Treatment methods of long bone fractures in equines

– comparing Swedish and foreign experience

Behandlingsmetoder för frakturer på långa rörformiga ben hos häst
- en jämförelse mellan svenska och utländska erfarenheter

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Swedish University of Agricultural Sciences, SLU
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Veterinary Medicine Programme

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Abstract

The treatment of long bone fractures in horses remains to be a challenge for equine veterinarians, since it is necessary to succeed treating an animal sometimes weighing over 500kg that will have to endure fracture repair procedures and rehabilitation for at least 3 months and manage the resulting complications. The objective of this study is to investigate and shed light over some of the treatment techniques for long bone fractures in equines, and to sample new data from a questionnaire, answered by experienced equine surgeons in Sweden, summarising the obtained results with the already existing research. In a literature review, this work starts by describing bone anatomy and physiology, gradually narrowing down to long bones. Then the different types of bone fractures are discussed, both in regards to their aetiology, impact and classification. This is followed by the mechanisms of bone healing through which bone fractures are healed. Further, this work investigates the most common and current treatment techniques of long bone fractures in equines. Various treatment techniques are reviewed, such as the internal and the external fixation, as well as the advantages and the disadvantages of every respective technique. Furthermore, the factors that affect long bone fracture repair are described, as well as the biomechanics of the strain forces that need to be counteracted for successful fracture treatment. Finally, the literature study describes the various complications that may follow bone fracture repair post-operatively or during the rehabilitation phase. In addition, the study encompasses a questionnaire that was sent to 20 Swedish senior equine surgeons, asking questions about long bone fracture treatment. Some of them replied to the questionnaire, elucidating on how the different types of long bone fractures are dealt with in Sweden, thus helping the study to exhibit the current practices of equine orthopaedic surgery, as they are adapted to the Swedish realities, including the animal welfare norms. The results of the survey showed that veterinarians who heavily rely on surgical treatment do tend to have a lesser need to resort to euthanasia, than other veterinarians, who do not apply osteosynthesis as their primary treatment. Moreover, there seems to be a general correlation between the orthopaedic practices applied by equine surgeons in Sweden and the ones described in foreign literature, with the distinction that the Swedish veterinary policy applies conservative treatment as standard, unless the fracture is displaced.

Keywords: equine, long bone, fracture, osteosynthesis

Sammanfattning

Behandling av frakturer på långa rörformiga ben hos häst är en utmaning för hästveterinärer. Det är svårt att behandla ett i grunden flocklevande flyktdjur, som kan väga över 500 kg, för skador som måste läka i minst 3 månader. Därtill kan man behöva hantera resulterande komplikationer. Syftet med denna studie var att undersöka och belysa några av de behandlingstekniker som används för frakturer på långa rörformiga ben hos häst. Dessutom, via en enkät besvarad av erfarna hästkirurger som arbetar i Sverige, få en uppfattning om hur dylika frakturer vanligen behandlas i detta land. I litteraturöversikten beskrivs benanatomi och fysiologi med fokus på hästens långa rörformiga ben. Olika typerna av benfrakturer tas upp avseende sin etiologi, inverkan och klassificering följt av frakturläkningens grunder. Behandlingstekniker såsom intern och extern fixeringen, samt fördelar och nackdelar med varje teknik gås igenom översiktligt. Vidare tas faktorer som påverkar reparation av frakturer på långa rörformiga ben upp inklusive de biomekaniska krafter som behöver motverkas för en framgångsrik frakturbehandling. Även olika komplikationer som kan uppstå perioperativt och under rehabiliteringsfasen berörs. Det frågeformulär som skickades till 20 erfarna hästkirurger i Sverige med frågor om behandling av frakturer på långa rörformiga ben hos häst besvarades av 9 personer som alla hade över 20 års erfarenhet av hästkirurgi. De redogjorde för hur de hanterat olika typer av frakturer i hästens långa rörben. Även djurskyddsaspekter förknippade med fraktur hos häst berördes. Resultaten visade att veterinärer som arbetar på klinik och lutar sig mot kirurgisk behandling i sin praktik troligen har ett mindre behov av att avliva patienter än veterinärer som inte har möjlighet använda osteosyntes i sin behandling. Det fanns en överensstämmelse mellan de ortopediska metoder som tillämpas av hästkirurger i Sverige och de som beskrivs i utländsk litteratur. Dock med skillnaden att svenska hästkiruger oftast tillämpar konservativ behandling, ofta i hängmatta, som standard då frakturen inte är öppen, dislocerad och/eller instabil

Nyckelord: häst, rörben, fraktur, osteosyntes

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Abbreviations

DCP	Dynamic Compression Plates
LCP	Locking Compression Plates
LC-DCP	Dynamic Compression Plates with Limited Bone Contact
MCIII	Third Metacarpal Bone
MIPO	Minimally Invasive Plate Osteosynthesis
MTIII	Third Metatarsal Bone

1. Introduction

Long tubular bone fractures are among the most complicated types of fractures in horses and generally they have a poor prognosis due to the body mass of the horse and the necessity of weight bearing on all the four limbs. There are two basic difficulties to it. Firstly, the veterinary-medical challenge of fixating a long bone fracture of an over 300 kg highly dynamic animal and, secondly, the ethical aspects of leaving a lame horse for a long rehabilitation period with all the related pain and suffering. The problem reaches its climax when an otherwise healthy young horse has to be put down because of such a fracture. Surgical treatment of long bone fractures in horses encompasses several stages, such as box rest, external fixation for the immobilisation of the fractured limb, internal bone fixation by osteosynthetic surgery, patient management, anaesthesia, recovery from anaesthesia and the post-operative rehabilitation. The aim of fracture repair is to return the bone to its original structure and function by, preferably, minimally invasive osteosynthesis, carefully dealing with the surrounding vascularised soft tissues. It is, therefore, important to opt for an implant system that is able to neutralize the biomechanical forces at the fracture site and allow for an accelerated consolidation of the fractured bone fragments (Perren 2002).Veterinary orthopaedic surgery has kept on developing, but the technical advances in this domain are mostly derived from extrapolating human surgery data. However, even at the beginning of the 21st century, long bone fracture repair in horses remains a challenge for veterinarians.

The objective of this paper was to delve into the available veterinary methods of treating equine long bone fractures, to sample new data from a questionnaire, answered by veterinarians that have practiced equine surgery at animal hospitals in Sweden, and intertwine the obtained results with the already existing research in the frontiers of contemporary veterinary medicine.

2. Literature Review

2.1. The structure and function of bones

The skeleton serves as the structural protection and carrier of internal organs (Maillet 1979), as a fastening for muscles, as well as for haematopoietic purposes (André *et al*. 2008), and as the body's mineral station depo for calciphosphoric metabolism (Maillet and Chiarasini 1979; Kierszenbaum 2002). The main component of the skeleton is the bone, which is characterised by its high density, its ability to undergo constant turnover and self-repair. The equine skeleton is held together by a system of ligaments and tendons, where ligaments link the bones together and tendons transmit forces between bones and muscles. In the animal kingdom, equine bones are among the densest bones (Junqueira and Carneiro 2005; Markel 2015a).

The equine skeleton reaches its maximal size by the age of five years; however, that highly depends upon the breed and condition of the horse. There are three types of bones in the skeleton:

- Short (irregular) bones, such as the small bones of carpus and tarsus, which are of cortico-spongy type and their cortex is thinner than that of the long bones.

- Flat bones, such as the scapula and the mandible, which are made up of two thin layers of compact bone enclosing a spongy bone.

- Long tubular bones, such as the humerus, radius, ulna, third metacarpal and third metatarsal bones, femur and tibia.

In this work, we shall be focusing on long bones. Long tubular bones consist of a diaphysis (hollow cylinder of compact bone with medullar yellow bone marrow inside), a metaphysis (binding the epiphysis and the diaphysis together), and an epiphysis (spongy cancellous bone with red bone marrow inside) (Fig. 1). The growth plate (physis), which lies within the metaphysis, regresses with age and it becomes absent in fully-grown animals, thereby the epiphysis and metaphysis are united with the diaphysis in adults (Junqueira and Carneiro 2005; Markel 2015a).

After enamel and dentin, bone is the hardest structure in the body. Its strength depends on both the compact (cortical) bone and on the trabeculae of the cancellous bone. The degree of porosity of the compact bone lies between 5% and 30% and that of the trabecular bone lies between 30% and 90%. The compact bone contains such tiny pores that they are only visible under the microscope, while the spongy bone consists of a network of osseous trabeculae in an intricate system of larger pores containing the bone marrow (Fig. 2) (Bloom and Fawcett 1994; Junqueira and Carneiro 2005).

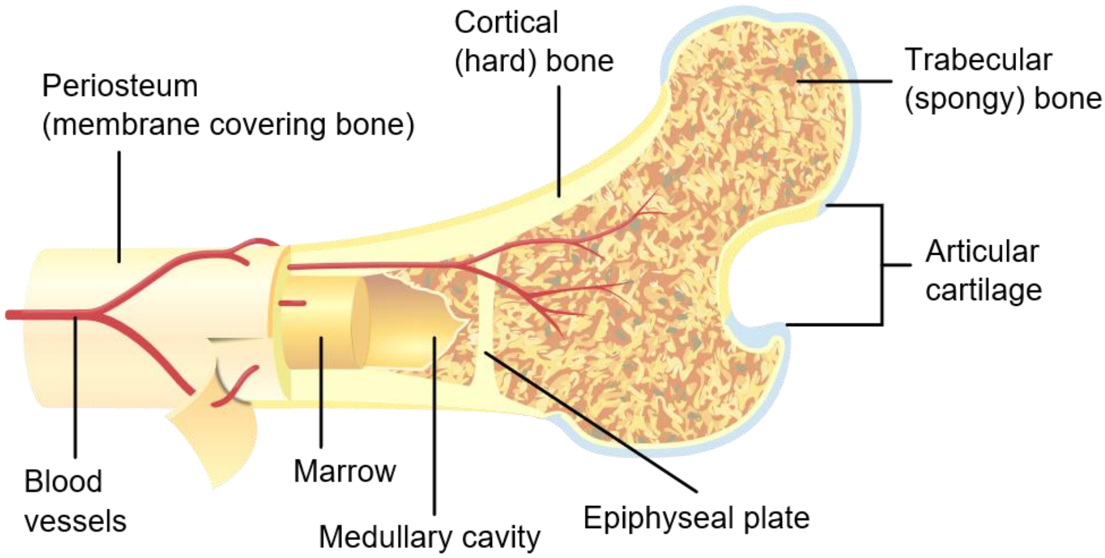

Figure 1. Sagittal section of an animal long bone with its internal structures (Copyright free) https://www.physio-pedia.com/Bone_Marrow_Lesions.

