Department and Clinic of Equine Medicine
University of Veterinary Medicine Budapest

Ex vivo study of proximal phalanx sagittal fracture fixation with two different screw implants in cadaver horses

By

Márk Balázs Mergl

Supervisor:

Dr.Izing Simon
Department and Clinic of Equine Medicine

Budapest
2022

TABLE OF CONTENT

1. ABBREVIATIONS

P1 - Proximal phalanx
CT - Computed tomography
ESFD - external skeletal fixation device
ORIF - open reduction and internal fixation
DJD - degenerative joint disease
HU – Hounsfield unit
MCP- Metacarpophalangeal
MTP – Metatarsophalangeal
MCIII - 3rd metacarpal bone
MTIII - 3rd metatarsal bone
AP – Anteroposterior
LM - Lateromedial

2. INTRODUCTION

It has become increasingly important in equine medicine to efficiently address fractures or traumas with the least invasive approaches and risks. More often than not, fracture treatments in horses follow the principles used in both human and small animal medicine and so, the innovation used in equine medicine also comes from these areas. In this study, we used bioabsorbable screws, which are a less well-known material in veterinary medicine. The most prominent advantage of these implants is that they provide support during the healing process. Moreover, the screws dissolve completely in carbon dioxide and water. Most importantly, we are able to reduce the number of surgical procedures as they are able to break down in the body at a predictable rate. These key properties prevent the need for further interventions as they do not need to be removed later on, thus also reducing the surgical cost and the risk of possible post-operative septic complications [1].

The proximal phalanx was chosen because the sagittal unicortical fissure or fracture of the P1 is one of the most common types of fractures and cracks in horses. Implant removal is not necessary unless complications and periosteal reactions occur. Incomplete or complete uniarticular fractures originating from the sagittal groove at the metacarpal/tarsal joint are typically repaired using 4.5mm cortex screws. This study intends to focus solely on the possible material innovation in this process [2].

This study compares the biomechanical properties of cortically positioned bioabsorbable and metal screws for proximal phalanx complete sagittal fracture fixation. Samples were taken from 10 cadaveric horses between 2 and 25 years of age, on which we stimulated the surgical therapy, which consisted of internal fixation by screws being inserted in a lag fashion. These implants were selected because, based on our knowledge, absorbable screws have an encouraging chance of being used in equine fracture treatment. In order to prevent the occurrence of inaccurate results and to be able to provide reliable comparative data due to the differences between individuals, we inserted bioabsorbable and metal screws into each forelimb of the same horse. To detect the contingent bone density differences, we applied computed tomography and Hounsfield unit measurements. During the test, steadily increasing pressure was applied to the metacarpal wedge until a 20% drop in resistance was detected, which we considered a fracture. In addition to this, our experiment measured and investigated the maximum applied force (N) and the extent of fracture opening (mm) during compression. According to the given data, we have a better understanding to estimate the usage of these implants in the future.

3. LITERATURE REVIEW

3.1.Principles of fracture treatments

In equine medicine, fracture treatments usually follow the base guideline, which is the same as in both human and small animal medicine. On the other hand, it is important to note that there are anatomical differences as a result of the unique and long bone traumas in horses. Therefore, the clinical significance varies and ranges from exercise-induced fractures causing only minor lameness, such as smaller traumas leading to non weight–bearing disorders. The treatment options available are either non-surgical or surgical, or both, which can be either external or internal [3].

Figure 1- Modular use of aluminium splint suitable for splinting [5]

Following the conservative management of traumas, including the use of external coaptation, non-surgical treatments may be enough for some fractures to heal. In the case of non-severe cases, the fractures are manageable with non-surgical management implementing the use of a bandage alone or stall rest. However, non-surgical management is not the first line treatment of choice for most fractures and so, should not be advocated.

Splints and casts are methods of external coaptation and are the essential elements with this type of treatment (Figure1). Splints are usually used in emergencies and as an intermediate fixation method before transportation. Casts and fibreglass cast materials are the primary treatment techniques used initially in fractures because they are considered as a form of less expensive treatment [4].

Although casts are an efficient and proper fixation technique, they must be carefully applied. Essential to proper conservative management, daily palpation must be carried out and good material choice ensured. According to the weight and breadth of the underlayer tissues, the fiberglass cast has some comfortable advantages. The cast should be changed after 3 to 4 days because, during this time, the initial swelling and bulge decreases, resulting in a loose cast that becomes ineffective at stabilizing. Casts applied to foals should be removed as soon as possible, as it can cause additional damage to the soft tissues. Complications may also arise during non-surgical treatment including, but not limited to; callus formation, which often impinges on soft tissue structures or tendons, skin traumas, infection, or even cast diseases. Cast disease is when the affected part of the leg loses flexibility due to the extended stay in the cast [4].

In the following group, surgical management is the step in fracture treatment [6]. After fractures in horses, osteons become mobilised and move to the affected areas to enable new bone formation and remodel the cortex; however, this process is relatively slow in comparison to other animal species. Due to this, any adjunct treatment that benefits bone healing is advantageous in fracture treatment. The two main fields we can differentiate within surgical management are external and internal fixation[7].

External fixation is more commonly used in human and small animal medicine. However, in the case of some severe comminuted fractures, when the anatomical use of the internal fixation is not attainable, the external fixation technique can be implemented. Using pins, transfixation allows a more even distribution of weight on the affected limb, and in turn will contribute towards the prevention of support limb laminitis. The transfixation cast is a half limb cast which includes the hoof and reaches the line of carpus and tarsus. Following cast removal, the application of a paper-cotton Robert-Jones bandage for an additional month is recommended, which should be replaced every 3-4 days. If the cast causes a break in the skin on the limb, it is necessary to change the bandage more often. External fixation and transfixation pin casting became a popular technique in the early 1990s. This treatment approach proved efficient and is indicated for comminuted fractures of the phalanges; however, the external skeletal fixation device (eSFD) was developed for fractures of the distal MCIII/MTIII, and breakdown injuries of the MCP/MTP joints. [8].

Based on surgical literature, the most common intervention in fracture treatment is internal fixation. The procedure is carried out through a stab incision or through an opening in the skin over a greater distance, followed by the separation of the soft tissues surrounding the fractured bones, called open reduction and internal fixation (ORIF). Depending on the fracture conformation and severity, both incision methods can be used in equine fracture treatment.

The prognosis of a simple P1 fracture or fissure is relatively good in most cases (76.7%) and these horses can return to training[9]. On the other hand, in the case of P2 fractures, where two joints are simultaneously affected, and arthrosis commonly occurs, the prognosis is even worse. Minor lameness is predicted and these horses usually cannot return to the sport. The worst prognosis is in the case of comminuted fractures, where the priority lies with saving the animal's life. Due to the significant arthrosis of each joint, a career in sport is almost impossible.

Depending on the instruments and implants used, internal fixation is a massive and complex discussion. Regardless, we concentrate on the most widely used procedures, such as lag screw fixation[4].

3.2. Lag screw fixation

In the early and mid-20th century, compression in rigid internal fixation was recognised as an essential solution to fractures. Rigid internal fixation became more critical in order to reach the early full function of the fractured limb and to enable fast healing. Based on surgical literature, the most common intervention in fracture treatment is internal fixation. Procedures are achieved through a stab incision or through opening the skin over a greater distance, followed by separation of the soft tissues surrounding the fractured bones, called open reduction and internal fixation (ORIF). Depending on the fracture type, both methods can be used in vivo for P1 fracture operations [10].

The origin of the lag technique comes from and is implemented routinely by engineers. The lag screw technique in equine surgery is generally performed using cortical bone screws instead of lag screws. This method suits the intra-articular fracture fixation of horses, where the correct anatomical position is critical to avoid secondary degenerative joint disease (DJD). Various fractures are amenable to lag fixation, including: sagittal fractures of the proximal and middle phalanx, mid-body fractures of the proximal and distal sesamoid, and pedal bone, and standard solvation of the distal condylar fractures of the third Mc/Mt bones. Lag screws are often used in combination with bone plates to repair main long bone fractures. In the repair of comminuted fractures, the fragments are fixed with lag screws before involving a neutralization plate or plates. Especially in the case of racing horses, it is essential for the bones to heal completely following orthopaedic surgery [11].

