KEY POINTS

- **High quality radiographs** of both affected and normal contralateral limb segments are critical to adequate surgical planning.
- **Additional imaging** modalities, including CT and intra-operative fluoroscopy, **may be** necessary to identify the full extent of lesions and to assist with reduction and fixation.
- **Loco-regional anatomy** thorough knowledge is a prerequisite in MIO.
- **Fracture specific patient positioning** is necessary to guarantee continuous visualization of adjacent joints and to allow unhindered procedures throughout surgery.

PREOPERATIVE IMAGING

Preoperative imaging is essential to the treatment of traumatic orthopedic injuries particularly in articular fractures. While accurate imaging is necessary to establish an optimal operative plan and to provide an overall prognosis following repair regardless of the surgical technique, it has become even more critical with the development of minimally invasive osteosynthesis (MIO). Indeed, the lack of direct fracture visualization in MIO may impair the surgeon’s ability to detect subtle abnormalities such as metaphyseal or epiphyseal fissures. Image quality greatly impacts diagnostic accuracy and therefore operative planning and execution. To enhance patient comfort and improve quality of care, avoid motion artifacts, and optimize image quality, appropriate pain management, up to general anesthesia, should be provided during diagnostic imaging.

**Standard Radiography:** Any surgical plan should include no less than standard orthogonal views in the sagittal and frontal planes. When compared to manual restraints, passive restraints are preferred as this technique enhances personnel safety and improves image quality by allowing subtle position adjustments until accurate projections are acquired. Additional special projections, as well as stress views, may be required to improve diagnosis. Imaging of the contralateral segment is highly recommended in MIO for several reasons: 1) it optimizes preoperative implant selection, particularly with regard to length and type (e.g. plate vs. interlocking nail), 2) it allows comparison with the fractured segment to identify normal vs. abnormal structures and 3) it allows accurate comparative evaluation of postoperative alignment. With MIO, image magnification **must** be taken into account as the surgeon mainly relies on pre-operative information, rather than fracture visualization, throughout the surgical procedure. While magnification is usually ~4 to 8% when using a table top technique, it can be as high as ~16 to 20% with under the table techniques and/or horizontal beam projections. Failure to evaluate the true bone size may have a disastrous effect during surgery as it may result in over distraction, joint violation and/or iatrogenic intra-operative fractures. The appropriate use of spherical or linear magnification markers in the radiographic field is therefore crucial as it allows for image resizing and improves planning accuracy. To be effective, the marker must be placed over (spherical) or alongside (linear) the bone of interest (Figure 1). The radiographic and actual sizes of the marker are then compared to allow calculation of a magnification ratio that will be used for analog (acetate) or digital templating. The main limitation associated with standard
radiography is the inability to reproduce the 3-D configuration of structures examined. It is however a relatively cost effective modality that addresses pre-operative needs in most instances.

**Figure 1:** Illustration of the effect of placement of a magnification marker (spherical or linear) for a horizontal beam projection of the femur (the X-rays are directed from the top of the image as shown in by the red arrow [center]). To avoid image distortion, the marker must be superimposed with the bone of interest (center). Only then will the magnification of the marker and the bone be identical on the radiographic image. Placement of the marker closer to (left) or away from (right) the X-ray generator will lead to misinterpretation of the magnification ratio in excess or default respectively.

**CT scan:** The major benefit of computed tomography is its ability to generate sectional images and allows a 3-D reconstruction of the fractured bone(s). It also provides detailed images of the fracture configuration and fragment displacement (Figure 2). Transverse images are used precise assessment of fissure lines, which is essential in optimizing implant placement, particularly with periarticular fractures. Coronal and parasagittal images also provide invaluable information in cases of sacro-iliac luxation associated with comminuted sacral fractures. The use of 3-D imaging helps in understanding complex intra-articular fractures and improves pre-operative planning. Furthermore, 3-D reconstruction is beneficial in evaluating fragment distribution and can be used to guide reduction maneuvers. The main shortcoming associated with CT imaging is the cost. However, because the benefits of accurate planning and subsequent avoidance of intra-operative complications likely overcomes this limitation, CT imaging should be considered an integral part of pre-operative planning when using MIO.

**MRI – Ultrasound:** Other imaging modalities such as MRI and ultrasound have limited indications in veterinary orthopedic traumatology today. While MRI is useful in the diagnosis of central nervous system lesions, its application in appendicular traumatology is limited. Similarly, ultrasound is not readily used in the diagnosis of appendicular musculoskeletal trauma.

**Figure 2:** Sacroiliac luxation (R) and sacral fracture (L). CT images showed involvement of sacral foramen. Due to the risk of sciatic entrapment, the left side was treated open. The right was treated using MIO techniques.
**SURGICAL APPROACHES**

In-depth knowledge of the loco-regional anatomy is paramount to a successful surgical outcome. While this statement holds true in all surgical fields, this prerequisite is even more critical with MIO as direct visualization of the fracture site is not available to the surgeon.

