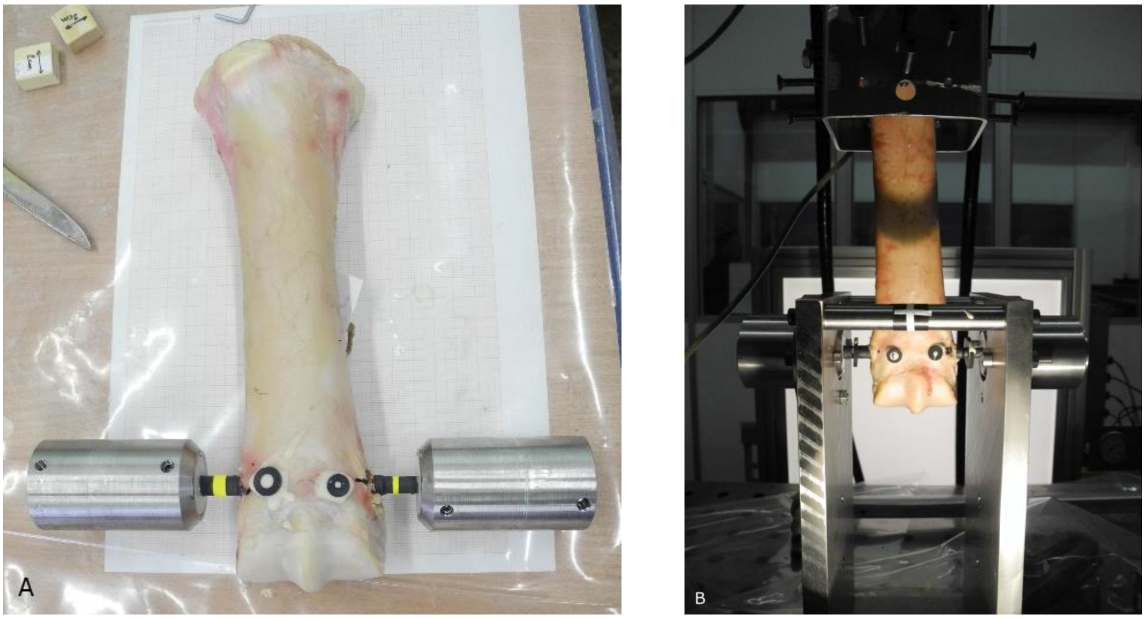

Fig. 3 (A) The polyoxymethylene-copolymer sleeves fastened at each end of the pin with a distance of 10 or 20 mm to the bone surface, according to the previously assigned group. (B) Test set-up with the proximal aspect of the metacarpus secured in the load cell and the polyoxymethylene-copolymer sleeves fitted into the base plate.

Each specimen was tested under cyclic loading until failure (Table 1). Preloaded with 100 N and a first load level of 2,000 N, incremental increases of 500 N for each following level were applied. The loads were applied with sinusoidal oscillation at a frequency of 2 Hz and each load level was maintained for 10,000 cycles. Failure was defined as complete loss of stability of the bone–pin constructs, as seen with pin breakage. Additionally, load and number of cycles at 25 % reduction in the apparent stiffness of the pin-bone construct compared with the initial apparent stiffness at the beginning of the loading cycle were evaluated. The apparent stiffness was calculated as the applied load divided by the displacement at the point of load introduction from the load cylinder. The rationale for this calculation at 25 % reduction in the apparent stiffness was the scenario that one side of the pin might break before the end of cyclic testing, that is, before complete loss of stability. The threshold value of 25 % was determined empirically to allow an earlier detection of loss of stability and possible weakening of one pin.

Table 1 Protocol of cyclic loading

Load step i	**Accumulated cycles (at end of step i)**	**Cycles per step**	**F_U**	**F_L**	**F_A**	**F_M**
-	-	-	**N**	**N**	**N**	**N**
1	10,000	10,000	**-2,000**	-100	950	-1,050
2	20,000	10,000	**-2,500**	-100	1,200	-1,300
3	30,000	10,000	**-3,000**	-100	1,450	-1,550

4	40,000	10,000	**-3,500**	-100	1,700	-1,800
5	50,000	10,000	**-4,000**	-100	1,950	-2,050
6	60,000	10,000	**-4,500**	-100	2,200	-2,300
7	70,000	10,000	**-5,000**	-100	2,450	-2,550
8	80,000	10,000	**-5,500**	-100	2,700	-2,800

Abbreviations: F_A: load amplitude; F_L: lower compressive load; F_M: middle load; F_U: upper compressive load.

