MMP Wedge
for Canine Cruciate Disease

User Guide

OrthoFoam MMP Wedge
User Guide

The Modified Maquet Procedure (MMP)

The Maquet Procedure (MP) was developed by orthopaedic surgeon, Dr P Maquet, in the 1960s to treat patellofemoral pain and knee osteoarthritis (OA) in people. The tibial tuberosity advancement (TTA) procedure is an evolution of the MP that was developed by Montavon, Tepic et al in 2002. The Modified Maquet Procedure (MMP) is an Orthomed modification of the TTA procedure used to treat cranial cruciate ligament (CrCL) deficiency-related lameness.

The MMP uses a wedge-shaped implant of OrthoFoam™ which both defines the degree of advancement of the tibial tuberosity and holds the bone in its new place while the bony ingrowth that provides permanent, biomechanically robust fixation develops.

The use of a carefully engineered saw guide ensures a controlled, precisely directed and positioned osteotomy of the correct length, resulting in an appropriately "thick" tibial tuberosity while at the same time protecting adjacent structures from iatrogenic injury.

The open porous structure and sympathetic mechanical characteristics of the OrthoFoam™ wedge provides robust early and sustained bony ingrowth fixation obviating the need for bone grafting, postoperative support bandages or a lengthy period of restricted activity. The potentially disruptive forces that act to displace the distal end of the tibial tuberosity cranially following advancement are controlled using either a tension band wire or a titanium staple.

Mechanics-modifying osteotomies

The tibial plateau levelling osteotomy (TPLO), developed and popularised by Dr Barclay Slocum and Theresa Devine during the 1980s, represented a paradigm shift in the treatment of the lameness caused by functional failure of the CrCL in dogs. Instead of trying to repair or replace the failed CrCL, the TPLO addressed the problem by altering the biomechanics of the stifle joint.

While there is still much to learn about stifle mechanics in dogs, it has become clear that lameness due to functional failure of the CrCL in dogs could be effectively managed by the TPLO to the extent that most dogs would return permanently to previous levels of athletic function.

The biomechanical theory underpinning the TTA and the TPLO remains rather speculative and controversial, however, there is widespread agreement that these mechanics-modifying osteotomies used in CrCL deficient stifles offer the best chance for a dog to return to normal or near-normal function. However, due to the cost, complexity and limited availability of TPLO and TTA, many dogs are denied their potential benefits.

Speaking at NAVC in 2013, Professor Ross Palmer, veterinary orthopaedic surgeon at Colorado State University, showed data to suggest that while most veterinarians consider mechanics-modifying osteotomies to be optimum, they are used on only 8% of surgical cruciate cases in the US. The situation is probably similar elsewhere in the world.

Development of MMP

It was postulated that if mechanics-modifying cruciate surgery could be made less costly and less complex, then it would become more accessible and widely available.

The design and development targets of the MMP, which were defined at the outset, included:

Simplify the surgical technique

- Surgical approach
- Instrumentation
- Fixation
- Bone grafting/void-filling

Shorten the convalescence

- Robust fixation system
- "Less invasive" surgical technique

Universal application

- Appropriate for dogs of any size

Define a scientifically sound, clinically effective and reproducible technique for estimation of required advancement

To a very large extent, the first three of these four criteria have been met and the success of the MMP project is reflected not only by those several thousand surgeons worldwide who have adopted the technique and used it on 60,000+ cases to date (2020) but also by the efforts of others following our lead in their attempts to simplify and popularise these operations.

MMP is an effective, relatively simple and accessible method for treating lameness due to functional CCL failure in dogs has been established.

The key features of the MMP are the simple pre-surgical planning; the precise, instrument- controlled osteotomy; the robust, distal fixation of the osteotomy and the use of a void filling, bone ingrowth implant.

Current controversies

Some areas of controversy remain. For example, a scientifically sound, clinically effective and reproducible technique for calculating required advancement remains elusive.

