Imaging Basics in Minimally Invasive Osteosynthesis
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The purpose of this lecture is to provide the veterinarian with some basic imaging principals that may be used for percutaneous procedures such as fracture repair and bone biopsy. Multiple imaging modalities may be used in such instances but particular attention will be paid to using the digital x-ray and fluoroscopy units.

Radiation safety
The radiation exposure rate for fluoroscopy is lower than conventional radiography 45 mGy/min vs 900 mGy/min respectively, however fluoroscopy exposure times are much longer, a 10 minute fluoroscopic procedure would yield a total dose of 450mGy while a single radiograph with a 200msec exposure, a total dose of 2mGy. A regular C-arm outputs 1,200 to 4,000 mrem/min and recommended yearly dose limits are 5000mrem to the torso and 50,000 to the hands (Singer). To limit radiation exposure proper radiation safety attire should always be worn. In addition to typical lead shielding, radiation attenuating surgical gloves and an extra dosimetry badge worn on the finger should be considered. The fluoroscopy unit itself should be calibrated and measured for scatter and be kept in spec. Previous studies have shown no exposure to dosimeter badges at the anesthesiologist position, 152cm from the fluoroscopy unit. However, all personnel within the room should remain gowned. Significant radiation exposure is present at <70cm from the unit thus operating personnel are at greatest risk for exposure (Mehlman).

Practices to lower radiation exposures:
1. Keep radiation-attenuating objects from the field (suture drapes to the patient instead of using towel clamps). The fluoroscope will auto adjust mAs and KVP therefore increased radiation attenuation within the field will yield higher exposures.
2. Keep the field collimated and keep the patient or part nearest the image intensifier.
3. Keep maximal distance from the fluoroscope or radiography unit and always avoid exposure to the primary beam.
4. Use lowest amount of exposure time needed to complete the procedure.

Equipment
- Multiple k-wires
- Hypodermic needle with ID large enough to accommodate K-wire
- +/- cannulated drill bits
- Long pair Carmalt or Kelly forceps for manipulating pins while keeping hands out of the primary beam
- Parallel pin guide
- +/- cannulated screws, cannulated depth gauge
- Drill sleeves
- Cannulated pin collet for drill

Targeting with fluoroscopy and radiography
Most surgeons will have access to a single fluoroscopic or radiographic unit capable of creating a 2 dimensional image. To accurately place an implant or biopsy device in a desired location using single imaging plane the surgeon must take 2D orthogonal images to gain a 3 dimensional perspective. First and foremost the orthogonal projections must be straight relative to the anatomical part receiving the fixation. For example, in an SI luxation the sacrum is the “target” thus the lateral view should be aligned with the anatomic site of implant placement (ie the sacral body not the ilial wing). In the spine, lateral positioning is easily achieved by superimposing the base of the vertebral transverse processes to gain rotational and cranial caudal alignment (a true lateral projection). Another example in a femur would be to use superimposition of the condyles to gain a true lateral projection of the bone.

Next, the target site of desired implantation should be centered in the image to limit projection artifact. A K-wire or needle can then be superimposed over the target. This K-wire is first placed perpendicular to the beam and moved along the skin using a long grasping forceps until it the tip is
centered over the desired area of placement (indicated by the A labeled arrow in Fig 1A). A stab incision is then made at the tip of the pin and the pin is advanced through the incision and moved parallel to the radiographic beam. This creates a “deshadowed” view of the implant such that only the outer diameter of the pin is seen (arrow B in Fig 1A). For a clinical example, a sacroiliac luxation is used. When the sacrum is in straight lateral as indicated by the transverse process alignment, and the pin is deshadowed over the target, the site of expected course of the implant is clearly outlined. This is shown in Fig 1B for a trans-iliac bolt placement and Fig 1C (pin on the left) for a k-wire placement prior to lag screw fixation of a sacro-iliac luxation. Once centered the pin is held in position and then driven a short distance at this angle and rechecked again for alignment. The orthogonal VD view can then be used to evaluate depth. If placement is not ideal this initial pin can be used as a guide for a second K-wire placement.

When predrilling for placement of a screw or threaded pin, a drill sleeve may be placed first to protect the soft tissues and allow the surgeon to more easily relocate the drill hole if the bit is removed. A hypodermic needle of appropriate gauge may also be used as a drill sleeve for a k-wire. When these guides are “deshadowed” in the image the central hole will be radiolucent and can help aid in drill bit placement as discussed with placement of a K-wire. A cannulated drill bit can help ease complex implant placements as they glide over a preplaced K-wire which nearly guarantees that a bit will follow this path (Fig 3A). Additionally a cannulated screw can be placed over a k-wire ensuring is that it can be placed directly over the K-wire following drilling improving efficiency. Many cannulated screws are self drilling and self tapping thus predrilling of the cancellous bone may not required (Fig 3B, C).

**Bone biopsy**

Percutaneous techniques may be used to help guide sampling of bone lesions such as osteosarcoma. In this particular tumor the central portion of the osteolytic lesion should be targeted for biopsy and one may easily use digital radiography to help position biopsy devices. The author prefers to first aspirate these lesions with an 18g needle to limit tumor seeding of large biopsy tracts. Once the needle is applied to the bone it is aggressively forced at a slight angle to skim the periosteum then aspirated with a 6 cc syringe. In some cases the needle may be driven through the cortex and the medullary canal aspirated. It is important to provide history to the pathologist and request ALP staining. Aspirates with positive ALP staining had a sensitivity of 100%, and the specificity of 89% for differentiating osseous sarcoma from other vimentin positive tumors (Barger).

**Percutaneous fracture repair**

Minimally invasive fracture repair has been shown to significantly decrease time to radiographic union (Pozzi). Intraoperative imaging can be used to facilitate reduction and guide implant placement while minimizing damage to soft tissues and blood supply.

To aid fracture reduction a hanging limb prep may be kept throughout the procedure to place traction on the limb during the operation. This type of positioning works well for fluoroscopic placement but can be difficult to achieve under digital radiography, as the imaging platform may not be manipulated (some mobile units do allow for this option). When using standard digital radiography the limb is draped into the field and patient repositioning is planned to obtain orthogonal views. The lateral view is most often used to help target implants in extremities.

For this procedure, preoperative radiographs should be of good quality and fully reviewed for fissures and fracture configurations as a plan should be made following AO principles. Furthermore anatomic knowledge of critical structures such as vascular bundles, tendons, etc. should be reviewed. Percutaneous placement of implants can be then targeted using imaging guidance, which may be quite advantageous when a fissure, critical structure or joint surface require adjacent implant placement. The proximal pin in Figure 4 is being targeted between a growth plate proximally and fissure cranially.

**Physeal fracture**

Repairing physeal fractures using fluoroscopy is previously mentioned (Guiont, Simpson). The main advantage for using a minimally invasive technique in this fracture is to limit further damage to the blood supply and proliferating cells of the growth plate, which may occur to a greater degree with an open approach.
In cases such as capital physeal fractures (figure 5) resorption and secondary remodeling occur following devascularization and result in a radiographic “apple core” lesion or narrowing the femoral neck in up to 70% of cases which may progress to fracture and collapse. Most physeal fractures are repaired in a minimally invasive fashion using percutaneous pins in parallel or cross pin fashion and intraoperative image guidance can be quite helpful to achieve pin guidance.

References
Mehlman CT, et al. Radiation exposure to the orthopaedic surgical team during fluoroscopy: "how far away is far enough?". J Orthop Trauma. 1997 Aug;11(6).