Keywords
Dog, plate, approach, fracture, MIPO

Summary
Fracture stabilisation techniques continue to evolve and to provide approaches which minimise the iatrogenic trauma associated with surgery. Minimally invasive plate osteosynthesis (MIPO) is a recently described method of biological internal fixation performed by introducing a bone plate via small insertional incisions that are made remote to the fracture site. The plate is slid adjacent to the bone in an epiperiosteal tunnel connecting the two insertional incisions. Screws are placed in the plate through the insertional incisions or via additional stab incisions made over the holes in the plate. In this paper we describe the surgical approaches used to perform MIPO in humeral, radial, femoral and tibial fractures in dogs. We found that these approaches allowed safe insertion of the plate without grossly damaging neuro-vascular structures. Further studies are needed to evaluate the clinical outcome of MIPO in dogs.

Introduction
The concept of biological internal fixation is predicated on maximising preservation of the blood supply to the fractured bone (1). The biological status of the fracture is not compromised at the expense of achieving the most stable construct; rather fixation is applied using less invasive techniques to achieve functional anatomical alignment of the limb. Open indirect reduction techniques, such as the ‘open but not touch’ approach (2), are examples of the application of the principles of biologic fixation. In an open indirect reduction technique, the fracture is exposed via a standard approach, but reduced without direct manipulation of the intermediate fracture fragments (2). Avoiding direct manipulation of the intermediate fracture fragments minimises iatrogenic trauma to the periosteum and regional soft tissues, which in turn facilitates rapid bone healing (3).

One of the most recent evolutions of biological internal fixation is minimally invasive plate osteosynthesis (MIPO) (4,5). The technique involves making small skin incisions remote to the fracture site at the proximal and distal aspects of a fractured long-bone for plate application (6). A soft tissue tunnel connecting the two incisions is created between the periosteal surface of the bone and the overlying muscular fascia. A plate is then slid along the surface of the bone through the previously created soft tissue tunnel. Screws are applied through the plate insertion incisions and through additional stab incisions as necessary. The technique has been utilised in human patients for several years, particularly in patients with comminuted long-bone fractures which are not amenable to nailing due to the bone involved or the fracture location. Several clinical studies have reported good success with rapid bone union and a low complication rate (7–9). More recently the use of MIPO has been reported in dogs for the treatment of tibial fractures (10).

Surgical approaches to long bones have been comprehensively described for open reduction and stabilisation of fractures in small animals (11). Approaches and applications for MIPO have been described for use in human patients, but similar information regarding surgical approaches for MIPO in dogs has not been reported (12). The successful use of any fracture fixation technique depends largely on the surgeon’s familiarity with the advantages and the limitations of the technique, as well as careful adherence to the principles of application of the implants. When minimally invasive techniques for fracture fixation are used, the precision of the surgical approach and the knowledge of the local anatomy are of primary importance (12). Because the fracture site is never exposed, it is essential to know the safe regions where implant insertion is feasible. Marti and Miller have described the safe corridors for the insertion of external skeletal fixation pins in dogs (13,14). Their study introduced the concept of safe, hazardous and unsafe corridors, and identified the locations that were safe for fixator pin insertion. The purpose of this report is to describe safe corridors for plate insertion when using MIPO for the stabilisation of long-bone fractures in dogs.

Surgical technique
Applications and guidelines for the use of MIPO in dogs presented within this paper were developed based on techniques described in human patients, dissections conducted on dog cadavers, and our clinical experience with using the technique. After conducting the MIPO approach on cadavers, the limbs were carefully dissected to assess the integrity of the major neurovascular structures.
Humerus

We advocate the use of a cranio-lateral approach to the humerus (Fig. 1); this is a combination and modification of the approaches to the proximal shaft of the humerus and the lateral aspect of the humeral condyle and epicondyle (11). Indications for this approach include diaphyseal and metaphyseal fractures of the humerus. The dog is initially positioned in dorsal recumbency with a foam pad placed under the shoulder. This position allows intra-operative radiographic assessment of the limb segment if a radiolucent surgical table is not available. The dog should be rotated into lateral recumbency for the surgical dissection and the plate insertion.

After identification of the greater tubercle of the humerus and the deltoid tuberosity by palpation, a 3 to 5 cm long incision is made over the greater tubercle slightly cranial to the acromial head of the deltoid muscle. Following retraction of the skin and subcutaneous tissue, an incision is made through the deep fascia along the lateral border of the brachiocephalicus muscle. After retraction of the brachiocephalicus muscle and the fascia, the insertion of the acromial part of the deltoideus muscle is also incised distally and elevated. Retraction of the deltoideus muscle allows the insertion of Metzembaum scissors to open the tunnel from proximal-to-distal.