Tests were performed using a hydraulic actuator (20 kN hydraulic cylinder with Instron IST Labtronic control unit 8800, Norwood, Massachusetts, United States; 50 kN load cell K-series from GTM Testing and Metrology GmbH, Bickenbach, Germany).

After testing, each specimen was examined macroscopically and radiographically (Fig. 4A, B).

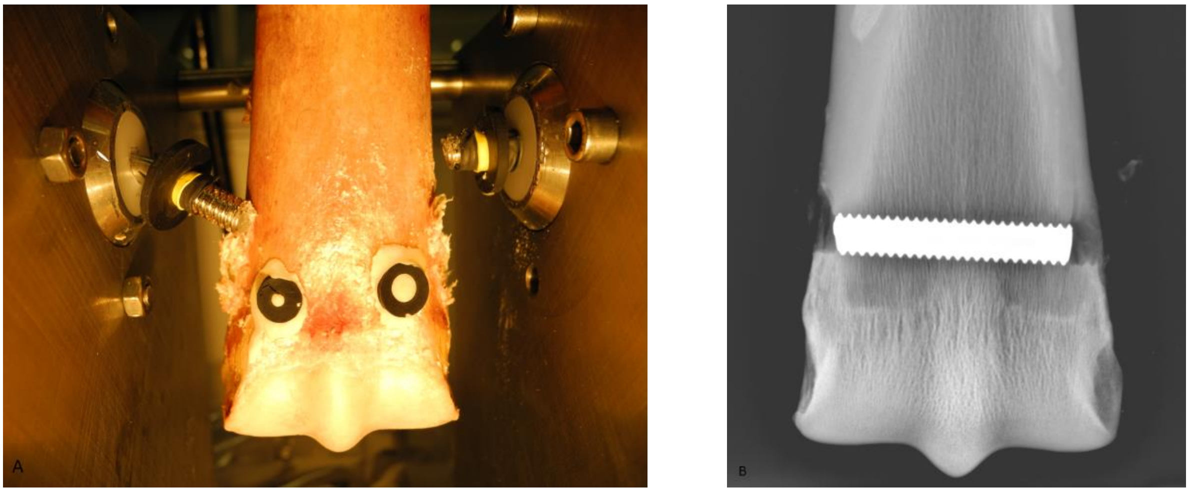

Fig. 4 (A) Specimen in test set-up after bilateral pin failure. (B) Dorsopalmar radiograph after testing showing remaining pin fragment and cortical wear-out medially and laterally.

4.5 Validation Study with Fibreglass Cast

Three pairs of metacarpi prepared with one transfixation pin each, as described above, were incorporated into a fibreglass cast as it is done in transfixation pin casting and reported previously in a pilot study.[9] The distance of 10 or 20 mm, respectively, from bone to cast was measured and marked bilaterally on the pin. Synthetic padding (Soffban synthetic; BSN medical GmbH, Hamburg, Germany) and elastic fixation bandage (Elastomull, BSN medical GmbH, Hamburg, Germany) were then applied around the bones up to the marks. Two 3-inch and two 4-inch fibreglass-polyurethan resin casting tapes (Nemoa Cast; AtozBio, Seoul, Republic of Korea) were then applied over the padding in standard fashion with a figure-of-eight pattern around the pin.

Again, the metacarpi were proximally secured to the hollow stainless steel profile and the distal aspect of the fibreglass cast was embedded in a methyl methacrylate resin (Technovit 3040; Kulzer GmbH, Hanau, Germany) set inside a baseplate. In this case, the load applied was transferred from the bone through the pin into the fibreglass cast and onto the baseplate.

The specimens were tested under cyclic loading until failure in the same manner as described above.

After testing, the casts were removed and each specimen examined macroscopically and radiographically.