The lag screw technique compresses the fracture fragments by threading them into the far cortex while gliding through a hole in the near cortex. During tension, the screw presses the screw head against the near cortex, resulting in fracture contraction.

The lag screw technique is used to fix slab or more diminutive sagittal fractures of P1 and third metacarpal bones. To prevent rotation, the use of two screws are recommended as they directly support the joint surface's proper position and aid faster healing. Lag screws are often used as a combined method in major fracture repairs, and in just a few cases, operated alone. This complementary technique is used to repair long, spiral, oblique fissures or fractures, which can primarily be fixed in this way before involving the neutralization plate or plates[11].

Two types of screws are available for the lag technique, including the cortical bone screw, and the cancellous screw. Differences in conformation may arise with regards to the position of multiple screws[12]. A cancellous screw is a true lag screw with a non-thread portion made for this procedure. The sizing varies within each type, but most commonly the 4.5mm is used, however, sometimes the 3.5mm, or the 5.5mm diameter cortical screws are indicated. In the case of softened bone structures, 6.5mm cancellous screws are most commonly used (Figure 2.)[13].

Cancellous Bone Screw

Cortical Screw

Figure 2 – Two main screw types [12]

The principle of the lag screw, is that the thread of the screws must always find support in only one bone fragment (Figure 3). The screws are inserted into the bone through drill holes. When using cortical screws, the *over-drilling* technique is used to make such a hole size that the screw thread will not gain purchase on this portion of the bone. This portion is called the *glide hole* because the threads of the screw do not engage with the bone in the cortex. The outside diameter of the drill sleeve is the same as the glide hole. Insertion of this drill sleeve provides concentric drilling of the trans-cortex. The hole drilled through this sleeve across the trans-cortex is referred to as the *threaded hole*. To achieve a greater contact area between the screw head and the bone, a depression is created near the cortex using a *countersink*. This decreases the stress between the bone and the screw head and in turn provides proper seating for the head. *Countersinking* is exceptionally important in screws inserted at oblique angles relative to the bone surface (Figure 3).

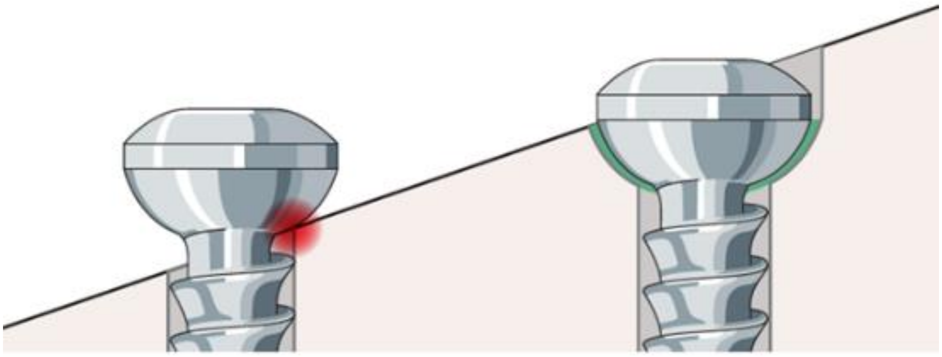
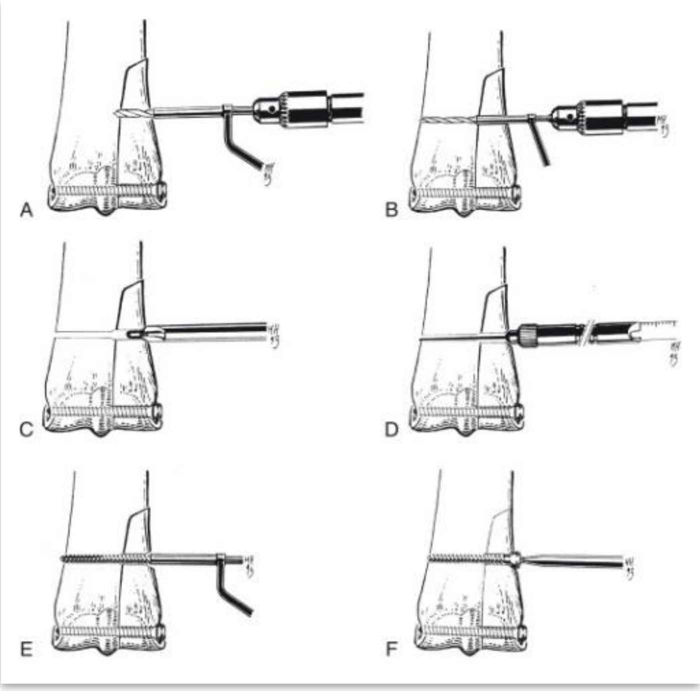


Figure 3 - Stress concentration at the bone-screw interface and the proper sitting with countersinking [13]

The *depth gauge* is used to determine the total length of the screw, including the head. The depth gauge has a small hook at the end of its thin shaft, which is inserted into the *thread hole*. By tilting the instruments, the hook catches the opposite cortex, and by sliding the movable portion towards the *countersink* depression, the exact length of the screw is determined. The tap is inserted through the *drill sleeve* into the *glide hole,* and the threads are cut into the *thread hole*. The tap sleeve protects the surrounding soft tissues and guides the instruments. The threads are cut by advancing the tap three half-turns clockwise and one half-turn counterclockwise. This counterclockwise motion helps to transport the swath materials from the thread hole. Once the hole has been tapped, it is necessary to flush and clean out swath debris from the area and lubricate it. Insertion of the screws using a hexagonal-tipped screwdriver or power equipment decreases the time of surgical procedures; however, the final tightening is always carried out by hand.



The cis-cortex is overdrilled. (B) The insert drill bit is placed into the glide hole and advanced past the fracture plane, and the concentric thread hole is drilled across the trans-cortex. (C) A depression for the screw head is prepared with the countersink. (D) The required length of the screw is determined with the depth gauge. (E) The threads are cut into the thread hole with the tap. (F) The screw of predetermined length is inserted and solidly tightened with the hexagonal-tipped screwdriver

Figure 4-Steps of the lag fashion surgical technique [4]

3.3. Repair of a sagittal fracture of P1

The sagittal groove corresponds to the most common site for fractures in equine P1[14]. Fractures of the proximal phalanx are usually seen in the case of strenuous activities such as racing, trotting, western performance events, racing, and jumping. These fractures are longitudinal with various configurations, ranging from hair-like fissures to severe comminuted fractures with many pieces but they are rarely open[15] (Figure 5).

The clinical signs observed during proximal phalanx fractures varies independently of their severity; however, severe non-weight-bearing lameness is the present majority of comminuted fractures. In some longitudinal fissures, despite only subtle lameness being observed, it may develop into a more complicated configuration under regular weight-bearing. The animal usually instinctively protects its limb when experiencing pain, however, the use of a large, tight-fitting pressure bandage or compression boots for emergency transport is necessary[10].

Figure 5- Short longitudinal fissure of the P1

Surgical techniques include stab incisions, although more than two screws are inserted. Most commonly, stab incisions are performed on the medial or lateral side of the P1, but a more dorsal approach is indicated for fractures with a configuration that runs in the more frontal plane. Essentially all of these sagittal fractures originate in the centre of the sagittal groove[16]. Additionally, at least four (AP, LM, and two obliques) radiographic views are required when this technique is adopted.

During lag fixation, the main goal is to place the screws in a way which ensures the maximum resistance to shortening and maximal compression of the fracture. During the insertion of screws placed perpendicular to the fracture plane, the horses are subjected to shear force during weight bearing. The screw nearest to the fetlock joint is usually inserted first at the appropriate position on the bone[10].

