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Making internal fixation work with limited bone stock

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Introduction

Fractures are common in small animal practice and there are many options for managing them. It is important that the fracture is evaluated and a plan made as to the most appropriate method to treat it (Shales 2008). The most popular method for managing many fractures, especially diaphyseal ones, is by using plates and screws as they provide rigid fixation, usually with reliable healing. Additionally, when compared to external skeletal fixation, there is typically less postoperative management required. 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).

Creating a stable internal fixation: 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, (Table 1). However, based on evaluation of over 1000 bone plate cases, 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 impossible to find and appears to be based on experience and logic. From a mechanical point of view, one screw alone, will only provide one point fixation, allowing rotation of the fracture fragment along the axis of the screw, and therefore will not provide fracture stability. Two screws (monocortical or bicortical), in each main fragment is therefore 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). 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. Beneficially, this is achieved using the standard inventory of stock plates and screws, and does not necessarily require additional locking instrumentation, or specialised 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 placed. Double plating can be ‘parallel’ (Fig 3) or bi-axial, often referred to as ‘orthogonal’ if placed at right-angles (Figs 4 & 5 & Table 2).

A warning, however, is that this approach comes with two potential downsides. The first is that, in using more screws to increase the stability of the fracture repair, the repair will become significantly stiffer which, if excessive, could theoretically slow or retard the healing process. I have, on rare occasions, had to remove one of a pair of plates due to these concerns. Secondly, in placing further implants on the bone, there can be more disruption to the soft tissues and the blood supply to the bone, potentially reducing the ability of the fracture to heal at the expense of using internal fixation. Careful surgical dissection and techniques such as minimally invasive plate osteosynthesis can be used to reduce the impact, but discussion of these is beyond the scope of this article.

Bi-axial double plating, most commonly placed orthogonally, frequently results in one of the plates being predominantly 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 bi-axial orthogonal double plating can provide a much stiffer construct than a single plate especially in resistance to torsion and bending. Therefore, 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 one or both plates can also reduce the increased plate profile from a second plate, 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 compared to the equivalent DCP (Fig 6). However, a single 2.0/2.7 VCP for instance, is significantly weaker to bending than a 2.7 DCP/LCP, having approximately 1/3 the stiffness, but by stacking two of them on top of each other the composite stiffness can be as much as doubled (Frutcher and Holmberg 1991). Factors affecting the stiffness achieved through stacking include the size of plate and the length of the upper plate in relation to the lower plate of the stack. A further disadvantage of the VCP is its inability to provide fragment compression as it does not have the oval-shaped holes seen on a DCP.

Locking Plates

Locking plates are of great interest to the veterinary orthopaedic community, and do have certain advantages over conventional non-locking plates as reviewed by Arthurs 2015. The main difference between locking plates and non-locking plates is non-locking plate stability is dependent upon friction at the plate to bone and screw to bone interfaces. Non-locking plates can fail by 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, non-locking 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, relies on friction at the threaded screw-plate interface i.e. its locking mechanism. This means that the construct does not rely on friction between the plate and the bone, or the screw and the bone, and hence should 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, by virtue of their being locked. This can mean that it may not be possible to aim two bicortical locked screws within the bone fragment (Fig 7).

Alternatives include placing a monocortical locked screw (see next section for more detail), or to use a locking system that can be easily contoured to allow placement of a locked screw into the bone segment (OrthoMed SOP (Fig 8), Vetisco Evolox). The OrthoMed SOP (String of Pearls), is popular, as it allows six degrees of contouring, and makes use of standard AO non-locking cortical screws (Fig 8). The use of non-locking AO style screws, is both its strength by minimising investment in inventory, but also its weakness as these screws have relatively narrow core diameters compared with other locking screws (Fig 9), and are therefore more prone to implant failure through screw breakage. Further systems, now available allow 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 been extensively evaluated yet (Arthurs 2015).

Creating a hybrid fixation

Adding a locked screw to a conventional fixations to create a 'hybrid fixation' can be very useful. Plating systems such as the DePuy Synthes Locking Compression Plates (LCP), have 'combi holes'. These plate holes combine the old Dynamic Compression Plate (DCP), style hole with a locking screw hole. One end of the plate hole allows for placement of a standard non-locking cortical or cancellous screw and can be used in either compression or neutral fashion. The other end has a thread cut into it, allowing it to accept a specially designed locking screw (Fig 9). This means that 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 veterinary mechanical study showed that adding a single locked screw 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 at least 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 also be adequately contoured so there is contact between the bone and the plate in the regions where non-locking screws are placed.

If contouring is suboptimal, the non-locking screws may distort the fracture alignment. Once the non-locking screws are placed, locked screws can follow. Placing non-locking screws *after* locked screws in any one fracture segment, will lead to the different types of fixation method working against each other, as the locking screw will prevent the non-locking screw from creating contact and friction between the plate and the bone. Therefore, rather than acting synergistically, the repair may fail.

If a monocortical screw is required, then a locking screw is preferable to a non-locking monocortical screw (Fig 11). Locking monocortical screws are mechanically more reliable than non-locking as they have two points of fixation; the near cortex of the bone and the plate itself, and therefore they resist 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 comparatively very thin cortices and therefore, bicortical screw fixation, or double plate fixation is probably safer if achievable.

The minimum number of locked or combination or locked and non-locked screws is unknown. The author would tentatively suggest aiming for an absolute bare minimum of four cortices IF at least one cortex had a locked screw and one or more bicortical screw(s) were present, in a reconstructed fracture. Extremely careful post-operative care would be necessary, and other considerations such as location, bone quality, other injuries, age, activity and quality of repair would need to be considered. Otherwise, a suggested minimum would be five cortices with at least a single monocortical or bicortical locked screw.

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 are the toy breed distal metaphyseal antebrachial fracture. The ‘T’ plate, (Fig 11) being wider at one end, with screws orientated along the wide portion of the 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 plate has been quite short, however longer plates with a T shaped head are now available. ‘Veterinary T’- and ‘L-plates’ for use in veterinary practice are available in different sizes (ranging from 2 mm to 3.5 mm plates).

Other useful plates include the hockey-stick or supracondylar plate ‘J plate’ (Fig 12), which is very useful for achieving a rigid plate fixation where there is limited bone for screw purchase due to the curvature of the femoral condyle in supracondylar fractures. Acetabular plates (Fig 13) are 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 and insert into the proximal aspect of the greater trochanter.

Other procedure specific plates can also be useful. For instance, the Tibial Plateau Levelling Osteotomy (TPLO) Plate for cruciate instability, 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 14).

Plates with Six Degrees of Freedom – Reconstruction, Malleable and Contourable plates

Reconstruction plates were the first available plates that allowed three-dimensional (six degrees) contouring by increased malleability and plate design (Fig 15). This means it is possible to contour the plate to obtain more screws in a smaller, or unusual shaped bone fragment, however these plates are inherently weaker to allow contouring, Therefore, compared to the same size DCP, the reconstruction plate is more likely to fail.

Locking plates with three degrees of contouring freedom 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, Veterinary Instrumentation Cuttable Malleable Locking Plate, and Vetisco Evolox..The OrthoMed SOP (Fig 8), also allows six degrees of freedom with locking screws, but has been biomechanically shown not to be mechanically inferior to the equivalent DCP (Arthurs 2015).