4.6 Statistical Analysis

Data were analysed using IBM SPSS Statistics 25. The Kolmogorov-Smirnov test was used for the evaluation of normal distribution. A paired t-test was used for normally distributed data and a Wilcoxon signed-rank test for data that was not normally distributed. The level of significance was set at $p < 0.05$.

5 Results

5.1 Determination of Conventional Bone to Cast Distance

The mean distance measured from the outer cortex of the bone to the cast in the patients treated with transfixation pin casting at our institution was 22.9 mm (SD = 4.4 mm) at the level of the most distal pin. As an approximation, the distance of 20 mm was considered the conventional distance for biomechanical testing (20 mm group).

5.2 Determination of Minimal Bone to Cast Distance

The distance measured from bone to cast in the limb prepared with minimal padding was 10 mm. This distance was implemented as the minimal distance for biomechanical testing (10 mm group).

5.3 Biomechanical Main Study

Of the eight pairs tested in the main study, all pins failed uni- or bilaterally. The mode of failure was comparable to that reported previously.[9] One pin failed only medially and showed no sign of pin failure laterally. One pin failed only medially but showed pin bending and a crack laterally. All bones showed signs of cortical wear-out in the form of fine bone disintegration and frayed cortical bone at the pin-bone interface (Fig. 4B). In one bone cortical wear-out was only noted laterally and in one bone only medially. One pair of bones was not further examined radiographically. One bone sustained a fissure extending proximally from the lateral pin-bone interface. This pin had been tested with a distance of 10 mm. It was not excluded from the study as it did not produce any outliers.

In the 10 mm group, the pins endured load levels between 4,000 and 5,000 N with a mean of 4,687.5 N (SD = 372.0 N) until failure. This corresponded with a mean of 58,673 cycles (SD = 7,525) measured until failure. In the 20 mm group, the pins endured load levels between 3,000 and 3,500 N with a mean of 3,437.5 N (SD = 176.8 N) and a mean of 32,888 cycles (SD = 3,003) until failure. Statistical analysis confirmed a significantly higher load level and total number of cycles endured until failure in the 10 mm group compared with the 20 mm group ($p < 0.05$; Figs. 5 and 6).

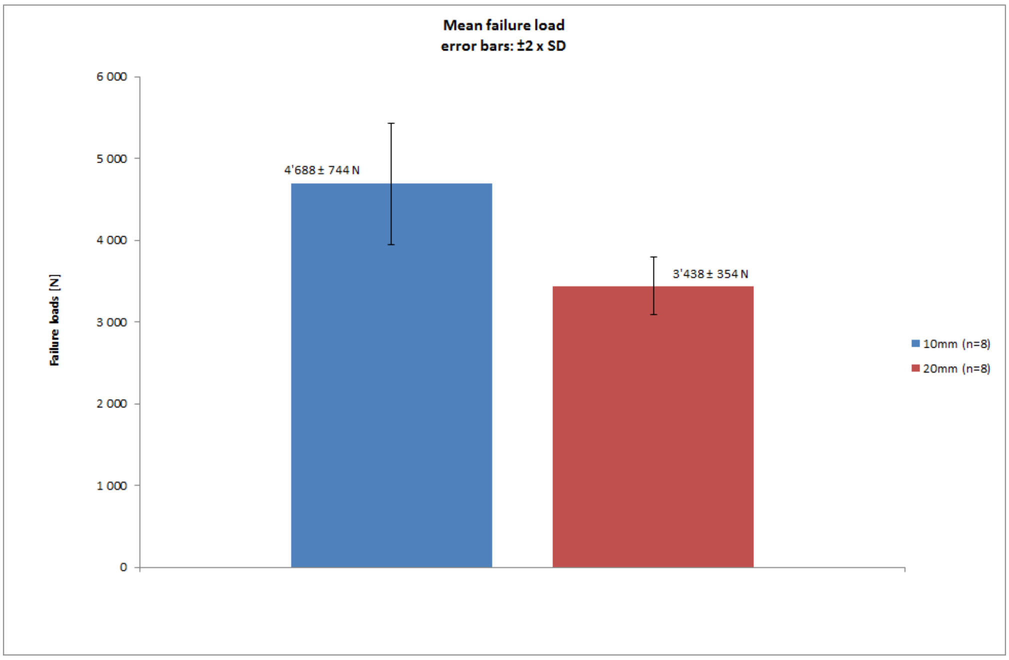

Fig. 5 Mean failure load of the 10mm group compared with the 20 mm group in the main study. Error bars ±2 standard deviation [SD].