Initially we relied on the established, already widely used methods, but these were inadequate - something that has been confirmed independently by the works of Rutherford (2012), Millet and others (2013), Cadmus and others (2014), and Kapler and others (2015).

Similarly, our review of the theory that underpins the TTA procedure, its pre-surgical planning methods – the crossover-point theory – reveal it to be unreliable. (See Appendix 1 for more detail).

The need to fix the osteotomy distally has been questioned. However, the forces acting on the tibial tuberosity following its advancement are considerable and there is a tendency for the distal end of the tibial tuberosity to displace cranially. Effective control of this potentially disruptive force is essential: some MMP surgeons use a figure-8 tension band wire (inexpensive, but very technique-sensitive), some use a titanium staple (stiff, strong and simple to use) and others use a plate and screws (costly and time-consuming, but robust and "familiar"). Interestingly, the other serious researchers that have looked at this question (the group at Liege who developed the Modified Maquet Technique/MMT and the Kyon group in their development of TTA2) have concluded that distal fixation can be avoided, but only if a very much longer osteotomy that extends well down into the tibial diaphysis is used; i.e. an unsupported osteotomy must be 1.5 x longer than the tibial tuberosity.

Finally, the OrthoFoam™ material has generated considerable interest and some imitators. There is very much more to bone-ingrowth science than making holes in a block of titanium. Titanium is an excellent material in terms of biocompatibility and established an important starting point for the enormous amount of research that went into developing a biomaterial that supports bone ingrowth.

OrthoFoam™ was developed over more than a decade by researchers at National Research Council of Canada (NRCC) specifically as a load-bearing implant material for use in orthopaedics. The features that distinguish the OrthoFoam™ material include, pure titanium (biocompatible); porous (high coefficient of friction so inherently stable); open pore structure (facilitates tissue fluid flows and supports micro-vascular development); optimal pore size (facilitates initial osteoconduction then the establishment of three-dimensional bone micro- structure); appropriate Young's modulus (exposes ingrown bone to essential near-physiological stress).

Adherence of bone occurs on all titanium implants but with genuine ingrowth there is deep penetration of bone that remains viable, self-sustaining and resistant to infection.

Complications

Complications are a feature of any and all surgical procedures. Some complications occur despite the very best efforts of even the most competent, experienced and diligent surgeon and can be considered little more than bad luck.

However, most complications arise as a consequence of technical error rather than bad luck and while nobody makes mistakes on purpose, the more complex the surgery is, the more likely it is that a technical error will be made and that observation was behind our aim to devise an MMP surgery that is relatively simple. In addition, and by collation and analysis of feedback data relating to complications, it is possible to identify recurring problems and eliminate them by altering the technique, by making design modifications or through a change in emphasis in teaching and instruction. It is noteworthy that most of the differences between this document and the earlier versions of the user guide have come about in response to analysis of the information and feedback from existing MMP surgeons.

We have highlighted those areas which are known to be technically sensitive, but do not appear obviously to be so, and similarly, there have been some minor modifications to the technique and some changes in emphasis which show how a complication risk can be minimised or avoided.

Experience to date indicates that the complication rate with MMP compares well with rates published for other mechanics-modifying osteotomies. However, while catastrophic complications following MMP may occur, they are extremely uncommon and it seems that there is a strong tendency for the MMP surgery to "fail-safe" in as much as many complications are minor and can be effectively managed without revision surgery. Major complications, typically, tibial diaphyseal fractures or broken wedges, may be seen, although many may be managed conservatively to excellent effect. (See Appendix 2 for more detail).

