How To Fix Fractures Online 'Mini Series'

Session 2: External Skeletal Fixation

Mark Glyde

BVSc MACVSc MVS HDipUTL MRCVS DiplomateECVS
RCVS Recognised Specialist in Small Animal Surgery
Associate Professor, Small Animal Surgery
Murdoch University

How To Fix Fractures- Session 2

What are the benefits of external fixators?

Fixators have great potential for rapid biologic healing if they are applied appropriately and with due consideration to the principles involved. The fact that fixators can be placed closed and that implants are not placed at the fracture site means that potentially the fracture biology is not disturbed at all unlike other methods such as IM pins, bone plates and interlocking nails. This minimally invasive approach has been shown to speed fracture healing.

Another great strength of fixators is their tremendous versatility. They can be used just about anywhere on the body and certainly in many locations where internal fixation methods have inherent disadvantages or are simply unsuitable. The flip side of this versatility however is that there is a steep learning curve with them – particularly if they are taken “off road “ into locations that we are not as familiar with.

Fixators also have some financial advantages over bone plating and interlocking nail systems. Not so much in cost to the owner as they tend to be pretty similar but more in the cost to the practice in that the equipment needed to apply fixators are very minimal and also that the inventory that is needed for routine fracture repair with fixators is relatively small when compared to plating and interlocking nails.

What are the disadvantages of fixators?

We mentioned the steep learning curve already – it is critical to understand both the decision making and the principles of application of external fixators to have success – especially if you are taking them “off road” in places like the spine, mandible or across joints. That is definitely a disadvantage relative to plating and interlocking nail systems which tend to have more defined rules and simpler decision making.

Fixators also need more postoperative care than internal fixation methods do – bandage and fixator maintenance in addition to repeat radiographs and further anaesthetics for pin removal.

Another problem is that there are so many possible variables – we covered these in the first section - for example type, number, size and location of the pin, connecting bar materials, type of clamp, frame design etc. This variation is both a strength and a weakness – it provides great versatility but it can be quite confusing in deciding exactly what to use for a particular case.

The main complication with fixators is premature pin loosening. The pin-bone interface which is the connection between the bone and the pin is a critical factor in the “life” or longevity of a fixator. If the pin-bone interface is not effectively maintained then the pin becomes loose and the stability of the frame is not then transmitted effectively to the bone. This also causes significant morbidity to the animals.

The simple fact is that unlike bone plates and interlocking nails, external fixators are a <u>temporary</u> method of fixation; in effect they are a temporary external splint that has a finite “life”.

What is needed for consistent success with external fixators?

Success with external fixators requires a number of things:

- Firstly a good understanding of **fracture assessment and decision-making**. Assess each individual fracture and determine the biologic, biomechanical and clinical factors – is a temporary fixation method like an external fixator suitable for that particular case? – or is a "permanent" fixation method such as a bone plate or interlocking nail needed?
  Why are ESFs "temporary"? Because they will all eventually loosen – so it is a "race" between bone healing and inevitable implant failure.
  The main problems with ESFs are premature pin loosening, morbidity and secondary pin tract infection. These lead to partial or complete failure of the ESF.

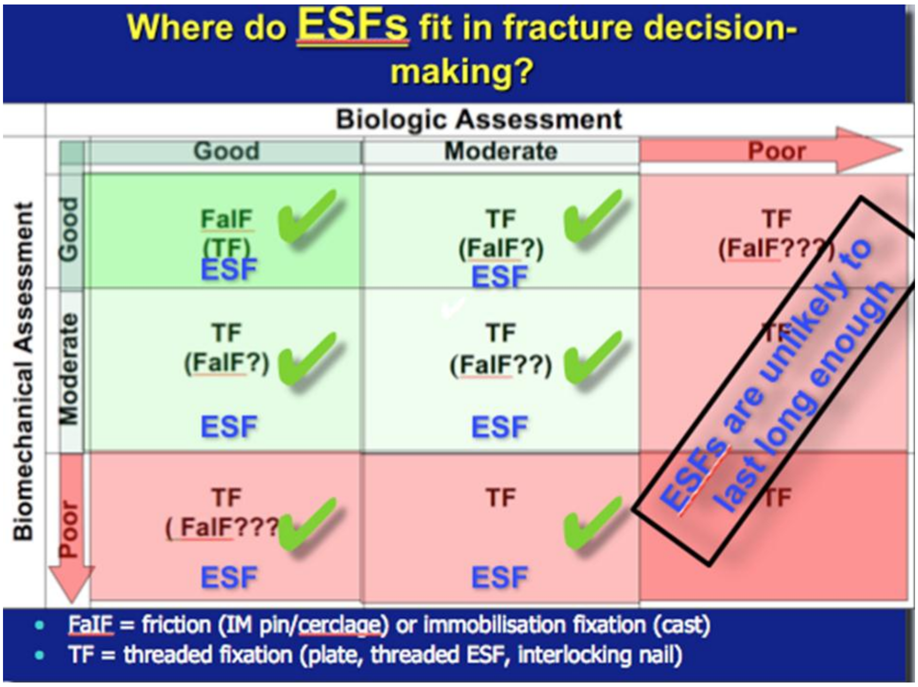
- The second thing is the application of a fixator of sufficient composite stiffness (that is the fixator and the bone combined) to allow bone healing to occur – essentially a working understanding of the biomechanics of fractures and of external fixators so that the right choice of fixator for that particular fracture is made. The biomechanical variables are greater for fixators than for bone plates and interlocking nails – this complicates the decision making to some degree.

- The third thing for success relates to the **principles of application and maintenance of fixators.** It is critical that the surgeon knows how to apply the fixator in such a way that the pin-bone interface is not damaged. Maintaining a healthy pin-bone interface is critical in being able to *effectively* maintain a fixator for the sufficient length of time to allow bone healing to reach functional completion.

- A good knowledge of **regional anatomy**

The fixator that you choose for a particular case has to be strong enough for that particular fracture in that particular animal. The stiffness of the external fixator depends on the biomechanics of the fracture, the biomechanics of the particular type of fixator frame applied and the biomechanics of the individual components of the fixator. We'll discuss this in detail later.

Then it is necessary that the fixator that is *applied* has to remain *effective* - this means that the transfixation pins have to remain "tight" within the bone until fracture healing is complete. If the pin-bone interface is damaged, either acutely at the time of pin insertion through microfracture or thermal necrosis, or subsequently through excessive bone strain, then this will lead to resorption of bone which leads to premature pin loosening before the fracture is healed. Remember that premature pin loosening is the main complication with fixators.



How do you decide between external fixators and bone plates or interlocking nails?

A good working understanding of fracture assessment and fracture planning are really important to have consistent success with external fixators – the same as with any form of fracture repair system. Fracture assessment involves considering the biological, biomechanical and clinical factors that will influence fracture healing in a particular case.

The biological and the clinical components of the fracture assessment really determine whether a case is suitable for repair with external fixation. The *type* of frame that is needed and the *strength* of the components of the fixator are determined from the biomechanical assessment.

Biological assessment

A fundamental decision making principle is not to use fixators in situations where prolonged fracture healing is expected – these are fractures or fracture complications where the fracture biology is poor –fracture healing will be prolonged. Typically this is where the animal's local capacity for bone healing is poor – generally through major damage or compromise of the soft tissue envelope around the bone, osteomyelitis etc – or where the animal's systemic capacity for bone healing is poor – for example a geriatric animal or an animal with diabetes or some other major disease process.

