In vitro biomechanical comparison of headless compression versus cortex screws for fixation of simulated midbody proximal sesamoid bone fractures in horses

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In vitro biomechanical comparison of headless compression versus cortex screws for fixation of simulated midbody proximal sesamoid bone fractures in horses

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Summary: A midbody fracture of a proximal sesamoid bone (PSB) is a severe injury, especially in racehorses. Screw fixation may be the only option for horses to return to athletic activity. In a cadaveric biomechanical study, fixation of simulated transverse midbody PSB fractures with a 4.5 mm headless compression screw (HCS) was compared to the fixation using a 4.5 mm cortex screw (CS) inserted in lag fashion. The front limbs of 8 horses were prepared with a standardized midbody transverse osteotomy in each medial PSB. The left or the right limb of each pair was randomly assigned to the CS or HCS group. Fracture reduction and fixation was controlled by radiography. Markers were fixed proximal and distal to the osteotomy to document gap opening by an image correlation measurement. Cyclic compressive loading was performed with a hydraulic cylinder in an axial manner. After mechanical testing all limbs were radiographed to document the mode of failure. The mean cycles to total failure were 27,803 for the HCS group and 36,624 for the CS group, respectively. A mean of 14,444 cycles (HCS group) versus 27,464 cycles (CS group) was recorded at a fracture gap opening of 10%. The mean value of initial stiffness was 300 N/mm (HCS group) versus 590 N/mm (CS group). On post-testing radiographs, failure by screw breakage was detected in 3/8 limbs of the HCS group and in 2/8 limbs of the CS group. Screw pullout and bone failure was noted in 5 limbs in each group. In one limb of the CS group, the medial suspensory branch was disrupted and the fracture fixation was intact. None of the differences between HCS and CS constructs reached statistical significance. However, the lower absolute numbers of cycles sustained before failure, at 10% gap opening and lower initial stiffness of HCS constructs as well as limitations of the study warrant further investigation before clinical use of the HCS for this indication can be recommended.

Keywords: proximal sesamoid bone, fracture, headless compression screw, cycling loading, horses

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Introduction

Fractures of the proximal sesamoid bones (PSB) are relatively common injuries in athletic horses, especially racehorses (Nixon 2019). PSB fractures were the most frequent fatal bone injury in Thoroughbred horses while racing (50%) or training (30%) observed over a 2-year period in California (Johnson et al. 1994). In a recent overview of fractures in racing Thoroughbreds at the Hong Kong Jockey Club between 2004 and 2011, fractures of the PSB represented 55% of all catastrophic fractures (Sun et al. 2019).

While arthroscopic fragment removal or conservative treatment is indicated for apical fractures involving up to one third of the proximodistal dimension of the PSB, abaxial and basilar fractures, internal fixation is required for midbody fractures (Wright 2018, Nixon 2019). Multifragment and bialaxial fractures represent severe breakdown injuries because of disruption of the suspensory apparatus and usually require fetlock arthrodesis or euthanasia (Nixon 2019).

For internal fixation of uniaxial transverse midbody fractures of the PSB, circumferential cerclage wire or a lag screw is required to achieve adequate fracture union (Wright 2018). Busschers et al. suggested that screw fixation is the only option for racehorses to return to athletic activity (Busschers et al. 2008). Interfragmentary screw fixation in lag fashion returns up to 60% of Thoroughbred horses to active racing (Henninger et al. 1991, Martin et al. 1991, Wheeler and McLaughlin 1998).

The headless compression screw (HCS) is a well-established implant in human medicine for fixation of intra-extraarticular fractures, nonunions or arthrodeses of small bones. It is used for scaphoid and other carpal/tarsal bone fractures, fractures of the patella as well as for radial head and styloid fractures (DePuy Synthes 2017). The advantage of the HCS is that the screw head can be countersunk in the bone, thus avoiding impingement of the screw head into surrounding soft tissue or cartilaginous surfaces (Galuppo et al. 2006). Furthermore, this screw is cannulated, the head and the tip are tapered and
it is inserted over a preplaced pin, which facilitates accurate screw placement in small bones. Successful clinical use of the HCS in equine surgery was reported for repair of nondisplaced lateral condylar fractures and for slab fractures of the third carpal bone (Galuppo et al. 2006, Hirsch et al. 2007).