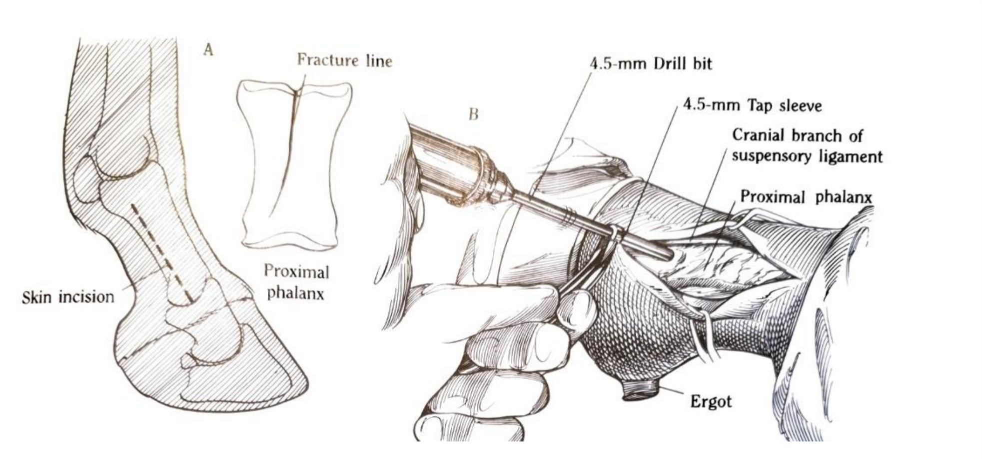


Figure 6- Steps in lag screw fixation of a sagittal fracture of the proximal phalanx[10].

The distance of the fracture site should be measured using radiographs prior to the procedure because the configuration dictates both the screw number and placement. In fissure fractures which are less displaced, it is more difficult to feel when the 4.5-mm drill bit reaches the fracture line. In these cases, it is important to avoid reaching the opposite cortex with this drill because of the holding power of the cortical screws[10].

Nowadays the implementation of radiographic monitoring of the drilling procedure during surgery is essential, as in the case of a fracture in the cleft bone, it is not possible to see with certainty whether the dorsal or palmar cortex is affected. In the case of multiple fractures of the bone, a CT scan allows for a more accurate diagnosis, and so, with its help it is possible to achieve more precise screw insertion. During the operation, intraoperative digital X-rays and C-arm fluoroscopy help to determine the exact position of the drill and screw.
Constant cleaning of the 3.2-mm drill bit will ensure that the small bone pieces and debris do not reach the other side of the bone, which may later lead to complications (Figure 14). It is important to prevent over-counting sinking the holes in the bones because the screw heads can pull through the soft bone and thus, lose their holding power. Following this, the hole depth is measured carefully to avoid the attachment of soft issues and produce an inaccurate long implant. Tapping is done with a 4.5-mm tap sleeve which is removed as the tap emerges from the opposite cortex[10] (Figure 4).

The first screw tightens completely after the following screws are inserted to provide the proper configuration of the fracture (Figure 16). The standard method recommends three radiographic views before the skin incisions are closed[10].

3.4. Postoperative management and complications

Postoperative management of the proximal phalanx includes placing a cast up to the top of the third metacarpus or metatarsus until recovery. Robert Jones bandages or compression boots are alternatives which may be used. Due to the high torsional forces, in some cases, comminuted fractures, long-term casts, and compression boots are recommended for an extended period of 2-3 months. Radiographic diagnostics methods allow for the continuous monitoring and evaluation of the healing process, as well as the degree of DJD. Generally, the prognosis after P1 fracture treatments is good when fresh, although diminished performance has been reported, and return to exercise is subjective and depends on the individual. If radiographic evidence proves successful healing, further postoperative management methods will include hand-walking after 4 weeks, turning the horse out into a small paddock after two months and training three months after surgery [7].

Following orthopaedic procedures, support limb laminitis is a complication which occurs as a result of excessive unilateral weight-bearing in adult horses. This condition can occur in the contralateral limb in horses with significant lameness in the opposite forelimb or hindlimb. However, it is unusual for any foot other than the contralateral foot to be affected, suggesting that support limb laminitis is a local pathological process within the digit which is highly influenced by the mechanical overload of the limb[17].

One of the most common complications is wound infection at the surgical site, which is an ever-present threat, regardless of the duration or the type of the surgery. Even the surgeon's experience is independent of the overall effect on the patient. Nevertheless, the high cost of wound infection treatments is as a result of extended hospitalisation, additional bandages, and antibiotics. Furthermore, the source of client dissatisfaction is often the result of wound infection after procedures, and so, the prevention of postoperative infection is crucial. The infection rate of clean wounds approximately doubles with every hour of surgery, therefore, one of the main methods of prevention is to reduce the operating time. Additionally, tissue handling has proven to be greatly associated with the risk of clean wound infections due to the subsequent serum formation, hemostasis, and inadequate debridement. Even simple precautionary measures such as the double glove technique should not be underestimated and should be used in all orthopaedic surgeries due to an increased risk of perforation. Furthermore, the surgeon's experience and the appropriate number of assisting staff aid in greatly reducing the incidence of postoperative complications. An appropriate and sterile surgical room, gown-over-scrub clothes should the basis of any modern equine practice. The frequency and extent of complications are reduced by using the appropriate tools and instruments, and implementing appropriate hygiene measures [18].

Foreign materials of any kind during surgical or conservative procedures potentiate infection, including suture materials or screw implants; therefore, the type of these materials can also influence the occurrence of postoperative infections. The use of antibiotics must be carefully considered, as their use is still considered to be questionable in some fields. According to literature, surgeons give antibiotics before contamination, during procedures, and most commonly postoperatively as a basis of postoperative care. Further studies on the clean wound infection topic suggest that there is no significant difference between perioperative antibiotic-treated and control patients[18].

"*Overall, there was no significant difference in the development of post-surgical complications between treated and control horses (p = 0.5). Completely uncomplicated healing was observed in 162/259 (62.6 %) antibiotic-receiving horses and in 235/393 (59.8 %) controls. On the other hand, 97/259 (37.5 %) horses with antimicrobial prophylaxis and 158/393 (40.2 %) control developed complications during the healing process. Neither was significantly different between the groups the character of complications*[19]."
To conclude, decreasing the number of surgical interventions may be the most beneficial method in reducing the risk of postoperative infections. With this knowledge, we can assume that bioabsorbable implants are suitable for this task because it is not necessary to remove the screws or perform further operations.

3.5. Hounsfield unit measurement

The Hounsfield unit (HU) is a relative quantitative measurement of radio-density used by radiologists to interpret computed tomography (CT) images.

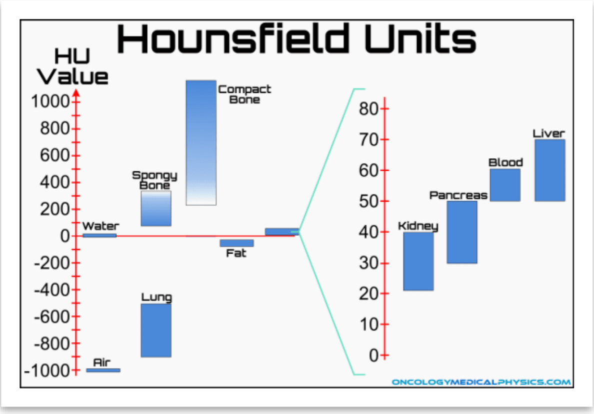


Figure 7-HU scale[20]

The radiation absorption/attenuation coefficient within a tissue is used during CT reconstruction to produce a grayscale image. This results in a scale running from -1000 HU for air, to +~2000 HU for very dense parts of a bone, such as cochlea (Figure 5). Several studies dealing with the possible use of Hounsfield unit during orthopaedic surgery have concluded: "HU value measurement is a simple and rapid technique to assess bone quality that should be performed in all patients with pre-existing CT scans. HU measurement has excellent inter and intra-rater reliability and can be performed on axial or sagittal images.[21] ",,Knowledge of the Hounsfield value as a quantitative measurement of bone density can be helpful as a diagnostic tool. It can provide the implant surgeon with an objective assessment of bone density, which could result in modification of surgical techniques or extended healing time, especially in cases where poor bone quality is suspected[22]."

3.6. Bioabsorbable and metal screws

The Syntes 4.5 mm metal screws have long been a mainstay of the equine orthopaedic surgeon's armamentarium. Regardless, despite the availability of stronger Synthes 5.5-mm standard cortex screws, 4.5-mm traditional cortex screw use continues to have many indications in equine fracture repair[23].

Bioabsorbable screws came into human medicine approximately 30 years ago, and their development is still ongoing. In human scientific literature, many studies have been performed in the comparison between metallic and absorbable screws, although not many articles or studies have been written about equine surgery[24]. These screws are made from poly L-lactic acid (PLLA) and are absorbed by the body and converted into carbon dioxide and water. Bioabsorbable materials have many useful advantages however, further research and investigations need to be performed in order to find their proper field of use[25]. These implants are becoming more frequent in veterinary medicine[26].