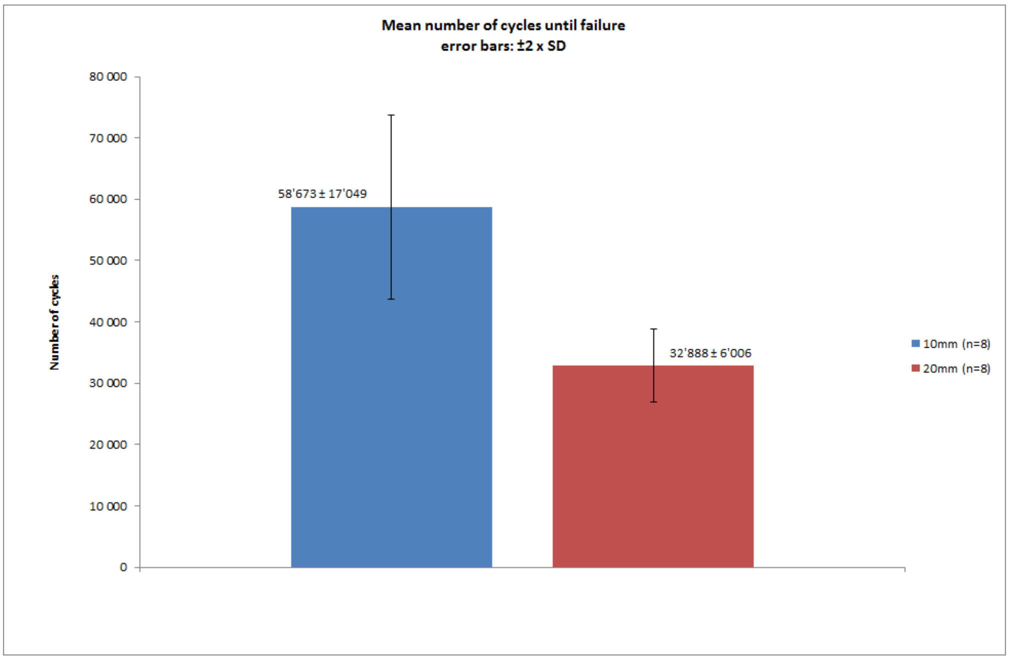

Fig. 6 Mean number of cycles endured until failure of the 10 mm group compared to the 20 mm group in the main study. Error bars ± 2 standard deviation [SD].

The pins in the 10 mm group sustained loads between 3,000 and 5,000 N with a mean of 4,000 N (SD = 755.9) and a mean of 43,651 cycles (SD = 15,082) until 25 % reduction in the apparent stiffness was measured. In contrast, the pins in the 20 mm group endured a load level of 3,000 N (SD = 0) and a mean of 26,268 cycles (SD = 2365) until 25 % reduction in the apparent stiffness was noted. Statistical analysis confirmed a significantly higher load level and number of cycles endured until 25 % reduction in the apparent stiffness in the 10 mm group compared with the 20 mm group ($p < 0.05$).

5.4 Validation Study with Fibreglass Cast

Of the three pairs tested with a fibreglass cast the primary failure was either uni- or bilaterally. One pin failed only medially but showed pin bending laterally. All bones showed signs of cortical wear-out. In one bone cortical wear-out was only noted medially. All other bones showed bilateral cortical wear-out. One bone showed a small superficial circular fracture of the cortex extending dorsoproximal from the medial pin-bone interface. No significant damage to the fibreglass casts was observed. The pin holes in the cast material were deformed in an angle according to the bending of the pin; however, no loosening was noted.