Both the apical and the basilar aspects of the equine PSB are associated with essential soft tissues, i.e. the suspensory ligament and the distal sesamoidean ligaments, respectively. In such an environment, the features of the HCS could be beneficial in terms of avoiding damage to these structures resulting from interference with protruding screw heads.

The purpose of this biomechanical study was to compare the stability and fatigue strength of a simulated medial midbody PSB fracture after fixation with a 4.5 mm HCS versus a 4.5 mm cortical screw (CS) implanted in lag fashion. Our hypothesis was that fixation using a HCS would result in similar resistance to cyclic loading compared to a construct using a cortical screw.

Material and Methods

The front limbs of 8 horses euthanized for reasons unrelated to this study and without any known pathology of the PSBs and the suspensory apparatus were prepared and stored as described by Eddy et al. 2004. In each limb a standardized midbody transverse osteotomy was created in the medial PSB using an oscillating saw. The osteotomy was created under fluoroscopic control in such a manner that the proximal fragment represented 40% and the distal fragment 60% of the proximodistal length of the PSB. The bone was cooled using a NaCl 0.9% rinse during sawing. The lateral PSB was left intact in all limbs. The left or the right limb of each pair was randomly assigned to the CS or HCS group.

The osteotomy was fixed with a reduction forceps applied to the bone until the threaded tip was anchored in the far cortex. The osteotomy was reduced and compressed. The HCS was countersunk using a cannulated screw driver with color markings to control the degree of countersinking. The hard and dense bone in this region required pre-drilling of the space accommodating the head of the HCS.

In the CS group, a 4.5 mm cortical bone screw was inserted in lag fashion. A 4.5 mm glide hole was drilled in the basilar PSB fragment to the level of the osteotomy. A 3.2 mm drill sleeve was inserted in the glide hole and a 3.2 mm thread hole was drilled through the apical part of the bone. A depression for the screw head was prepared with the countersink and the depth gauge used to determine screw length. The threads were cut into the thread hole using the tap and a 4.5 mm cortex screw was implanted in lag fashion.

The specimens were radiographed (lateromedial and dorsomedial-palmarolateral oblique views) to evaluate fracture fixation and screw position. The limbs were prepared with a polymethylmethacrylate (PMMA, Technovit 3040 from Kulzer GmbH, Wehrheim, Germany) imbedding at the level of the distal and proximal carpal bone rows for fixation in the mechanical testing machine at the proximal end (20 kN hydraulic cylinder with Instron IST control unit 8800, Norwood, Massachusetts, USA; 50 kN load cell from GTM, Testing and Metrology, Bickenbach, Germany). Two markers were fixed at the PSB 5 mm proximal and distal to the osteotomy, respectively, using PMMA to document gap opening by an image correlation measurement (camera: ECO655 MVGE, Monochrome 2448 × 2050 Pixel, mounted with a f = 40 mm lens, SVS Vistek, Seefeld, Germany, analysis with MatroxTM Image Design Assistant, Quebec, Canada). The hoof was placed in a support designed to allow normal fetlock joint movement and immobilized with 2 screws on each side (Figure 1).

Cyclic compressive loading was performed with a hydraulic cylinder in an axial manner at 1 Hz with an initial upper load of 1000 Newton (N). The load was increased every 5,000 cycles by 400 N.

The total number of load cycles before failure were recorded. The number of load cycles until the fracture gap reached an opening of 10% and until the stiffness reduction rose to 50%, respectively, were documented. After mechanical testing all limbs were radiographed to document the mode of failure.