While mini open approaches remote from the fracture site are most often used in MIO, in advanced applications, implants may be fed transcutaneously through large gauge needles used as cannulas. In such cases, the surgeon relies exclusively on percutaneous landmarks and on intraoperative fluoroscopy to achieve fracture reduction, to restore alignment and to complete fixation. Because a comprehensive 3-D understanding of the bone’s anatomy is necessary to enable adequate implant contouring and fixation, using dry specimens, during pre-operative planning and in the operating room in addition to CT reconstruction, is highly recommended.

Standard open approaches to long bone repair have been extensively described in the veterinary literature. Modifications that confine these approaches to epiphyseal and metaphyseal regions have been developed for use in MIO. These mini-open approaches must however provide sufficient access to manipulate the fractured bone and achieve fixation without interfering with the fracture site. It should be noted that with MIO, the use of bone grafts is rarely recommended. The critical evaluation of the clinical outcome of femoral fractures in people showed that, following MIO techniques, healing time and complication rates were significantly improved, although the use of bone grafts had significantly decreased. One must bear in mind that a thorough knowledge/review of standard open approaches is highly advised prior to starting any MIO procedures, as conversion to conventional osteosynthesis may become necessary in some instances.

**IMPLANT SELECTION**

The choice of a specific implant is made based upon fracture configuration, patient signalment and the surgeon’s preferences. All systems described for conventional osteosynthesis may find MIO applications. Once a fixation system is selected, specific implant dimensions must be determined. Appropriate templating is mainly based on the preoperative radiographs of the contralateral intact side, corrected for magnification. In contrast, implant position is based on a detailed evaluation of the fractured bone. The fracture pattern, including the presence and extent of fissures, as well as the spread of the fragments, should be carefully evaluated as it may influence the choice and/or position of an implant. As an example, the choice of a bone plate may be ill advised for the repair of a comminuted tibial fracture with medial longitudinal fissures extending in the proximal and/or distal metaphysis. In such a case, the choice of an interlocking nail with locking bolts oriented in the sagittal plane may be more appropriate.

While rigid fixation and anatomical reconstruction remain critical in the treatment of intra-articular fractures, in metaphyseal and diaphyseal fractures, implants spanning the entire length of the bone are selected to achieve flexible bridging osteosynthesis. These implants may be slightly downsized in MIO applications when compared to conventional techniques. This creates a more flexible construct, which in turn promotes rapid formation of a bony callus. One must keep in mind, however, that the risk of implant failure through plastic deformation increases along with construct compliance. Therefore, proper case selection, based on careful evaluation of patient signalment, health and compliance is essential. When in doubt, selection of an implant based on published charts is recommended. As with conventional osteosynthesis, a plate-rod combination using relatively thin implants is suitable for MIO and may be preferred to the use of a larger, more rigid, single bone plate.
PATIENT POSITIONING

Preoperative planning includes identification of optimal patient positioning on the surgery table. The importance of this step is often underestimated and it should be emphasized that adequate positioning is essential to the smooth execution of the surgical procedure from fracture reduction to restoration of alignment to proper implant position. Ultimately, patient positioning may also affect the post-operative outcome.

In each case, the patient position should be evaluated by both the anesthesiologist and the surgeon to prevent anesthetic complications while facilitating the surgical procedure. First and foremost, the position must not compromise patient safety. From an anesthetic standpoint, the final patient position should allow easy access to airways, prevent ventilation compromise, permit adequate monitoring and allow the utilization of an extra-corporal warming apparatus. From a surgical standpoint, the patient should be positioned so as to facilitate all surgical phases including approach, reduction maneuvers as well as implant insertion and fixation. It must also permit unrestricted C-arm mobility around the patient so that intra-operative views of adjacent joints in both sagittal and frontal planes can be easily obtained throughout the surgical procedure (Figure 4). One should bear in mind that poor positioning may result in circulatory compromise, perioperative pressure ulcers and neurological injury, even in routine surgical procedures. In addition, poor positioning will impair image accuracy, which in turn may lead to inadequate restoration of alignment and/or improper fracture fixation. Once positioning is deemed adequate, the patient should be secured on the table using resting devices, sandbags or tape to prevent inadvertent displacement during the surgery. Following completion of patient positioning, C-arm mobility is re-assessed to ensure that orthogonal views of the joints proximal and distal to the
fracture can be obtained (Figure 4). This ultimate pre-operative assessment is made before final preparation to allow modification of the position if necessary.

**Figure 4:** Pre-operative view of the operating room set up illustrating proper positioning of the patient for the treatment of a humeral fracture. The chest has been elevated to allow unrestricted C-arm motion around the limb. In turn, this provides intra-operative views of the joints adjacent to the fracture in 2 orthogonal planes and facilitates restoration of alignment.