The external surface of bone is covered by periosteum that is attached to the cortical bone. The internal surface of the bone is outlined by endosteum. Osteoblasts participate in the ossification process and osteoclasts participate in bone resorption. Osteocytes are also active in bone remodelling.

2.2. Fractures of equine bones

A fracture is defined as a loss of continuity in the bone, or any interruption, where a bone is broken into two or more fragments (Jennings 1984; McRae and Esser 2008). The bone is able to withstand loads to a certain extent, but when the load becomes excessive (overload), i.e. it surpasses the elastic limit, the bone undergoes plastic deformation and, since the bone is stiff, a fracture occurs.

Both mechanical and geometric properties of the bone determine its capacity to counteract excessive biomechanical forces and resist being deformed or fractured (Markel 2015a). Fractures have both contributing and determining causes, table 1.

Fractures are divided into pathological, which occur spontaneously due to a pathological fragility of the bone, and traumatic that occur due to external trauma. The latter phenomenon is a lot more common than the former.

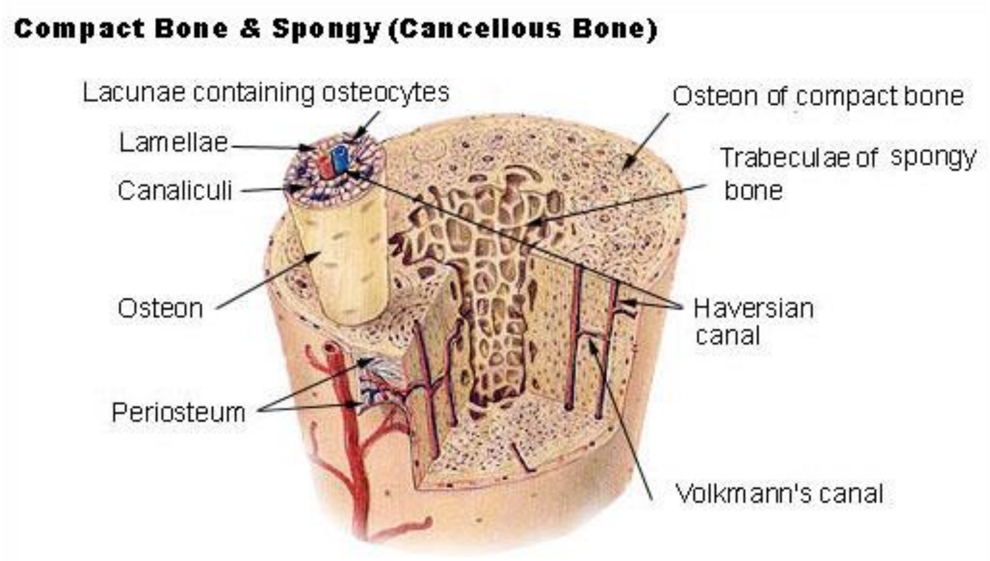

Figure 2. Cross-section of an animal long bone with its internal structures (Copyright free) https://med.libretexts.org/Bookshelves/Anatomy_and_Physiology/Book%3A_Anatomy_and_Physiology_(Boundless)/6%3A_Skeletal_System/6.3%3A_Introduction_to_Bone/6.3A%3A_Gross_Anatomy.

Table 1. The tables list the most common contributing and determining causes of equine fractures (Krook and Maylin 1988).

Contributing causes		**Determining causes**
Breed, sex, age, (race horses)		Osteitis (osseous demineralization)
Training ground/Surface		Osteochondral necrotic lesions
Tiredness/Fatigue		Osteochondritis lesions
Type of use/Exploitation of the horse		Trauma
Previous treatment (neurectomy, repeated intra-articular corticosteroid injections)		Degenerative tendon and ligament injuries (calcinosis, fibrosis)
Nutrition (deficiency or excess in phospho-calcic intake)		
Farriery		

There are different ways of classifying fractures, but all classification systems generally boil down to the following points: the affected bone (e.g. radius, tibia, etc.), the location of the fracture on that bone (diaphyseal, epiphyseal, etc.), intraarticular (joint involvement), whether the fracture is open (three grades of open fractures) or closed (intact skin), the degree of comminution (simple/two fragments, minimal, moderate and severe), and if the fracture is displaced or non-displaced. Direct fractures are located on the trauma site, while indirect fractures can be found at a distance from the trauma site. There can be complete double fractures, where there is an intermediate fragment between the two larger ones. There are also incomplete fractures or fissures and infractions that imply that the bone is not divided up completely. Greenstick fractures are most common in growing bones and primarily appear as pathological fractures. They are long bone fractures that only involve the cortex, leaving the periosteum intact. Fractures can also be categorised as stable (e.g. fissures) and unstable (e.g. comminute dislocated fractures). Salter Harris fractures are physeal fractures that involve the growth plate in immature animals (Fig. 3). Fractures can also be classified by the geometric shape that they form, such as transverse, oblique, spiral, etc. (Auer and Stick 2018). Stress fractures are particularly common in equines. When the bone is exposed to repeated yet minor stresses, micro-cracks and fissures in the bone structure may occur. Both the magnitude and the frequency of the applied stress determine the frequency of the micro-fissure occurrence, which eventually predisposes the bone to fracture upon a minor stimulus. This type of fracture has mainly been reported in racehorses (Norwood 1978; Schaffler *et al.* 1989; Nunamaker *et al.* 1990). Further, a distinction between simple fractures and comminute fractures is that the former give rise to a single fracture line, whilst the latter comminute fractures are characterised by plural fracture lines, a state known as multifragmentation. Open fractures perforate the skin, while closed fractures leave it intact (Bramlage 1983; Walmsley 1993; Auer and Stick 2018).

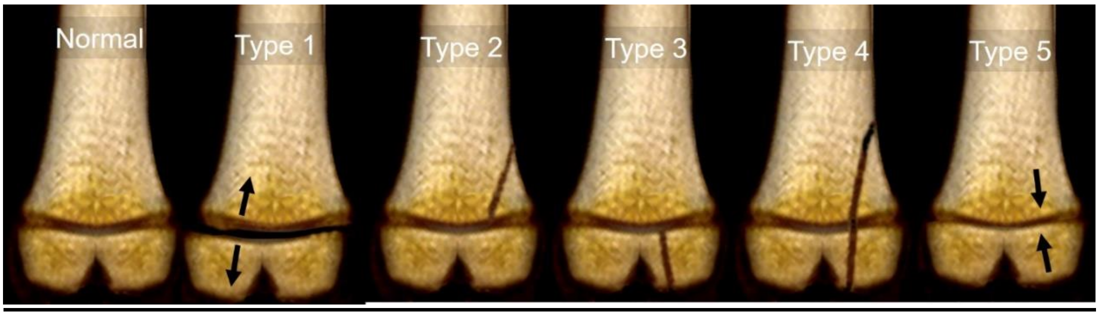

Figure 3. Classification of Salter Harris fractures.

Correct fracture classification enables the surgeon to opt for the right treatment. Fractures of long bones are often the result of direct trauma, for example, a kick from another horse or a fall. Complete fractures occur frequently as the bone segments of the distal parts of the limbs are poorly covered with soft tissues, thus they become easily perforated by the sharp bone fragment ends, bringing forth the risks of infectious complications, preventing proper functional recovery (Perrin 2010). Open fractures, comminute fractures and fractures involving long bones above the fetlock generally have a poor prognosis (Rossignol 2006). The prognosis is also poorer in overweight horses. (Perrin 2010).

Sports-related fractures are those fractures that arise because of intense dynamic training of the horse, such as racing. These fractures are highly energetic, usually explosive and accompanied by comminution and abundant soft tissue damage. Complete bone and soft tissue damage restoration is usually almost impossible to attain after such an injury, thus fracture reduction becomes more complicated. Muscle contractions and the inability of the horse to avoid bearing weight on its fractured limb complicate reduction even further and may cause eburnation. Another issue is that equine tissues are sensitive and tend to react by excessive oedema and soft tissue swelling (Denny 1990; Nixon 1996).

2.3. Fracture healing

Fracture healing aims to render the damaged bone back to its original state. Depending on the extent of the trauma, one of the two bone-healing processes can take place, namely healing by primary or by secondary intention (Jennings 1984).

Healing by primary intention depends on special conditions that must be fulfilled at the site of the fracture. These conditions include containment of the bone fragments with a proper anatomical reduction without loss of substance, exerted pressure upon the fracture line, a non-contaminated wound, intact peripheral soft tissues and vascularization via Haversian canaliculi (Jennings 1984). The phase of resorption and reconstruction between the two fragments follows the phase of acute inflammation, same as in the secondary intention healing (Mansmaan *et al*. 1982). Revascularization takes place through Haversian canaliculi and osteoclasts resorb the opposite fragment, whereupon osteoblasts form new osteons. Bone continuity is thus regained within ten weeks without callus formation (Mathon 1999).

Healing by secondary intention, or indirect healing, occurs in fractures with evident interfragmentary movements and where the fracture space is greater than 1 mm (Reikerås 1990; McKinley 2003). This type of healing can be subdivided into four stages or three overlapping phases: inflammatory phase (first 2-3 weeks of injury, characterised by vasodilatation and chemotaxis), reparative phase (formation of soft and hard callus, also known as consolidation phase) and remodelling phase (necrotic regions are replaced by osteonal remodelling) (McKibbin 1978; Nixon 1996).

These phases involve a sequence of events, where different tissues substitute each other during fracture healing, which, eventually, renders the bone stiff and strong; the rule of thumb being that tissues cannot be formed that could not exist under the given biomechanical conditions. The sequence of events includes hematoma formation, inflammatory phase, formation of soft then hard callus, and remodelling. The aim of these phases is to stabilise the bone fragments, starting by means of external callus formation, which characterizes this type of healing (by secondary intention) (Perren and Rahn 1980; Nixon 1996).