The distal window is obtained by making a limited approach to the distal humeral metaphysis and lateral epicondyle. The lateral epicondyle is palpated to determine the distal extent of the incision and a 2 to 4 cm long incision is made, extending proximally from the lateral epicondyle. After identification of the lateral head of the triceps muscle, and retraction of the skin and subcutaneous tissue, an incision is made through the deep fascia along the cranial aspect of the humerus and kept in contact with the humeral cortex. Some difficulty may be encountered during the passage of the tunnelling instrument proximally due to the intimate blending of the fibres of the brachialis and deltoid muscles along the lateral aspect of the tunnel at this point. Incision of these muscle fibres at the tip of the tunnelling instrument through the proximal incision will allow the instrument to pass more readily, and communicate with the proximal incision.

Radius

We advocate using a cranio-medial approach to the radius (Fig. 2); this is a combination and modification of the approaches to the diaphysis of the radius through a medial incision, and the distal aspect of the radius and carpus through a dorsal incision (11). Indications for this approach include diaphyseal and distal metaphyseal radial fractures.

The dog should be positioned in dorsal recumbency with a foam pad placed under the dog’s ipsilateral shoulder. The limb is extended caudally during the surgical dissection, reduction and fracture stabilisation. The antebrachio-carpal joint is identified by palpation or by the insertion of a hypodermic needle if necessary. A 2 to 4 cm dorsal skin incision is made, centred over the antebrachio-carpal joint. After retraction of the skin margins, the deep antebrachial fascia is incised between the tendon of the extensor carpi radialis and the tendon of the common digital extensor muscles. The tendon of the adductor pollicus longus muscle is transected if further exposure is needed.

The approximate location of the proximal holes of the plate is marked on the skin. A 2 to 3 cm cranio-medial skin incision is made at the level where the two proximal holes of the plate will be positioned. The deep antebrachial fascia is incised between the tendon of the extensor carpi radialis and the pronator teres muscles. A tunnel is made from proximal-to-distal using Metzembamba scissors, and if necessary, the tunnel can be completed from distal-to-proximal using the scissors. The plate is generally inserted from distal-to-proximal, but the direction of plate insertion may depend...
on the presence of a persistent step at the fracture site after indirect reduction. The plate should be inserted along the fracture segment that is more cranially displaced to facilitate sliding the plate across the fracture site and to avoid plate impingement at the fracture.

**Femur**

We advocate using a lateral approach to the femur (Fig. 3), which is a combination and modification of the approaches to the greater trochanter and subtrochanteric region of the femur, and the approach to the distal femur through a lateral incision (11). Indications for this approach include diaphyseal and proximal and distal metaphyseal femoral fractures. The dog is initially positioned in dorsal recumbency with a foam pad placed under the hip on the side of the fractured femur to elevate the surgical site. A supporting pad is placed under the stifle to facilitate reduction of distal femoral fractures. The dog is tilted laterally with the non-fractured limb dependent during the procedure.

A 3 to 5 cm long incision is made distal to the greater trochanter of the femur. Following retraction of the skin and subcutaneous tissue, an incision is made through the superficial leaf of the fascia lata along the cranial border of the biceps femoris muscle. Retraction of the deep fascia lata exposes the vastus lateralis muscle, which is partially elevated off the proximal femur. A Hohmann retractor is placed cranial to the femur to retract the vastus lateralis muscle cranially, exposing the lateral aspect of the proximal femur.

After palpation of the patella and the lateral trochlear ridge, a 2 to 4 cm longitudinal skin incision is made, beginning at the level of the patella and extending proximally. The subcutaneous fascia is incised along the same line as the skin incision. The fascia lata is incised along the cranial border of the biceps femoris muscle. The biceps femoris muscle is retracted caudally. To separate the vastus lateralis and the biceps femoris muscles, the intermuscular septum formed by fascia lata attached to the femur needs to be incised. Muscular branches of the distal caudal femoral artery and vein are transected and ligated for distal plate placement. Retraction of the vastus lateralis muscle cranially and the biceps femoris muscle caudally, exposes the distal femoral metaphysis.
**Tibia**

We advocate using a medial approach to the tibia (Fig. 4), which is a combination and modification of the approaches to the proximal tibia through a medial incision and to the shaft of the tibia (11). Indications for this approach include diaphyseal and metaphyseal fractures of the tibia. The dog is positioned in dorsal recumbency.

A linear incision is initiated 1 cm proximal to the medial tibial condyle and extended distally for approximately 3 cm. The tendons of insertion of the sartorius, gracilis, and semitendinosus muscles are incised and elevated from the tibia. Caudal retraction of these muscles allows exposure of the medial aspect of the proximal tibia. An epiperiosteal tunnel is developed under the skin, carefully sparing the medial saphenous artery and vein. A 2 to 4 cm skin incision is made over the medial aspect of the distal tibia. Blunt dissection with Metzembaum scissors allows the tunnel to be extended from distal-to-proximal.

**Discussion**

Surgical approaches for performing MIPO to stabilise humeral, radial, femoral and tibial fractures in dogs are simple and allow safe insertion of the plate through submuscular, epiperiosteal tunnels. Open surgical approaches aim to expose the entire bone segment to facilitate direct reduction of the fracture, as well as plate and screw application. In contrast, the MIPO technique provides sufficient exposure for sliding the plate through small insertion incisions without causing additional trauma to the soft tissue at the fracture site (15). The application of the concept of bridging osteosynthesis to MIPO allows placement of fewer screws through the proximal and distal incisions (6). Additional screws, however, may be inserted through stab incisions made between the proximal and the distal insertion incisions if supplementary fixation is deemed necessary.

Preoperative planning is an essential step to achieve an optimal outcome when performing MIPO. The length and position of the plate determines the precise placement of the proximal and distal insertion incisions. For example, in the case of a skeletally immature dog with open growth plates, the distal cranio-medial radial insertion incision is modified to a more proximal cranio-medial position to spare the growth plate. If an articular fracture is present at one end of the fractured long-bone, sufficient exposure of the joint should be obtained to confirm that there is anatomic reduction of the articular component of the fracture. The metaphyseal component of the fracture can be treated using MIPO (16, 17). The length of the insertion incisions may vary depending on the type of plate implanted and the size of the dog. In general, each skin incision should allow sufficient exposure to directly access two plate holes (12).

In human patients, neurovascular injuries associated with MIPO are uncommon, and mostly occur with stabilisation of humeral fractures (16). While evaluating MIPO in the humerus of dog cadavers, we found that the radial nerve lies in close proximity to the epiperiosteal tunnel. The radial nerve is vulnerable to injury during dissection of the tunnel from both the proximal and the distal insertion incision. To avoid injury to the radial nerve in these locations, retraction should be carried out with a Senn or Army Navy retractor instead of a Hohmann retractor. The radial nerve is also at risk during the preparation of the tunnel, and while inserting the plate. During insertion of the plate under the brachialis muscle, the plate tends to deviate caudally, most likely due to impingement on the origin of the lateral head of the triceps muscle. We recommend sliding the plate cranially along the humerus during insertion to prevent caudal displacement of the plate.

Minimally invasive plate osteosynthesis of the tibia and the radius carry a small risk of injury of the saphenous and cephalic veins, respectively. However, we found that the approaches to the tibia and the radius were easier and safer than those involving the proximal regions of the limbs. Very little muscle overlies the medial aspect of the tibia. Only the proximal window requires elevation of the aponeurosis of the gracilis and the semitendinosus muscles. In the radius, the dissection is performed directly under the extensor carpi radialis muscle. Therefore, there is little risk of entrapping any muscle unless the initial dissection of the tunnel is initiated superficial to the extensor carpi radialis muscle.

One of the limitations of our cadaveric dissections is that we applied MIPO to intact bones and limbs without traumatic injuries. Admittedly we have found these approaches to be more difficult in clinical cases; however, the insertion incisions are usually located far enough from the fracture site that the soft tissues are minimally affected by trauma. Sliding the plate along a fractured bone is more difficult than on an intact bone because the plate may impinge on the fracture site. Also it may be difficult to advance the plate in chronic fractures due to callus development. If a step between the two main segments persists after reduction, the plate may not slide readily across the fracture. In this situation, inserting the plate along the bone segment...
that is displaced towards the surface of the bone that will be plated will facilitate sliding of the implant across the fracture site. Another limitation of our dissections was that we only used large dogs for investigating the surgical approaches. Anatomical variations between dogs of varying size and conformations may require slight modifications of the approaches that we have described.

Based on our experience, MIPO can be safely performed in dogs for stabilisation of humeral, radial, femoral and tibial fractures. In our cadaveric dissection, all plates were inserted without gross damage to the major regional neurovascular structures, and we have yet to recognise any neurovascular complications in clinical cases in which we have utilised this technique. Further clinical data are needed to evaluate the advantages of this technique compared to other techniques of biological fixation.

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References