The initial apparent stiffness at the beginning of cyclic loading was noted to be higher in the main study than in the fibreglass cast model. The initial apparent stiffness for the 10 mm distance in the main study was 4,096.3 N/mm compared with 2,458.5 N/mm in the fibreglass cast model. For the 20 mm distance, the values were at 2,208.8 N/mm and 1,508.4 N/mm respectively.

Overall, the fibreglass cast model showed the same trend as the main study, with the 10 mm group enduring higher loads and number of cycles, but the differences between the 10 mm and 20 mm group were not as large (Figs. 7 and 8). The mean load level endured until failure was higher in the 10 mm (mean [M] = 4,833.3 N) group compared with the 20 mm group (M = 4,500.0 N). The mean load level endured until 25 % reduction in the apparent stiffness was also higher in the 10 mm group (M = 4,000 N) compared with the 20 mm group (M = 3,500 N). This corresponded with a mean of 64,387 cycles endured until failure in the 10 mm group compared with a mean of 57,594 cycles in the 20 mm group. A mean of 46,687 cycles was endured until 25 % reduction in the apparent stiffness was measured in the 10 mm group compared with 33,721 cycles in the 20 mm group.

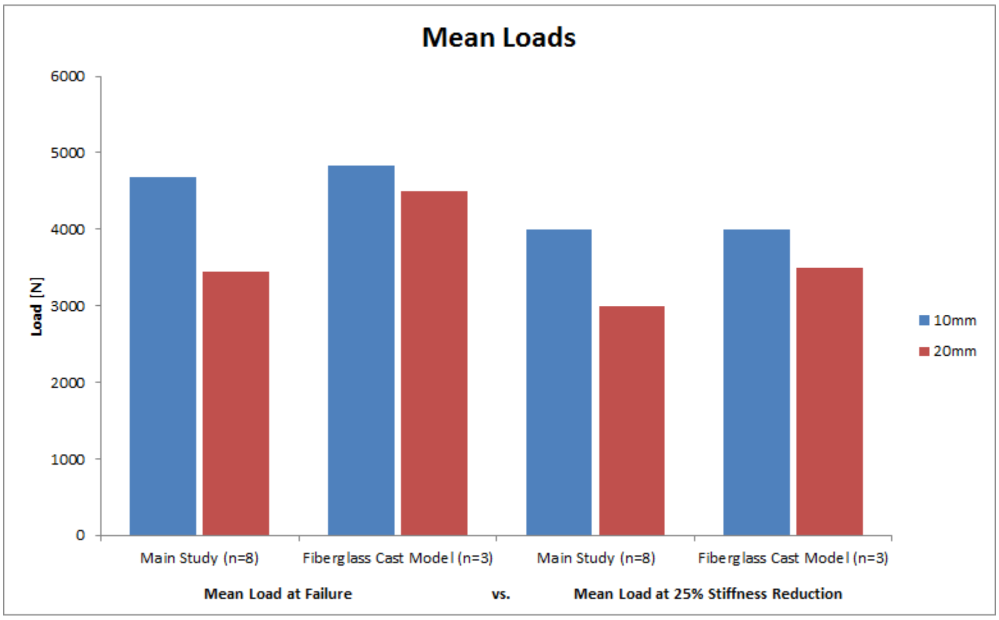

Fig. 7 Mean loads of the 10 mm and 20 mm groups of the main study and fiberglass cast model at failure and at 25 % reduction in the apparent stiffness.