Bone consolidation takes place from 3 weeks to 3 months post-trauma, starting with the differentiation of the periosteum and of the endosteum stem cells into osteoblasts, which synthesise the bone matrix. Intramembranous ossification progresses centripetally towards the interfragmentary gap, this occurring rapidly in the periosteum and slowly in the endosteum. Endochondral ossification goes on until complete bone union of the fragment ends is reached, thus forming the hard callus, whereas the soft callus is destroyed with its constituent chondrocytes, becoming hypertrophic and calcified. Therefore, it can be said that the synergy of endochondral and intramembranous ossifications forms the hard callus (immature bone) (Einhorn 1998). The consolidation phase stabilizes the fracture site by further increasing its stiffness, due to both a larger diameter of the callus improved bone and successive tissue differentiation. The interfragmentary movements decrease, enabling lamellar bone formation in the fracture site. Sufficient strength and stiffness of the newly formed bone is now gained, allowing its further functionality resumption, even though the bone is still not identical to its original state (Augat *et al*. 2004).

The remodelling phase follows the hard callus formation. Immature bone is gradually replaced by mechanically competent lamellar bone (compact bone/cortical bone). The remodelling phase can extend from several months to 6 or even 9 years after the initial trauma. Its intensity and duration are strongly linked to the constraints applied at the level of the fracture site (Frost 1994; Ruff *et al*. 2006; Wolff 2011).

2.4. Surgical techniques used for stabilizing fractures in horses

Internal fixation consists of bone reconstruction by placing internal compression implants that will aid bone healing by restoring bone continuity and holding it together, e.g. metal devices such as plates are applied in and on the bone to align and stabilize the bone fragments (Fig. 4). Compression devices, consisting of metal plates and screws, align the bone fragments, thus enabling primary healing to occur. Transfixation devices bind the bone fragments together through horizontally inserted pins, where external casts support them.

Figure 4. Internal plate fixation of an almost healed fracture. *Courtesy: Prof Nabil Ebraheim, University of Toledo, Ohio, USA.*

Osteosynthetic surgery aims to stabilize the fracture by internal fixation and promote rapid consolidation of the bone segments. There are currently many different implants that are available for osteosynthesis, e.g. compression screws and plates (Fig. 5) (Fig. 13). For compression screws, a notched drill is used to drill a hole in the bone for the screw to be placed there. The hole corresponds to the thread of the screw, which is, in its turn, adapted to the type of bone that is fractured, such that fine thread is used for cortical bone and wide thread is used for cancellous bone, respectively.

Figure 5. Different bone screws

Careful application of the screws and their positioning with respect to the fracture line enables proper fractured fragment fusion. Compression screws are used whenever possible, e.g. if the bone is still able to withstand biomechanical forces, they can be used alone; otherwise, plates are applied to reinforce them. If the limb is loaded, the screws are placed perpendicular to the axis of the limb and not in the fracture line, in order to avoid gliding. The optimal diameters for the screws used in adult equines are 4.5 - 5.5 mm alternatively 3.5 mm (for very small fragments). The screws have to be well fitted and not overly tightened. (Moncelet *et al*. 2009; Launois 2012).

The modern advances of surgical bone fracture repair include techniques such as arthroscopy, dynamic compression plates (DCP), limited contact dynamic compression plates (LC-DCP) and locking compression plates (LCP) (Fig. 6). For example, interlocking nails and nail plate combinations can be used to repair fractures of the humerus and femur. Horses up to 300 kg mass have an overall successful fracture treatment rate of 75% (Ruggles 2016). A proper reduction of the fractured bone fragment ends renders the bone stress resistant and allows it to regain its solidity without affecting the implants, while a poor reduction can lead to the formation of

bone calluses. Wound infections that may follow internal fixation can alone compromise the success of the surgery (Markel 2015a; 2015b; Ruggles 2016).

Figure 6. Illustration of plate holes.

DCP (Dynamic Compression Plates) are self-compressing plates that are placed under the periosteum. Sometimes, two perpendicular plates are placed instead of one, where screws of different lengths are used. The screws can be angled in different directions and sometimes even placed orthogonally or up to a 25-degree angle, thereby enabling internal fixation for each particular situation. If the hole is located above a fracture line, it is better to put a compression screw, or not to put a screw at all, if it is not possible to provide compression. The holes in the plates are oval, and the edge of the hole is an inclined plane, allowing two possible placements of the screw: either in a centred position or in an off-centre position (Nixon 1996; Auer and Stick 2018; Moncelet *et al.* 2009; Launois 2012).

LC-DCP (Limited Contact Dynamic Compression Plates) have a limited contact with the surface and they are uniformly stiff. The so-called self-compressing plates have oval holes (Fig. 7).

Figure 7. LC-DCP plate.

Screwing causes the bone to slide towards the fracture site when the head of the screw enters the plate. It is thus possible to create compression of the two fractured ends (Nixon 1996; Auer and Stick 2018; Ruggles 2015).

LCP (Locking Compression Plates) can undergo dynamic compression and they have combi-holes that permit the combination of conventional or locking screws (Fig. 8); they are stiff, quick to set up and can be applied with minimal invasiveness, providing MIPO (Minimally Invasive Plate Osteosynthesis). Locking screws together with cortex screws are used with LCP plates, where the locking screws provide angular stability and the cortex screws provide compression. This technique is an important advancement of bone fracture repair, inter alia, since it provides fracture repair stability by a higher construct holding strength, instead of increased bone-plate friction. A disadvantage of this method is the requirement of the specific surgical skill of angling screws across the medullar cavity (Ruggles 2016).

Figure 8. LCP plate.

The implantation can be carried out by tunnelling, using a plate passer, or through a mini-incision, which speeds up the procedure and protects the soft tissues even more. The screws are also self-tapping, which is a real timesaver in such extensive surgical procedures. LCP plates are particularly recommended for comminute fractures of the proximal long bones, spiral non-displaced condylar fractures of MCIII or MTIII and comminute fractures of the olecranon. In fact, the plate-screw solidity provided by the LCP allows for a greater stability than that of the DCP technique (Moncelet *et al*. 2009; Launois 2012; Richardson 2015). Moreover, the location of the plate influences its strength, such that plates work better on the tension side than on the compression side of the bone, enabling interfragmentary compression to occur (Moncelet *et al*. 2009; Launois 2012).

Intramedullary nailing involves the principle of inserting a rod into the central canal of a long bone. When a thread is formed, nailing with bore can even sometimes prevent rotations in the fracture site (Fig. 9 A+B). These techniques have been scientifically described but so far rarely applied in equines (Moncelet *et al*. 2009; Launois 2012).

A B

Figure 9. A) Intramedullary pins, in the form of interlockimg nails, in drawings of a recently fractured bone above and 9. B) A bone undergoing the healing process with successful periosteal and intramedullary callus formation. *Courtesy: Prof Nabil Ebraheim, University of Toledo, Ohio, USA*

Interlocking nails are generally used to repair humeral fractures (Fig. 10). Interlocking nails are rotationally stable, such that they resist collapse at the fracture site, prevent migration of the implant and they are not too invasive. However, they are unsuitable for adult equines and require special equipment and techniques for their exploitation (Watkins 2015).

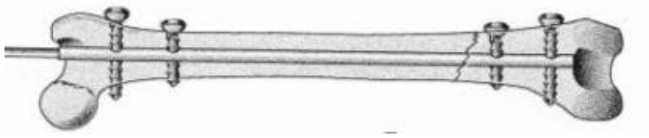

Figure 10. Interlocking nails

Other systems such as external fixators or intramedullary pins are based on the same principle of immobilisation. The materials that are used have to be biocompatible, i.e. not trigger toxic or inflammatory reactions, and resistant to corrosion. (Moncelet *et al*. 2009; Launois 2012).

Transfixing pins transfer the load to the healthy part of the bone, by redirecting the biomechanical forces, which allows the fractured part to be naturally healed (Fig. 11). An external frame, acrylic resins and casts can be used to support transfixation pins. For example, an incision on the lateral side of the limb is made, and the pins each sized 6.35 mm are inserted between the muscles (Nixon 1996; Auer and Stick 2018). However, casts that support the pins should be placed in such a way that the bone becomes only partially unloaded, otherwise callus formation will not be stimulated. Transfixing pins are usually withdrawn after 6-8 weeks, since they cease to resist biomechanical forces any longer. Even during these 6-8 weeks, an excessive load can break them, or even lead to another fracture. Therefore, it is crucial for the rest boxes to be equipped with a shock-absorbent floor, in order to prevent vibratory shock waves from acting on the transfixing pins (Moncelet *et al*. 2009; Launois 2012).

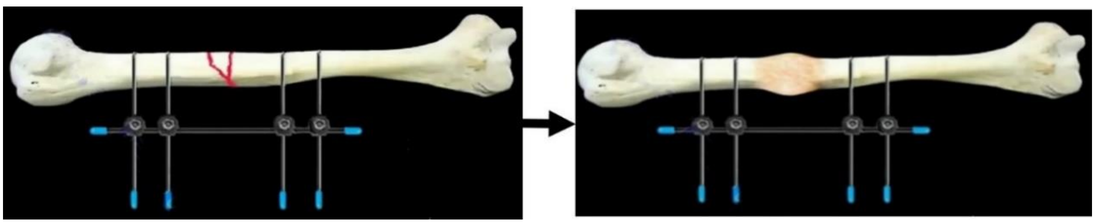

Figure 11. External fixators provide coaptation from the exterior. To the left is a recently fractured bone, while to the right is the same bone after some time elapsed, undergoing callus formation. Courtesy: Prof Nabil Ebraheim, University of Toledo, Ohio, USA.

Sling is perhaps the most classic and least invasive external immobiliser (Fig. 12). It provides long-term weight bearing relief, and is used in severe orthopaedic injuries, like long bone fractures. Its main aim is to prevent the horse from lying down, i.e. avoid raising procedures. The sling has proved itself useful and even successful in complicated fractures, where internal fixation is impossible and external coaptation is useless. The main drawbacks of the sling include its bulkiness, difficulties in removal, rubbing (gives rise to sores and stress), and difficulties in controlling and evenly distributing pressure. Nevertheless, the sling is widely used for treating sophisticated fractures today (Jurga 2017).

Figure 12. Sling is one of the most widespread conservative treatment methods in equine fracture repair.