I usually recommend 12 weeks as a <u>conservative</u> rule of thumb for maximum reliable time that you can effectively keep a fixator on – provided you follow all the principles of application that we are going to discuss in the third segment. If you estimate from your biological fracture assessment that fracture healing is likely to be prolonged past 12 weeks then I would recommend against using a fixator. Go for other repair methods that can be maintained indefinitely – strong bone plates, plate –rod combinations, interlocking nails.

Clinical assessment

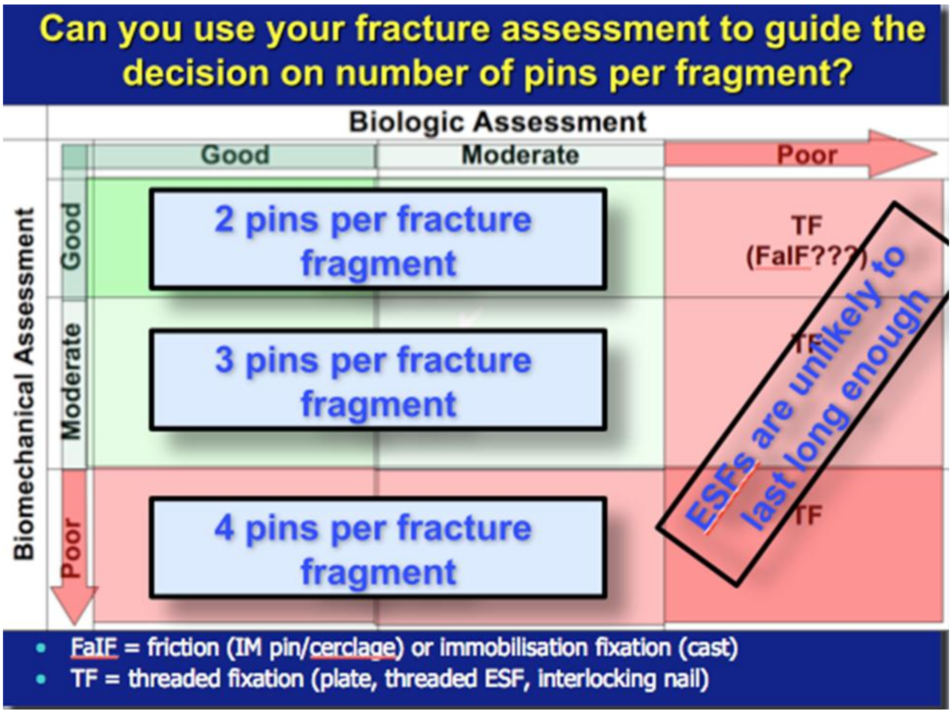
Two important parts of the clinical assessment that need to be considered are whether the owner and the animal are suitable for an external fixator. Fixators need more veterinary care and intervention in the healing phase than do internal fixation methods. So if you have an owner who you expect will be unreliable or an animal that is aggressive or difficult to handle then these are factors that would swing me away from using a higher maintenance method like external fixators.

Biomechanical assessment

The biomechanical assessment of a fracture really determines how strong the frame and the fixator components needs to be. In fractures that are badly comminuted, load sharing between the fractured bone and the fixator will not occur - all of the load of weight bearing will go thru the fixator. In these cases the stronger frame designs like Type Ib and modified type II frames are necessary. Increasing strength in the frame by using stronger connecting bars and more pins per fracture fragment are also recommended.

For simpler fractures, simpler frame types like Type Ia frames, standard connecting bars and fewer pins per fracture fragment are more suitable.

Similarly multiple limb injuries or fractures in large breed or obese animals complicate the biomechanical assessment and indicate the need for stronger frame constructs.



Biomechanical decision making and the different types of frames

Linear fixators can be applied in three basic forms (Type I, Type II and Type III) each of which has different biomechanical strength. Definition of these types of frame is based on whether they are unilateral or bilateral frames, and by how many planes the frames form. Type 3 frames are no longer required since the advent of newer ESF equipment where stability can be achieved without “heavy” or complex frames.
For the large majority of tibial and radial fractures a Type1b frame of “new” equipment like the Imex Sk™ system are all that is required.

Some definitions we need to make are:

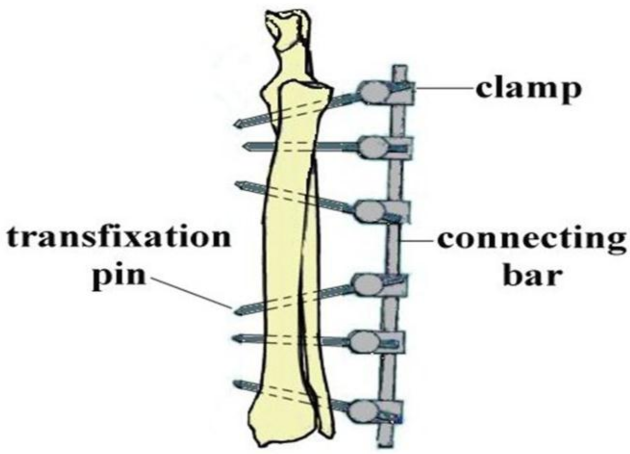
A unilateral frame is defined by at least one half pin in each of the main bone fragments joined by a connector.

A bilateral frame consists of connecting bars on opposite sides of the limb connected by at least two full pins that transfix the bone.

A linkage or articulation is a connection *between* two frames. It can go from or to a connecting rod or a pin. It does not constitute a frame.

Type I ESF

Type Ia – is the simplest form of fixator – it is unilateral and uniplanar.. It comprises half pins and a single connecting bar.



Type I ESF

How strong are type Ia fixators*?*

Type Ia frames using the KE system are really only suitable for simple fractures with a high fracture assessment score. If using some of the newer ESF systems with stronger connecting bar systems then Ia fixators can be used on more biomechanically challenging fractures. Axial compressive loads applied to type Ia fixators cause bending of the connecting bar and bending of the pins. So to increase their resistance to axial compression use:

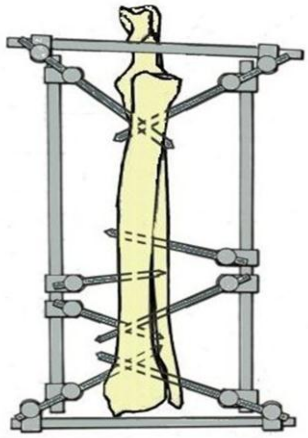
- stronger or reinforced connecting bars
- larger diameter pins – up to the limit of the 20% rule that we will discuss later

Torsional or rotational loads applied to type Ia fixators cause rotation of the clamp on the connecting bar and bending of the pins. SO to increase resistance to torsion in a type !a fixator then:

- Use a new style clamp that better resists friction than the traditional KE clamp
- larger diameter pins – up to the limit of the 20% rule that we will discuss later

The type Ib is a really useful and relatively simple frame that is stronger than the type Ia. It is the one I would use almost exclusively on comminuted radial fractures and on many tibial fractures.

The Type Ib frame is unilateral and biplanar It is an articulation of two type Ia frames. The planar angle between the two frames should be between 60 – 90 degrees for maximum strength.



Type Ib ESF

The articulations or connections between the two frames significantly increase resistance to compression, bending and torsion. Transverse articulations primarily increase torsional resistance while diagonal articulations increase resistance to compression and bending.