Creating a plate rod

Adding an intra-medullary (IM) pin to a plate fixation is a useful and popular technique (Hulse 1997, Reems and others 2003). An IM pin helps to distract the fracture and maintain alignment during surgery. If the pin can be placed from the shorter fragment into the longer fragment, such as in a proximal femoral fracture with a pin placed from proximal to distal, it will improve the stability of the construct. However, if the IM pin can only be placed from the longer fragment into the shorter fragment, such as the case with distal femoral condylar fracture, there may be no meaningful increase in stability provided, although, it may help in initial reduction by re-aligning and distracting the fragments. A pin size of 40% of the canal diameter is usually recommending and taken from the pre-operative radiographs, potentially from the contralateral limb, measured on the radiographic projection that the screws are placed from and to i.e. with a laterally applied plate, the lateral, not the caudocranial projection should be used.

Choosing a pin of 40% the diameter allows the placement of screws past the pin whilst still providing a mechanical advantage. In the example shown, the medullary canal isthmus measured 5.3mm on the lateral radiographic view (not shown) and a 2mm pin was selected to give 38% fill (Fig 17). If locking screws are used, then monocortical screws may be necessary as placing locking screws past the pin can be impossible at times.

Additional implants to reconstruct the bone and improve stability

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 of 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 17), and I have used these in a range of fractures including cat pelvic fractures, complex ulna fractures and humeral Y fractures, where bone stock is limited (Fig 18). Some have contouring planes so that corners can be bent over relatively easily without deforming the screw holes. Furthermore 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 human plates were not designed for weight bearing application as bipedal humans will not weight bear on forelimb/upper limb plates. As such the plates are relatively thin and should be used with due consideration in veterinary small animal orthopaedic applications where weight bearing may be intended.

Fixation combinations

Combining the different fixation options outlined above can have excellent results (Fig 19). 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. The circular external skeletal fixator has been shown to be particularly useful in this context, as well as circular-linear hybrids containing a single ring allowing several pins to be placed in a short segment of bone and then connected to a linear fixator along the longer bone fragment.

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, and some lend themselves well to a particular fracture location or configuration (Table 3). Some approaches are straightforward, while others 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 (Fig 20).

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, but not as much as orthogonal, increased screw purchase	May struggle to fit two plates on same surface Soft tissue closure may be difficult
Bi-axial: Orthogonally placed	Plates placed at 90 degrees – orthogonal bone surfaces	Large increase in bending resistance, due to edge-loading of implant, increased screw purchase Increased room available for second plate	More extensive dissection may be 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 curve 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 assessment of fracture healing due to the metalwork obscuring the fracture on radiographs is a significant problem and care should be taken with soft-tissue closure. 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

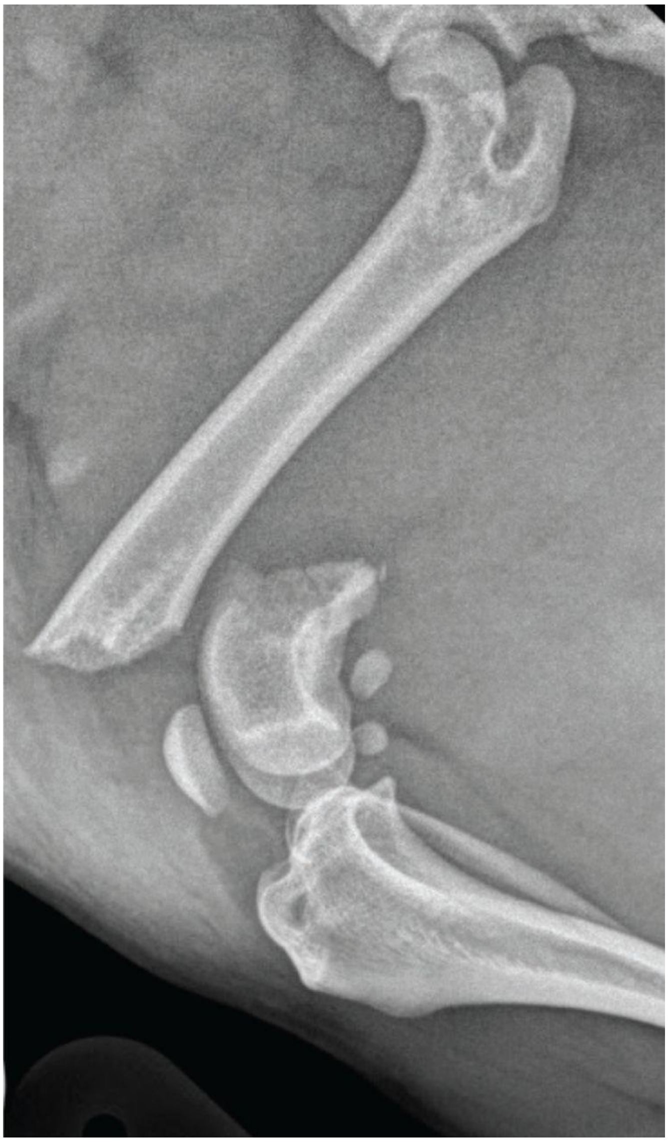

Figure 2: Three screw doctrine: One bicortical screw per segment allows rotation. Two bicortical screws prevents rotation but remains at high risk of failure. Three bicortical screws are therefore the recommended minimum.

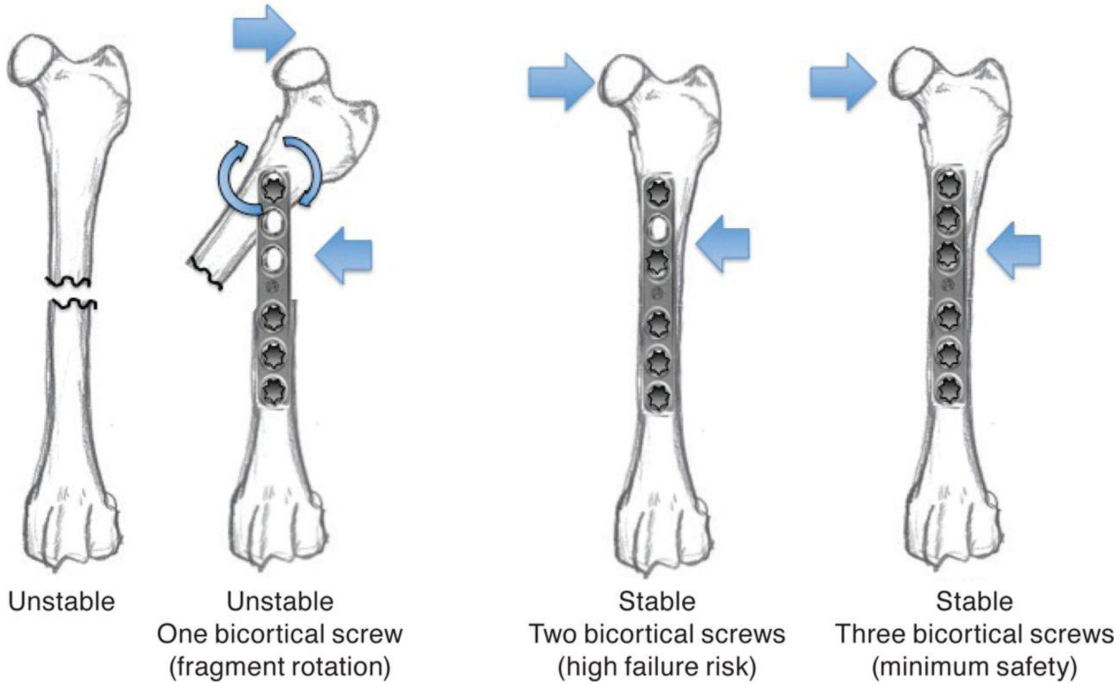

Figure 3: Parallel double plated ilial fracture. Based on the dog's weight a 2.7mm plate would have been selected however there was only room for two bicortical screws. By placing two 2.0mm plates (DePuy Synthes DCP), five bicortical screws were placed in the shorter fragment.