Successful long bone fracture repairs have been reported (Bramlage and Hanes 1982; Auer and Watkins 1987; Denny 1990). Unfortunately, due to lack of stability, long bone fractures in adult horses are still generally characterised by a poor prognosis, especially if they are comminute and compound; thus, euthanasia is still applied in many cases. Solving this main problem would give rise new approaches with fewer complications and greater overall success (Richardson 2008).

2.5. Equine long bone fracture repair

Exterior fixation of the massive equine limbs can hardly completely immobilise the bone fragments; moreover, such repair techniques can cause severe injuries on the soft tissues that could be caught under the fixation. Thus, casts and/or sling remain to be a common conservative fracture treatments primarily for the distal limb, as well as support for surgical repairs even today. (Nixon 1996; Auer and Stick 2018).

A general description of different aspects of medical and surgical treatment of long bone fractures in horses as seen in tab. 2, shows what kind of treatments are applied in different fracture types.

Table 2. Example of treatment suggestions according to fracture configuration (Nixon 1996).

Fracture configuration	**Treatment**
Incomplete long bone fracture	Stall confinement in standing position preferably at least 6 to 7 weeks
Incomplete articular fracture	Internal fixation by compression screws Intraarticular lavage
Complete nondisplaced MCIII and MTIII fracture	External restraint (cast) or internal fixation.
Complete displaced fracture	Internal or external fixations (rare cases of healing after a long period of rest in the stall by formation of a functional malunion). Euthanasia.

Fracture repair depends on factors that can be split up into two categories: controlled and uncontrolled. Controlled factors are listed below:
- biomechanical forces
- anatomical fracture reduction including thorough debridement of the fracture bed
- radiographic control
- surgical skill
- immobilisation,
- equipment
- soft tissue management
- sterile environment (preventing infection)

Sufficient preoperative preparations include appropriate choice of the implants. Examples of uncontrolled factors:

- patient's size
- handling, age and condition
- fracture's site and classification (open or closed, severe or mild, etc.)
- intact blood supply and prognosis. (Denny 1990; Ruggles 2015; American College of Veterinary Surgeons 2020).

The horse mass is a factor to consider lest both the fractured limb and even the contralateral limb bear the entire load, increasing the risk of complications in the fractured bone and supporting limb laminitis. The greater the weight the higher the risk of developing laminitis (Perrin 2010).

Surgical treatment of fractures usually requires general anaesthesia, which is has a certain risk especially in the recovery phase, when the horse sometimes does premature attempts to stand up before the effect of anaesthesia has ceased. During such attempts, a heavy or stressed horse is more likely to turn even a correctly executed surgical operation into a disaster by placing an excessive load on the newly inserted implants. Therefore, an important task of surgical implants is to render horses ambulatory and fully weight bearing in the immediate post-operative period after osteosynthetic surgery (Nixon 1996; Auer and Stick 2018). The recovery prognosis is naturally ameliorated for closed and non-displaced fractures, especially in calm horses that are adapted to human environment and handling. Conversely, open displaced comminute fractures in heavy horses (>250kg) that are difficult to handle have a poor recovery prognosis. Challenges of surgical fracture repair in large animals include large plates that complicate skin closure, implant failure and post-operative lameness (Nixon 1996; Auer and Stick 2018).

Orthopaedic surgery requires knowledge of the biomechanical forces that are exerted on the limb, such as tension, compression, shear, bending, avulsion and torsion, since the bone experiences these forces (Fig. 13). MCIII and MTIII are mostly exposed to compression, which occurs during weight bearing but when suffering transverse fracture, they have been subjected to multiple forces such as shear, bending and torsion forces at the same time. Excessive tension typically causes a transverse fracture, excessive compression produces a short oblique fracture and excessive torsion gives rise to long, oblique, spiral fractures (Schneider 2015).

When having to repair a fracture, it is essential that the surgeon be aware of the specific constraints of each bone surface. For example, the upper limbs (radius) of a walking horse is subject to craniolateral-caudomedial bending, the cranial surface experiences tension, the caudal surface is subject to compression, the lateral surface is under tension, the medial surface is under compression, and the distal radius experiences torsion. A fixation cast can counteract these natural strain forces. For example, by placing the cast on the cranial surface enables it to experience compression and the caudal surface experiences, respectively, tension. Casts are usually not applied to radial fractures repaired by double plate fixation (Schneider 2015).

The same can be considered when investigating strains in tibia of a walking horse. Tension in the tibia occurs on its cranial surface, whereas caudal tibia is subject to compression. These strain forces reach their maximal magnitude in the proximal metaphysis and mid-diaphysis. Distal tibia is under torsion, which even exhibits itself in lateral and medial tibia. The cast placed in the proximal and midshaft region of the tibia did not alter the magnitude and the direction of the strains. However, the cast did manage to reverse the direction of torsion distally. The cast only affected torsion, and, therefore, cannot be used to protect the bone from axial compression (weight-bearing loads) and tension (Schneider 2015).

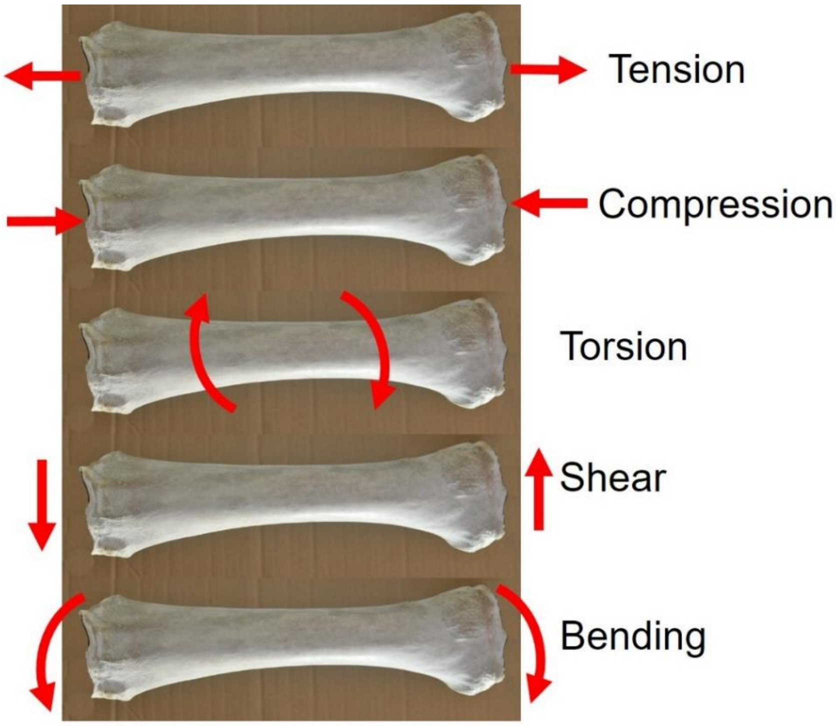

Figure 13. Forces applied to long bones.

Successful post-operative recovery is typically characterised by minimal pain, the absence of infection in an open fracture and a stabilised limb that renders the horse transportable. External coaptation with limb casts can ensure such a positive recovery, whereas poor support can make even a treatable fracture irreparable (Bramlage 1983; Walmsley 1993).

Long bone fracture repair should enable load sharing between the implants and the bone, thus rendering internal plate fixation technique useful at counteracting biomechanical forces, such as tension, compression, bending and torsion (Fig. 14). When combined with cortex screws applied in lag fashion, even shear can be stabilised. Therefore, plate fixation technique is used to repair most long bone fractures in horses today; however, it is recommended to apply double plate fixation for most equine long bone fractures, due to the biomechanical forces and the particular qualities of the equines. For example, locating the second plate at 90º (perpendicularly) to the first plate optimizes resistance to compression, bending and torsion, where one of the plates can compress and neutralise, whereas, the second plate is used solely for neutralization (Markel 1992; Rahn 1999; Ruggles 2015).

Fixation plates are better at resisting tension than compression; therefore, strong plates need to be applied on strong tension surfaces to counteract bending forces. The location of the fixation plate is dictated, primarily, by fracture configuration, but also by anatomy of tissue structures, biomechanical studies and surgical experience. Postoperative repetitive loading is counteracted by the bone-plate construct, when the plate is on the tension surface, because the plate-bone construct is maximally stiff when the plates are placed in tension and not in compression. Thus, the plates should preferably be placed on the tension surface of the bone (Tab. 3) (Markel 1990; Rahn 1999; Ruggles 2015).

Table 3. Positioning of the DCP plates according to the fractured bone (Launois 2012).

Fractured bone	**Plate location**
Femur	Cranially and laterally
Tibia	Medially and cranio-laterally
MCIII and MTIII	Dorso-medially and dorso-laterally

As of external fixation and immobilisation, intramedullary nailing should not be placed in areas where significant torsional stresses are exerted, and coaptation can alter the tension surface of the bone, such as a cast is able to convert the compressive caudal surface of the bone into a tension surface in e.g. radius and tibia (Markel 1992; Rahn 1999; Ruggles 2015).

The stabilization of long bone fractures in equines is often limited by the resistance of the implants to the cyclic load forces of tension and torsion. The evolution of these implants allows more and more complex surgeries to take place (Denny 1990).

2.6. Long bones with their respective types of fractures and suggested repair

MCIII and MTIII bone fractures are usually traumatic, often transverse and comminute. These bones are the most intensely loaded bones, and are therefore vulnerable to single trauma as well as to repetitive cyclic fatigue injuries (Auer and Stick 2018). Condylar fractures occur almost exclusively in racehorses, where they are further predominant in thoroughbreds. In 80% of the cases, the lateral condyle is involved and in 20% of the cases, the medial condyle is involved. The fracture line of a lateral condyle usually goes from the joint up proximally to the lateral cortex, whereas the fracture line of a medial condyle usually rises in the diaphysis (Nixon 1996; Rossignol and Perrin 2001; Launois 2012).

There are several types of MCIII and MTIII fractures, including Salter Harris type fracture (physeal), proximal articular fracture, dorsal cortex fracture, lateral condylar fracture, medial condylar fracture, diaphyseal fracture, both simple and comminute, etc. (Rossignol and Perrin 2001).