For Type Ib fixators on radial fractures one frame is applied on the craniomedial aspect and the other to the craniolateral aspect of the antebrachium. This placement avoids some of the problems in placing a type II frame to radius. The type 1b ESF allows the pins to be placed into the wider cranial surface of the radius. This avoids the problem of placing pins through the narrowest part of the craniocaudally compressed radius which is necessary with medial to lateral pin placement in a type II ESF.

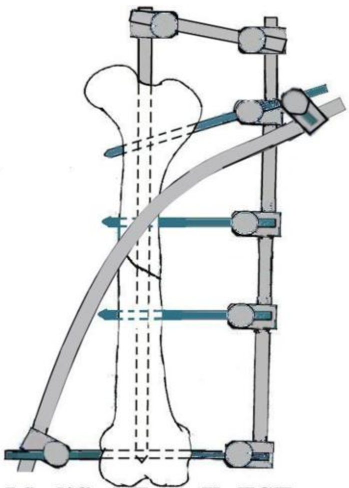
On the tibia a frame is placed on the medial aspect – this tends to be the one with the most pins, typically 2 per fragment. The second frame is placed on the cranial aspect of the bone (proximally just on the medial aspect of the tibial crest) and usually has 1 pin per fragment unless maximum stability is needed when 2 pins per fragment would be placed.

The advantage of the Type Ib frame over the Type II frame in the tibia is that the frame can be placed without having to insert pins through the large muscle mass of the cranial tibial muscle on the proximal lateral aspect of the tibia. Placing pins through large muscle masses causes discomfort to the animal and is more likely to result in premature pin loosening.

Modified Type Ib fixator

Type 1a fixators applied to the humerus or femur tend to be very weak constructs and really only suitable for very simple fast healing fractures. However because of the proximity of the body wall in animals tot he humerus and femur the stronger frames such as the type II can not be placed. To try and overcome this the Type I fixator can be strengthened by placing a modified Type IB frame or by tieing the frame to an intramedullary (IM) pin to provide additional strength. The IM pin is left protruding through the skin of sufficient length that an articulation to the ESF frame may be connected.

By doing this it increases the resistance of the frame to bending and to compression. This method of tieing-in IM pins to Type Ia and Type Ib ESFs has become increasingly popular in the treatment of humeral and femoral fractures. Femoral fractures are not ideal for ESFs for a number of reasons. If a fixator is to be applied to the femur then I would strongly recommend that it be tied in.



Modified Type Ib ESF tied-in to an IM pin

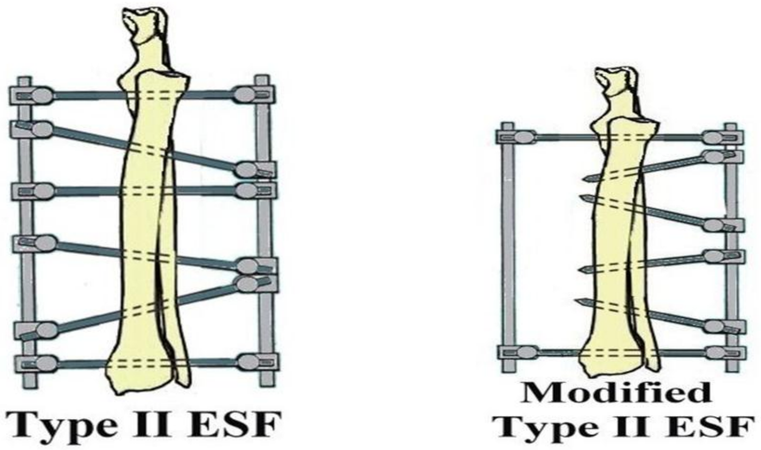
Type II ESFs are bilateral and uniplanar. Being bilateral they are only suitable distal to the elbow and stifle joint. They are good in unstable fractures such as comminuted fractures because they are very resistant to compression.
There are two forms of Type II fixator:

- **standard or full Type II**

  These consist of all full pins. They are technically much more difficult to place than a modified Type II fixator as all the pins need to be placed in the same plane (while in a modified Type II the pins may be placed in different planes - see below). This may be achieved by using an aiming device or by making a "pin guide" by placing a temporary second connecting bar on the side from which the pins are being placed.

  The pins are then placed through clamps on both the connecting bars on the one side which ensures they will be on approximately the same plane. After placement the second connecting bar is removed.

  Since the advent of the stronger connecting bar technology I have not found it necessary to place a full type II frame



- modified Type II fixators are a simpler version of the full type II that is much easier to apply although is not as strong.

The modified Type II fixators have only two full pins – on placed proximally and one placed distally –these are the first two pins placed. The subsequent pins are only half pins – this overcomes the difficulties of having to place all the pins in the same plane.
This tends to be the more commonly used form of Type II ESF used.

The **Type III fixator is** bilateral and biplanar. It comprises a Type II fixator linked to a Type I fixator. They involve a lot of hardware and make assessment of the fracture on postop radiographs very difficult. They are very rigid configurations - they are ten times stronger than a Type Ia fixator. With improved fixator technology and a better understanding of fixator biomechanics Type III fixators are unnecessary and rarely used today.

What other ways can you increase the strength of an external fixator?

Changing the connecting bars from stainless steel to carbon fibre or titanium will increase the stiffness of the same frame type.

Increasing the number of pins per fracture fragment will increase the stiffness also. 2 is the minimum number of pins per fragment. Increasing to 4 pins per fracture fragment and spreading the pins evenly over the fracture fragment will further increase the stiffness.

Using larger size pins will increase the stiffness of the pins but it is really important not to exceed the 20-30% of the bone diameter.

Ensuring that the frame is not standing off to far from the bone. The stiffness of the pin is inversely proportional to the cube of the distance from the bone to the clamp so reducing the standoff distance significantly increases the pin stiffness. There is a limit to how close you can go to the skin with the clamps – too close and you will cause soft tissue irritation. 1-2cm is about the right distance.

What are the components of a linear fixator?

Standard linear external skeletal fixators are comprised of 3 basic components:

- transfixation pins
- connecting bars
- linkage devices

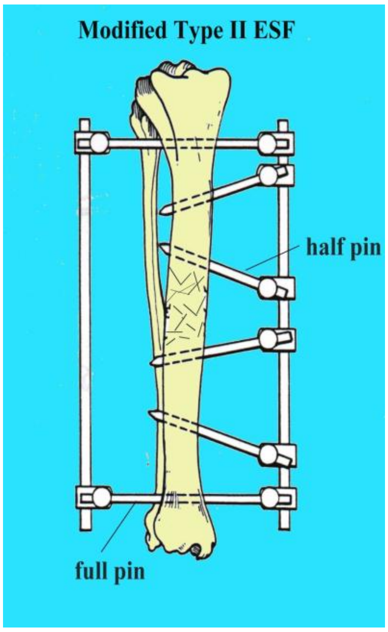
Transfixation pins

Transfixation pins are inserted into the bone fragments – they connect the frame to the bone. There are a number of different types of pins available. They are classified by their implantation method and their design.

The implantation method refers to whether they are half pins or full pins.

Half pins penetrate both cortices but only *one* skin surface.

Full pins penetrate both cortices and *both* skin surfaces.



.

This picture shows modified Type II frame with a centre face pin proximally and distally and an end threaded pins for the remainder.

Pin design:

There are several variables with regard to pin design. Transfixation pins can be

- **threaded or non-threaded** (i.e. smooth)
- threaded pins can be classified by:

thread profile: they can have a positive or a negative profile. Positive profile pins have a thread that is wider than the shank or core pin diameter. Negative profile pins have a thread that is the same diameter as the shank – the thread is cut into the shank.

- **Thread location:** The thread can be located:
  - at the centre of the pin (centre-threaded or centre-face pins) – these are used as full pins with type II frames
  - or at the end of the pin (end-threaded or end-face pins) -these are used as half pins
- **Thread length:** end-threaded pins can have a short thread length designed to only engage the far or transcortex of the bone (Ellis or Scat pins) or can have a standard thread length designed to engage both cortices of the bone
- **Thread type:** and finally threaded pins can have a cortical or cancellous thread. As with bone screws cortical thread pins have a narrower thread pitch designed for harder cortical bone than cancellous thread pins which have a wider thread pitch and usually a deeper thread profile.

Threaded or non-threaded:

Which is better out of threaded and non-threaded pins?

Threaded pins have been proven to be superior to smooth pins. The only advantages of Smooth pins are that they are cheaper and easier to use than threaded pins.

There are a number of disadvantages with smooth pins; the disadvantages of smooth pins outweigh the advantages:

- **Smooth** pins rely on friction with the bone to remain stable – smooth pin fixators are a form of friction fixation which is a very "light-weight" and temporary form of fracture repair. Friction has a very limited capacity to neutralise physiologic loads. It is really only suitable for fractures with a very high fracture assessment score – simple fractures that are inherently stable and that will heal rapidly. Threaded pins on the other hand are "screwed" into the bone and so have thread contact with the bone – they do not rely on friction.

- **Smooth** pins have also been shown to have less holding power both immediately and over time (Bennet et al. Vet Surg 16:207-211 1987).

- **Threaded pins** have 4-5 times the resistance to pull-out than smooth pins.

- **Threaded pins** not only have superior pull out strength compared to smooth pins but also have been shown to be less likely to suffer premature pin loosening. Smooth pins have been shown to loosen much earlier than threaded pin fixators in two clinical studies. – In the first case series study (Aron et al JAAHA 22: 659-670 1986) comparing smooth pin fixators with threaded pin fixators in comminuted tibial fractures it was shown that the smooth pin fixators remained stable for a mean of 2.2 months whereas the threaded pin fixators were stable for a mean of 4.8 months.

Essentially if you change nothing else other than switching from smooth to threaded pins you will double the time that the fixator provides effective stability. In a more recent clinical study from the RVC smooth pins were found to be significantly more likely to loosen than Ellis pins (Beck,AL and Pead MJ Veterinary-and-Comparative-Orthopaedics-and-Traumatology. 2003; 16(4): 223-231). This image shows significant lysis around a smooth full pin in the radius. While there is some reaction around the threaded half pin there is no apparent lysis.

Avoid using non-threaded pins – the disadvantages outweigh the advantages.

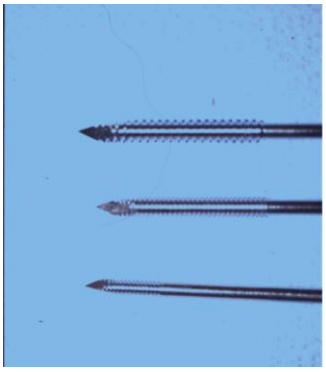
We need to consider each of the variations in threaded pin design as this is important for decision-making:

- Thread profile
- Thread location
- Thread type

Thread profile*: positive vs negative profile pins.*

Positive profile pins have a raised thread that is wider than the shank or core pin diameter. Negative profile pins have an outer thread diameter that is the same diameter as the shank – the thread is made by cutting into the shank or shaft of the bone. This means that the pin is weaker at the point where the shank meets the thread – and so potentially more likely to break in situations where large loads are being placed on a small number of pins.

This picture shows an end thread cancellous positive profile pin, end thread cortical positive profile pin, Ellis pin and a centre thread cancellous pin.



What are the advantages of positive profile pins over negative profile pins?

Positive profile pins or “raised thread” pins are preferable to negative thread profile pins for two main reasons:

- firstly positive profile pins are stronger than negative profile pins and less likely to break at the point where the pin enters the bone. *Why is that?* Because negative profile pins have the thread cut at the expense of core diameter this weakens the area moment of inertia of the pin (which is the resistance of a structure to bending) at that point creating a stress riser or weak point predisposing the pin to breakage at the thread-shaft junction. *Does pin breakage happen commonly?* Not any more since the advent of Ellis pins. In the “older” days when non-Ellis pins (standard negative profile pins such as small threaded Steinmann intramedullary pins) breakage was not uncommon.

- Positive profile pins also have greater resistance to pull-out than negative profile pins as they have a greater thread depth and so greater thread contact with the bone.

***Are there any disadvantages with positive profile pins**?*

Yes there are:

- Firstly Positive profile pins are more difficult to insert if you are using old style KE clamps as the raised thread will not fit through the standard old style KE clamps. This can be overcome with KE frames by some manipulation of the frame on application – essentially it means "backing" the pin into the clamp which is time consuming. The other way this can be overcome is to use the newer style clamps which are designed to accommodate positive profile pins.

- Secondly Positive profile pins are also more expensive than negative profile pins as they are more expensive to machine. Like most things in surgery you get what you pay for.

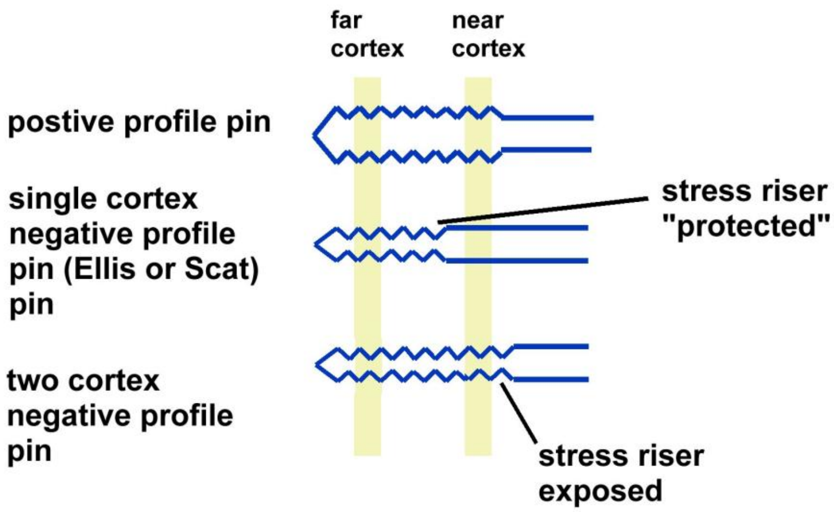
Thread location: *The thread can be located:*

- at the centre of the pin (centre-threaded or centre-face pins) – these are used as full pins
- or at the end of the pin (end-threaded or end-face pins) -these are used as half pins

Thread length: End threaded pins have the thread at the tip of the pin and are used as half pins. These can be further classified as:

- single-cortex end threaded pins (**Ellis** or Scat pins) –these have a short thread length designed to only engage the far or transcortex of the bone (see pic below)

- two-cortex end threaded pins. It is very important that standard thread length or two-cortex end threaded pins are positive profile and not negative profile because end-threaded pins experience their maximum load stress at the junction of the pin and the bone. Negative profile pins should not be used as two-cortex pins because the exposed thread-shaft junction acts as a stress riser right at the point where the bending strain on the plate is realized and so is potentially more likely to break at that point. Single cortex end-threaded pins (Ellis pins) have been designed specifically to "protect" the weak stress riser point within the medullary cavity.



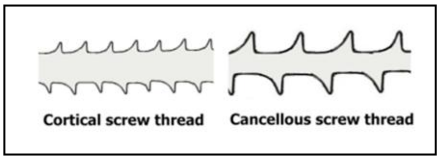
I … e pins – there
is …

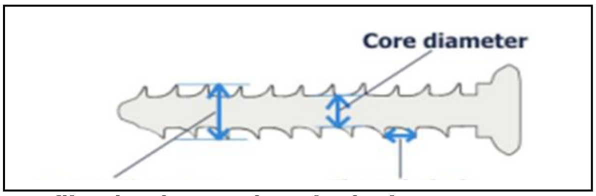
Does the design of the Ellis pin work effectively in preventing pin breakage?
Yes it seems to -despite what has been written in the literature over the years to the contrary. In a 2003 study by Beck et al they reported Breakage of Ellis pins was uncommon (Beck,AL and Pead MJ Veterinary-and-Comparative-Orthopaedics-and-Traumatology. 2003; 16(4): 223-231 Year: 2003)

None the less I would strongly recommend that Ellis pins are not used in complex fractures (i.e. fractures with a poor biomechanical and poor biological fracture assessment score) where biomechanical loads are high or where healing times are likely to be prolonged. In simpler fractures they are often combined with two positive profile pins; one most proximal and one most distal.

Thread type: *cortical or cancellous thread.*

The more commonly used pin is the cortical thread, designed to for hard cortical bone, while the cancellous thread has a greater thread height and greater thread pitch for use in cancellous or soft bone such as in immature dogs and particularly in locations with a thin cortical shell like the proximal humerus, and proximal tibia. For most cancellous thread ESF pins the shaft of core diameter is the same as for the equivalent cortical thread pin. The thread diameter is wider.





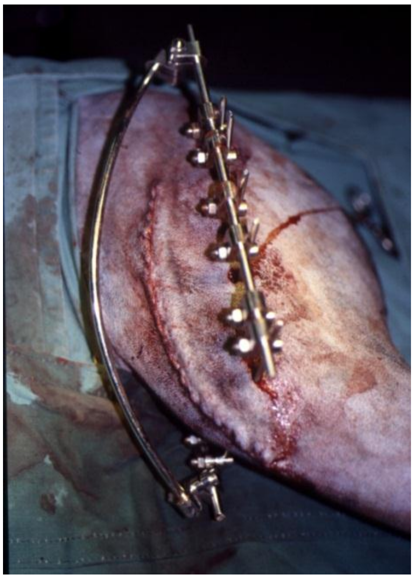
Should positive profile pins be used exclusively?

Not necessarily – although in complex fractures where there is a poor biomechanical fracture assessment I would strongly recommend using all
positive profile pins. We'll discuss that in more detail a little later in the section under decision making.

- **connecting bars**

Connecting bars are the external splint that provides support for the fractured bone. In the original Kirschner-Ehmer or KE system the connecting bars were stainless steel (pictured below). Today the connecting bars are available in various materials including stainless steel, acrylic, titanium, carbon fibre and aluminium.

A lot of development has gone into how to increase the stiffness of the connecting bars in recent years. Various options exist for this – we'll discuss the different materials available. In addition to that some companies have systems where they can attach a support to the connecting bar to increase its stiffness.



<u>Acrylic frame fixators</u> are a modification of the original K-E apparatus where the connecting bar and linkage device are made of acrylic. Acrylic connecting bars are able to be moulded to non-linear shapes so they are often used in situations where standard straight connecting bars are unsuitable such as the mandible and across joints. There are a number of different types of acrylic that are used.

Acrylic has a number of advantages over the standard K-E fixator (although has more potential "learning curve" pitfalls!):

- more variation possible in shape as the pins do not have to be in a linear configuration (e.g. mandibular fractures)
- different sizes of transfixation pin may be used. This is important when using transarticular frames across the carpus or tarsus. (note: some of the newer types of K-E type systems will allow different size clamps to be attached to the one connecting bar)
- radiolucency of the acrylic allows radiography without the frame obscuring image.
- lighter than K-E ESFs
- adaptable to animals outside the standard K-E range (e.g. very small animals – birds and exotics etc)

- cost. Largely because the acrylic fixators act as both connecting bar and clamp both the commercial APEF (acrylic pin external fixation) system and the “home made” acrylic frame are cheaper than the comparable K-E frame.

Acrylic 4 pin type II ESF used in a dog with metatarsal fracture

Acrylic fixator used on a dog with mandibular fractures

The main disadvantages of the acrylic frame system are:

- lack of adjustability after applied. K-E systems allow intra- and post-operatives adjustment to be made

- chemical reaction. The exothermic reaction when the acrylic sets produces considerable heat that is transmitted along the transfixation pins. This may result in thermal necrosis of the bone. Some reports have suggested that the fumes produced in this reaction may be harmful and care should be taken in this regard

- messy

- not reusable

The most common type of acrylic is non-sterile methylmethacrylate – bone cement or hoof cement. You can get the components individually or commercially in a complete set called APEF (acrylic pin external fixation). The methylmethacrylate is mixed in the liquid phase and then poured into preprepared plastic tubing where it sets. It can be messy to use and does have some health concerns if inhaled in high concentration so a well-ventilated room is necessary. It is recommended not to have anyone who is potentially pregnant in the room when it is being used.

The other type of acrylic used are the “knead it” type products. Some practitioners like this material because it is less messy than the bone cement. I don’t use this material any more.

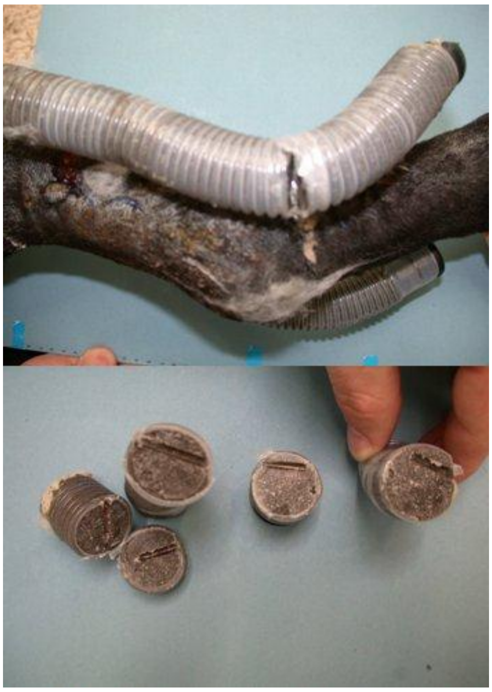
The methylmethacrylate Acrylic has also been shown to have

- better resistance to bending loads than K-E
- however has less resistance to compression and tension loads than K-E

In terms of comparable strength of acrylic to stainless steel it has been shown that for methylmethacrylate columns:-

- the 10mm acrylic column has the same strength as a small K-E stainless steel connecting bar and
- a 20mm acrylic column has the same strength as a medium K-E stainless steel connecting bar

It is important when using the acrylic too make sure that transfixation pin passes through the centre of the tubing. If it is offset from the centre of the acrylic column it predisposes to fracture of the column. The pictures below show an acrylic column that has failed due to eccentric pin placement.