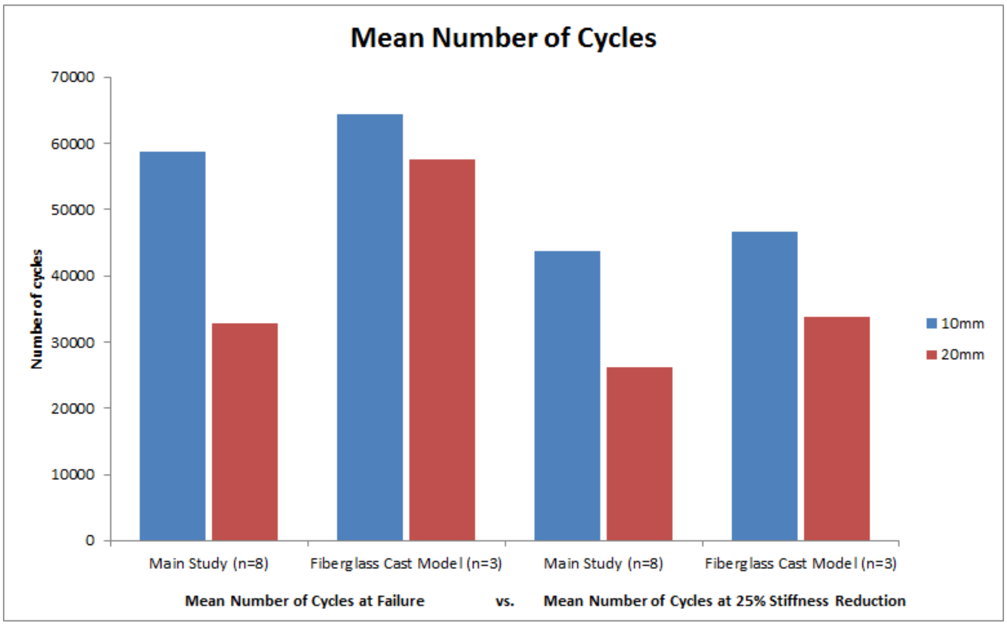

Fig. 8 Mean number of cycles endured of the 10 mm and 20 mm groups of the main study and fiberglass cast model at failure and at 25% reduction in the apparent stiffness.

6 Discussion

This study confirmed our hypothesis that the reduction in the distance between bone and cast from 20 to 10 mm in a simplified transfixation pin cast model increases the load and number of cycles endured until failure of the pin.

The results of this study clearly show that the distance between bone and cast in a transfixation pin cast has a significant effect on the durability of the pin. This distance is given by the soft tissue surrounding the bone and the amount of padding applied. For standard half-limb casts, a double layer of stockinette is recommended as padding, but often additional synthetic padding is applied to minimize the risk of pressure sores.[1] To the author's knowledge, no clear recommendations concerning the amount of padding to be applied underneath a transfixation pin cast have been published in literature. The reduction or omission of the additional synthetic padding in the area of the transfixation pins may allow a reduction in the bone to cast distance. Studies trying to minimize the bone to cast distance have focused on implementing tapered-sleeves over the pin and incorporation of pins into a metal sidebar instead of a fibreglass cast.[13, 15, 17] There is no padding required in these constructs. The addition of the tapered-sleeves causes a substantial reduction in concentrated stresses and therefore strengthens the construct under axial loading. In the tapered-sleeve systems, the fatigue strength of the pin is increased making the bone the limiting component and leading to possible secondary fractures as a complication.[13] In our study, no secondary bone fractures were observed; only one fissure line was discovered on the post-test radiographs. This observation is in agreement with the biomechanical ex vivo study that reported no cases of bone failure with use of conventional pins.[13] This indicates that, in contrast to other approaches, the reduction in the bone to cast distance may increase the stability of the pin without increasing the risk of bone failure leading to secondary fractures.

The implemented test set-up was according to the previously reported study.[9] The utilization and direct comparison of contralateral bones allowed a reduction in possible confounding variables with regard to the bone diameter, density and structure between different individuals. However, the use of cadaveric bone has some limitations affecting the clinical application of the results. The response of the bone to implant insertion, as well as any resorptive and remodelling processes of the bone caused by cyclic loading of the implant, is missed. The cortical wear-out of the bones noted after testing is, in the authors' experience, not seen to this extent in clinical cases. This may have had an effect on the stability of the pin as well as the location of failure of the pin. However, as cortical wear-out was noted in both groups, it is not thought to have an impact on the outcome comparing the 10 mm to the 20 mm group. The study protocol of cyclic loading allowed loads and number of cycles to be endured until failure comparable to clinical relevant compression forces and loading activity in horses confined to box stalls. The endured load levels of 3,000 to 5,000 N are comparable to the 2,753 N described at a standstill and 7,517 N at a walk.[18] The mean of 58,673 cycles endured until failure in the 10 mm main study group would correlate with the movement over almost 13 days taking into account the 4,560 loading events per 24 hours of horses confined to a box.[19] In transfixation pin casts applied clinically, the load is distributed over two to three pins in comparison to the one pin tested in this study. In our biomechanical testing model, only one pin was used to avoid confounding variables associated with application of a second implant. A construct with two or more pins, as commonly used clinically, should be more resistant against cyclic loading. In such a construct, the axial and bending forces are transferred to the proximal pin to a greater amount than to the pins further distal in the cast.[20]