Internal fixation surgery with two DCP plates can be applied for treating simple traumatic diaphyseal fractures (Nixon 1996; Rossignol and Perrin 2001; Launois 2012). This can be combined with external coaptation depending on the fracture configuration, if seen as necessary by the surgeon (Nixon 1996; Auer and Stick 2018). A combination of LCP plates, compression screws, and a transfixing cast with transfixing wires in the distal radius can be applied for repairing comminute fractures. Compression screws can be successfully used for lateral condylar fractures, whereas LCP plate and compression screws are recommended to be combined for treating medial condylar fractures, since there is a risk that the fracture progresses proximally, especially in the post-operative phase (Nixon 1996; Rossignol and Perrin 2001; Launois 2012). However, other authors suggest repairing comminute fractures merely by the transfixation pin casting technique (Nixon 1996; Auer and Stick 2018).

Radial fractures can be distinguished as strain fractures, diaphyseal fractures, metaphyseal fractures and Salter Harris (physeal fractures) (Rossignol and Perrin 2001).

Conservative treatment such as stall confinement, sling and external coaptation is indicated for non-displaced fractures. Transfixation pinning can sometimes be used, in foals or small ponies, keeping in mind that fracture configuration and extent of soft tissue damage determine the therapeutic choice (Nixon 1996). Post-operative rehabilitation includes a Robert Jones bandage that is remounted every 3 weeks.

Humeral fractures can be divided into 6 types. Type I is typical to foals and is a Salter Harris fracture of the glenoidal head of the humerus, type II are tuberculum majus fractures, type III are deltoid tuberosity fractures, typeIVare mid-diaphyseal fractures, type V are distal metaphyseal fractures, and type VI are condylar and epicondylar fractures (Rossignol and Perrin 2001).

Type I non-displaced fractures can be treated conservatively, whereas patients with displaced fractures of this type are usually euthanised. Type II fractures are treated differently according to the size of the minor fragment displacement, which if it is less than 2 cm it is treated conservatively by immobilization in the box for 2 months with Robert-Jones with one month sling; a palmar splint may be added to prevent contracture. If the minor fragment has a displacement of greater than 2 cm, then resection is applied. In cases of a large fragment, either conservative treatment or osteosynthesis by compression screw and plate is used. Type III fractures with minor fragments are repaired by resection, while if the fragments are large, osteosynthesis is usually used. Adults with unstable type IV fractures are usually euthanised; otherwise, conservative treatment that encompasses immobilization with stall confinement for 3 months together with a month sling, as applied in stress fractures, may be attempted. Type V fractures are attempted osteosynthetically by double plate fixation with dorsal and lateral plates. Type VI fractures are also attempted surgically by compression screws on the medial epicondyle (Rossignol and Perrin 2001).

Femoral fractures include physeal fractures that can both be proximal or distal Salter Harris type I or type II, both displaced and non-displaced. (Rossignol and Perrin 2001; Simon 2009; Launois 2012).

Distal physeal fractures with minimal displacement are treated conservatively with stall confinement. If the displacement is more substantial, osteosynthesis by internal fixator with cross pins can repair such fractures in foals or small ponies. Proximal physeal fractures can be repaired osteosynthetically by reduction and internal fixation with 6.5mm screws. Diaphyseal fractures have a generally pessimistic prognosis, such that if the patient weighs more than 150 kg, euthanasia remains to be the only choice. However, osteosynthesis by double plate fixation with one cranial and one lateral plate together with 5.5mm screws can repair such fractures in lighter patients weighing less than 150 kg (Rossignol and Perrin 2001; Launois 2012).

Tibial fractures. Incomplete stress fractures, complete simple non-displaced closed diaphyseal fractures, as well as tibial tuberosity fractures in adults can be treated conservatively by sling. Displaced tibial tuberosity fractures can be repaired by internal fixation with tension plates and/or compression screws. Simple closed displaced diaphyseal as well as open diaphyseal fractures are only attempted if the patient weighs less than 150 kg; otherwise, only euthanasia remains available. In the case when the animal is under 150 kg, double plate internal fixation is carried out, the plates placed cranio-laterally and cranio-medially, respectively. Unfortunately, all patients with comminute diaphyseal fractures still do not have any successful treatment available and are therefore euthanised (Launois 2012).

3. Materials and Methods

A questionnaire was sent out to 21 veterinarians, with long time experience of equine surgery, to investigate their attitudes, knowledge and experience in equine long bone fracture repair. The respondents reside in different equine clinics in Sweden. Some of them are already retired (for less than a 10 year period), but others are still professionally active and they could all answer anonymously. The survey contained the questions below. For full questionnaire, see Appendix.

1. How long have you worked as a veterinarian in general and with equine surgery in specific?
2. Are you currently active or already retired?
3. Do you perform equine orthopaedic surgery and if yes then how frequently?
4. Do you encounter fractures in your clinical practice and if yes then how often?
5. Have you dealt with long bone fractures in you clinical career and if yes then which ones?
6. How frequently have you dealt with each long bone fracture, in specific?
7. How did you treat the cases that you encountered, in specific?
8. What is the success rate? Please, distinguish between the different fractures.
9. What is the most reliable treatment method according to your clinical experience?
10. In which cases of equine long bone fractures is euthanasia the only alternative?
11. What is the general prognosis of equine long bone fracture repair?
12. What type of fractures would you say are the most complicated to treat and why?

The questionnaire contained multiple choice questions, yes/no questions, and slightly longer text questions. If the respondent had no experience in equine orthopaedic surgery, or never performed long bone fracture repair, the surgeon was guided away from answering questions about the following more specific areas of expertise. The survey encompassed only adult equines, leaving the foals outside the spectrum of our current study.

4. Results

Nine respondents completed the entire survey, seven currently active and two retired. All respondents had more than 20 years' experience as veterinary surgeons and clinical experience of working with orthopaedic surgery. All of the respondents had also dealt with long bone fractures during their career. Five had performed orthopaedic surgery a few times a month and encountered fractures at least once a month.

Regarding question 6, type of long bone fractures together with the frequency of occurrence, the most frequently presented fractures were those of MCIII, MTIII, radius and tibia. Cannon bone fractures were seen more frequently than fractures of other long bones.

The different types of long bone fractures were treated both surgically and conservatively, depending on the fracture configuration and the surgeon's clinical practice.

- Scapular fractures were usually treated by sling; however, some specific cases were treated by certain surgeons osteosynthetically by glenoidal fixation with surgical resection of the fragments. The patients with severe fractures were euthanised.
- Humeral fractures were also repaired either by sling or by osteosynthesis and severe cases were euthanised as well.
- Radial fractures were treated surgically or conservatively, depending on both fracture configuration and surgeon's preference.
- MCIII and MTIII fractures were treated osteosynthetically in the overwhelming majority of cases. However, in case of a closed and stable fracture conservative treatment, i.e. sling was always considered as an option for treatment.

Most of the respondents considered femoral and tibial fractures as among the most complicated equine long bone fractures.

- Femoral fractures were attempted conservatively, e.g. sling, or euthanasia. Only intraarticular fractures were repaired by surgical resection.

- Tibial fractures were attempted surgically (osteosynthesis) or conservatively (sling), where sling showed itself more successful. Apart from fractured crista tibia cases, almost every surgical treatment attempt ended up in euthanasia for dislocated tibial fractures; sling left at least some successfully repaired tibial fractures.

The respondents differed in opinion as to what treatment technique should be considered the best for equine long bone fracture repair. Most preference was given to, and divided between osteosynthesis and sling. Certain surgeons preferred applying a combination of methods. Immobilisation techniques, such as plaster casts or external fixation pins, were rarely used on their own, as opposed to the sling, which was often used on its own. Some surgeons even mentioned that immobilisation methods, as well as stall confinement, should only be used in combination with other treatment techniques. Most surgeons tend to agree that conservative treatment (sling) was useful for the cases where surgical treatment (osteosynthesis) either cannot be applied or when there was a reasonable chance for fracture healing without external fixation, i.e. non-displaced reasonable stable fractures.

Most of the respondents were in agreement as to what factors inevitably lead to euthanasia, naming open fractures, comminute fractures, infected fractures, extensive soft tissue damage, great mass of the patient (> 300 kg), old patient and low condition of the patient.

The general prognosis for long bone fractures was seen as unfavourable by the respondents; however, it differed depending on the fractured bone and the configuration of the fracture. Displaced humeral/scapular, femoral and tibial fractures were generally considered to have an unfavourable prognosis. Radial fractures were believed to have a guarded prognosis, whereas MCIII and MTIII fractures were considered to have a favourable prognosis, unless they were open and displaced.

Most surgeons agreed on that humeral/scapular, femoral and tibial fractures were the most difficult to treat and that they still give the highest euthanasia rate.

Humeral and femoral fractures were considered difficult to treat because they are located deeply in soft tissue and surrounded by thick musculature, thus the access to them is limited. Moreover, humeral and femoral fractures were both considered complicated to treat due the abundant soft tissue damage that usually accompanies these fractures, as well as the impossibility to fixate bone ends.

Tibial fractures were considered difficult to treat, since only a thin layer of soft tissue and skin covers them, thereby the fractures easily become open and infected.

In addition, tibial fractures are usually severely overriding, comminute and unstable.

Both humeral and tibial fractures are often also severe, due to the great mass of the horse that they both have to bear and that hinders fracture healing.

When thinking of the type of fracture, open fractures and splitter fractures were considered as the most complicated to treat. Blood supply was mentioned as an important factor too and when it was lost, then fracture repair was no longer possible. Comminute and contaminated fractures appeared to be the most difficult to treat as well.

Ulnar and radial fractures were generally treatable and MCIII and MTIII (cannon bone) fractures were the most convenient to treat.