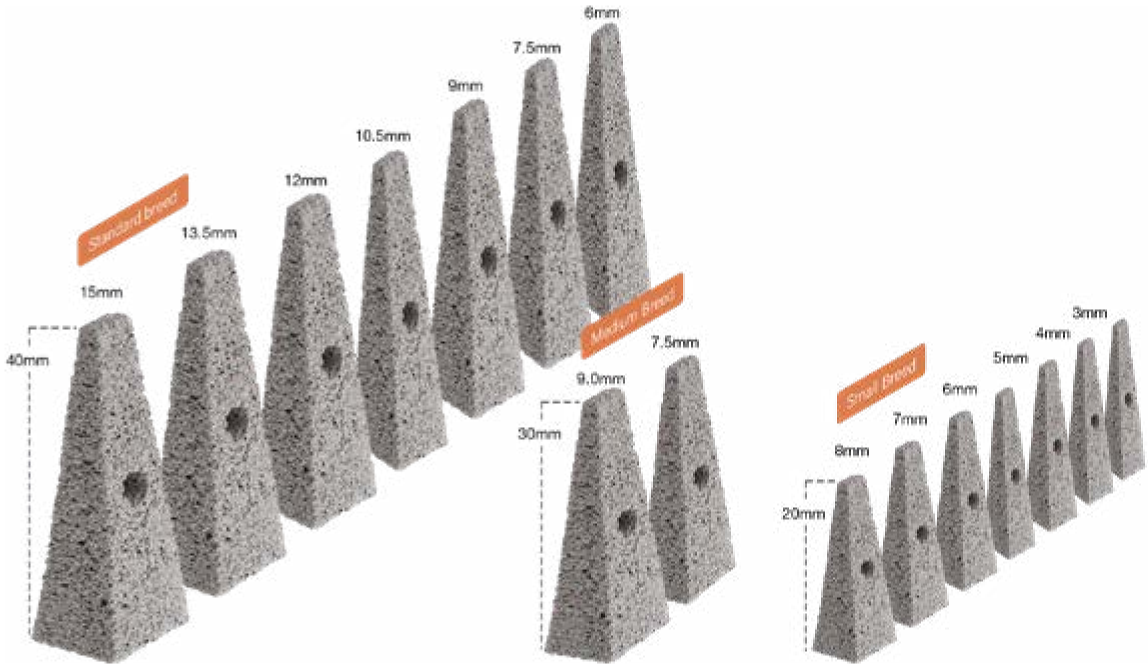
MMP – Getting started

The MMP concept is simple and the surgery is relatively straightforward. The instruction and guidance in this booklet derive from a significant research and development effort as well as the experience, expertise and feedback of many MMP surgeons who have operated on thousands of cases.

The technique does not require a specialist veterinary orthopaedic background and is within the capabilities of most primary care veterinary surgeons with reasonable surgical experience and expertise. For example, surgeons who already can perform extracapsular cruciate repair surgery competently will usually find the MMP within their grasp. However, attention to detail is an important part of surgical success and attendance at an MMP training course is essential to understand the concepts and technical detail behind the procedure.

The following description gives an overview of the technique, but the devil is in the detail. The information provided in this User Guide must be carefully read and properly understood before embarking on a clinical case.

MMP comes in three wedge lengths to accommodate variety in breed sizes



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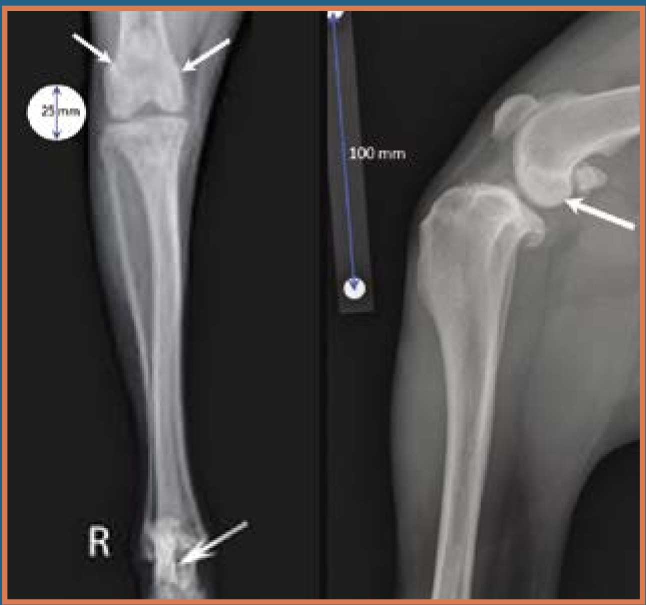
MMP Pre-surgical Planning



01 Pre surgical planning is essential to ensure optimal wedge placement.

Obtain well-positioned orthogonal radiographic projections of the affected limb, including the stifle and tarsus. Include a calibration marker.