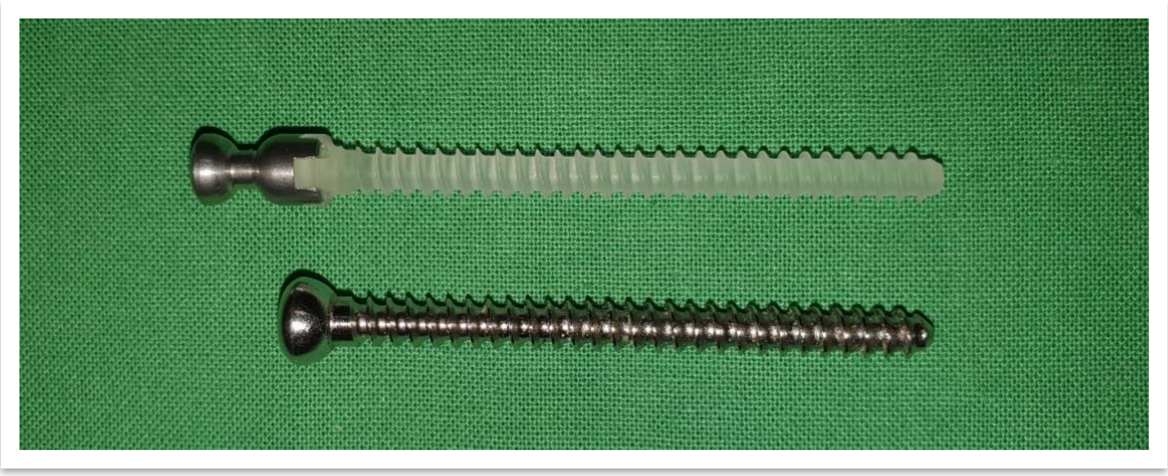


Figure 8- 4.5mmx55mm FreedomScrew and Sythes implants

Among other bioactive implants, we can find composite systems comprised of inorganic fibers or particles and organic polymers, which can be further divided into the following three classes:

a.) both non-bioresorbable reinforcing and matrix components
b.)bioactive particles for reinforcement with a non-bio- reservable polymer
c.) bioactive but not resorbable reinforcing components with a bioresorbable matrix.

This study focuses on one special product, INION FreedomScrew®, INION Core Technology®, and its properties.

"*Inion's core biomaterials technology, Inion® Polymers, represents a range of proprietary biodegradable biomaterials with great potential for use in medical implants that enhance the healing of bone or soft tissue injuries to the skeleton. A key benefit of Inion® implants is that they provide support during the healing process, prior to safely and completely degrading into carbon dioxide and water at a predictable rate in the body. Inion FreedomTM is the only full biodegradable system with both plates and screws. Inion FreedomPlateTM and Inion FreedomScrewTM together form a resorbable locking plate system, which is unique of its kind*[1]."

Studies carried out on the strength of these implants concluded that they were adequate for demanding orthopaedic fixations, even in some areas of equine medicine. The use of these implants is as simple as using a metal screw for insertion, because they are delivered with a disposable metallic adapter compatible with most of the universal instrumentation used in veterinary hospitals worldwide: ISO, ASIF, and AO. In addition to this, the unique and innovative benefits of their properties include being able cut the material to fit the required length during surgery. This property is extremely beneficial as it can aid in shortening the duration of surgical procedures.

Figure 9- Radiological image after screw insertion, radiolucent FreedomScrew on the left

Additionally, these implants are radiolucent, meaning that the surgical interventions are almost imperceptible independent of biodegradation (Figure 9). The advantage of this is mainly evident in young animals and those destined for resale. Nevertheless, the most prominent benefit is the absorption itself, and the lower risk of wound infection, which would otherwise arise from any subsequent interventions required [1]. Further studies are needed, however, bioabsorbable screws offer a promising alternative in the treatment of fractures, and may potentially be used for other orthopaedic surgical treatments as the next-generation material[27].

4. AIM OF RESEARCH

This study aimed to establish an ex vivo model of horse metacarpal and proximal phalanx bones to simulate the usage of two different screw implants. In addition to this, they were used to estimate the potential future practical uses of the bioabsorbable screws in "in vivo" procedures. A further goal is to compare the biomechanical properties of the INION FreedomScrew™ and the metal cortical (Synthes) screws' pullout strength.

Our model comprises of twenty 15cm long metacarpals and twenty corresponding proximal phalanx bones with an inserted metal or bioabsorbable screw. Each measurable unit was a pair of front legs, which the teams divided into subunits of, the right and left legs. The units were numbered 1-10, while the subunits were always (a, right) and (b, left). All the units contained one metal and one bioabsorbable screw in the P1, but always randomly chose the right or left leg for each to investigate efficiency differences of the implants.

For this purpose, we put them on the biomechanical compression test to investigate their properties. The test was applied until a 20% drop was detectable in terms of resistance, which we considered to be when the screw was pulled out. Following this, we investigated the given data to create a simple and paired T-test and analyzed the differences between the measurement units. With this comparison, we could observe the advantages and predispose the potential future usage of these implants.

5. MATERIALS AND METHOD

5.1. Instruments and chemicals

Chemicals: MR 3010/MH3124 (100:33) epoxy resin, Bradolin,

Instruments and devices: Zwickk Z250 is a computer-controlled universal material testing machine,

TC-SB 200/1 Band-saw – Einhell,

Canon Aquilion TSX-201A Computed Tomography

Scalpel blades, scissor, and forceps

Mercury Monet 3D DIC (Sobriety, Kurim, Czech Republic)

Synthes Cortex Screw Ø 4.5 mm, self-tapping, length 54 mm, stainless steel

INION FreedomScrew Ø 4.5 mm 55mm bioabsorbable co-polymers composed of L-lactic and D-lactic acid.

Instruments required to lag fixation:

Synthes Compact Air Drive II
Synthes 3.5 mm and 4.5 mm Drill Bits, Quick Coupling,
Synthes 4.5/3.2mm Double Drill Sleeve,
Syntes 4.5mm tap sleeve,
Synthes Countersink
Synthes Depth Gauge,
Synthes tap for cortex screws 4.5 mm
Synthes Hexagonal Screwdriver

5.2.Preparation of the bones of carcasses

Preparation of the cadaver legs began in a room temperature laboratory 12 hours after taking the forelimbs out of the fridge. The horses in this research were euthanized in the Department and Clinic of Equine Medicine and had no orthopaedic diseases. For this stage, we were confident about the dissection method and did not alter what we had applied to previous studies (Figure 8).

Figure 10- Steps of the removing the soft tissue, melting the labeled legs at room temperature (left), dissection (middle), and bones needed for the experiment (right).

5.3.CT scan and Hounsfield unit measurement

In order to ensure that the right and left legs had a similar bone density, the bones were subjected to a CT scan (Figure 11).

Figure 11- Preparation of CT scan

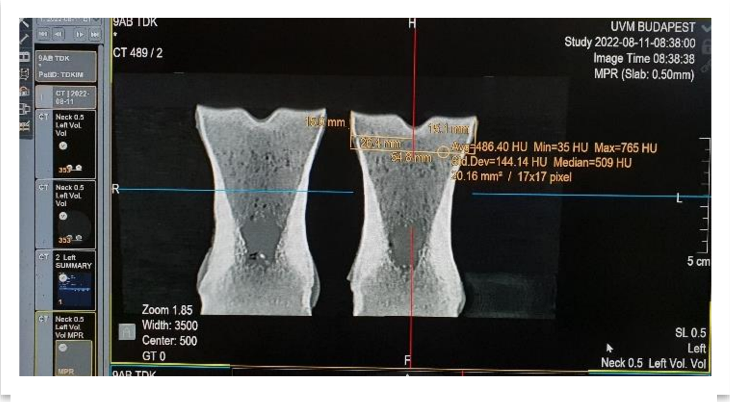


Figure 12- Lateral parasagittalis HU measurement of the left P1

Using these images, we could apply the Hounsfield unit measurement. The HU measure took place at the cross-sagittal section, which is the area where the screws were supposed to be inserted (Figure 12). At each bone, the 20mm2 observation units were taken from 3 different regions (sagittal and two parasagittal).