4.1 A case illustrating when sling was used to treat an MTIII fracture

A case with a 12-year old Anglo-Arabian thoroughbred mare weighing 482 kg with a fractured MTIII on the right hind limb is brought up in this paper. The reason for bringing up this case is to demonstrate a real clinical example that took place at our university equine clinic, where a successful treatment of a long bone fracture was witnessed by the author of this study. In October this year, during a training session, the horse exhibited lameness on the left forelimb. This lameness disappeared after 4 days but it was followed by lameness on the right hind limb instead. The rider experienced a notable difference on the diverse running laps, such that left laps were performed well, while right laps were carried out with difficulty. At the equine clinic, the horse was examined both radiographically and ultrasonographically, where the patient was diagnosed with a non-displaced fissure/fracture of the MTIII right hind limb. The horse was treated by sling for approximately 2 months, where the treatment went successfully and the horse was back home. Since the fracture was not 100% complete, sling was applied and it became a successful treatment in this case. (Fig. 14)

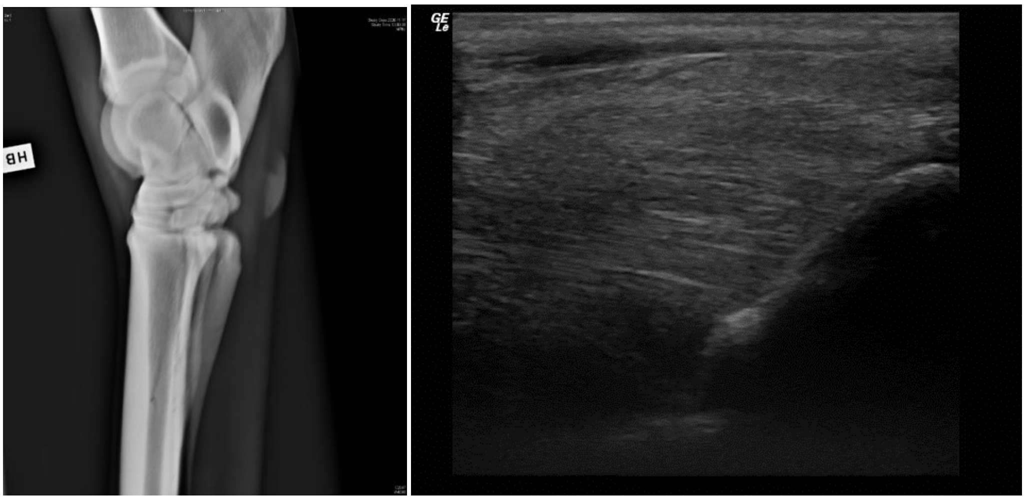

Figure 14. A radiographic x-ray image of the fractured MTIII of our Arabian horse (to the left) and an ultrasonic image of the same fractured MTIII. It can be visualised that the fracture is depicted ultrasonically in a clearer manner than the radiographic image.

5. Discussion

Swedish equine surgeons are in concord with what is described in the literature in treating humeral fractures either by sling or osteosynthetic fragment resection, depending on the configuration of the fracture (Rossignol and Perrin 2001). Mez *et al.* (2007) mentions a 90% successful outcome of surgically treated humeral fractures of the greater tubercle and a 40% success rate after conservative treatment by stall confinement. The study only considered 15 fractures of the greater tubercle, thus the trend that surgical treatment can arrange for a higher success rate, provided it is done properly and the fracture can be accessed through all the muscular layers, still cannot be backed up with satisfactory scientific evidence. On the other hand, Zamos and Park (1992) suggest the opposite, namely that in the 22 cases, conservative treatment had a higher success outcome (at least 70%) compared to the surgically treated humeral fractures (30%). A similar conclusion is drawn from another subsequent study with 54 cases, carried out a year later (Carter *et al*. 1993). It showed that conservative treatment had a 53% success rate, compared to the 23% outcome success after the surgically treated humeral fractures, where, in this surgical group, the successfully treated patients were all foals. It can thus be concluded that although it is the configuration of the humeral fracture that decides whether the fracture be treated surgically or conservatively, the default treatment for humeral fractures is conservative.

Radial fractures are also treated similarly, i.e. both surgically and conservatively, both in Sweden and abroad (Nixon 1996; Launois 2012). Stewart, *et al*. (2015) showed that in a 54 case study, conservative treatment had an 86% success (incomplete fractures) compared to the 56% success after internal fixation surgery (osteosynthesis). Young equines showed a significantly higher survival rate as compared to adults. This recent study reciprocates with an older 47 case study (Sanders-Shamis, *et al*. 1986), which suggests that age ant the size of the horse plays a more important role in success rate than even fracture configuration, and that radial fractures in adults have a generally poor prognosis. Auer and Watkins (1987) in a 15 case study quantified the survival rate of radial fractures in adult equines after osteosynthesis to 23% and suggested improvement for further osteosynthetic surgical practice. However, these studies summarised fracture repair from 1980s, which is relatively old data. In the recent years, a certain meta-analysis (Wei *et al*. 2012) suggested that both internal and external fixation techniques can be used interchangeably and can substitute each other depending on e.g. fracture configuration, age and mass of the patient; the difference being in the distinct functions that each treatment technique recovers most.

MCIII and MTIII fractures in Sweden are mostly treated by internal fixation, such as it has been described in foreign literature (Nixon 1996; Rossignol and Perrin 2001; Launois 2012). It is self-explanatory that the cannon bone is frequently fractured, since the distal parts of the limb are mostly subject to stress and because the cannon bone is relatively thin, covered merely by a thin layer of skin, compared to the other long bones. Regarding the case with the horse in the university clinic, the fracture was not 100% complete and therefore it was a non-displaced fracture; thus, it could be successfully treated by sling. A retrospective study investigating 10 horses and 11 foals showed that osteosynthesis performed on fractured MCIII and MTIII had a survival rate of approximately 90% in foals and 30% in adults. Furthermore, this survival rate decreased in open fractures to 86.7% in foals and 12.5% in adults (Bischofberger *et al*. 2009). This study concluded that age, mass and infection are the main factors that predetermine the prognosis. It can be seen that internal fixation with open reduction provides a threefold higher survival rate in foals as compared to adult equines. Although our study only considered adults, Swedish equine surgeons admitted that the general prognosis of fractured cannon bone repair is favourable. The questionnaire showed that, when including condylar fractures, the generally preferred treatment method for MCIII and MTIII fractures in Sweden was osteosynthesis. Since the overall prognosis was considered favourable, it can thus be concluded that in the clinical practice of these equine surgeons, internal fixation probably provided a higher survival rate in adults than it was shown in the retrospective study. What still gives uncertainty to this claim is that the survival rates, together with the fracture configurations, have not been studied through our questionnaire. Another technical imperfection of the survey was that the prognostic outcomes (favourable, unfavourable and guarded) have not been quantitatively defined in the questionnaire. McClure, *et al*. (1998) reported that the average survival rate after MCIII and MTIII fracture repair for adults was 64%, i.e. from the 25 included horses, 16 did not have any postsurgical complications at all. This result is higher than what is reported by Bischofberger *et al*. (2009). However, Mc Clure *et al*. (1998) recorded more treatment techniques in their cases: both internal fixation, external coaptation and a combination thereof, thereby rendering the study more representative, inasmuch as different treatment methods are usually applied in real clinical conditions. This study seems to overlap with our survey results better, showing a generally favourable outcome of repairing cannon bones fractures in adult equines.

Some authors suggest a more surgical approach for treating femoral fractures (Rossignol and Perrin 2001; Launois 2012), whereas Swedish surgeons usually omit osteosynthesis and either attempt conservative treatment (typically sling) or euthanise the animal. This could be explained by the fact that all the patients that the Swedish surgeons treated were heavy (over 150 kg), since in such cases even foreign specialists euthanise the patients. In addition, the fracture configuration has not been specified in our study and the low number of surgeons is not representative enough. Furthermore, as mentioned earlier, the standard treatment in Sweden remains conservative, unless the fracture is displaced and requires surgery. Moreover, the distinction in treatment approach may be due to personal surgical preference and skill, as well as due to the specific settings of each clinic. Hance, *et al*. (1992) presented 38 cases, where they showed a 50% successful humeral fracture surgical repair by osteosynthesis in the diaphysis, which is considered to have the poorest prognosis (most complicated repair). Unfortunately, the treated patients were all foals, which cannot be representative when comparing to our study that only included adult horses.

A similar picture can be seen when treating tibial fractures, such that in Sweden conservative treatment by sling has given a more positive result than that provided by osteosynthesis (same as in foreign literature, where almost all patients were euthanised (Launois 2012)). However, this depends on the configuration of the fracture. All patients with severe fractures have been euthanised. Even in fractures of this bone, there is a distinction between the conservative Swedish approach and the surgical approach described in the literature. Same as for femoral fractures, also in the case with tibial fractures, it is a question of fracture configuration, lack of data, Swedish therapeutic approach and individual surgical preference that determine the choice of treatment. A recent retrospective study with 21 patients showed that 65% of the equines with surgically treated tibial intercondylar eminence fractures by arthroscopic fragment removal underwent complete convalescence and returned to their previous activities (Rubio-Martínez *et al*. 2017). However, intercondylar eminence fractures cannot be compared to e.g. diaphyseal fractures in prognosis, due to the anatomo-physiological distinctions of these osseous structures. Otherwise, the few studies that review tibial fractures, usually consider them among the most untreatable fractures in the horse, usually being open, contaminated and comminute, where the mass of the patient and fracture configuration play the most important role in deciding over therapy method versus euthanasia.

This agreement between the practice of Swedish senior equine surgeons and what is described as being standard of practice in the literature provides extra evidence for the clear consistency and correlation of the respective treatment techniques documented in veterinary textbooks and scientific articles.

The preference given by the respondents to osteosynthesis and sling, together with immobilisation used in a combined treatment and not alone find their support in foreign scientific literature (Nixon 1996; Rossignol and Perrin 2001; Auer and Stick 2018; Launois 2012), etc. The same trend can be noticed in the case with sling that it is often successfully used in cases, where osteosynthesis cannot give a positive result.

It is interesting to note how the therapeutic approach varied among the equine surgeons when treating different long bone fractures. As one respondent said, conservative treatment generally gives a good result, as long as no dislocation has occurred, and a fractured bone needs to undergo osteosynthesis usually only when dealing with a dislocated fracture; therefore, it is the dislocation itself that gives a poor prognosis and not the actual type of treatment.

This study has only considered adult patients, leaving the foals behind. Treating fractures in foals has its own peculiarities, which from one hand simplify fracture repair by e.g. light mass of the foal, but from the other hand complicate the repair by constant bone growth that implies the impossibility of long-term immobilisation of the foal.