Carbon fibre is a relatively recently available material for connecting bars. It has the great advantages of increased stiffness, lightweight and of radiolucency – it makes it very easy to see the fracture site on the postop radiographs. It is more expensive than stainless steel but the strength, weight and radiolucency really make it an excellent option.

In terms of comparable strength some figures are available on the Imex™ SK® system. They have shown that the

- small SK carbon fibre = 5 times strength of small K-E
- small SK carbon fibre = ~ same strength of medium K-E
- large SK carbon fibre = 7.7 times strength of medium K-E
- large SK carbon fibre = 2.9 times strength of large K-E

Another recently available material is titanium. Again this is more expensive than stainless steel but not hugely so. In terms of comparable strength the

- small SK titanium bar is 9 times strength of small K-E and almost twice the strength of the small SK carbon fibre.

- small SK titanium = 1.7 times strength of medium K-E

This picture shows Titanium connecting bars on a hybrid (combination ring and linear ESF) fixator.

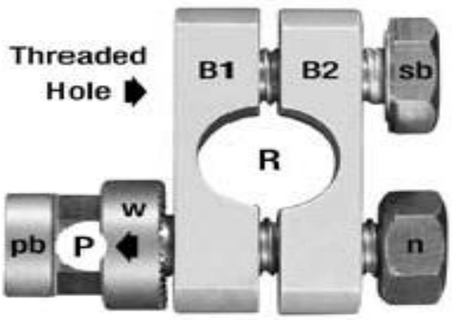
- **clamps or linkage devices**

Clamps connect the transfixation pins and the connecting bars. In most cases the linkage device is a single clamp that attaches to both the pin and the connecting bar.
With acrylic frame ESFs the connecting bar and the linkage device is the same thing.

The traditional KE clamp has a number of limitations:

- positive profile pins cannot be placed directly through the clamp.
- It is also not possible to add or remove a clamp once the frame is assembled. For anyone that has realized that they need to add one more clamp after they have struggled to distract and align a fracture, they will know what a problem this is.
- The other disadvantage is that the KE clamp would normally deform after use which made re-usage a problem.

Similarly to connecting bars there has been a lot of effort and some research in developing a better clamp than the original KE clamp. It has been shown that clamp design significantly affects the strength of an ESF in its response to axial compression, shear and torsional loads (Egger Vet Surg 12. 130-136 1983). Most companies now have new clamps or at least modified clamps that either address or partly address the limitations of the KE clamps. The Imex SK clamp system – ImexR - pictured greatly simplifies application of positive profile pins and allows subsequent removal or addition of clamps to a frame.



Principles of application: The 12 rules for ESF success

Premature loosening of the transfixation pin is the most common postoperative complication encountered with the use of ESFs and the main reason for fixation failure. It has been said that fracture treatment with an ESF is a race between the rate of bone healing and the rate of pin loosening. Successful fracture treatment requires that the stability of the pin-bone interface is maintained for as long as possible.

The stability of the pin-bone interface is related to:

- the amount of force that the transfixation pin has to carry
- method of pin insertion

The following principles of application are all aimed at maximising the stability of the pin-bone interface to maximise the rate of healing and minimise premature pin loosening.

1. Predrill holes for pin placement

In cortical bone using the fixation pin to "drill" its own hole causes thermal necrosis and microfracture which may result in subsequent pin loosening. Unlike a drill bit a fixation pin does not have cutting blades or flutes to remove bone debris during drilling which results in excessive temperatures.

In study by Clary and Roe (*Vet. Surg*.25 (6): 453-462 1996) they found that predrilling with a drill bit 0.1mm smaller than the shank diameter of the positive profile pin will not only improve initial pin stability compared with no predrilling, but it will also reduce microstructural damage that may lead to excessive bone resorption and premature pin loosening.

Predrilling softer more cancellous bone such as the proximal humerus, proximal and distal femur, or proximal tibia is not usually necessary.

Ideally the drill bit diameter should be 0.1mm less than the shank diameter (non-threaded part) of the pin. For Ellis pins pre-drilling with a drill bit 90% of the shank diameter is recommended.

Pin Size	Shank Diameter	Drill Bit Size
Small (cortical or cancellous)	**2.4mm**	**2.3mm**
Medium (cortical or cancellous)	**3.2mm**	**3.1mm**
Large cortical	**4.0mm**	**3.9mm**
Large Cancellous	**4.8mm**	**4.7mm**

2. Use threaded pins – either positive profile pins or Ellis pins

We discussed the benefits of threaded pins over smooth pins and of positive profile threaded pins over negative profile pins in the first section.

3. Use between 2 and 4 pins either side of the fracture line

Strength of an ESF depends on a number of factors including the type of frame, the stiffness of the connecting bars, the stiffness of the pins and the number and positioning of the pins within the fracture fragment.
Three or four pins either side of the fracture line is ideal.

Three pins per fracture fragment are two thirds stiffer than two pins per fragment. Four pins are one third stiffer than three pins. Five pins per fragment provide little further increase in stiffness.

So in simple fractures with a good biological and good biomechanical assessment two pins either side of the fracture line are probably adequate. In cases with a poor biomechanical assessment, such as badly comminuted fractures, multiple limb injury cases, large or giant breed animals etc, then the maximum 4 pins per fragment are needed.

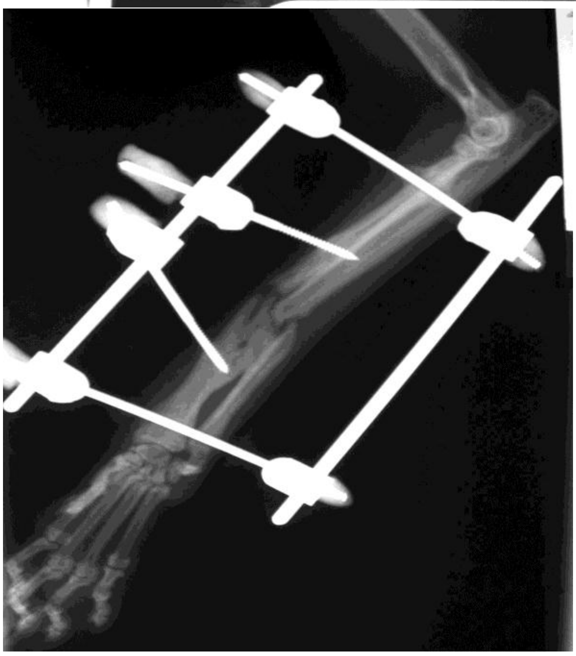
4. Pins should be evenly spaced over the length of the fracture fragment

This is called the far-near-near-far principle. Spacing the pins as widely as possible over the fracture fragments increases the stability of each fragment. The proximal and distal pins are placed as close to the joint as is anatomically comfortable for that location. The pins are then placed between 2 and 3 pin diameters from the fracture line. If there are fissures then this distance will need to be increased to prevent iatrogenic fracture. Any further pins are then spaced evenly between the most proximal and most distal pins.