- Ensure femoral condyles are superimposed on mediolateral projection
- The fabellae should be bisected by the medial and lateral cortices of the distal femur
- The medial border of the calcaneus should bisect the tibiotalar joint surface

02 Measurement here of 44mm indicates the use of standard wedge.
On the mediolateral radiographic projection we are assessing the morphology of the tibial tuberosity to ensure the correct system (standard, medium or small wedge) is used and that enough bone is maintained for the distal fixation.

Aim for proximal TT thickness of 6mm in small dogs, up to a maximum of 12mm in giant dogs. Draw a line beginning at the tibial plateau surface just caudal to the patellar ligament, down to the distal tibial tuberosity shown by the blue line and dot on image. This line represents the proposed TT osteotomy. The TT osteotomy should be confined to the tuberosity and not extend into the tibial diaphysis. The proposed osteotomy should not be directed cranially or caudally and its length allows selection of the appropriate wedge:

- Approximately 20mm to 30mm for small breed wedges
- 31mm – 40mm for medium wedges
- > 41mm for standard wedges

03 Asses morphology and thickness of the distal TT to determine the planned distal fixation type (staple vs tension band wire) and location.

During surgery, pay particular attention to the periosteal thickness at the cranial aspect of the TT.
It is relatively thick and therefore the cortical bone is actually 2mm - 3mm caudal to the most cranial aspect of the tibia seen at surgery.

Thin distal TT, minimal flare

Wide distal TT

Giant dog pre op planning

Medium dog pre op planning

Small dog pre op planning

MMP Surgical Technique

01 The affected limb is clipped and prepared for aseptic surgery from just distal to the hip down to the hock joint. The patient is placed in dorsolateral recumbency and the limb draped to allow the lateral aspect of the limb to contact the operating table surface, thereby affording unrestricted flexion and extension of both the stifle and hock joints.

This shows the ‘surgeon’s eye view’ looking at the craniomedial aspect of a left pelvic limb with the stifle towards the upper, right corner of the picture.

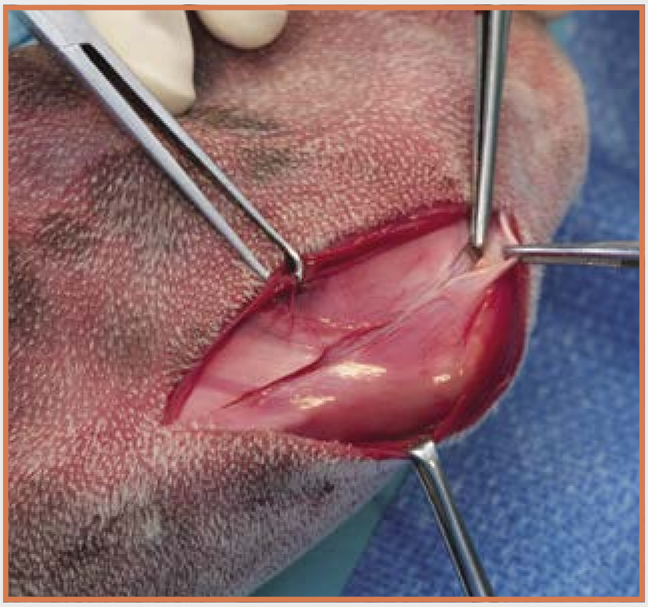
02 It is important that the limb is positioned carefully and precisely such that the greater trochanter of the femur, the lateral aspect of the distal femur at the stifle, the lateral malleolus of the hock and the lateral aspect of the paw are all in contact with the tabletop while maintaining approximately ninety degrees of stifle flexion.