The questionnaire had its drawbacks, among which it can be mentioned that not enough questions were posed and the ones that were posed were not specific enough. This led to certain lack of detail in the responses, thus depriving the scrutiny from the necessary information. For example, when asking about how the different fractured bones were dealt with, there could be a specifying question added on the different fracture configurations on each respective bone. The same goes for specifying the most appropriate treatment and prognosis for the different fracture types on each bone and not merely mentioning the fractured bone. Moreover, the cases have not been specified, i.e. apart from the configuration, fractures are also subdivided into categories in the classification discussed earlier in this work. This made it impossible to compare the clinical practice of equine surgeons in Sweden to foreign literature completely. Neither did the study contain enough respondents (10 out of 20 replied), in order to provide us with the representative amount of data to draw proper conclusions. If all these aspects would have been considered in the questions, the responses would have provided us with more accurate detailed data. However, considering the objective of this study and the type of data gathering (its main focus lied on sampling quality data and not quantity, i.e. few experts usually suffice when asked about their area of expertise), as well as the fact that also foreign literature was supported by a similar number of specialists, still makes the data reliable. The objective of this study was to provide a general overview of equine long bone fracture treatment and not provide detailed data on how specific long bone fractures are treated. This is more of a basic study that gives an introduction into the matter of equine long bone fracture repair.

6. Conclusion

This study gave a brief overview of the currently available surgical and conservative repair methods for equine long bone fractures in Sweden and other countries. It can be concluded that many of such fractures can be successfully repaired; however, many remain a challenge for equine orthopaedic surgeons worldwide. The gathered data from our respondents neatly corresponds to the international scientific data, with eventual discrepancies perhaps due to lack of details in the responses. Nevertheless, this study gives a basic insight into the matter of equine long bone fracture repair. Further in-depth scrutiny of this matter can be achieved by looking into the sources that this study used, as well as gathering clinical data from equine surgeons in other countries.

References

André, J.M., Catala M., Morere J.J., Escudier E., Katsanis G. et Poirier J. (2008). *Histologie, service d'histologie – embryologie.* Faculté de Médecine, Pierre et Marie Curie, p. 68.

Acvs.org. (2021). *Fractures In Horses (Surgical Repair).*| American College of Veterinary Surgeons - ACVS. [online] Available at: <https://www.acvs.org/large-animal/fractures-horses-surgical-repairs> [Accessed 7 January 2021].

Auer, J., Stick, J. plus associate editors Kümmerle J and Prange T. (2018). *Equine Surgery*. 5th ed. Philadelphia: Elsevier - Health Sciences Division.

Auer, J. and Watkins, J. (1987). Treatment of radial fractures in adult horses: An analysis of 15 clinical cases. *Equine Veterinary Journal*, 19(2), pp. 103-110

Augat, P., Simon, U., Liedert, A. and Claes, L. (2004). Mechanics and mechano-biology of fracture healing in normal and osteoporotic bone. *Osteoporosis International*, 16 (S02), pp. S36-S43.

Bischofberger, A., Fürst, A., Auer, J. and Lischer, C. (2009). Surgical management of complete diaphyseal third metacarpal and metatarsal bone fractures: Clinical outcome in 10 mature horses and 11 foals. *Equine Veterinary Journal*, 41(5), pp.465-473.

Bloom, W. and Fawcett D.W. (1994). *Textbook of Histology*, 12th ed. New York: Chapman and Hall.

Bramlage, L.R. (1983). Current concepts of emergency first aid treatment and transportation of equine fracture patients. *Compendium on Continuing. Education for the. Practising Veterinarian,* 5: S564-574.

Bramlage, L.R., & Hanes, G.E. (1982). Internal fixation of a tibial fracture in an adult horse. *Journal of the American Veterinary Medical Association, 180* (9), pp. 1090–1094.

Brinker, W.O., Piermattei, D.L. and Flo, G.L. (1994). *Handbook of Small Animal Orthopaedics and Fracture Repair*. 2nd edition. WB Saunders Company, pp. 9-137.

Carter, B., Schneider, R., Hardy, J., Bramlage, L. and Bertone, A., (1993). Assessment and treatment of equine humeral fractures: retrospective study of 54 cases (1972-1990). *Equine Veterinary Journal*, 25(3), pp. 203-207

Claes, L., Augat, P. and Wilke, H. (1997). Influence of size and stability of the osteotomy gap on success of fracture healing. *Journal of Orthopaedic Research*, 15(4), pp. 577-584.

Cormack D. (1993). Dense connective tissue, cartilage, bone and joints in *Essential Histology*. Philadelphia: Lippincott Co., pp. 159–190.

Denny, H. (1990). The principles of equine fracture fixation. *Equine Veterinary Education*, 2(4), pp. 191-196.

Einhorn, T. (1998). The cell and molecular biology of fracture healing. *Clinical Orthopaedics and Related Research*, 355S, pp. S7-S21.

Feron, P. (2000). *Vade-Mecum de l'évaluation médico-légale*. Paris : De Boeck Université, p. 351.

Frost, H.M. (1994). Wolff's law and bone's structural adaptations to mechanical usage: an overview for clinicians. *Angle Orthodontist*, 64 (3), pp. 175-188.

Hance, S., Bramlage, L., Schneider, R. and Embertson, R. (1992). Retrospective study of 38 cases of femur fractures in horses less than one year of age. *Equine Veterinary Journal*, 24(5), pp.357-363.

Kahn, C.M., Line, S. and Aillo, S.E. (2008). *Merck Veterinary Manual*. 3rd edition. Merck CO Inc., pp. 973.

Jennings, P. B. (1984). *The Practice of Large Animal Surgery*, vol. 2. Philadelphia/London: WB Saunders Company.

Junqueira, L.C.U., Carneiro, J. and Kelley, R.O. (2005). *Basic Histology*. Stamford, Conn, Appleton and Lange.

Jurga, F. (2017). The evolution of equine slings: taking a load off, then and now. *Equus Magazine.* https://equusmagazine.com/blog-equus/slings-horses-history-hope-equine-support-system-32212

Kierszenbaum, A.L. (2002). *Histologie et Biologie Cellulaire une Introduction à l'Anatomie Pathologique,* 1ére édition, Mosby, pp.119-120.

Krook, L. and Maylin, G.A. (1988). Fracture in thoroughbred racehorse. *The Cornell Veterinarian,* vol 78 (2) supplement.

Launois, T. (2012). *Guide Pratique d'Orthopédie et de Chirurgie Équine*. Paris: MED'COM.

Maillet, M. (1979). Le tissu osseux, En: *Les Tissus de Soutien*, tome 3. Paris: Vigot, pp. 51-68.

Maillet, M. et Chiarasini, D. (1979). *Collection PCEM Histologie*, tome 1, Bréal éditeur, Montrantuil, pp. 97-121.

Mansmann, P.W., McAllister, R.A. and Pratt, E.S. (1982). *Equine Medicine and Surgery*, 3rd ed., vol. 2. Santa Barbara: American Veterinary Publication.

Markel, M.D. (1992). Fracture biology and mechanics. In: Auer, J.A. and Stick, J.A. (eds.) *Equine Surgery*, Philadelphia: WB Saunders Company, pp. 798-807.

Markel, M.D. (2015a). *Fracture Healing in the Horse*. AOVET North America Equine Advanced Techniques in Fracture Management LECTURE ABSTRACTS, accessed from: https://events.aona.org/AONA-Content/Abstracts/2015_Equine_Advanced_Abstract_Book.pdf [07.01.2021]

Markel, M.D. (2015b). *Biomechanics of Internal Fixation in the Horse*. AOVET North America Equine Advanced Techniques in Fracture Management LECTURE ABSTRACTS, accessed from: https://events.aona.org/AONA-Content/Abstracts/2015_Equine_Advanced_Abstract_Book.pdf [07.01.2021]

Mathon, D. (1999). *Contribution à la mise au point d'un tissu osseux bioartificiel*. Thèse doctorat vétérinaire, Toulouse: Université Toulouse III - Paul Sabatier.

McClure, S. R., Watkins, J. P., Glickman, N. W., Hawkins, J. F., & Glickman, L. T. (1998). Complete fractures of the third metacarpal or metatarsal bone in horses: 25 cases (1980-1996). *Journal of the American Veterinary Medical Association*, *213* (6), pp. 847–850.

McKibbin, B. (1978). The biology of fracture healing in long bones. *The Journal of Bone and Joint Surgery,* British volume, 60-B (2), pp. 150-162.

McKinley, T. (2003). Principles of fracture healing. *Surgery (Medicine Publishing)*, 21, 9, pp. 209-212.

McRae R. and Esser M. (2008). *Practical Fracture Treatment.* 5th ed. Elsevier: Churchill Livingstone, pp. 1-122.

Mez, J., Dabareiner, R., Cole, R. and Watkins, J. (2007). Fractures of the greater tubercle of the humerus in horses: 15 cases (1986–2004). *Journal of the American Veterinary Medical Association*, 230(9), pp. 1350-1355

Moncelet A., Mespoulhes-Riviere C. and Rossignol F. (2009). Les ostéosynthèses implants LCP et transfixation chez le cheval. *Le Nouveau Praticien Vétérinaire Équine* n°20, pp. 40–44.

Ness, M.G. (1998). *Manual of Small Animal Fracture Repair and Management*. BSAVA, Shurdington, pp. 311-315.

Nixon, A.J. (1996). *Equine Fracture Repair*, W.B. Saunders Company, Philadelphia

Norwood, G. (1978). The bucked-skin complex in thoroughbred. In: *Proceedings 24th Annual Convention American Association Equine Practice*, pp. 319–336.

Nunamaker, D.M., Butterweck, D.M. and Provost, M.T. (1990). Fatigue fractures in thoroughbred racehorses: relationship with age, peak bone strain and training. *Journal of Orthopaedic Research*, pp. 604–611.

Perren, S.M. (2002). Evolution of the internal fixation of long bone fractures-the scientific basis of internal fixation: choosing a new balance between stability and biology, *Journal of Bone and Joint Surgery*, 84, pp.1093-2110.

Perren, S.M. and Rahn, B.A. (1980). Biomechanics of fracture healing. *Canadian Journal of Surgery*, 23 (3), p. 228-232.

Perrin, R. (2006). Immobilisation et transport d'un cheval traumatisé. *Pratique Vétérinaire Équine,* n°38, pp. 65–77.

Postacchini, F., Gumina, S., Perugia, D. and De Martino, C. (1995). Early fracture callus in the diaphysis of human long bones. *Clinical Orthopaedics and Related Research*, (310), pp. 218-228.