Test result groups of each test parameter used for statistical analysis were first checked for normal distribution using a Kolmogorov-Smirnov test (OriginLab Corporation, Northampton, United States). Tests groups were compared and checked for significant difference of mean values using a paired two-tailed t-test with p set < 0.05.

Results

Fracture fixation as evaluated by radiographs was adequate in 15/16 operated limbs. One specimen of the HCS group (Horse 5, Table 1) had mildly incomplete fracture reduction on pre-testing radiographs. The median screw length was 32 mm in the HCS group and 37 mm in the CS group. All result parameters were normally distributed.

Pferdeheilkunde – Equine Medicine 35 (2019)
In vitro biomechanical comparison of headless compression versus cortex screws

Fig. 1 Illustration of the test setup. a) Overview of the testing construct with the limb fixed in the testing machine for cycling compressive loading. b&c) Two markers were attached to the PSB, proximal and distal to the osteotomy, to document fracture gap opening by an image correlation measurement. Illustration des Aufbaus. a) Übersicht des Prüfkonstrukts mit einer für die zyklische Belastung in der Testmaschine fixierten Gliedmaße. b&c) Zwei Marker wurden proximal und distal der Osteotomie angebracht, um die Öffnung des Frakturspalts mit einer Bildkorrelationsmessung zu dokumentieren.

Tab. 1 Legs and types of screws, number of cycles and type of failure

| Horse | Leg   | Screw type | Screw length (mm) | Number of cycles until fixation failure | Number of cycles until the fracture gap opens 10% | Type of failure          |
|-------|-------|------------|-------------------|----------------------------------------|-------------------------------------------------|--------------------------|
| 1     | right | CS         | 38                | 32,859                                 | 32,126                                          | screw pull out           |
| 1     | left  | HCS        | 32                | 27,912                                 | 17,724                                          | screw break              |
| 2     | left  | CS         | 34                | 35,896                                 | 33,509                                          | screw pull out           |
| 2     | right | HCS        | 32                | 30,742                                 | 25,599                                          | screw pull out           |
| 3     | right | HCS        | 34                | 34,800                                 | 12,190                                          | screw break              |
| 3     | left  | HCS        | 34                | 27,860                                 | 12,185                                          | screw break              |
| 4     | right | CS         | 40                | 30,801                                 | 12,796                                          | screw pull out           |
| 4     | left  | HCS        | 36                | 21,205                                 | 6,103                                           | screw pull out           |
| 5     | right | HCS        | 38                | 81,623                                 | 75,483                                          | intact fixation/SL disruption |
| 5     | left  | CS         | 40                | 40,271                                 | 10,358                                          | screw pull out           |
| 6     | right | HCS        | 30                | 23,831                                 | 23,820                                          | screw break/SL disruption |
| 6     | left  | HCS        | 24                | 36,889                                 | 36,881                                          | screw pull out           |
| 7     | left  | CS         | 38                | 33,001                                 | 13,131                                          | screw pull out           |
| 7     | right | HCS        | 28                | 19,000                                 | 1,219                                           | screw pull out           |
| 8     | left  | CS         | 36                | 21,298                                 | 5,483                                           | screw pull out           |
| 8     | right | HCS        | 26                | 18,915                                 | 15,851                                          | screw pull out           |

CS = cortex screw, Kortikalisschraube; HCS = headless compression screw, kopflöse Kompressionsschraube; SL = suspensory ligament, Fesselträger
The mean cycles to failure were 27,803 for the HCS group (SD = 7,472) and 36,624 for the CS group (SD = 18,854). A mean of 14,444 cycles (HCS group, SD = 11,863) versus 27,464 cycles (CS group, SD = 21,294) was recorded at a fracture gap opening of 10% (Figure 3). The mean of the corresponding failure load values was 3,006 N (HCS group, SD = 930 N) versus 3,931 N (CS group, SD = 1,584 N), respectively. The mean value of initial stiffness was 300 N/mm (HCS group) versus 590 N/mm (CS group), respectively.

None of these differences between the HCS and the CS group was statistically significant (p < 0.05).
On post-testing radiographs, failure by screw breakage was detected in 3/8 limbs of the HCS group and in 2/8 limbs of the CS group. In one specimen (Horse 6, Table 1) of these two cases in the CS group, the lateral branch of the suspensory ligament was ruptured in addition to screw breakage. Screw pullout and bone failure was noted in 5 limbs in each group (ure 2). In one limb of the CS group (Horse 5, Table 1), the medial suspensory branch was disrupted and the fracture fixation was intact.

Discussion

This study did not find significant differences in resistance towards cyclic loading between simulated mid-body transverse fractures of the medial PSB stabilized with either a 4.5 mm cortex screw (CS) inserted in lag fashion or with a 4.5 mm cannulated headless compression screw (HCS). However, fixation with a HCS showed a trend to be less stable and weaker compared to fixation using a CS. The means of initial stiffness, of the corresponding failure load values, of the number of cycles at total failure and of the number of cycles at 10% fracture gap opening were smaller in the HCS group than in the CS group.

Studies comparing biomechanical properties of fixations using the HCS versus a CS under cyclic loading conditions are sparse. A human cadaveric study found no differences between stability of simulated radial head fractures repaired with either a 3.0 mm HCS or a 2.0 mm CS (Burkhart et al. 2010).

In equine orthopaedics, a different headless compression screw (Acutrak) which is tapered and variable pitched was suggested for third carpal bone fracture repair (Bueno et al. 2003), lateral third metacarpal condylar fractures (Galuppo et al. 2001, Galuppo et al. 2006), proximal interphalangeal joint arthrodesis (Walker et al. 2009) and even for repair of midbody PSB fractures (Eddy et al. 2004) based on biomechanical studies that found similar stability compared to that achieved with use of a CS. However, these studies relied on single cycle to failure testing and cyclic loading was not performed. The screws used in these four studies are tapered over their whole length and variable-pitched which represents a significant difference to the design of the HCS screw from Synthes that has a non-tapered shaft. Furthermore, biomechanical testing performed in cyclic fashion as performed in our study is clinically more relevant as it more closely mimicks the clinical situation and results are hardly comparable to single cyclic testing.

Failure by screw breakage was more frequent in the HCS group. This might be attributed to differences in implant design: the HCS is cannulated which reduces the area moment of inertia and thus bending stiffness.

It is interesting to compare the biomechanical loads achieved at failure to the forces present in the in vivo situation. In vivo, the vertical ground reaction force in Warmblood horses has been documented as 7 N/kg (3.5 kN/500 kg) at the walk for forelimbs (Merkens et al. 1988). This is in the range of mean failure loads (3.0 kN for the HCS constructs, 3.9 kN for the CS constructs) achieved in our study. Concerning number of cycles to failure, it is known that healthy horses confined to a box in a new environment make a mean of 4,560 steps in 24 hours (McDuf-fee et al. 2000). This would mean that the mean number of cycles sustained before failure would be reached in 8 days for the CS constructs and 6 days for the HCS constructs, respectively. However, several characteristics of the ex vivo situation during biomechanical testing impair cyclic fatigue life, e.g. the lack of other supporting structures such as the flexor tendons, lack of muscular activity, lack of protection by a cast, and lack of the protective effect of pain.

Our study is not without limitations. Some limitations are associated with the cadaveric nature of the specimen, e.g. lack of muscular activity and changes in tissue properties during limb preparation and storage. Other limitations were introduced with preparation of the limbs to allow installation into the testing machine, e.g. removal of additional supporting structures such as the flexor tendons. Although a standardized technique was used for screw implantation, some degree of variability concerning screw position was present which could influence cyclic fatigue behavior and might explain the high standard deviation in our results. Furthermore, the threadless shaft of the HCS means that interfragmentary compression forces can vary based on fracture location (Patel et al. 2017). The suboptimal fracture fixation detected on pretesting radiographs in the right limb of horse 5 had no negative effect on the number of cycles until failure or until fracture gap opening of 10%. Finally, the limited number of specimens combined with a high standard deviation could lead to a type II error, i.e. erroneous acceptance of the null hypothesis that there are no differences between HCS and CS constructs.

In conclusion, this study did not find significant differences in cyclic fatigue behaviour of simulated midbody transverse PSB fractures repaired with either a HCS or a CS applied in lag fashion. However, the lower absolute numbers of cycles sustained before failure, at 10% gap opening and lower initial stiffness of HCS constructs as well as limitations of the study warrant further investigation before clinical use of the HCS for this indication can be recommended.

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Conflict of interest statement

The authors declare no conflict of interest related to this study.

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400 Pferdeheilkunde – Equine Medicine 35 (2019)
In vitro biomechanical comparison of headless compression versus cortex screws

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Erweiterte Zusammenfassung

Biomechanischer In vitro-Vergleich zwischen kopflosen Kompressionsschrauben und Kortexschrauben für die Fixation von simulierten zentralen Gleichbeinfrakturen beim Pferd

Eine horizontale Fraktur durch den Gleichbeinkörper stellt eine schwerwiegende Verletzung dar und kommt vor allem bei Rennpferden vor. Ein betroffenes Pferd wird reaktiv geschult und kann sich vor allem bei Rennpferden nutzen. Ein betroffenes Pferd wird reaktiv geschult und kann sich vor allem bei Rennpferden nutzen. Ein betroffenes Pferd wird reaktiv geschult und kann sich vor allem bei Rennpferden nutzen. Ein betroffenes Pferd wird reaktiv geschult und kann sich vor allem bei Rennpferden nutzen. Ein betroffenes Pferd wird reaktiv geschult und kann sich vor allem bei Rennpferden nutzen. Ein betroffenes Pferd wird reaktiv geschult und kann sich vor allem bei Rennpferden nutzen. Ein betroffenes Pferd wird reaktiv geschult und kann sich vor allem bei Rennpferden nutzen. Ein betroffenes Pferd wird reaktiv geschult und kann sich vor allem bei Rennpferden nutzen. Ein betroffenes Pferd wird reaktiv geschult und kann sich vor allem bei Rennpferden nutzen. Ein betroffenes Pferd wird reaktiv geschult und kann sich vor allem bei Rennpferden nutzen. Ein betroffenes Pferd wird reaktiv geschult und kann sich vor allem bei Rennpferden nutzen. Ein betroffenes Pferd wird reaktiv geschult und kann sich vor allem bei Rennpferden nutzen. Ein betroffenes Pferd wird reaktiv geschult und kann sich vor allem bei Rennpferden nutzen. Ein betroffenes Pferd wird reaktiv geschult und kann sich vor allem bei Rennpferden nutzen. Ein betroffenes Pferd wird reaktiv geschult und kann sich vor allem bei Rennpferden nutzen. Ein betroffenes Pferd wird reaktiv geschult und kann sich vor allem bei Rennpferden nutzen. Ein betroffenes Pferd wird reaktiv geschult und kann sich vor allem bei Rennpferden nutzen. Ein betroffenes Pferd wird reaktiv geschult und kann sich vor allem bei Rennpferden nutzen. Ein betroffenes Pferd wird reaktiv geschult und kann sich vor allem bei Rennpferden nutzen. Ein betroffenes Pferd wird reaktiv geschult und kann sich vor allem bei Rennpferden nutzen. Ein betroffenes Pferd wird reaktiv geschult und kann sich vor allem bei Rennpferden nutzen. Ein betroffenes Pferd wird reaktiv geschult und kann sich vor allem bei Rennpferden nutzen. Ein betroffenes Pferd wird reaktiv geschult und kann sich vor allem bei Rennpferden nutzen. Ein betroffenes Pferd wird reaktiv geschult und kann sich vor allem bei Rennpferden nutzen. Ein betroffenes Pferd wird reaktiv geschult und kann sich vor allem bei Rennpferden nutzen. Ein betroffenes Pferd wird reaktiv geschult und kann sich vor allem bei Rennpferden nutzen. Ein betroffenes Pferd wird reaktiv geschult und kann sich vor allem bei Rennpferden nutzen. Ein betrof...
Auf den Röntgenbildern vor der biomechanischen Prüfung wurde die Frakturfixation in 15/16 Fällen als gut beurteilt. Ein Exemplar der HCS-Gruppe (Pferd 5, Tab. 1) hatte eine leicht unvollständige Frakturreduktion. Die mediane Schraubenlänge betrug 32 mm in der HCS-Gruppe und 37 mm in der CS-Gruppe. Alle Ergebnisparameter der beiden getesteten Gruppen zeigten eine Normalverteilung.

Die mittlere Zyklenzahl bis zum Versagen der Fixation lag bei 27 803 für die HCS-Gruppe (SD = 7 472) und 36 624 für die CS-Gruppe (SD = 18 854). Ein Mittelwert von 14 444 Zyklen (HCS-Gruppe, SD = 11 863) gegenüber 27 464 Zyklen (CS-Gruppe, SD = 21 294) wurde bei einer Frakturspaltöffnung von 10% ermittelt (Abbildung 3). Der Mittelwert der entsprechenden Fehlerlastwerte betrug 3 006 N (HCS-Gruppe, SD = 930 N) gegenüber 3 931 N (CS-Gruppe, SD = 1 584 N). Der Mittelwert der Anfangssteifigkeit betrug 300 N/mm (HCS-Gruppe) gegenüber 590 N/mm (CS-Gruppe). Keiner dieser Unterschiede zwischen der HCS- und der CS-Gruppe war statistisch signifikant (p < 0,05).

Auf den Röntgenaufnahmen nach der mechanischen Prüfung wurde ein Versagen durch Schraubenbruch in 3/8 Gliedmaßen der HCS-Gruppe und in 2/8 Gliedmaßen der CS-Gruppe festgestellt. In einer Probe (Pferd 6, Tabelle 1) dieser beiden Fälle in der CS-Gruppe war neben dem Schraubenbruch auch der mediale Fesselträgerschenkel gerissen. Schraubenausriss und Knochenversagen wurden bei 5 Gliedmaßen in jeder Gruppe festgestellt (Abbildung 2). Bei einer Gliedmaße in der CS-Gruppe (Pferd 5, Tabelle 1) war der mediale Fesselträgerschenkel gerissen und die Frakturfixation intakt.

Es wurden keine signifikanten Unterschiede zwischen HCS-Gruppe und CS-Gruppe festgestellt. Die Fixation einer simulierten zentralen horizontalen Gleichbeinfaktur mit einer HCS zeigte einen Trend zu geringerer Stabilität bei zyklischer Belastung als die CS. Die Mittelwerte der Anfangssteifigkeit, der entsprechenden Bruchlastwerte, der Anzahl der Zyklen bei Totalausfall und der Anzahl der Zyklen bei 10% Frakturspaltöffnung waren in der HCS-Gruppe kleiner als in der CS-Gruppe.

Zwar wurden keine statistisch signifikanten Unterschiede festgestellt; die deutlich geringer durchschnittlichen Werte in der HCS-Gruppe bezüglich aller Ergebnisparameter sowie Limitationen des Testmodells lassen aber eine eingehendere wissenschaftliche Prüfung ratsam erscheinen, bevor die HCS für die Reparatur horizontaler zentraler Gleichbeinfakturen beim Pferd empfohlen werden kann.

Schlüsselwörter: Gleichbeine, Fraktur, kopflöse Kompressionsschraube, zyklische Belastung, Pferd