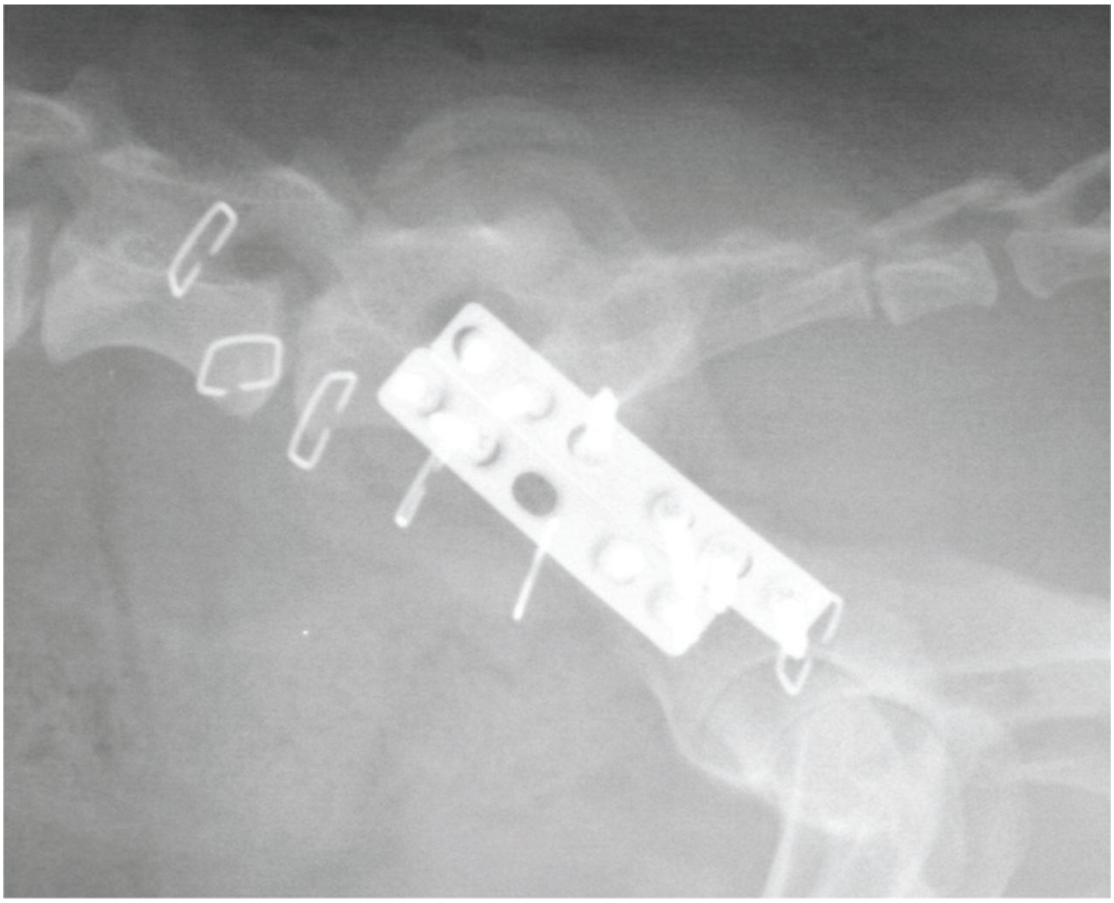

Figure 4: Orthogonal double plated feline ilial fracture, allowed 4 bicortical screws to be placed (DePuy Synthes DCP laterally, DePuy Synthes 1.5/2.0 VCP stacked dorsally)

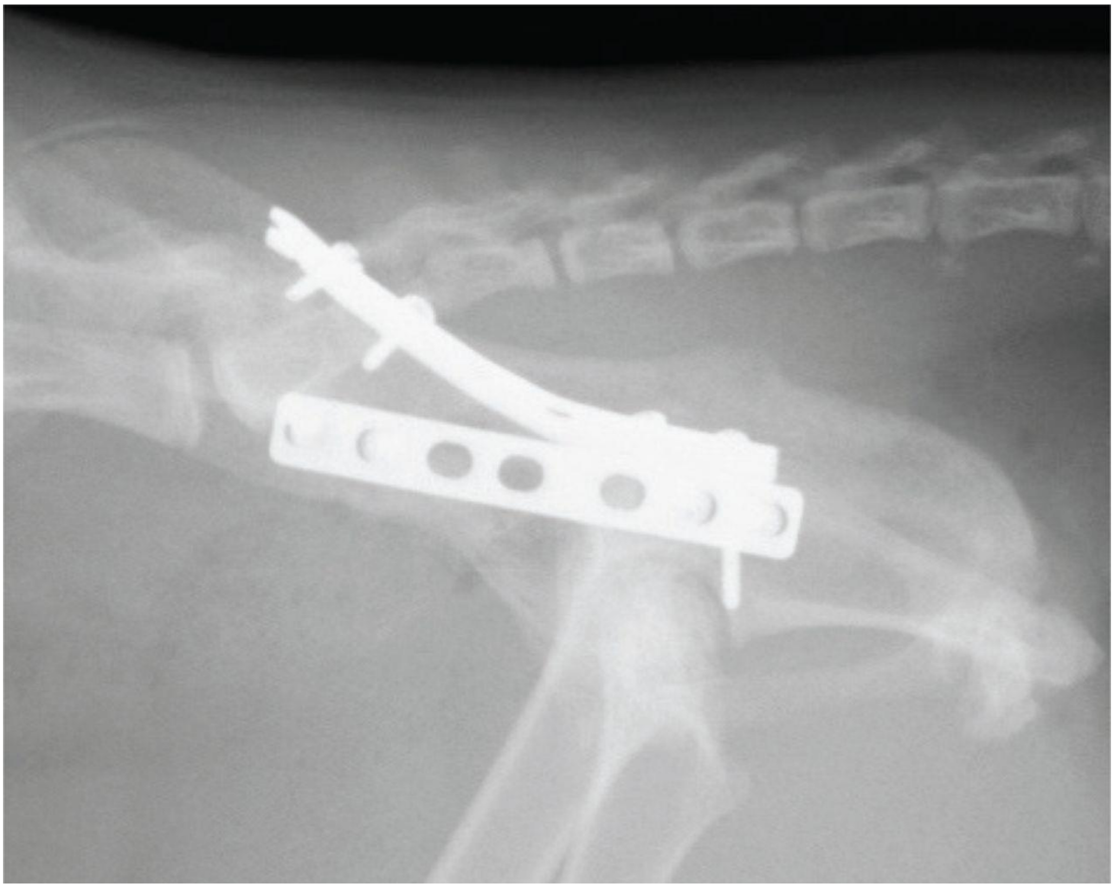

Figure 5: (a) Short comminuted calcaneal fracture. (b) The fracture was double plated, which allowed for placement of four bicortical screws into the calcaneus

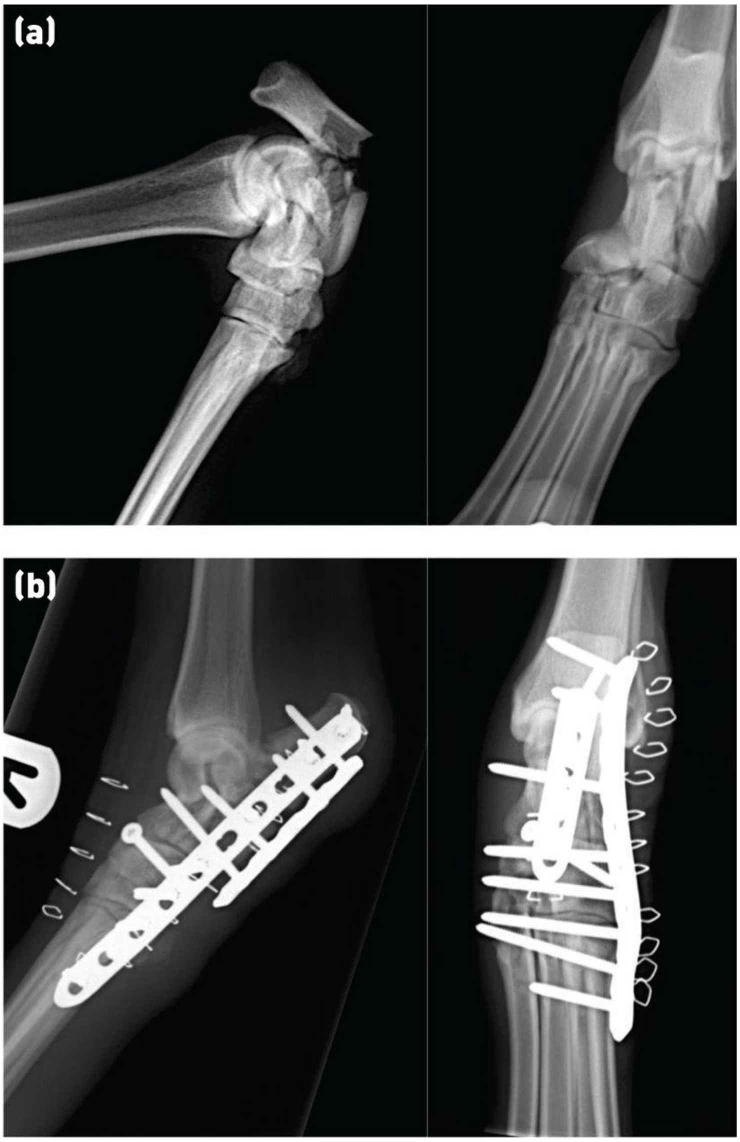

Figure 6: The 2/2.7 mm veterinary cuttable plate (top) has more screw holes per unit length than the 2.7 mm locking compression plate (bottom), or a dynamic compression plate

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

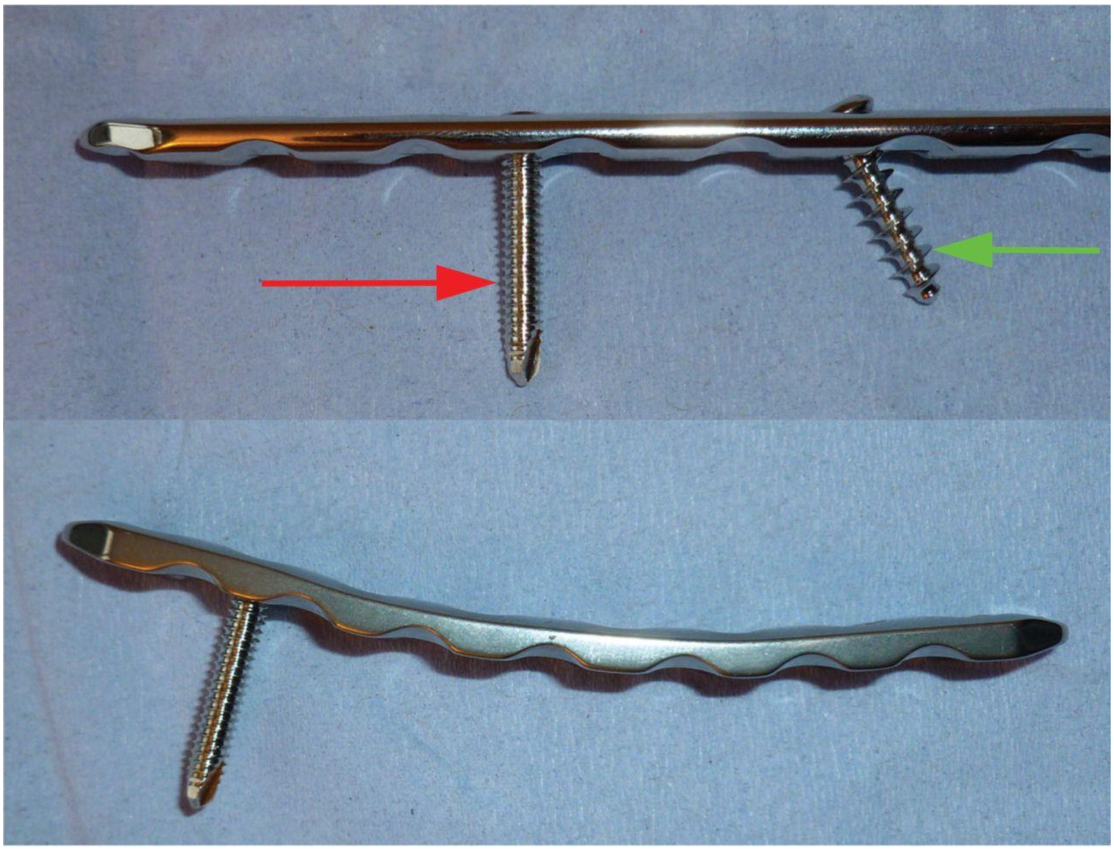

Figure 8: String-of-Pearls plate (SOP, OrthoMed), allows for contouring in 3 planes, and uses non-locking cortical screws as part of its locking mechanism.

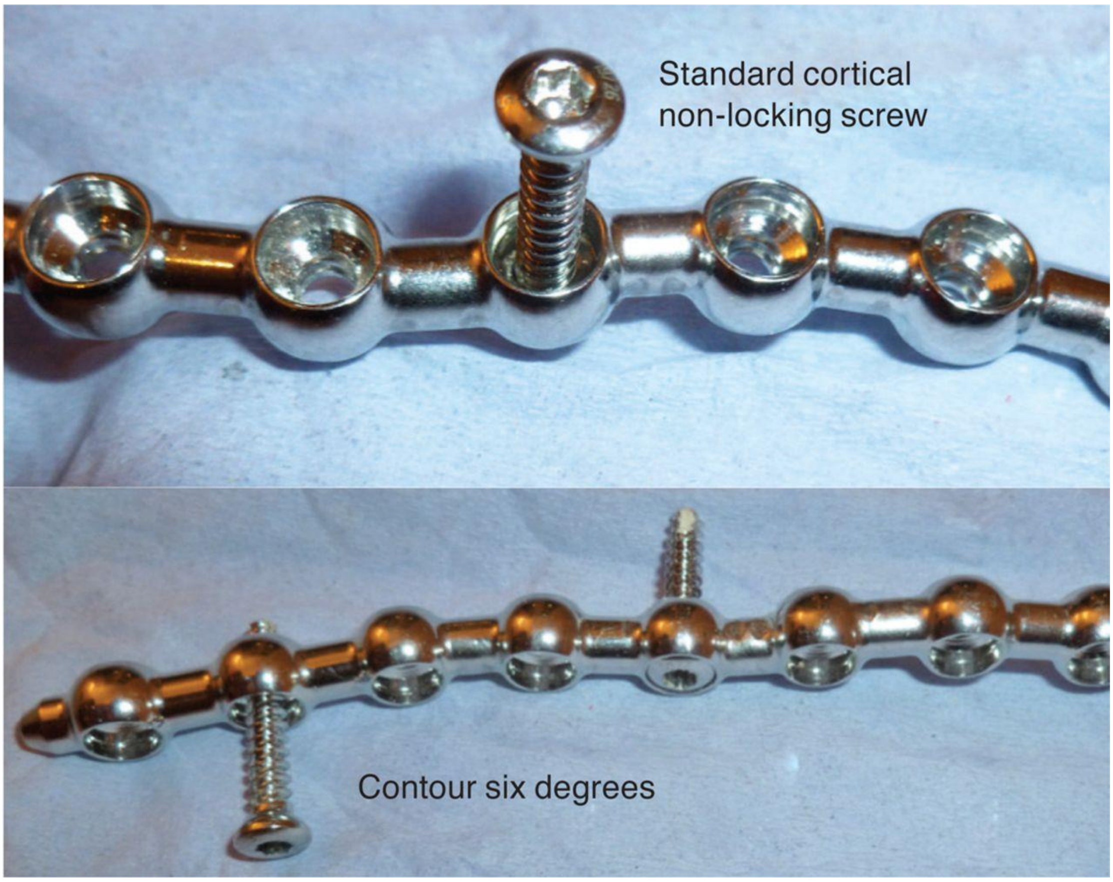

Figure 9: A locking compression plate (LCP) has 'combi-holes' allowing placement of a locking or non-locking screw. LCP locking screws have a thread on the head to engage in the plate hole, and also have an increased core diameter to make the screw stronger, thus reducing the chance of failure

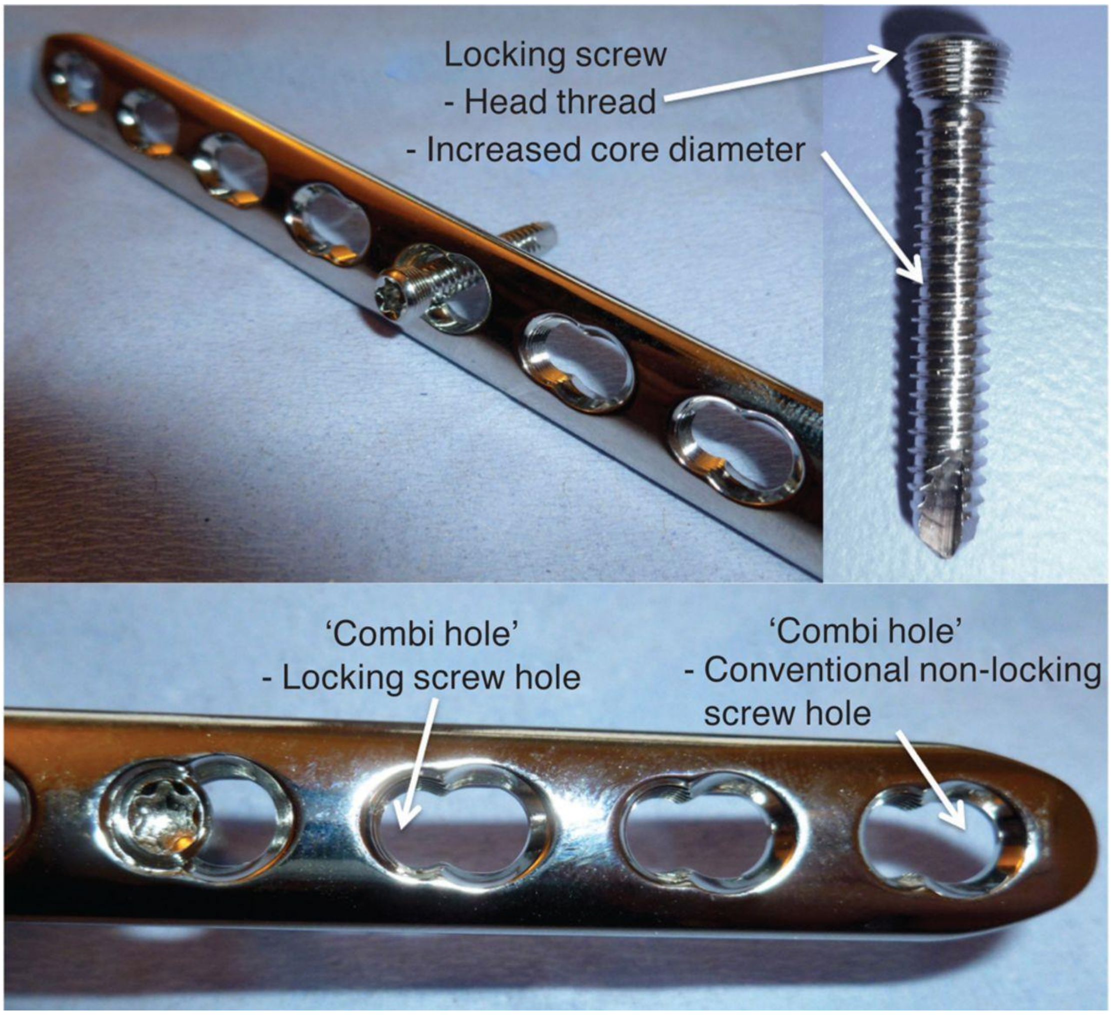

Figure 10: (a) Orthogonal view radiographs of double spiral tibial fracture with a short distal fragment. (b) Postoperative orthogonal radiographs show locking screws marked *. Only two screws were placed in the distal segment (circled); however, one was placed as a locking screw (*) increasing the stability of the fixation

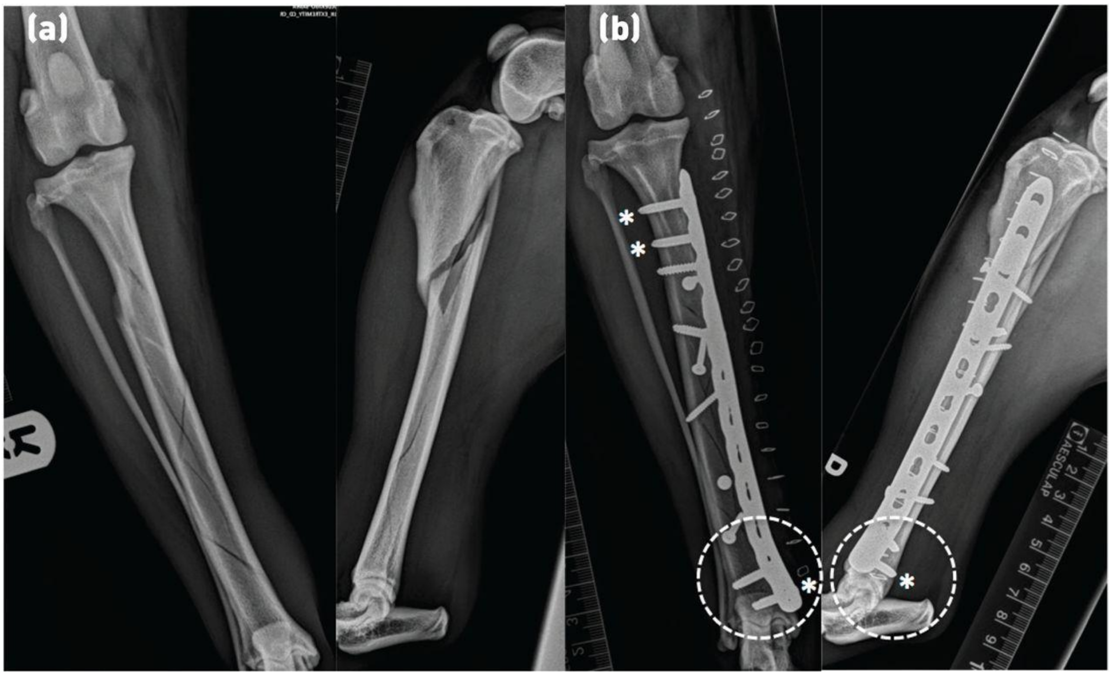

Figure 11: (left) Distal radial fracture in a toy breed dog, stabilised with a veterinary T plate employing two distal screws. (right) Other designs of veterinary T plates with three distal screw holes are also available

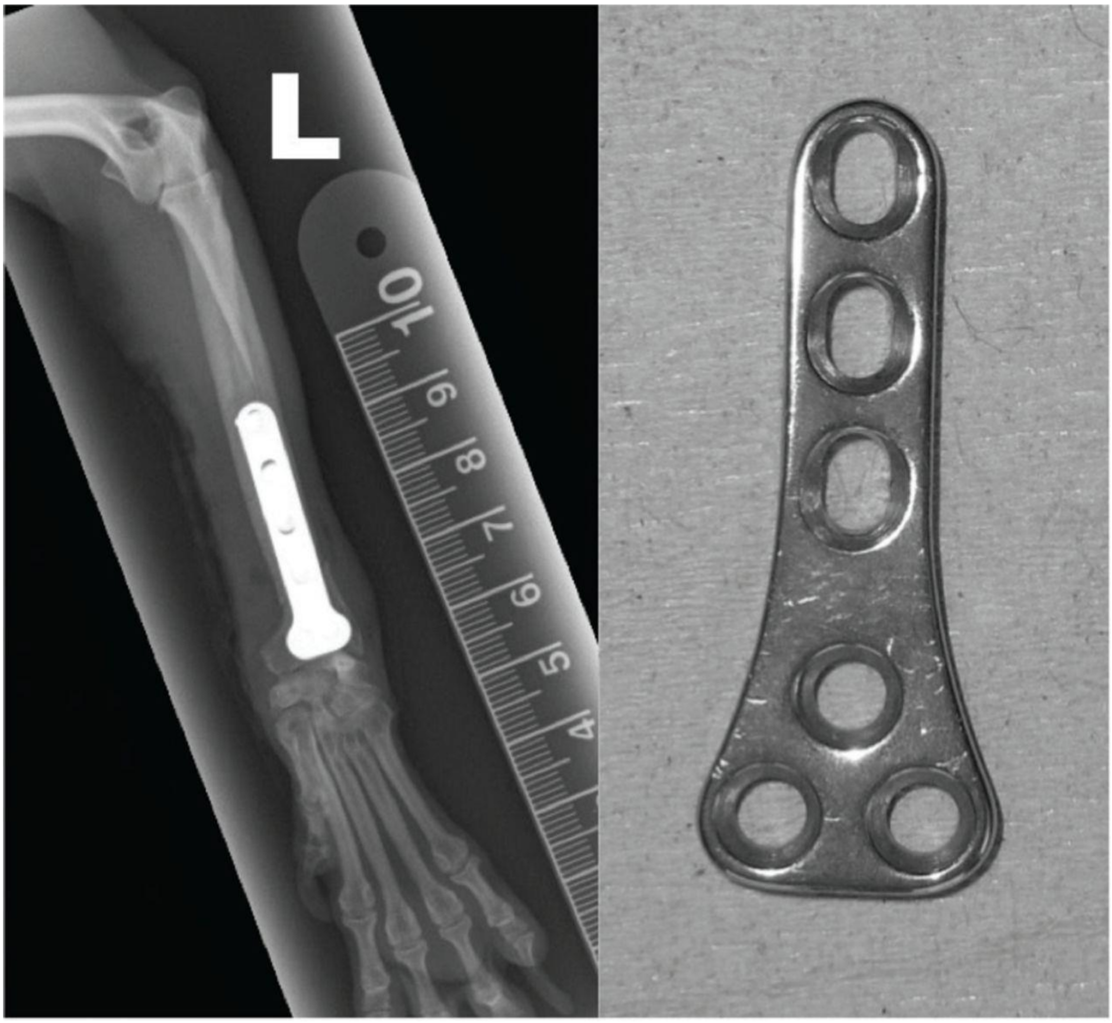

Figure 12: (left) 'Hockey-stick' plate which allows three bicortical screws to be screwed into the curved distal condyle. (right) This type of plate was used to stabilise a supracondylar femoral fracture

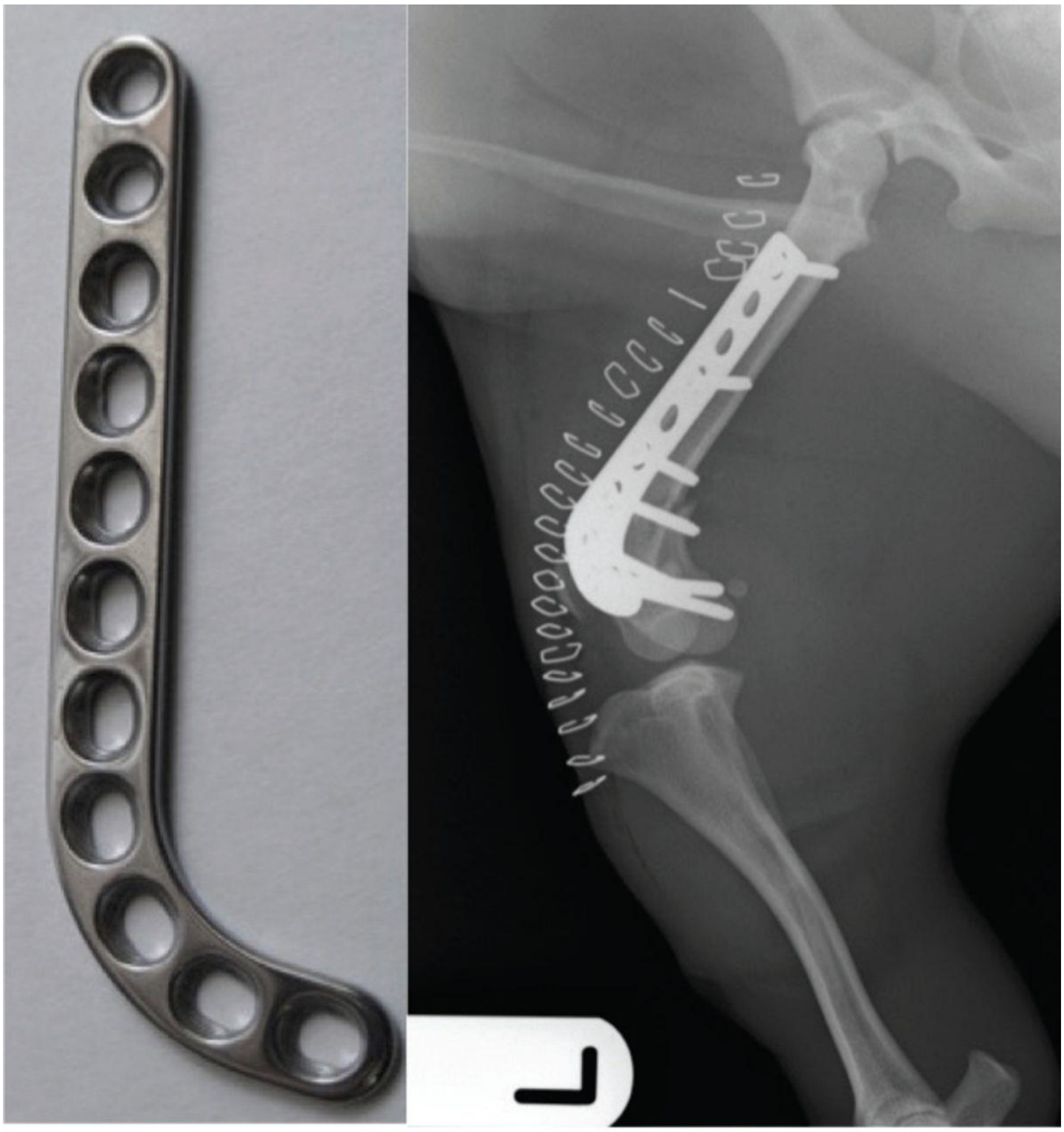

Figure 13: A mid-acetabular fracture in a cat which was stabilised with an anatomical acetabular plate. An additional ilial fracture was plated with a seven-hole dynamic compression plate. A sacroiliac luxation was also present and was stabilised with a 2.7 mm screw.

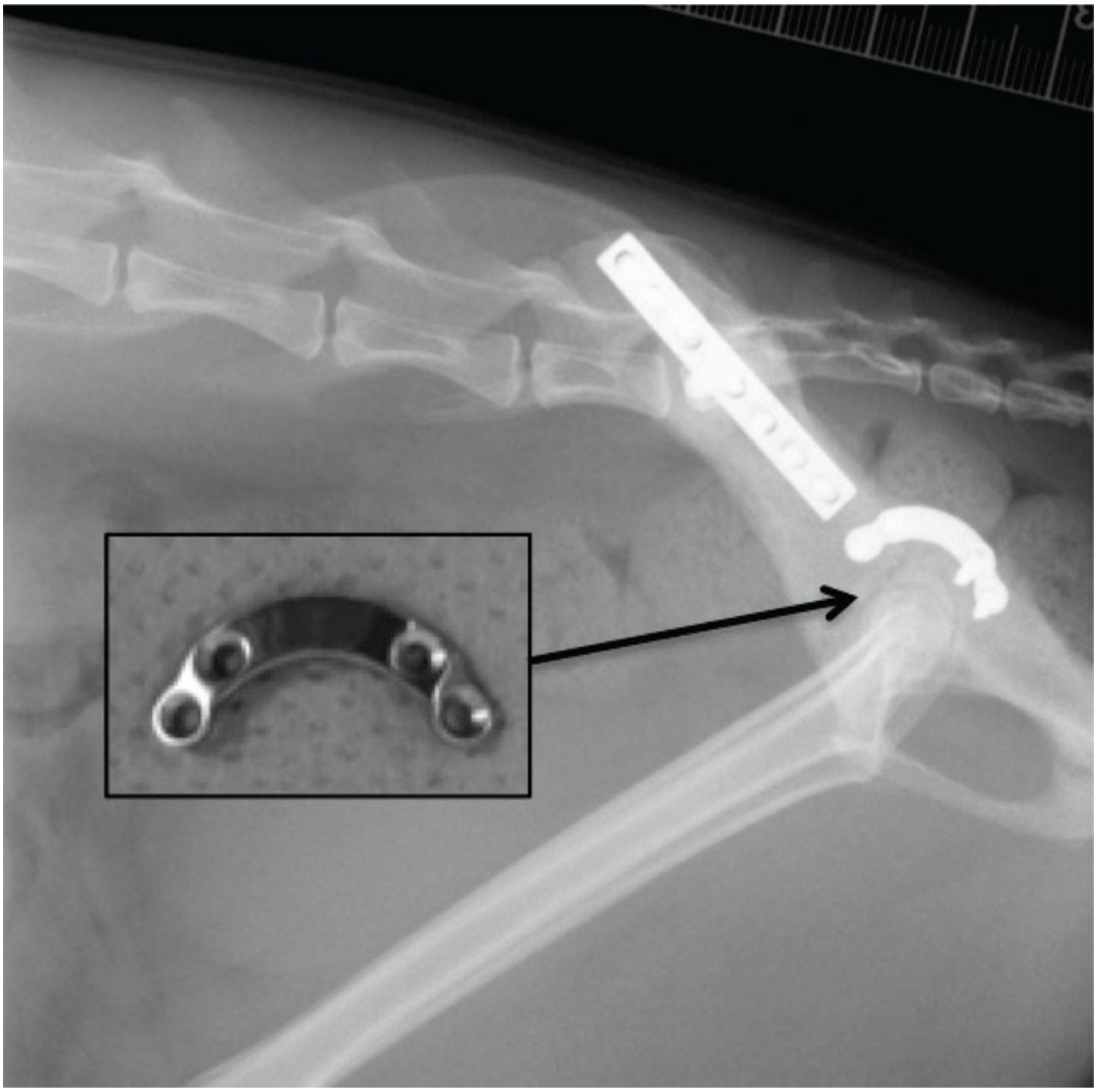

Figure 14: Broad locking tibial plateau levelling osteotomy plate. This plate is useful for proximal tibial fractures due to the proximal locking screws being clustered in a small space and orientated to avoid each other

Figure 15: Reconstruction plates have increased malleability to allow six degrees of freedom, which is useful to achieve increased numbers of screws in some short bone fragments. However, the plates are weaker than the equivalent-sized straight dynamic compression plate

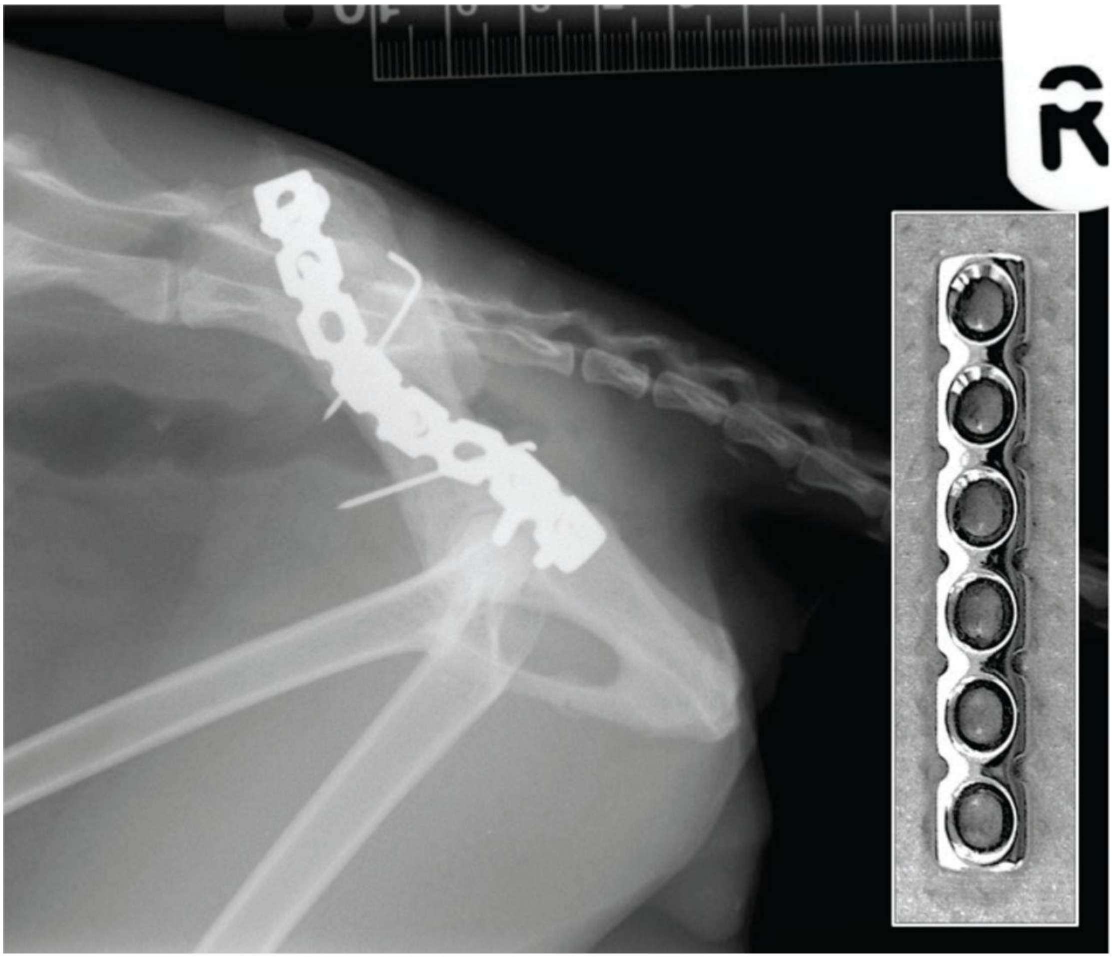

Figure 16: Proximal comminuted femoral fracture in a cat. A plate has been contoured over the greater trochanter to make use of the proximal bone stock (DePuy Synthes 2.4mm LCP). Further, an intra-medullary pin (2mm) has been added to increase stability.

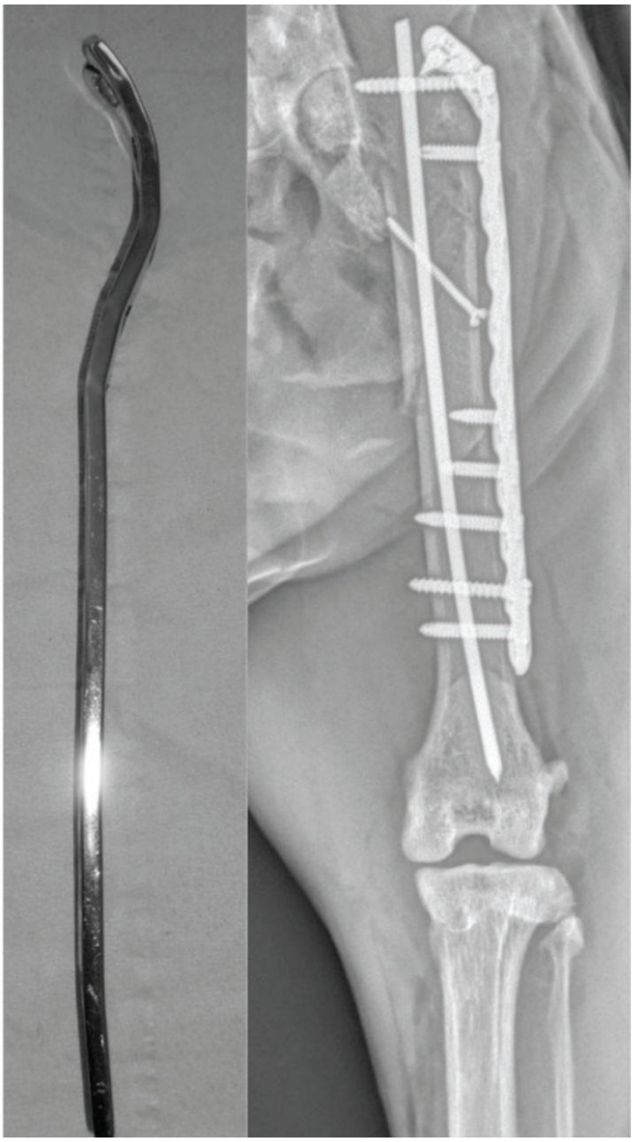

Figure 17: Human anatomical plates - 2.4mm Distal Radial Plates (DePuy Synthes 2.4mm Distal Radius Plates). These plates have 'combi holes' allowing flexible usage. They come in a range of shapes, and have contouring planes, to allow plate contouring without damaging the screw holes. They are thinner and relatively weaker than the equivalent LCP/DCP stock plate.

Figure 18: Veterinary use of Human 2.4 Distal Radial Plates (DePuy Synthes). 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.

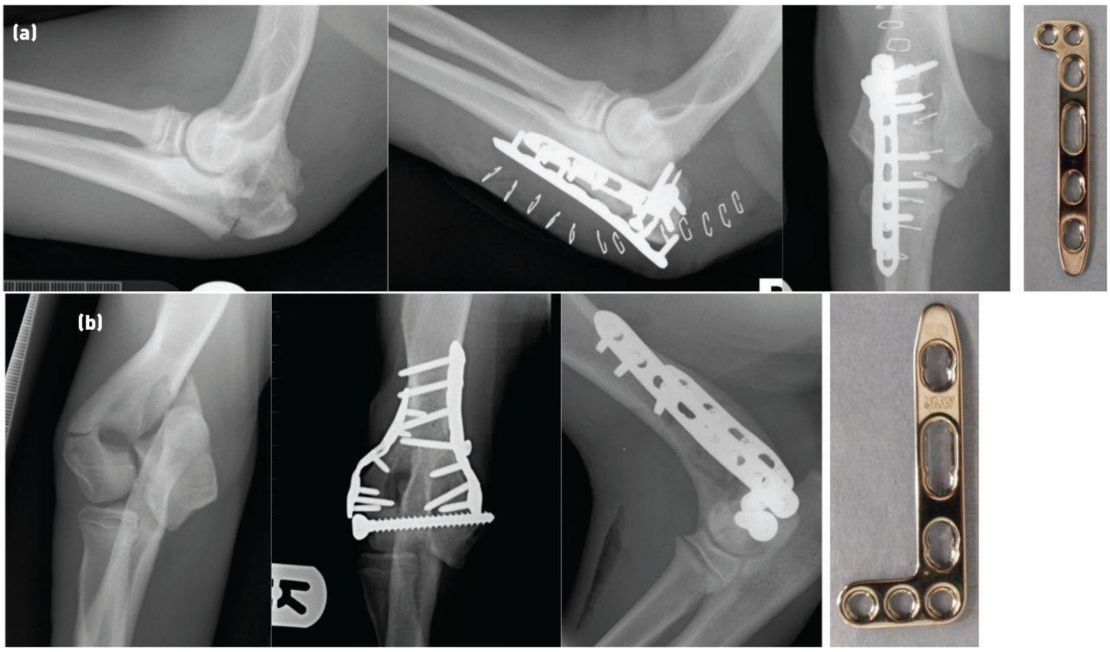

Figure 19: Comminuted articular distal radial fracture in a lurcher was repaired using multiple techniques. The distal fragments were stabilised with a lag screw to reduce and stabilise the articular surface. K wires were placed to temporarily position the distal fragment to the radial diaphysis which was stabilised with a veterinary T plate (DePuy Synthes 2.7mm), 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) (DePuy Synthes 2.7mm LCP), which allowed an additional monocortical locked screw to be placed.

Figure 20: Suggested algorithm for dealing with limited bone stock with internal fixation. Preferred methods bold arrows, suitable methods thin arrows, and possible methods dashed arrows.