Rahn B. (1999). Fracture biology mechanics and healing. In Auer, J.A. and Stick, J.A. *Equine Surgery*, 2nd ed, Philadelphia: WB Saunders Company, pp. 727-738.

Reikerås, O. (1990). Healing of osteotomies under different degrees of stability in rats. *Journal of Orthopaedic Trauma*, 4(2), pp. 175-178.

Richardson, D. (2008). Less invasive techniques for equine fracture repair and arthrodesis. *Veterinary Clinics of North America: Equine Practice*, [online] 24 (1), pp.

177-189. Available at: <https://pubmed.ncbi.nlm.nih.gov/18314042/> [Accessed 7 January 2021]. DOI: 10.1016/j.cveq.2007.11.004

Richardson, D. (2015). *Clinical Use of Locking Plate Systems in the Horse*. AOVET North America Equine Advanced Techniques in Fracture Management LECTURE ABSTRACTS, accessed from: https://events.aona.org/AONA-Content/Abstracts/2015_Equine_Advanced_Abstract_Book.pdf [07.01.2021]

Rossignol, F. and Perrin, R. (2001). Tableau de gestion des fractures chez le cheval. *Pratique Vétérinaire Équine n°33*, pp. 37-60.

Rossignol, F. (2006). Réhabilitation du cheval opéré de l'appareil locomoteur. En : *Proceedings Association des Vétérinaires Équins Français (AVEF), Conférence Annuelle, 2006.* Versailles, France.

Rubio-Martínez, L., Redding, W., Bladon, B., Wilderjans, H., Payne, R., Tessier, C., Geffroy, O., Parker, R., Bell, C. and Collingwood, F. (2017). Fracture of the medial intercondylar eminence of the tibia in horses treated by arthroscopic fragment removal (21 horses). *Equine Veterinary Journal*, 50(1), pp. 60-64.

Ruggles, A.J. (2015). *Principles of Long Bone Fracture Repair in the Horse*. AOVET North America Equine Advanced Techniques in Fracture Management LECTURE ABSTRACTS, accessed from: https://events.aona.org/AONA-Content/Abstracts/2015_Equine_Advanced_Abstract_Book.pdf [07.01.2021]

Ruggles A.J. (2016). Equine fractures in the new decade; What can we repair? *Equisan*, pp. 55-59. Found on https://www.equisan.com/images/pdf/fractures.pdf

Ruff C., Holt B. and Trinkaus E. (2006). Who's afraid of the big bad wolff?: "Wolff's Law" and bone functional adaptation. *American Journal of Physiology and Anthropology*, 129 (4), pp. 484-498.

Sanders-Shamis, M., Bramlage, L. and Gable, A. (1986). Radius fractures in the horse: A retrospective study of 47 cases. *Equine Veterinary Journal*, 18(6), pp.432-437.

Schaffler R., Radin, E.L. and Burr, D.B. (1989). Mechanical and morphological effect of strain rate on fatigue compact bone. *Bone*, 10(3), pp. 207–214

Schneider, R.K. (2015). *Tension Surfaces of Long Bones in the Horse*. AOVET North America Equine Advanced Techniques in Fracture Management LECTURE ABSTRACTS, accessed from: https://events.aona.org/AONA-Content/Abstracts/2015_Equine_Advanced_Abstract_Book.pdf [07.01.2021]

Simon, O. (2009). Diagnostic et pronostic des fractures des os longs chez le cheval. *Le Nouveau Praticien Vétérinaire Équin*, 5(20), pp. 17-21.

Slater, M., Hood, D. and Carter, G. (1995). Descriptive epidemiological study of equine laminitis. *Equine Veterinary Journal*, 27 (5), pp. 364-367.

Stewart, S., Richardson, D., Boston, R. and Schaer, T., (2015). Risk factors associated with survival to hospital discharge of 54 horses with fractures of the radius. *Veterinary Surgery*, 44(8), pp. 1036-1041.

Walmsley, J. P. (1993). First aid splinting for the fracture patient. *Equine Veterinary Education* 5 (1): 61-63.

Whitford, R.E. (2019). Making the rounds: surgical treatment of an ulnar fracture complicated by anconeal process fragmentation - case presentation. *Compendium Equine*. 3 (3). Found on: https://www.vetfolio.com/learn/article/making-the-rounds-surgical-treatment-of-an-ulnar-fracture-complicated-by-anconeal-process-fragmentationcase-presentation

Wolff, J. (2011). The classic: on the significance of the architecture of the spongy substance for the question of bone growth: A preliminary publication. *Clinical Orthopaedics and Related Research*, 469(11), pp. 3077-3078.

Wraighte, P. and Scammell, B. (2006). Principles of fracture healing. *Surgery (Oxford)*, 24(6), pp. 198-207.

Wei, D., Poolman, R., Bhandari, M., Wolfe, V. and Rosenwasser, M. (2012). External fixation versus internal fixation for unstable distal radius fractures. *Journal of Orthopaedic Trauma*, 26(7), pp. 386-394.

Zamos, D.T. and Parks, A.H. (1992). Comparison of surgical and nonsurgical treatment of humeral fractures in horses: 22 cases (1980–1989). *Journal of American Veterinary Medicine Association*; 201:114–116.

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Popular science summary

Long bone fractures have always been a challenge for veterinary medicine, but the grandiose goal of not putting down a young otherwise healthy horse after a fracture has always led veterinarians to find new ways for treating such complicated fractures. This paper takes up some common surgical and conservative methods of dealing with long bone fractures in equines and analyses their application both in Sweden and abroad. The structure and function of bones in general, and long bones in specific are explained. Further, long bone fractures are taken up, starting from their aetiologies, going through their classification and ending in their healing process that renders the fractured bone back to its original state. Furthermore, long bone fracture repair is observed. Starting with the factors that need to be considered when treating equine fractures, the reader is guided into the problems that the surgeon encounters when repairing these fractures, pre-operatively, operatively and post-operatively in the recovery phase. These problems are both of a general type (encountered in other species during fracture repair) and specifically horse type, typical for horses only (such as the fact that horses require their limbs to be fully weight-bearing directly upon post-operative recovery). This is followed by considering the biomechanical forces that act upon the bone and disable its fracture repair, and which should therefore be neutralised by the treatment techniques. This leads the reader into the different treatment methods used, which can be classified into two main types: surgical and conservative treatment methods. Surgical treatment involves invading operations, while conservative treatment stays outside of the horse. Another classification distinguishes between fracture repair techniques as internal fixation and external fixation, where internal fixation implies invasive surgery that places the implants (plates, screws, etc.) inside the horse, over the bones, and external fixation keeps all the equipment outside of the horse (immobilisation by sling, plaster, casts, transfixing pins, nails, Ilizar apparatus, etc.). Even if some techniques, such as transfixing nails and Ilizar apparatus invade the limb of the horse, they are not completely submerged in the body, but at least partially stay on the surface. Moreover, the different internal and external fixation techniques are taken up one by one and briefly explained: transfixing pins, different plates (LCP, DCP, etc.), screws, etc. In addition, some common complications are taken up and explained one after the other. This is all followed by the different long bones with their respective fractures and some treatment techniques that can be applied for successful fracture repair.

The next part of the study is comprised of the practical part, which includes a questionnaire that was sent to over 20 senior horse surgeons in Sweden, where a few of them answered the survey, thereby providing us with valuable information on how long bone fractures are treated in Sweden. The questionnaire asked about the surgeons' clinical experience, the frequency of performed orthopaedic operations and encountered long bone fractures. It asked about the methods that each surgeon preferred to use for each long bone fracture. The result of the questionnaire showed a good correlation with the theoretical results, obtained from foreign experts in horse surgery. This provided extra evidence of the treatment suggestions documented in scientific articles and textbooks.

Appendix – Questionnaire

Questionnaire for equine surgeons in Sweden

- How long have you worked as a veterinarian?
- 0-5 years
- 5-10 years
- 10-15 years
- 15-20 years
- 20-25 years
- 25-30 years
- Over 30 years

2. How long is your veterinary surgical experience?

- 0-5 years
- 5-10 years
- 10-15 years
- 15-20 years
- 20-25 years
- 25-30 years
- Over 30 years

3. Are you still active as a surgeon or are you already retired?

4. Do you, or did you, perform orthopaedic surgery on equines in your clinical practice?

- Yes
- No
- If yes, then how often in general?
  - Seldom
  - Every year
  - Every month
  - Every week
  - On a daily basis

6. Are there, or have there been, any cases of fractures in equines in your surgical practice?

- Yes
- No

7. If yes, then how often?

- Seldom
- Every year
- Every month
- Every week
- On a daily basis

8. Throughout your clinical career, have you ever dealt with or encountered treatment of scapula-, humerus-, radius-, MCIII-, femur-, tibia- and MTIII-fractures in equines?

Your answer:

If your answer on question no. 8 is yes please continue below.

For the following questions, please differ between adult horses, foals and year-lings.

- Approximately how many fractures of the following bones have you encountered in your practice? Please differ between Salter-Harris fractures (SH) and non Salter-Harris (NSH) as well as dislocated vs non dislocated fractures (including fissures and greenstick fractures).

Scapula: ………………

Humerus: ………………….

Radius: …………………..

MCIII: ………………….

Femur: ………………….

Tibia: ………………….

MTIII: ………………….

9. How did you treat the above cases (consider each bone with respective treatment in specific)?
    - Treatment by immobilisation (plaster/gypsum)
    - Sling
    - Surgical treatment (osteosynthesis)
    - Euthanasia
    - Other or a combination of treatments
10. If other, then specify which method exactly is applied?

Your answer:

Scapula: ………………

Humerus: ………………….

Radius: …………………..

MCIII: ………………….

Femur: ………………….

Tibia: ………………….

MTIII: ………………….

11. What is the success rate, please differ between different fractures?

    Your answer:

12. In your opinion and according to your experience, which is the most reliable method?

- Surgical treatment (ex. osteosynthesis)
- Immobilisation, Plaster/gypsum
- Sling
- Other

13. If other, please specify which method?

Your answer:

14. Regarding treatment of fractured long bones, in what cases is euthanasia the only remaining alternative, and why? What factors would influence your decision?

    Your answer:

15. In your opinion and according to your experience, what is the general prognosis for long bone fractures in horses?

    - Favorable
    - Guarded
    - Unfavorable

16. What types of fractures would you say are the most complicated to treat and why?

Your answer: