How to Make Internal Fixation Work with Limited Bone Stock

Introduction

Fractures are common in small animal practice and there are many options for managing them. After stabilisation and assessment of the patient, the fracture should be evaluated and a plan made as to the most appropriate method to treat the fracture (Shales 2008). Plates and screws remain a popular means to manage many fractures, especially diaphyseal ones, as they provide rigid fixation with reliable healing, and minimal post-operative management when compared with external skeletal fixation. However, some fractures are comminuted, or sufficiently close to a joint (juxta-articular), that they limit the amount of bone available to achieve a standard stable plate and screw fixation (Fig 1). This article discusses the options to achieve a stable internal fixation when there is limited bone stock.

What do you need for stable internal fixation with plates and screws? - Three Bicortical Screws Doctrine

Various factors should be considered when choosing the size of implant, such as type and location of the fracture, age, activity, size of bone, weight of animal, and condition of the soft tissue (Shales 2008), (Table 1). However, based on evaluation of over 1000 bone plate cases and 300 screw fixations, the most important factor was *patient weight* (Brinker 1977), and hence the AO plate sizing chart, which is based on weight, is the starting point for plate size selection (Johnson and others

2005,Piermattei and others, 2006). Once a plate size has been identified, an overlay templating method using an acetate or digital software determines whether and how the implant may fit. Conventional wisdom is at least three or four bicortical screws (six to eight cortices) should be placed in each fracture fragment (Johnson and others 2005, Piermattei and others, 2006). Interestingly the original evidence for this is not forthcoming and appears to be based on experience and logic. From a mechanical point of view, one screw only provides one point fixation allowing rotation of the fracture fragment. Therefore two screws (monocortical or bicortical) in each main fragment is the minimum for stability. Unfortunately, such a construction will fail if one screw breaks or if the interface between bone cortex and screw is threatened due to bone resorption. Thus, for safety reasons a minimum of three screws in both the proximal and the distal fragment is recommended (Fig 2). Therefore, short fracture fragments can make this requirement difficult to achieve, but not necessarily impossible.

Double Plating

Double plating can be extremely useful for achieving a rigid fixation and increased numbers of cortices within a fracture fragment. Critically, this is achieved using the standard inventory of stock plates and screws, and does not necessarily require additional locking instrumentation, or specilised plates and implants. A good rule of thumb is at least one of the plates needs to ideally have two bicortical, or one bicortical and one monocortical (preferably locked – see later) screws. Double plating can be ‘*parallel’ (Fig 3) or ‘orthogonal / polyaxial* (Figs 4 & 5 & Table 2).

A warning however, this approach comes with two potential downsides; in gaining more screws to increase the stability of the fracture repair, the repair has become significantly stiffer which if excessive, may slow or retard healing. It is therefore feasible that one of the plates may need to be removed in the future. Secondly, placing a large amount of metal work over the bone lends itself to the carpenter rather than the gardener type approach to orthopaedics, meaning the ability of the fracture to heal is reduced at the expensive of reconstructing the bone. *Orthogonal double plating, or 'polyaxial plating'* usually results in one of the plates being edge loaded (bending forces are applied against the width, not the depth of the plate, thereby significantly increasing its resistance to bending). Theoretically, the use of orthogonal double plating can provide a much stiffer construct than a single plate especially in resistance to torsion. When double plating, it is important to consider the sizes of the plates used. More often than not, one and sometimes both may be downsized to avoid excessively stiff repairs and to increase the numbers of screws available, such as in figure 3, where a 2.7mm plate was appropriate for the dog's weight, however wouldn't allow minimum numbers of bicortical screws. As an alternative, two 2.0 plates were placed instead, allowing increased numbers of cortices to be achieved. Downsizing can also reduce the plate profile making it easier to close the soft-tissues over the top.

Plates with increased screw hole density - VCP

The Veterinary Cuttable Plate (VCP) has relatively higher numbers of screws per unit length of plate when comparing the 2.7 DCP/ LCP to the 2.0/2.7 VCP (Fig 6). A single 2.0/2.7 VCP is significantly weaker to bending than a 2.7 DCP/LCP, having only approximately 1/3 the stiffness, however by stacking two of them on top of each other, this can be approximately doubled (Frutcher 1991). The main disadvantage is the inability to provide fragment compression as it does not have the oval DCP style holes.

Locking Plates

Locking plates are of great interest to the veterinary orthopaedic community, and do have certain advantages over conventional plates as reviewed by Arthurs 2015. The main difference between locking plates and conventional plates is conventional plate stability is dependent upon friction at the plate to bone and screw to bone interfaces. Standard plates can fail by cortical screw toggling (screw head moving within the screw hole) which leads to screw loosening and loss of plate-bone fixation (Smith and others 2007). Therefore, conventional systems rely on each individual screw's resistance to pullout; hence the more screws placed, the more cortices and the more stable the fixation. A locking screw on the other hand, has a fixed-angle construct that does not rely on friction at the plate to bone and screw to bone interfaces. Instead, the system relies on friction at the threaded screw-plate interface i.e. its locking mechanism. This potentially means that the construct may be more stable with fewer cortices or poorer quality bone. These plates are extensively used in osteoporotic fractures in people for this very reason. The down side of these systems is nearly all them have a fixed angle of the screws. This can mean that you simply may not be able to get two bicortical locked screws aimed at the bone fragment (Fig 7). Alternatives include placing a monocortical locked screw, or to use a locking system that can be easily contoured to re-orientate the screw (OrthoMed SOP (Fig 8), Vetisco Evolox), or a system that allows the placement of screws at different angles within the hole and still achieve a 'locked screw'. These newer variable angled locked screw systems (Securos PAX, Freelance vetLox), however, have not currently been extensively evaluated yet (Arthurs 2015).

Add a locked screw to a conventional fixation 'Hybrid Fixation'

This can be very useful. Plating systems such as the DePuy Synthes Locking Compression Plates (LCP), have 'combi holes'. These plate holes basically combine the old DCP style hole with a locking screw hole. One end of the plate hole allows for placement of a standard cortical or cancellous screw and can be used in either a compression or neutral fashion. The other end has a screw thread cut into it, allowing it to accept a specially designed locking screw (Fig 9). Hence, each combi hole can be used in one of two modes: either in a 'Locking mode' – with special locking screws, nor in a non-locking 'conventional DCP mode' – with standard cancellous or cortical screws.

A recent veterinary mechanical study showed that adding a single locked screw in to an otherwise non-locking construct will increase its resistance to torsion (Gordon 2009), and may be clinically useful (Fig 10). The use of locking screws also has advantages in poor quality bone, or when insufficient cortices are available. Therefore if there is only room for two bicortical screws, it is advisable to place one as a locked screw. There are important rules when mixing locking and non-locking screws in any one bone segment, so called 'hybrid usage'; *it is essential to* ***place the non-locking screws first*** and the *plate must be adequately contoured so there* ***is contact*** *between the bone and the plate*. If contouring is suboptimal, the conventional screws may distort the fracture alignment. Once the conventional screws are placed, locked screws can follow. Placing conventional screws *after* locked screws in any one fracture segment, will lead to the different types of fixation method working against each other and the repair may fail.

If a monocortical screw is required, then use a locking screw wherever possible (Fig 11). Locking monocortical screws are more reliable as they have two points of fixation; the near cortex of the bone and the plate itself, and therefore they resist axial load to failure better than standard monocortical cortex screws in bone. Monocortical locked screws are supposed to provide sufficient stability and load transfer, despite only loading the near cortex. This latter concept has been questioned in small animals due to the presence of very thin cortices and therefore, bicortical screw fixation, or double plate fixation is probably safer if achievable.