This standard reference position establishes the sagittal plane of the limb parallel to the tabletop.

Dotted line represents area of incision.

03 A skin incision is made on the medial aspect starting proximally at the level of the mid-point of the patellar ligament and extending 1 to 2 centimeters distal to the tuberosity.

Avoid any further dissection. **Avoidance of unnecessary dissection is an essential feature of the MMP surgical technique**



04 The incision is developed at the proximal end only. A short, medial, parapatellar joint capsule incision is made less than 2 centimeters long and approximately 5 millimeters behind the straight patellar ligament.

The distally sloping, cartilage covered surface of the proximal tibia adjacent to the insertion of the straight patellar ligament is identified. **Again, careful attention is paid to avoid any unnecessary dissection.**

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05 A closed pair of Metzenbaum scissors is pushed firmly behind the patella ligament to puncture the lateral joint capsule. The limb is held in the standard reference position (see 02 above) and the instrument is driven perpendicular to the tabletop.

This step is intended to facilitate the subsequent placement of the proximal (longer) saw-guide locating pin.

Small saw guide with three proximal and three distal pins

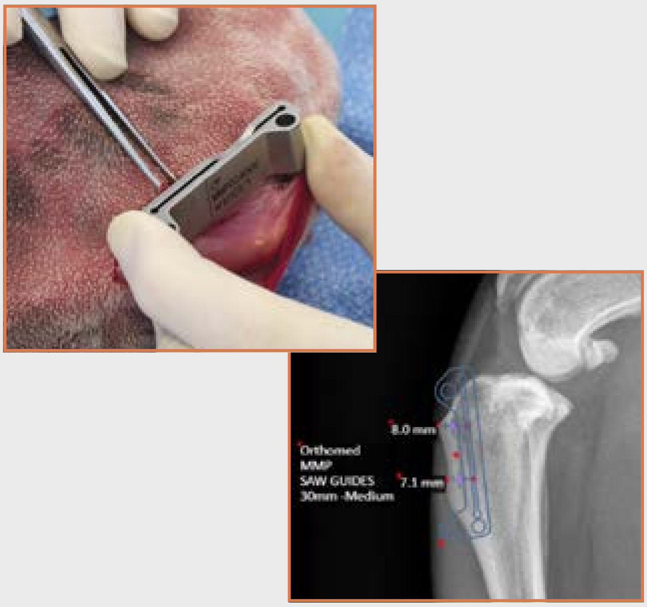
Standard and medium saw guide with one long proximal pin and three distal pins

06 The saw guides accept pins at the proximal and distal ends and can be used for the left and right limb based on saw guide orientation. At the proximal end is one hole that accepts the longer pin which screws into the hole from each side.

The Small Breed saw guide has 3 different proximal pin thicknesses from which to choose, while the Medium and Standard Breed guides share a single pin.

At the distal end of the saw guide are two holes, one for the Maquet drill hole at the end of the osteotomy and one for the distal pin. These are shorter than the proximal pin. **There are 3 different distal pin thicknesses from which to choose for all 3 guide sizes.**

The thicker the proximal pin in the SMALL saw guide, the more proximal and caudal is the start of the osteotomy, resulting in a thicker proximal TT. The thicker the distal pin, the more cranial the osteotomy and the thinner the distal TT and vice versa.

