RADIOLOGY OF FRACTURES – CLASSIFICATION, HEALING, COMPLICATIONS.

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Long bone fractures occur commonly in small animals. Several treatment options exist, ranging from very invasive to non-invasive.

Fresh fractures are classified based on:
1. the number of fragments,
2. the type of bone,
3. the fracture site within the bone,
4. whether they are open or closed and whether the fracture is complete or incomplete.

The biological event of fracture healing itself can be divided into several categories:
1. Direct fracture healing, subdivided into:
a. primary osteonal reconstruction,
- contact healing
- gap healing
b. secondary osteonal reconstruction (osteonal remodeling)
2. Indirect fracture healing.

In direct fracture healing no or just a minimal amount of external callus is formed. The strain in the fracture gap is low enough to allow direct bone formation. This can only occur in anatomically reconstructed fractures that are rigidly stabilized.
In indirect fracture healing, new bone is formed by transformation of fibrous tissue or cartilaginous tissue (endochondral bone formation). This occurs when the circumstances are not conducive to immediate ingrowth of bone (for instance: high strain, movement, less vascularization or if the defect is too wide).

There are several important possible complications that can occur during fracture healing:
1. malunion,
2. implant failure,
3. delayed union,
4. non-union,
5. osteomyelitis.

If a fracture is malaligned (angulation, shortening, rotation) and heals in this position, it is called a malunion. Although strictly speaking, it is not a complication during fracture healing, as the fracture has healed, it is classified as a complication, as it can lead to lameness and decreased limb use, or joint disease.
Catastrophic failure of implants can occur mostly either through uncontrolled activity of the patient early postoperatively or mistakes in implant application.
Delayed union can occur due to biological reasons or management reasons. Examples of management reasons are: lack of complete immobilization, infection and foreign bodies in the fracture gap. Examples of biological reasons are: lack of vascularization, poor healing capacities and poor quality bone. Generalized disease can also interfere with normal fracture healing.
Non-union occurs because of the same reasons as a delayed union. A non-bridged fracture in which no progression of healing has been seen in 2-3 check-ups spaced several weeks apart or has not progressed over the space of 3 months is called a non-union. Non-union has

been divided into hypertrophic, oligotrophic and atrophic. This division is based mostly on the radiographical presence of a large amount of periosteal callus, a small amount of callus (oligotrophic) or absence of callus.

Osteomyelitis can occur due to local conditions or less likely, due to haematogenous spread of a generalized disease, however, it is most often implant related. Chronic infections can only become evident after several weeks to months. If it occurs early during fracture healing, the healing process can cease and a delayed or non-union can develop. Additionally, if the bone has lytic areas, the plate can loosen or even fail. If a large gap exists, the load will not be shared by bone and plate, but only by the plate. This excessive load will cause implant failure.

Classical diagnosis of fracture healing: Radiography.

The most classical way of evaluating the progression of fracture healing is radiography. Directly postoperatively the Alignment, Apparatus and Apposition are assessed and as the follow up progresses, the Activity is also assessed (four A's). Radiological evaluation is based on the amount of calcified (anorganic) material at the fracture site and the continuity of 3 to 4 of the 4 cortices visible on a combination of a mediolateral and craniocaudal view taken together. However, the radiological signs of healing lag behind the physiological state of healing by as much as weeks to months. The main reason for this disparity is the fact that the organic components of the callus also contribute to its stability (for as much as 50%). In primary osteonal reconstruction, the healing process consists only of intense remodelling, which might be mistaken for resorption. No callus will be formed in this type of fracture healing. The fracture line will gradually disappear. In secondary osteonal reconstruction both fracture ends will resorb, while a small external callus will be formed at the same time. The fracture gap will be filled by a process called osteonal remodelling, and gradually disappear. These two types of direct fracture healing do not show a significant amount of callus formation and radiographical assessment is based on complete filling of the fracture gap and achievement of cortical continuity.

In indirect fracture healing, new bone formation is through the transformation of fibrous tissue or cartilage. Immediately after reduction and stabilization, the fragments are sharply delineated. A defect may or may not be visible at the fracture site. The defect will become wider and the bony ends less sharply delineated (more fluffy). This represents the resorption that occurs at the fracture site. After this stage, the callus will become visible, which at first is not mineralized and very irregular in shape and outlining. As the healing progresses, the callus will progressively mineralize and ossify, and therefore become radiographically visible. The site where the callus will first appear is immediately adjacent to the exterior to the cortex (site of the radiographically invisible periost) and away from the immediate fracture site.

Ultrasonographic evaluation of fracture healing:

Using ultrasonography (US) to evaluate bones and fractures might not have seemed feasible at first, as the bony surface reflects approximately 56% of incident acoustic waves, while the remaining 44% is absorbed. Therefore structures below the bone surface will not be visualized. The images that might be present deep to the bone surface are reverberation artefacts and acoustic shadowing. The long bones in dogs are readily accessible to US and good images of all the diaphyses can be obtained. The changes of the fracture callus (fracture hematoma, formation of a distinct callus, and mineralization of the callus) can be identified by US examination. US can be used to document complete fracture healing earlier than conventional radiography in long bone fractures of dogs and cats. The criteria for diagnosing a healed fracture are echogenicity, the structure and the surface of the fractured bone and its callus. The image of the callus progressively becomes hyperechoic with its structure changing from homogeneous (fresh hematoma) to inhomogeneous, and then to homogeneous again with mature callus formation. The surface of normal bone induced a reverberation artefact and acoustic shadowing, but these properties are lost after a fracture and will return gradually as the fracture heals. Fracture union can be detected significantly earlier by US than by radiography. These results indicate that clinical and bony union may

occur earlier than previously thought and therefore implant removal or dynamization of the fixation could be performed earlier after surgery. To take full advantage of this, check-ups should be scheduled sooner after surgery than the current recommendations (3-4 weeks). Thus, we would therefore recommend a check-up every 2-3 weeks for adult animals and every 1-2 weeks for animals 7 months old or younger. Although US proved to be a reliable technique for early diagnosis of fracture healing, radiography still has an important role in follow-up evaluation. Because radiography allows evaluation of the entire bone and US is useful for a detailed view of the surface of the bone and fracture, the 2 modalities are complementary. A possible disadvantage of using US to evaluate fracture healing is the fact that US is considered to be operator dependent. B-mode US has been proven to be useful for diagnosing normal fracture healing and power Doppler US is able to demonstrate the neovascularization present during fracture healing. However, complications do occur after fracture treatment. Delayed union is fracture healing that progresses more slowly than expected and in non-union no progression of fracture healing is present. US provides both an earlier diagnosis of healing and also provides information about vascularization at the fracture site – therefore US (B-mode and power Doppler) can also be assessed for its possible use in the pre-operative evaluation of non-unions. Hypertrophic non-union will be visualized as a structure with a hypo- to anechoic, inhomogeneous tissue echogenicity filling the fracture gap with no progression to hyperechogenicity over time and in atrophic non-union no development of callus is visible.
In general, it can be stated that US can be used to evaluate fracture healing, and it also provides an earlier diagnosis of complete healing and more information regarding the type of non-union than radiography does.

Suggested reading:

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