Veterinary Anatomical Plates

There is an increasing diversity of veterinary designed plates on the market, from a range of providers. Probably the most common day-to-day indication for these sorts of plates is the toy breed distal metaphyseal antebrachial fracture. **The 'T' plate**, (Fig 12) being wider at the distal end, with screws orientated in the horizontal plate, allows increased screw purchase in a short wide fracture fragment, such as the distal radial epiphysis. These T plates are also useful for short ilial fractures just cranial to the acetabulum, "cotyloid fractures". Historically the vertical portion has been quite short, however longer plates with a T shaped head are now available. 'Veterinary T'- and '**L-plates'** are available in different sizes from 2.0 to 3.5. Other useful plates include the **hockey-stick** or **supracondylar plate 'J plate'** (Fig 13) is very useful for achieving a rigid plate fixation where there is limited bone for screw purchase due to caudal curvature of the femoral condyle in supracondylar fractures. **Acetabular**

plates (Fig 14) are of course useful for acetabular fractures but have also been used for femoral trochlea ridge fractures. **Double hook plates** can be used in proximal femoral fractures as well as for intertrochanteric osteotomies. These can be manufactured for cats using a VCP and pin cutters to fashion two hooks to fold over the proximal aspect of the greater trochanter. Other procedure specific plates can also be useful. The Tibial Plateau Levelling Osteotomy **(TPLO) Plate** for cruciate instability, for instance is very well adapted to short proximal tibial fractures, especially the DePuy Synthes TPLO plate, that has fixed angled locked screws proximally, specifically orientated not to breach the articular joint surface or to impinge on each other (Fig 15).

Malleable / Reconstruction Plates

Reconstruction plates are more malleable and allow three-dimensional contouring (Fig 16). That means it is possible to manipulate the plate to obtain more screws in the smaller bone fragment, however the plates themselves are inherently weaker, being less resistant to bending. Therefore for the same size DCP, the reconstruction plate is more likely to fail. Locking plates with three degrees of contouring freedom now also exist. They combine the increased contouring potential with the advantages of locking screws, but have the disadvantage of usually being ‘weaker plates’. Systems available include the Depuy Synthes UniLock plate, OrthoMed SOP, Vetisco Evolox, to name a few (See Arthurs 2015 for more details). The SOP makes use of standard AO cortical screws (Fig 8), which is both its strength by minimising investment in inventory but also its weakness as these screws have relatively narrow diameters compared with other locking screws (Fig 9) and are more prone to implant failure through screw failure.

Add an IM Pin ‘Plate-Rod’, and other additional implants K-Wires, Lag Screws

Adding an intra-medullary pin to a plate fixation is a useful and popular technique (Hulse 1997, Reems and others 2003). However, often in fractures with limited bone stock, the fragment is too short to be meaningfully stabilised, but it may help in initial reduction by re-aligning and distracting the fragments. A pin size of 40% of the canal diameter is recommending to allow the placement of screws past the pin and to avoid the fixation being too stiff (Fig 17). Other small implants, such as additional small K-wires are useful for fracture reduction and alignment but will not add much to the mechanical strength and therefore shouldn’t be relied upon to shore-up a tenuous plate-screw fixation. Compression from a lag screw is extremely beneficial as it creates absolute stability for bone healing, and the compression also results in impaction of fragments with a marked increase in frictional resistance to motion. What this means is that it greatly reduces the forces born by implants. An option if a fracture component is completely reconstructable is to lag two segments together to in effect make a single larger fragment, which then provides more bone for screw purchase in the newly formed larger fragment.

Human Anatomical Plates

In recent years, aided by the development of locking technology there has been an explosion in human site-specific anatomical pre-contoured, shape specific plates. Some of these can be made use of in veterinary orthopaedics and offer the advantage of the ability to use a mixture or locking and conventional screws in addition to offering varied screw positions and plate shapes. Most of these plates are derived from the DePuy Synthes locking (LCP) and DCP systems. Therefore, they are compatible with veterinary LCP screws and instrumentation, or compatible style veterinary offerings. The human distal radial plates probably are the most useful for veterinary patients (Fig 18), and have been used by this author and others in a range of fractures including cat pelvic fractures, complex ulna fractures and humeral Y fractures, where bone stock is availably but not linearly (Fig 19). Some have contouring grooves so that corners can be bent over relatively easily without deforming the screw holes. Further some plates have locking screw holes intentionally angled to ensure maximum purchase and to avoid physes or articular surfaces. The main consideration is most of these plates were not necessarily designed with weight bearing in mind; the 2.4 Distal Radial Plates for instance are thinner than a straight veterinary 2.4 LCP and therefore they will be weaker.