5.4.Sagittal cuting

Following skinning and CT scans, the bones were immediately labeled and stored in the fridge until the insertion of the surgical implant (Figure 13). A longitudinal cut was performed with a band-saw, making sure the cut remained along the central line of the bones (Figure 14).

Figure 13- P1 bones after labeling

Figure 14- P1 with an applied sagittal cutting

For the 10mm thread, rods were inserted into the piece of the metacarpus, and a suitable hole was drilled lengthwise. Anchoring was achieved with epoxy resin and 15 cm long thread rods, which were drilled into each metacarpus in order for them to be used for clamping/fixation in the biomechanical pressure machine (Figure 15).

Figure 15 – Band-saw and the 10 pairs of P1 with the corresponding metacarpus

5.5.Simulation of the surgical procedure

In the third phase, we simulated the surgical fixation using a lag fashion method. Simulated fractures were repaired with the application of 1 lag screw at a 4 Nm insertion torque, as observed in an in vivo operation (Figure 15). Before drilling, we fixed the two fracture ends with large pointed reduction forceps, just like in clinical cases. The 4.5-mm over-drilled *glide hole* was subsequently drilled in the (cis) cortex, just 15 mm ventral to the proximal articulation (Figure 17).

Figure 16 – 3.2 mm drill cleaning

Figure 17 – Screw insertions by Dr.Izing Simon

The process was followed by inserting a 3.2-mm drill sleeve and creating a 3.2-mm *thread hole with the* help of a 3.2mm tap, as the thread cut would cut the bone evenly everywhere. After *countersinking*, the length of the screw was determined with the depth gauge and the 4.5-mm cortical bone screws were inserted. Thus 2 different preparations were made for the two types of screws: Inion FreedomScrews and Synthes metal screws. The insertion of the metal and bioabsorbable screws were done randomly for each pairs of the legs.

Figure 18- Screw insertion with hexagonal-headed screwdriver

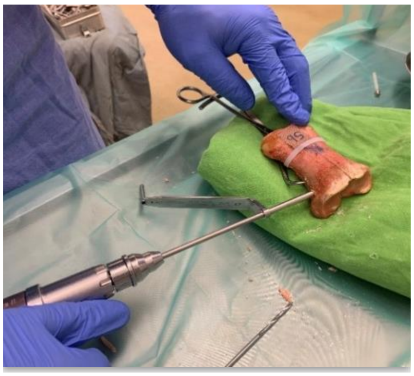


Figure 19 – Drilling of the 4.5mm glide hole

5.6.Resin embedding

During embedding, each P1 sample was evenly placed in 10mm Ipox MH 3124 / MH3124 (100:33) epoxy resin. For the vertical positioning of the bones, a vertical spirit level was used in each case.

5.7.Biomechanical fracture test

Mechanical tests were carried out in an accredited laboratory of the Department of Polymer Engineering at BME on calibrated equipment. The load was exerted by a universal load machine of the Zwick Z250 (Zwick, Ulm, Germany) type, equipped with a force cell with a measuring limit of 20 kN. The opening of the fracture was observed using Mercury Monet 3D DIC (Sobriety, Kurim, Czech Republic) optical strain measurement using full-field digital image correlation technology (Figure 20).

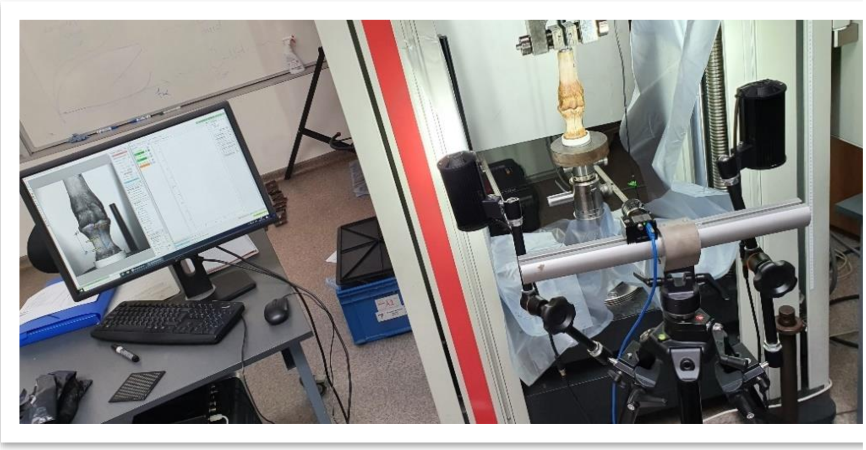


Figure 20- Coordinated operation of the camera and the tensile machine during the compression test.

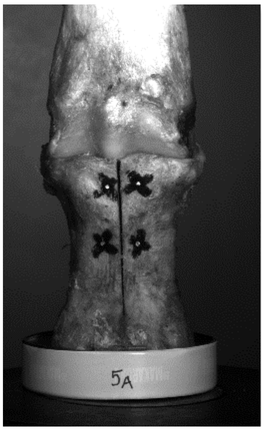


Figure 21- P1 fracture opening at the moment of the maximal applied force.

The measurement speed used was 20 mm/min (cross-head speed), and the data collection frequency used was 10 Hz. We used the prepared metacarpal bone part as a wedge. During the test, steadily increasing pressure was applied to the metacarpal wedge until a 20% drop was detectable in terms of resistance, which we considered a fracture (Figure 21).

5.8. Statistical analysis

For statistical analysis of the data, R 3.3.2 software was used from the measurements. The paired T-test was observed according to the maximum applied force and opening the fracture.

6. RESULTS

Ten left, and ten right forelimbs from ten different breeds and ages (2-25) of horse cadavers (three mares, three stallions, and four geldings) underwent fracture creation and repair. The average weight (±SD) of the horses was 522.4 kg (±25.22). All bioabsorbable and metal screw insertions, and repair constructs were successfully placed in 20 legs; however, the 3rd and 10th specimens gave us non-evaluable data, and so, those two specimens were disregarded (Table 1).

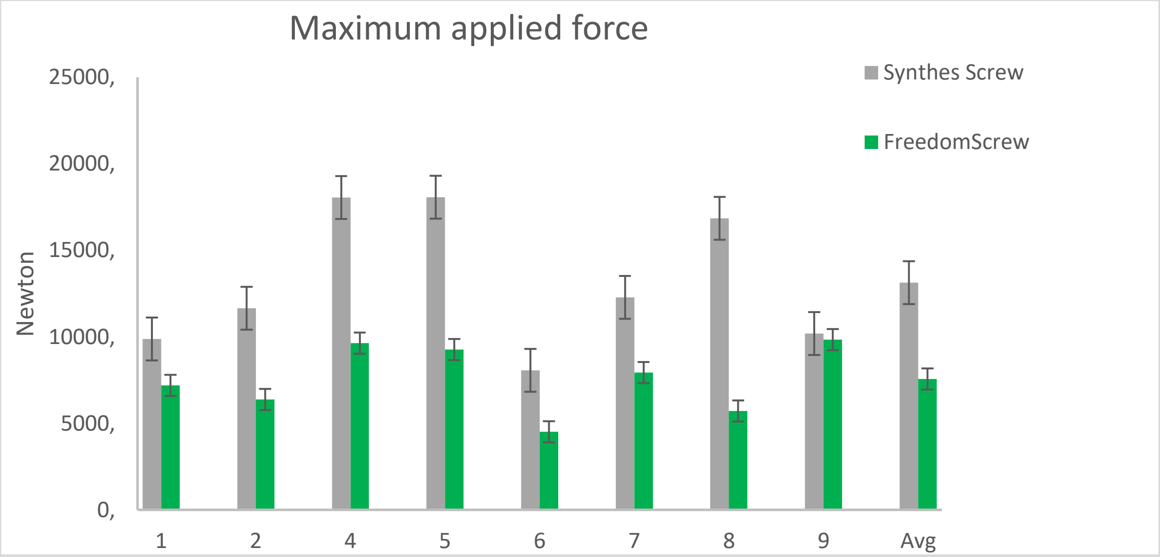


Table -1 differences between screws according to maximum applied force.

Based on statistical analyses, we can determine that the average pullout strength of the bioabsorbable screws is 61.71% (7895.24 N) compared to metal medical screws. Thus, this 805.1 kg value is a clinically acceptable high number; therefore, the use of these implants is promising in equine medicine. According to 8 pairs of legs' maximum strength data, we found a significant difference between the metal and bioabsorbable screws' pullout strength (Table 2). The paired T-test shows t = 3.0259, df = 7, where the mean difference was 4899.73 N (*499.63kg*). Due to the observed p-value = 0.01922, the difference is considered statistically significant, and the metal screws are superior according to absolute mechanical strengths.

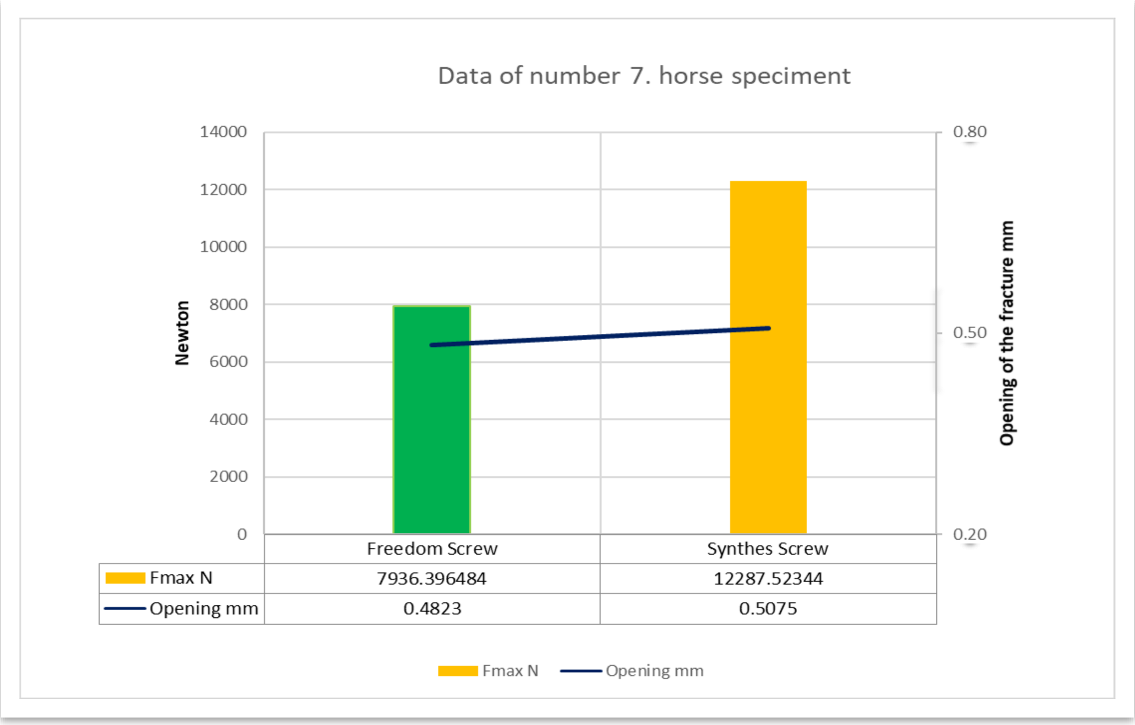


Table 2 – The sequel of horse number seven best characterize the results obtained in the entire research.

During these biomechanical compression tests, we measured the opening of the fracture (mm) in each examination (Figure 23). As a result, the opening dimensions can be the same in both cases, t = 0.013849, df = 7, p-value = 0.9893, and the mean difference was *0.004311 mm*. After this investigation, we concluded that the opening of the fractures is exact; however, the bioabsorbable screws are significantly inferior but clinically acceptable at the maximum strength.

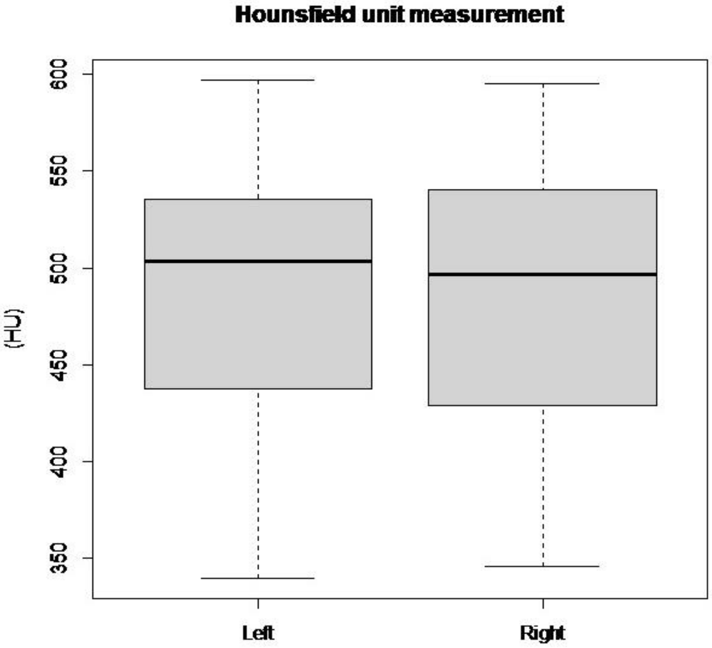


Figure 22 - HU differences between legs

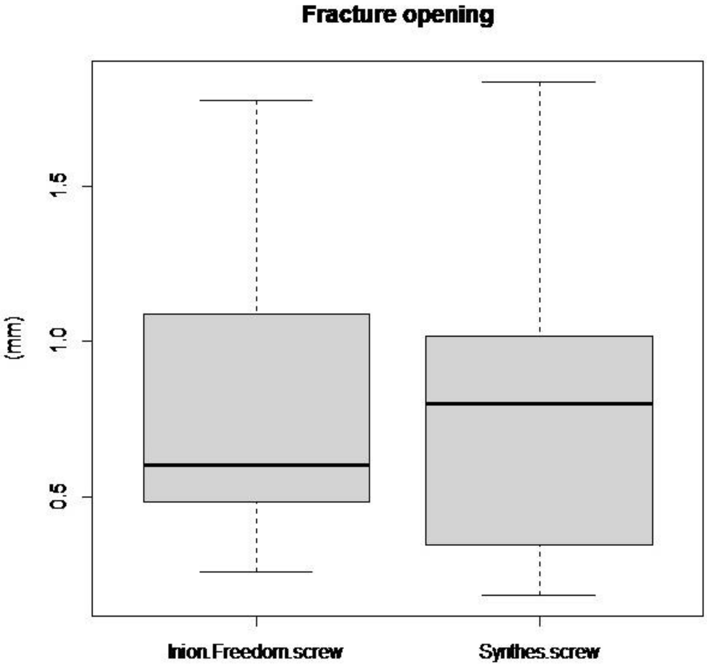


Figure 23 - Opening contrasts in fractures

To ensure that the right and left legs have a similar bone density, the bones were subjected to a CT scan, and a Hounsfield unit (HU) measurement was applied (Figure 22). According to the paired t-tests data,: t = 0.39875, df = 9, p-value = 0.6994 mean difference = 4.203333, no significant differences were found between the right and left legs, where the mean HU was 487.24 for the left and 483.04 for the right limbs.

7. DISCUSSION

Fracture fixation with cortical lag screws, is a typical procedure carried out as a form of fracture treatment in horses. This procedure is often employed to treat longitudinal cracks and fractures of the bones or to stabilize individual fractures during plate osteosynthesis. Since so far only screws made of medical steel have been used, in our experiment, we investigated whether absorbable screws can also be used for this purpose with this indication. We saw the advantage of absorbable screws in that we do not need a second surgery to remove the implant, thus reducing the risks associated with general anaesthesia, as well as the costs associated with a second surgery. In addition to this, in cases where it is necessary to remove the screw a couple of months after drilling the cysts in the bone, which is usually carried out near the joint surface, this second intervention can be avoided with the application of these absorbable screws.

Nevertheless, in order to use these implants safely, we needed to perform a basic test to determine the resistance of these absorbable screws on the horses' extra-stressed bones. After all, if the tensile strength of these implants is insufficient, then their use in equine medicine in clinical conditions is questioned. Therefore, in our experimental study, the sagittal fracture of the P1 bone was fixed on the right and left forelimbs of 10 horses with ten metal and ten bioabsorbable screws, where the comparative fracture tests were performed up to an average load of approximately 805 kg.