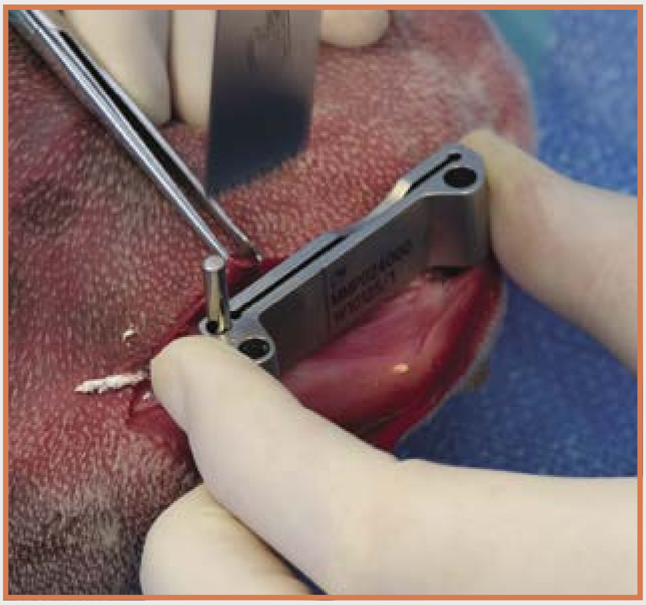


07 The proximal (longer) pin of the MMP saw guide is placed behind the patellar ligament such that the proximal pin contacts the angled, cartilage-covered surface of the proximal tibia. The shorter, distal pin of the saw guide is pressed firmly against the distocranial aspect of the TT/proximal tibial diaphysis. Note that the precise position of the osteotomy can be varied first by moving the saw guide cranially and distally (while ensuring that contact between the longer pin and the sloping proximal tibia behind the patellar ligament is maintained) and second, by selecting a thinner, or thicker, distal pin thereby moving the distal end of the osteotomy (and the Maquet hole) more caudally or cranially within the tibial diaphysis.

08 Select a distal pin that ensures unimpeded contact with the distocranial cortex of the TT. Pull the saw guide distally, ensuring the proximal long locating pin is positioned immediately caudal to the patellar ligament and in contact with the sloping aspect of the tibial articular surface.

09 Insert the 3.5mm Maquet drill bit through the hole in the guide until the tip of the drill bit contacts the medial tibial surface perpendicularly. Gently lift the saw guide off the bone to assess the intended position of the Maquet hole is ideally 2-4mm caudal to the cranial cortex of distal tuberosity/cranioproximal tibial diaphysis but also ensuring the osteotomy is not extending into the diaphysis.
A drill insert allows you to convert the distal drill hole to a 2.5mm in smaller dogs.

Proceed to drill through both cortices, and then remove the drill but leave the drill bit in position to affix the saw guide to the tibial surface.

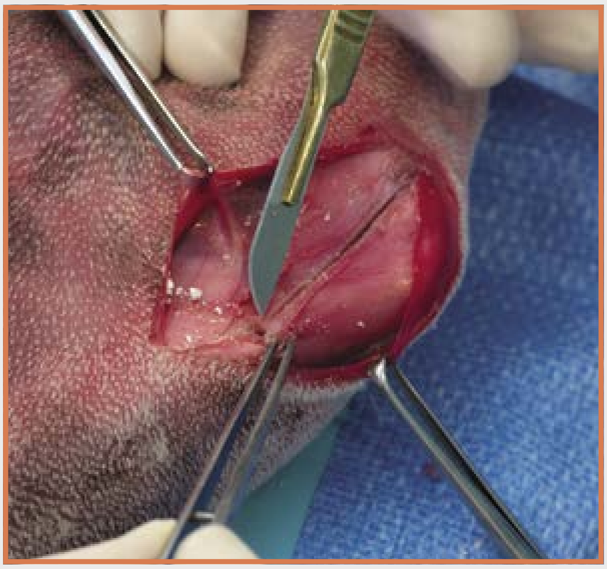


10 The osteotomy is made: a saw blade with a thickness of approximately 0.6mm should be used. The MMP saw-guide and the geometry of the MMP wedge is designed around a saw cut of this size. Thicker blades will not fit into the saw guide and thinner blades may not cut straight through the hard tibial bone.

Employ a gentle painting technique, advancing proximally and distally within the osteotomy channel to gradually and sequentially cut from the medial to lateral cortices.

NB: The bone of the tibial tuberosity is hard so copious irrigation should be used to prevent osseous thermal injury. Irrigation was not used in this cadaver series to ensure image quality.