Combinations

Combining these different options can have excellent results (Fig 20). However, if after considering all internal fixation options, it is not possible to provide two bicortical screws in a single plate, or one bicortical and one locked monocortical screw then other fixation systems such as external skeletal fixators may be necessary.

Summary

Plates and screws are an excellent means to stabilise many fractures however for fractures with short fragments, a range of approaches should be considered to achieve a stable and reliable fixation. There are many ways to achieve this, each with relative advantages and disadvantages. Some are more straightforward, some are more costly and some require more advanced planning. In any case, consideration of double plating, locking implants, anatomical plates, human orthopaedic plates, plate-rods, malleable plates, or combinations should allow the veterinary orthopaedic surgeon to achieve a stable, reliable fixation, even when it appears unachievable on first inspection.

Tables:

Table 1: Factors Influencing your Choice of Implants

General Animal Factors

Age (young, adult, geriatric), weight relative to bone size (overweight, breed conformation), systemic illness, nutritional state, patient activity

Veterinary Factors

Implants and equipment available, expertise and experience available, time and availability for follow-up

Fracture factors

Complexity of fracture, location of fracture, soft-tissues available (for closure and blood supply), open or closed, bone loss

Table 2: Types of Double Plating

Double Plating Type	Plate Position	Advantage	Disadvantage
Parallel	Plates placed next to each other - same bone surface	Increase in bending resistance, increased screw purchase	May struggle to fit two plates on same surface Soft-tissue closure may be difficult
Orthogonal	Plates placed at 90 degrees – orthogonal bone surfaces	Large increase in bending resistance, increased screw purchase Increased room available for second plate	More extensive dissection needed, may retard healing Soft-tissue closure may be difficult

Table 3: Common Juxta-articular Fractures

Common juxta-articular fractures and ideas for management

Femoral Supracondylar Fractures

These are challenging usually due to caudal bow of the femoral condyle. It often helps to place one or two temporary or permanent crossed K-wires to aid initial stability. An arthrotomy into the proximal stifle joint also helps ensure good exposure. The femoral condylar veterinary plate ‘Hockey-Stick’ ‘J plate’ is particularly good here (Fig 13), to ensure at least 3 bicortical screws, however care needs to be taken to avoid the proximal section of the plate diverging away from the femoral diaphysis when concentrating on plating over the condyle distally.

Distal radius and Ulna

Most commonly seen in toy breeds, options include a straight plate if you can achieve 2 bicortical screws distally ± IM pin in the ulna for additional stability. Veterinary or human T plates make use of the distal widening of the radius and allow two bicortical screws in the short distal fragment (Fig 12). Again ulna IM pin can help with stability.

Proximal Femur

The best option here is to take time to accurately contour a plate along and over the top of the greater trochanter (Fig 17). The greater trochanter offers a large block of bone stock and screws can be angled in to this to achieve purchase. A plate bending press if usually necessary to get sufficient bend on the proximal aspect of the plate. A screw can be angled up the femoral neck to increase purchase. A forked plate is another option and can be manufactured from a VCP in cats. Additional intra-medullary pins in the femur can also be beneficial.

Distal tibia

These can be particularly challenging. It is important to avoid the tarso-crural joints surface, and orthogonal plating may help, however soft-tissue closure can be a problem as can assessment of fracture healing due to the metalwork obscuring the fracture on radiographs. It is also worth considering placing locked screws if available (Fig 10).

Proximal Tibia

The TPLO plate is essentially a plate designed to stabilize a short proximal tibial fragment and works well here. T plates can also be used, but be aware that there are strong rotation forces acting in these region, potentially rotating the proximal femur caudally. Additional placement of a pin and tension band may be advisable.

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Figure Legends

Figure 1: Distal femoral fracture with limited bone stock in distal fragment

Figure 2: Three screw doctrine: One bicortical screw per segment allows rotation. Two bicortical screws prevents rotation but remains at high risk of failure. Three bicortical screws therefore, are the recommended minimum.