Based on our results, the bioabsorbable screws could withstand a large amount of resistance. This weight load leads us to conclude that they can be used with sufficient safety in horses with smaller body weights, foals, or in cases where the screws do not have to withstand forces corresponding to the total body weight of an adult horse (drilling bone cysts). After all, with metal screws, we obtained an average load maximum of 1282.8 kg, while with absorbable screws, we acquired 61.71% of this value, where the load maximum was 805.1 kg. However, there was no significant difference in the degree of fracture opening, and both implants showed a fracture opening average of 0.8mm. Therefore, absorbable screws behaved similarly to the metal screws, and they could be used to exert sufficient forces during the compression of the edges.

The screws did not break, possibly because they required more careful insertion, but even the screw heads fit comfortably into the cortical bone. The most commonly used AO equipments were: the bore diameter, thread profile, and tap pitch, which perfectly matched the absorbing screws. [28]. Radiological control of these implants is complicated, but MRI is suitable for this purpose. However, in intraoperative images, the screws are not visible, unlike the screws made of metal, and so their precise control, based on the x-rays, requires other additional methods.

The limitation of the experiment is the number of limbs, since more accurate results could have been presented on a more significant number of elements, although based on the values obtained, the study proved successful.

The data obtained during the process of maximum pressure and fracture opening were subjective, because for the paired T-test we used a statistical program called R. During the pressure test, we can say that significant results were obtained based on the difference in maximum pull-out strength. (4899.73 N, t = 3.0259, df = 7, p-value = 0.01922.) While the test of the degree of the opening shows us no differences (t = 0.013849, df = 7, p-value = 0.9893, difference = 0.004311 mm), we can say that significant results were obtained with this number of elements.

It would also be worth attempting the use of absorbing screws in actual clinical cases, so there is a clinical experience on the subject. Another limiting factor may be the price of the implants, as it is currently several times higher than the cortical screws, which are made of routinely available medical steel. However, once we consider the additional surgical costs associated with removing implants, and consider the risks associated with additional anaesthesia and awakening in horses (myopathy, catastrophic fractures during recovery), the advantages may outweigh the economical setback. This is a new option for the surgical procedures of bone fractures in horses in appropriate cases.

8. ABSTRACT

In equine medicine, surgical procedures and implants have been significantly developed in the last few decades. In this paper, we will deal with tensile screw fracture treatments. Horse fracture treatments most often follow human and small animal principles, so in general, their innovation also comes from these areas. Therefore, absorbable screws, which are already used in human medicine, also raise the possibility of their use in equine medicine. Among other things, these screws reduce the number of surgical procedures since the implant does not need to be removed later, thus reducing the cost of surgery and the risk of possible septic complications[29].

This study aimed to compare the biomechanical properties of the INION FreedomScrew™ and the metal cortical (Synthes) screw's pullout strength. During the experiment, an artificially formed sagittal fracture of the P1 bone of 20 anterior limbs of 10 cadaver horses was drilled and fixed with ten metal and ten absorbable screws. During the execution of the experiment, we randomly selected which of the two P1 bones belonging to a particular horse should use metal, and which should use a bioabsorbable cortical screw. The parameters of all 20 screws used were the same regarding thread angle, major diameter (4.5mm), and pitch; only the material was different (Figure 6).

In all cases, the screws were inserted by surgeon Dr.Izing Simon, following the rules of the cortical screw in a lag fashion. Each specimen was embedded in 10mm epoxy resin to make it suitable for the test. In the interest of reliable pressure testing, we used the corresponding metacarpus for each P1 bone as a wedge. Biomechanical pressure tests were observed with the same equipment each time; the Zwickk Z250 is a computer-controlled universal material testing machine for tensile tests. During the test, steadily increasing pressure was applied to the metacarpal wedge until a 20% drop was detectable in terms of resistance, which we considered a fracture.

Our experiment measured and investigated the maximum applied force (N), deformations, and the extent of fracture opening (mm) during compression. Based on our results, the bioabsorbable screws could withstand a large amount of resistance. However, based on the data collected, their use looks more promising for foals or interventions subjected to a lower

load. At the same time, these implants reduce the number of surgical procedures since there is no need to remove implants later, and so the risk of septic complications or irritation of permanently inserted screws by their absorption over time is reduced. These listed benefits are essential for surgical interventions in equine medicine, especially for foals and sports horses. Overall, we can say that with this examination, it can be proved that absorbable screws have an encouraging chance of being used mainly for the treatment of partial or minor fractures in foals or transcortical drilling of cysts[30].

9. ÖSSZEFOGLALÁS

A lógyógyászatban az elmúlt évtizedekben jelentősen fejlődtek a sebészeti és belgyógyászati eljárások. A 20. század elején és közepén a merev belső rögzítésben való összenyomást a törések alapvető megoldásának tekintették. A merev belső rögzítést kritikus fontosságúnak ismerték el a törött végtag teljes működésének eléréséhez és a gyógyulás felgyorsításához. Ebben a tanulmányban a töréskezelésre és a mozgásszervi traumákra összpontosítunk. A belső rögzítés és a csavar eltávolítása utáni posztoperatív szövődmények eltérőek lehetnek habár a ló töréskezelése leggyakrabban a kis állati és emberi elveket követi, így általában az innováció is ezekről a területekről származik. Ezért a felszívódó csavarok használata, amelyeket a humán gyógyászatban már elismertek, a lógyógyászat további fejlesztésének lehetőségét is felveti. Ezek a csavarok többek között csökkentik a sebészeti beavatkozások számát és a fertőző szövődmények kockázatát.

Ennek a tanulmánynak az volt a célja, hogy összehasonlítsa az INION FreedomScrew™ felszívódó csavarok és a fém kortikális csavarok kihúzószilárdságát és biomechanikai tulajdonságait. Ebből a célból húsz szimulált P1 sagittalis törött csontot használtunk a cadavers-ből 10 párban, tíz bioabszorbeálható és tíz fémcsavarral. Ezen kívül az egyének közötti különbségek miatti pontatlan eredmények elkerülése érdekében véletlenszerűen kiválasztott felszívódó és fémcsavarokat helyeztünk el ugyanazon ló mellső lábaiba, hogy összehasonlító adatokat szolgáltassunk. Annak érdekében, hogy megbizonyosodjunk a jobb és a bal láb, hasonló csontsűrűségéről, a csontokat CT-vizsgálatnak vetettük alá. Mind a 20 használt csavar paraméterei azonosak voltak, a menetszög, a fő átmérő és a menetemelkedés tekintetében; csak az anyag volt eltérő természetesen, A csavarokat minden esetben, Dr.Izing Simon sebész helyezte be a már említett lag fashion technikával. Minden mintát 10 mm-es epoxigyantába ágyaztunk, hogy alkalmassá tegyük a biomechanikai vizsgálatra illetve a megbízható nyomásvizsgálat érdekében ékként minden csüdcsonthoz a megfelelő metacarpust használtuk.

Biomechanikai nyomáspróbákat minden alkalommal, ugyanazzal a berendezéssel; a Zwickk Z250 számítógép által vezérelt univerzális anyagvizsgáló gép szakítószilárdsági, hajlító, kompressziós, szakadási és interlamináris tesztekhez. A vizsgálat során folyamatosan növekvő nyomást gyakoroltunk a metakarpális ékre, illetve ezálltal a

csüdcsont ízületi felszínére, amíg 20%-os csökkenés nem volt kimutatható az ellenállás szempontjából, amit a csavar szempontjából funkcióvesztésnek tekintettünk.
Kísérletünk mérte és vizsgálta a maximális alkalmazott erőt (N), a deformációkat (mm) és a törésnyitás mértékét (mm) a nyomáspróba során. Eredményeink alapján a felszívódó csavarok nagy ellenállásnak (7895 N) tudtak ellenállni; az összegyűjtött adatok alapján azonban használatuk ígéretesebbnek tűnik a csikók vagy az alacsonyabb terhelésnek kitett beavatkozások esetében. A szerves polimerek általában kiváló plaszticitással és rugalmassággal rendelkeznek, de merevségi tulajdonságaikban és abszolut mechanikai szilárdságukban alacsonyabbak.