5. Pin diameter should not exceed 20-30%% of bone diameter

If fixation pin diameter exceeds 20-30% of the bone diameter it has been shown to weaken the bone in bending and in torsion which can predispose to iatrogenic fracture. This is of most significance in the radius and the metacarpals/metatarsals. Placing a type II or modified type II fixator on the radius means that the pins are being placed in a lateromedial plane which is the narrowest diameter of the radius. Nearly always this means that the ESF pins exceed the 20-30% rule. As we discussed in the first section placing a type Ia overcomes this problem.

The radiograph below shows pins on a transarticular esf exceeding the 20% rule



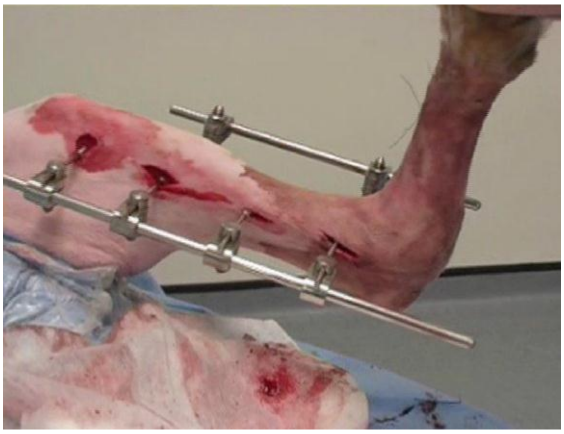
Rad (above) showing a modified type `II smooth pin fixator on a radial nonunion where the pins would greatly exceed the 20-30% rule in the mediolateral plane

6. Avoid soft tissue tension on the pins

Excessive soft tissue tension on the fixation pins will increase patient morbidity post operatively and will encourage premature pin loosening.

To avoid excessive soft tissue tension on pins:

- make a 1cm skin incision at the site for pin insertion. With a pair of haemostats blunt dissect through the soft tissue to the bone. Predrill the bone with the drill bit of the appropriate size in a drill sleeve taking care not to damage the surrounding soft tissues. After placement of the pin the 1cm wound should be left open. If areas of skin tension exist on completion then the skin should be incised to relieve the tension.



- ensure proper packing of the ESF post operatively (see later) to limit movement of soft tissue against the pins.

7. Slow speed insertion of pins with a power drill

High speed power insertion of fixation pins can lead to thermal necrosis. Hand insertion of fixation pins typically produces "pin wobble" which enlarges the hole. Both lead to premature pin loosening.

Slow speed (150 rpm) power insertion is ideal. 150 rpm is estimated to be a speed such that the teeth on the chuck are still visible.

8. Ensure the threaded portion of the pin has engaged the cortex and that not just the pin tip is protruding

As with placement of bone screws it is essential that the body of the pin and not just the tip has engaged the far cortex. This ensures that the pin thread is fully engaged.

The protruding tip is quickly covered by fibrous tissue.

This means that the trochar tip of the pin needs to be clear of the cortex. This causes short term soft tissue irritation and the tip is eventually covered with fibrous tissue. ESF pins with a short blunt tip are made to overcome this problem. A sharp point is not needed on pins that have been predrilled prior to pin insertion.

Angle pins 70 degrees to long axis ??

Traditionally it has been recommended that pins should be placed at 70 degrees to the long axis of the bone to lessen the likelihood of the frame pulling out. This is still in some textbooks however this is a carry over from the old days of smooth pin fixators. These would loosen relatively quickly and angling the pins lessened the likelihood that the fixator would just "pull off". Angling the pins decreases the number of pins that you can fit in a bone segment.

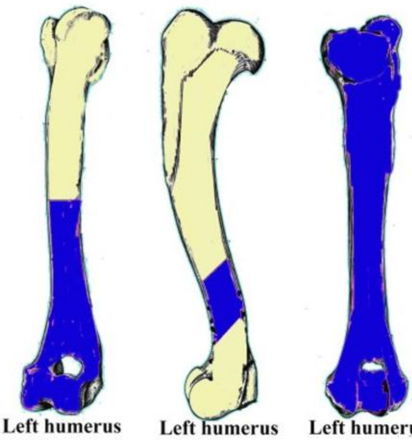
The angle of pin placement is not critical when using positive profile pins. Place the pins perpendicularly to the long axis of the bone. This will allow you to fit more pins per fracture fragment

9. Avoid “no go” or high morbidity areas in pin placement

Consideration of the local anatomy prior to pin placement is essential to avoid “no go” areas, in which placement of pins will risk damage to neurovascular structures or impinge on significant soft tissue structures to an extent that will result in unacceptable morbidity and/or rapid pin loosening.
These so called “safe corridors” have been defined areas have are as follows:

❖ **Humerus**

- caudal aspect (triceps)
- cranial distal ½ (biceps)
- lateral distal ¼ over radial nerve and supracondylar foramen
- medial proximal ¾ (body wall)

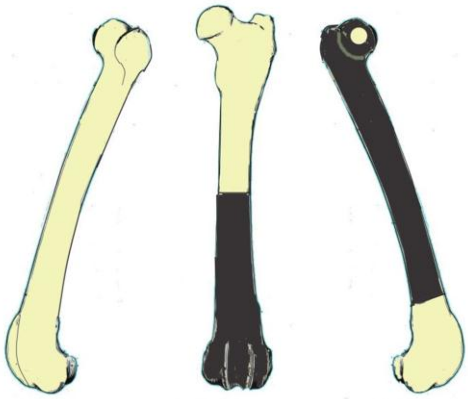


❖ **Radius**

- caudal aspect
- cranial aspect proximal ¼ (considerable s to pin loosening)

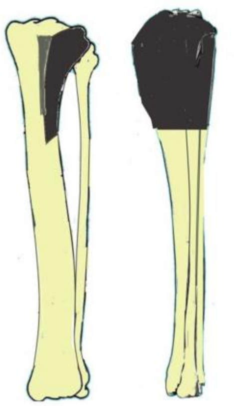
❖ **Femur**

- caudal aspect
- cranial distal ½ (quadriceps mechanism)
- medial proximal ¾ (body wall)



No-go zones femur

Tibia



No-go zones tibia

- caudal aspect
- lateral proximal 1/3 (cranial tibial muscle)(place proximal full pin more distally and half pins more proximally on medial side if using type II or type III)
- cranial proximal ¼

10. Use modern technology

The Kirschner-Ehmer (KE) system is a cheap readily available system that has been around for over 50 years. Modern systems are better engineered and use lighter and stronger materials and design that GREATLY facilitate effective ESF placement. (See the earlier notes on pins, clamps and connecting bars)
I would strongly advise you to use one of the modern systems.

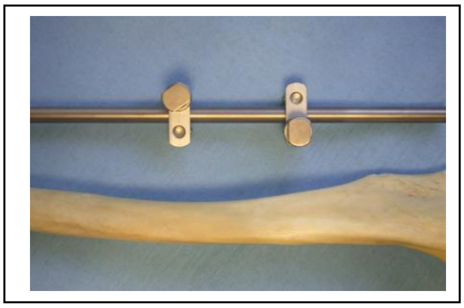
11.Limit the distance between the bone and the clamp.

The stiffness of the pin is a function of:

- the pin diameter. Bending stiffness of the pin is a function of its radius to the 4^{th} power – so bigger pins are stiffer but we know that we are limited by the 20-30% rule to limit the likelihood of iatrogenic fracture.