Even though the use of positive-profile pins is currently recommended for equine transfixation casts,[1] a pin with a thread-run-out design[21] was used in this study. The thread-run-out pin was designed to reduce the concentrated peak stress at the transition from the threaded to non-threaded part of the pin. In a full pin, the thread-run-out design can only be implemented at one end of the threaded part of the pin. The other end has the same design as a positive-profile pin. In this study multiple pins failed only at the part with the thread-run-out design, whereas no pins failed exclusively at the part with the design corresponding to a positive-profile pin. This indicates that the thread-run-out design did not increase cyclic fatigue resistance in our study. One possible explanation may be the increased apparent stiffness due to the increased core diameter of the thread-run-out design, which leads to less bending but may accelerate failure of the pin. Another consideration is that the length of the centrally threaded part of the thread-run-out pin exceeded the width of the third metacarpal bones at the site of pin insertion. For this reason, it was always the threaded part of the pin that was located at the stress-concentrating bone cortices. Looking at the literature, the thread-run-out pin was significantly stiffer and performed better in cyclic fatigue testing than a positive-profile pin in an in vitro study.[21] However, a recent ex vivo biomechanical study found no significant difference in cycles to failure comparing the thread-run-out with a positive-profile pin.[9] Different test set-ups may explain these contradicting results. While unilateral fixation of the pin as seen in half pin external fixators was used in one study,[21] pins were implanted as full pins as seen in equine transfixation pin casting in this and a previous study.[9] To the authors' knowledge, there are no clear data concerning optimal placement of thread-run-out pins for use in equine transfixation pin casting available in the literature. We chose to insert the pins from medially to laterally based on the manufacturer's recommendation to position the thread-run-out part of the pin in the medial cortex. Further research is needed to better understand the mechanics of thread-run-out pins in a full pin configuration as used in equine transfixation casts.

The fibreglass cast model confirmed the data from the simplified main study. Comparing the test results from the main study to the fibreglass cast model, the main study represented a slightly more critical loading condition, as the mean number of total load cycles and failure loads were slightly lower. A recent study found two interesting differences in the apparent stiffness of the constructs in the simplified test versus the fibreglass cast model.[9] First, the apparent stiffness of the simplified test model was higher.[9] This finding was consistent with the higher initial apparent stiffness values of the simplified test model compared with the fibreglass cast model in the present study. Second, there was an accelerated reduction in the apparent stiffness of the pin-bone construct with increasing number of loading cycles in the fibreglass cast, but not the simplified testing model.[9] This reduction in the apparent stiffness can be explained by wear-out at the pin-cast interface and a higher extent of deformation of the cast material compared with the POM-C sleeves.[9] After testing, we noted some deformation of the pin holes in the fibreglass cast which supports this theory. Thus, the pins are exposed to higher stress concentrations in the simplified test model because the sites of pin incorporation are less compliant. This can explain the higher number of cycles endured until failure in the fibreglass cast model compared with the simplified test model. It is likely that the fibreglass cast model is more representative for a 'real' transfixation pin cast than the simplified test model in terms of the apparent stiffness. However, the simplified test model eliminated many confounding variables allowing us to detect qualitative differences between the 10 versus the 20 mm group, although the quantitative effect of these groups on pin durability might be less distinctive under clinical conditions.

Besides use of cadaveric bones and implantation of only one pin, the different mechanical properties of the simplified test model used in the main part of this study should be considered a limitation of this study.

In conclusion, the distance between the bone surface and the cast at the location of pin insertion in a transfixation pin cast has a significant effect on resistance to cyclic loading. Decreasing the thickness of the padding layer applied underneath the cast can increase the durability of the construct by increasing the number of load cycles endured before pin breakage occurs.

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