Ugyanakkor ezek a csavarok csökkentik a műtéti eljárások számát és a fertőző szövődmények vagy a véglegesen behelyezett csavarok irritációjának kockázatát azáltal, hogy idővel felszívódnak. A jelzett előnyök elengedhetetlenek a lógyógyászat sebészeti beavatkozásainál, különösen csikókban és a sportlovakban. Ezzel a vizsgálattal kapcsolatban a felszívódó csavaroknak biztató lehetőségük van a részleges vagy rövid törések kezelésére.

10. REFERENCE LIST

1. Inion FreedomScrew^{TM} Bioabsorbable Screw. In: Inion. https://www.inion.com/product/inion-freedomscrew/. Accessed 20 Aug 2022

2. Fractures of the First and Second Phalanx in Horses - Musculoskeletal System. In: MSD Veterinary Manual. https://www.msdvetmanual.com/musculoskeletal-system/lameness-in-horses/fractures-of-the-first-and-second-phalanx-in-horses. Accessed 20 Aug 2022

3. Chapter 12 - Surgical Techniques | Elsevier Enhanced Reader. https://reader.elsevier.com/reader/sd/pii/B9780323484206000120?token=43BD1D79B4454F1AEC6115A16AFD05DB91986C6EA9868491F3A599174A11544A7587451CC3D625E04E2555ECC3AA3B68&originRegion=eu-west-1&originCreation=20220921073715. Accessed 21 Sep 2022

4. Chapter 77 - Principles of Fracture Treatment | Elsevier Enhanced Reader. https://reader.elsevier.com/reader/sd/pii/B9780323484206000776?token=E0F2820041694CBAA77C07B8ED7CEE30EFF0BFF2F06A95800B963BAD47829ABB18560A9D7532587C5960A69D5047D504&originRegion=eu-west-1&originCreation=20220921074412. Accessed 21 Sep 2022

5. Racecourse Fracture Support System | Trainer Magazine | European Trainer Article Index. In: Trainer Magazine. https://trainermagazine.com/european-trainer-articles/racecourse-fracture-support-system/2022/3/30. Accessed 8 Oct 2022

6. Kuemmerle JM, Auer JA, Rademacher N, Lischer CJ, Bettschart-Wolfensberger R, Fürst AE (2008) Short incomplete sagittal fractures of the proximal phalanx in ten horses not used for racing. Vet Surg 37:193–200. https://doi.org/10.1111/j.1532-950X.2007.00359.x

7. James T.Robertson CWM (1998) Equine Surgery, second

8. Nixon AJ, Auer JA, Watkins JP (2019) Principles of Fracture Fixation. In: Nixon AJ (ed) Equine Fracture Repair, 1st ed. Wiley, pp 127–155

9. Markel MD, Richardson DW (1985) Noncomminuted fractures of the proximal phalanx in 69 horses. J Am Vet Med Assoc 186:573–579

10. James T.Robertson CWM Repair of the fracture of the proximal phalanx (P1). In: Equine surgery. pp 66–71

11. James T.Robertson CWM 5 Orthopedic Surgery. In: Equine Surgery. pp 51–55

12. Labens R, Khairuddin NH, Murray M, Jermyn K, Ahmad RS (2019) In vitro comparison of linear vs triangular screw configuration to stabilize complete uniarticular parasagittal fractures of the proximal phalanx in horses. Veterinary Surgery 48:96–104. https://doi.org/10.1111/vsu.13123

13. Wild JR, Taljanovic MS, Hunter TB (2017) Orthopedic Apparatus. In: Radiologic Guide to Orthopedic Devices. Cambridge University Press, Cambridge, pp 18–157

14. O'Hare LMS, Cox PG, Jeffery N, Singer ER (2013) Finite element analysis of stress in the equine proximal phalanx. Equine Veterinary Journal 45:273–277. https://doi.org/10.1111/j.2042-3306.2012.00635.x

15. Richardson D (2019) Fractures of the Proximal Phalanx. pp 295–319

16. Santschi EM (2008) Articular Fetlock Injuries in Exercising Horses. Veterinary Clinics of North America: Equine Practice 24:117–132. https://doi.org/10.1016/j.cveq.2007.11.011

17. Baxter GM, Morrison S (2008) Complications of Unilateral Weight Bearing. Veterinary Clinics of North America: Equine Practice 24:621–642. https://doi.org/10.1016/j.cveq.2008.10.006

18. James T.Robertson CWM Wound infection. In: Equine Surgery. pp 24–30

19. Stöckle SD, Failing K, Koene M, Fey K (2018) Postoperative complications in equine elective, clean orthopaedic surgery with/without antibiotic prophylaxis. Tierarztl Prax Ausg G Grosstiere Nutztiere 46:81–86. https://doi.org/10.15653/TPG-170491

20. CT Design and Operation | Oncology Medical Physics. https://oncologymedicalphysics.com/ct-design-and-operation/. Accessed 13 Oct 2022

21. Greenway K Hounsfield unit | Radiology Reference Article | Radiopaedia.org. In: Radiopaedia. https://radiopaedia.org/articles/hounsfield-unit. Accessed 10 Oct 2022

22. Zaidi Q, Danisa OA, Cheng W (2019) Measurement Techniques and Utility of Hounsfield Unit Values for Assessment of Bone Quality Prior to Spinal Instrumentation: A Review of Current Literature. Spine 44:E239. https://doi.org/10.1097/BRS.0000000000002813

23. Colgan SA, Hecker AT, Kirker-Head A, Hayes WC (1998) A Comparison of the Synthes 4.5-mm Cannulated Screw and the Synthes 4.5-mm Standard Cortex Screw Systems in Equine Bone. Veterinary Surgery 27:540–546. https://doi.org/10.1111/j.1532-950X.1998.tb00529.x

24. Qi L, Chang C, Xin T, Xing PF, Tianfu Y, Gang Z, Jian L (2011) Double fixation of displaced patella fractures using bioabsorbable cannulated lag screws and braided polyester suture tension bands. Injury 42:1116–1120. https://doi.org/10.1016/j.injury.2011.01.025

25. Konan S, Haddad FS (2009) A clinical review of bioabsorbable interference screws and their adverse effects in anterior cruciate ligament reconstruction surgery. The Knee 16:6–13. https://doi.org/10.1016/j.knee.2008.06.001

26. Mageed M, Steinberg T, Drumm N, Stubbs N, Wegert J, Koene M (2018) Internal fixation of proximal fractures of the 2nd and 4th metacarpal and metatarsal bones using bioabsorbable screws. Aust Vet J 96:76–81. https://doi.org/10.1111/avj.12673

27. Ravanetti P, Hamon M, Lechartier A, Zucca E (2021) Surgical Repair of a Unicortical Condylar Fracture in a Thoroughbred Racehorse Using a Bioabsorbable Screw. Journal of Equine Veterinary Science 99:103384. https://doi.org/10.1016/j.jevs.2021.103384

28. Rüedi TP (2007) AO Principles of Fracture Management. AO Publishing

29. Böstman O (1994) Economic Considerations on Avoiding Implant Removals after Fracture Fixation by Using Absorbable Devices. Scandinavian Journal of Social Medicine 22:41–45. https://doi.org/10.1177/140349489402200107

30. Ravanetti P, Lechartier A, Hamon M, Zucca E (2022) A composite absorbable implant used to treat subchondral bone cysts in 38 horses. Equine Veterinary Journal 54:97–105. https://doi.org/10.1111/evj.13428

11. ACKNOWLEDGEMENT

I would like to thank the entire Department and the Clinic of Equine Medicine, but firstly, my supervisor Dr.Izing Simon, who allowed me the opportunity to do this TDK and taught me a lot about equine surgical approaches during this study. I am grateful to Prof. Dr.Bodó Gábor, Head of the Department, for having me and allowing me the chance to perform this study. I would like to thank the University of Veterinary Medicine Budapest for the financial support needed to carry out this research.

Also, I owe gratitude to Dr. Szebényi Gábor for the biomechanical tests carried out Department of Polymer Engineering at BME and to Petra Pogány, who assisted with purchasing INION FreedomScrew implants.

Lastly, I would like to thank my family and all the contributors for their help.