- The distance between the bone and the clamp. Pin stiffness is inversely proportional to the cube of this distance (Bouvey et al Vet Surg 22. 194-207 1993). So in effect doubling the distance between the bone and the clamp reduces the stiffness of the pin 8 times. Unfortunately if the clamp is too close to the skin it can cause soft tissue irritation.

  - ➢ So leave about 1-2cm between the skin and the clamp. Less distally and more proximally. Also ensure that the clamp is placed on “nut to bone” and not vice versa as this will increase the distance and weaken the stiffness of the pin.

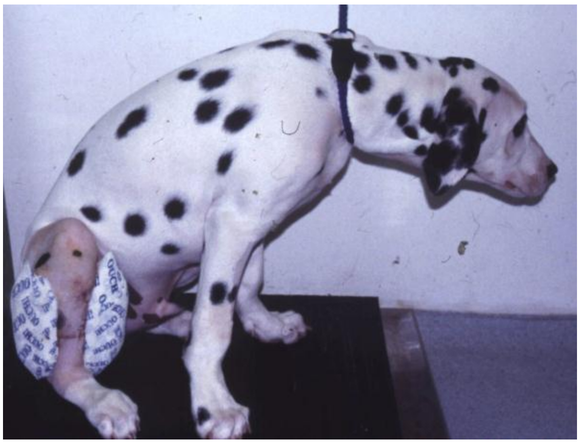


The picture on the left shows the KE clamp on the left (distal) side of the tibia facing the wrong way. The picture on the right shows the three proximal clamps all the wrong way around.

The large muscle mass on the lateral aspect of the femur means that the stand-off distance between the frame and the bone is quite large. This is one of the reasons why femoral fixators are quite difficult.

12. Ensure correct post-op care of the fixator.

This is an area of some controversy. “Packing” is loosely but firmly packing either gauze or foam between the skin and the connecting frames to limit movement of the soft tissue against the pins. Soft tissue movement is thought to increase patient morbidity and lead to premature pin loosening. Some surgeons prefer not to “pack” fixators in the postop period.



Either “fluffed up” gauze swabs or sponges from disposable scrub sponges can be used.

I use Melolin as a primary layer, then foam from the back of scrub sponges, then wrap all that with elastic open weave gauze and then cover that finally with vetrap or coplus.

This not only limits soft tissue movement but also protects people and furniture etc from the sharp edges of cut pins.

In the first three to five days immediately post op it is important that any dressing changes are done sterilely (i.e. sterile gloves and dressing material) to prevent ascending infection along the pins. Once granulation tissue has formed (usually around 5 days) around the pin sites sterile dressing changes are not essential.
I would normally change dressings at 2 days post op, then 5 days (both of these with sterile gloves), then a week later and then usually check them every two weeks thereafter. I like to keep the fixator “packed” for the whole time. I think this makes a difference to soft tissue movement on the pins though this has yet to be proven.
Other surgeons don’t keep them packed for the whole time. They just cover the clamps and any sharp ends on the frame. This is the absolute minimum - It is really important to cover the sharp pin or connecting bar ends so that they don’t cut the animal or any people the dog scrapes again or the furniture.

There should be no pin tract discharge. Pin tract discharge is a sign of a loose pin and should be investigated. If the pin is loose it should be removed as it is not providing any stability as the pin bone interface is destroyed and secondly will be causing the dog significant discomfort.
Pin tract discharge is rarely a sign of primary infection. Usually once a pin tract is discharging it will become secondarily infected by skin organisms and will respond temporarily to antibiotics but is not a primary infection.

Some surgeons recommend to their owners to clean the pin skin interface each day with peroxide or apply antibiotic cream. I don’t find this necessary. If the pin is well placed and not loose there is a nice granulation collar around the pin with a very small crust. This does not need to be cleaned.

Owners should be advised to encourage regular limited walking exercise as physiotherapy. I tell them that their dog should become progressively less lame and I expect good weight-bearing while the frame is on. If the dog becomes suddenly lame it is usually because there is a loose pin.

Tips for simplifying the application of the fixators?

It is very important to preplan the fixator that you are going to put on. Trace out the fracture and draw in the fixator that you are going to put on. Check that you have all the components that you need. This saves a lot of operating time as all the thinking is done before you start the surgery. This makes a big difference.

Revise the surgical anatomy of the area and particularly review the no-go areas and the safe corridors. Revise the principles of application that we have discussed. Think through the process of applying the fixator in your mind. Which pins you will apply first, how to connect it up, how many clamps you will need on each connecting bar etc.
Hanging the leg from a pulley or bolt in the ceiling above the surgery table greatly simplifies application for radial and tibial fractures. This takes a little getting used to if you have not done it before but once you are used to it is a great time saver.

For radial fractures hanging the limb automatically aligns the fracture. Often you need to manually align the fracture the last bit but it is usually pretty close. Remember that we are not aiming for perfect anatomic fracture alignment in fixator cases. The goals of fracture alignment are that the two fragments ends have more than 50% overlap, less than 5 degrees of angulation and less than 5 degrees of rotation – in other words it does not have to look perfect.

For tibial fractures application of a Type1b in lateral recumbency is a simple and effective approach that I prefer to hanging the leg.

How to avoid soft tissue tie-up in when you are predrilling the bone and Inserting the pin?

There are a number of different types of drill sleeve that are designed to help with this. What I find works best is to make a reasonably large skin incision at the point where you will insert the pin – usually about 1-1.5cm. Then with mosquito haemostats blunt dissect your way down thru any soft tissue to the bone. Have an assistant hold the tips of the mosquitoes either side of the bone. This will retract the soft tissues and it will also define the limits of the bone for you – this makes it much easier to predrill in the centre of the bone. It is important to not drill near the edge of a bone as this will weaken the bone at that point and increase the risk of iatrogenic fracture.

Always drill through a drill sleeve. For the first and second pins the drill sleeve is hand-held. For all the subsequent holes the drill sleeve is inserted into the clamp hole and you drill through the clamp. This ensures all the subsequent pins are perfectly aligned with the connecting bar.

Remember that predrilling is done with the drill on full speed while pin insertion is then done with the drill at as slow a speed as you can without the drill stalling. Drill bits are designed for cutting bone and the drill flutes are designed to remove the bone dust. Both of these greatly reduce thermal bone damage.

Don’t forget to keep the flutes of the drill bit clean – wipe them with a gauze swab to clean out the debris.

Tips for preventing the drill bit sliding off the bone when you are predrilling?

This is a problem when you are drilling at an angle to the bone surface for example when you are placing a type Ib on the radius. – it is even more problematic for drilling the radius if you are placing a type II fixator – which as we discussed I would not recommend.

Using the mosquitoes as we discussed to define the centre of the bone is a help in centring the drill bit. The other thing that is really excellent in preventing sliding is a Sticktite® type drill bit. These have a fine pin point almost like a needle that allows the drill bit to penetrate the bone easily and not slide off. These are really worthwhile – Imex were the first company to make them – I think most suppliers have a version of them now.

What order should the pins be placed?

The first priority is to place the most proximal pin and the most distal pin. Once these are placed the connecting bar is attached and the fracture distracted and aligned. Once you are happy with the alignment then tighten the clamps – this will maintain the distraction.

Now the remaining pins are placed remembering the far-near-near-far principle. If you are using standard KE clamps you have to remember to have all the clamps loaded on to the connecting bar before you distract and connect the first two pins. If you are using split clamps that can be added later then this is not necessary.