Figure 3: Parallel double plated ilial fracture. Based on the dogs weight a 2.7mm plate would have been selected however there was only room for two bicortical screws. By placing two 2.0mm plates, five bicortical screws were placed in the shorter fragment.

Figure 4: Orthogonal double plated feline ilial fracture, allowed 4 bicortical screws to be placed.

Figure 5: Double plated (LCP plates using locking screws) short comminuted calcaneal fracture, allowed placement of 4 bicortical screws.

Figure 6: 2.0/2.7 Veterinary Cuttable Plate (VCP) (left-hand-side) has higher screw hole density that 2.7mm LCP (right-hand-side) or DCP plate.

Figure 7: Locking Compression Plate (LCP) allows for placement of fixed angle locking screw, which requires plate contouring to orientate screw position, as well as standard screws which can be angled within the screw hole.

Figure 8: String-of-Pearls plate (SOP), allows for contouring in 3 planes, and uses standard screws in its locking mechanism.

Figure 9: LCP plate has 'combi-holes' allowing placement of a locking or standard screw. LCP locking screws have a thread on the head to engage in the plate hole, and also have an increased core diameter to reduce screw failure.

Figure 10: Double spiral tibial fracture with short distal fragment. Only two screws were placed in the distal segment, however one was placed as a locking screw increasing the stability of the fixation.

Figure 11: Comminuted tibial fracture with long lateral fragment preventing bicortical screw placement. A series of locked mono-cortical screws were placed to achieve an additional 4 cortices.

Figure 12: Distal radial fracture in toy-breed dog, stabilised with veterinary T plate employing 2 distal screws (left). Example of veterinary T plate with 3 distal screw holes (right).

Figure 13: Supracondylar femoral fracture, stabilised with 'hockey-stick' plate, allowing 3 bicortical screws in curved distal condyle.

Figure 14: Feline ilial fractures stabilised with a 7 hole DCP, and sacroiliac luxation stabilised with 2.7mm screw. An anatomical acetabular plate has been placed to stabilise a mid-acetabular fracture.

Figure 15: Veterinary locking Tibial Plateau Leveling Osteotomy Plate (TPLO). Proximal locking screws clustered in a small space and orientated to avoid each other make this a useful plate for proximal tibial fractures.

Figure 16: Reconstruction plates, have increased malleability to allow 3 degrees of contouring, which is useful to achieve increased numbers of screws in some short bone fragments, however the plates are weaker than the equivalent sized straight DCP.

Figure 17: Proximal comminuted femoral fracture in a cat. A plate has been contoured over the greater trochanter to make use of the proximal bone stock. Further, an intra-medullary pin has been added to increase stability.

Figure 18: Human anatomical plates - 2.4mm Distal Radial Plates. These plates have 'combi holes' allowing flexible usage. They come in a range of shapes, and have contouring planes, to allow plate contouring without damaging the screw holes. They are thinner and relatively weaker than the equivalent LCP/DCP stock plate.

Figure 19: Veterinary use of Human 2.4 Distal Radial Plates. a) Comminuted canine olecranon fracture was stabilised by placement of a lag screw to reconstruct the main fragment, and then a radial L-plate was placed laterally to achieve 2 bicortial screws in the fragment. A second caudal plate (double orthogonal plating), was also placed due to the dog being known to be highly active. b) Distal humeral bicondylar 'Y' fracture with very short lateral condylar fragment. A human radial L plate was also used here, this time with 3 screws in the distal segment, all placed as locking screws, combined with a standard 2.7 LCP plate on the medial aspect.

Figure 20: Comminuted articular distal radial fracture in a lurcher was repaired using multiple techniques. The distal fragments were stabilised with a lag screw to reduce and stabilise the articular surface. K wires were placed to temporarily position the distal fragment to the radial diaphysis which was stabilised with a veterinary T plate, placing 2 bicortical screws in the newly formed single distal fragment. The lag screw was then removed and replaced through a medial plate (orthogonal double plating), which allowed additional mono cortical locked screw to be placed in the distal fragment.