11 Remove the Maquet drill bit and saw guide. A narrow bony bridge will typically remain just proximal to the Maquet hole. This is identified and the osteotomy completed using the saw free hand and perpendicular to the bone. **Avoid excessive dissection – it is essential that all soft tissues distal to the Maquet hole are preserved untouched.**



12 A pair of small pointed reduction forceps are placed across the thicker proximal end of the osteotomised TT. Gentle traction confirms that the osteotomy has been completed successfully.

Occasionally, further use of the bone saw will be required to complete the osteotomy proximally. In that case, careful use of the saw should be employed along with an instrument (e.g. forceps, periosteal elevator, Metzenbaum scissors) inserted behind the patellar ligament to protect it and other intra-articular structures from iatrogenic damage.

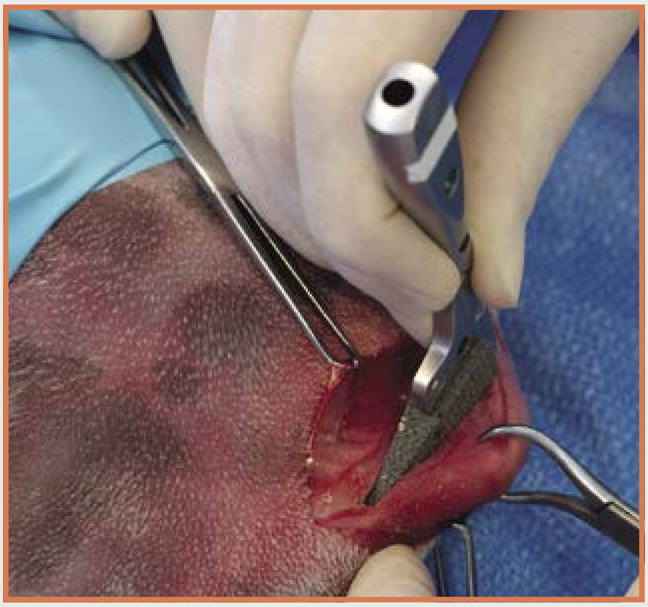
Additionally, scissors may need to be inserted into the proximal aspect of the osteotomy gap to release the lateral soft tissues that may sometimes restrict tuberosity advancement.

13 Insert the smallest trial wedge and then place sequentially larger trials until the desired wedge advancement is reached. Extending the stifle will facilitate their placement and tibial advancement.

It is essential that the medial aspect of the trial wedge should lie very slightly proud of the medial tibial cortex such that the surgeon is completely confident that the medial tibial cortex contacts the wedge along its length – this position should be replicated when the OrthoFoam™ wedge is placed.

Note: All Trial Wedges are now metal and double-ended.

14 The appropriate OrthoFoam™ MMP wedge is loaded into MMP wedge introducer. Ensure the wedge is aligned straight within the introducer. Twist the handle clockwise to secure tightly.



15 The saw guide is longer than the wedge and, if the saw guide was positioned correctly, the osteotomy will be longer than the wedge. Therefore, the proximal end of the wedge will typically lie safely "behind" the proximal extremity of the tibial tuberosity. Ensure that there is no soft tissue accidentally "dragged" in between the wedge and the bone, and check behind the patellar ligament to ensure that the wedge is not protruding above the bone into the fat pad.

16 Final positioning of the wedge is reviewed: the medial aspect of the wedge must lie very slightly proud of the medial tibial cortex and, in the ideal case, the distal tip of the wedge should lie proximal to the Maquet hole.

Verify that the proximal end of the wedge is lying safely behind the bone at the proximal extremity of the tibial tuberosity and not protruding into the joint. Finally, check that there is no soft-tissue entrapment.

17 If the TT is unstable, a pair of reduction forceps can be applied distally prior to K-wire insertion. Flexion of the stifle will increase tenson on the patellar ligament and also the TT and wedge. The butterfly drill guide is placed into the MMP wedge introducer ensuring its correct orientation

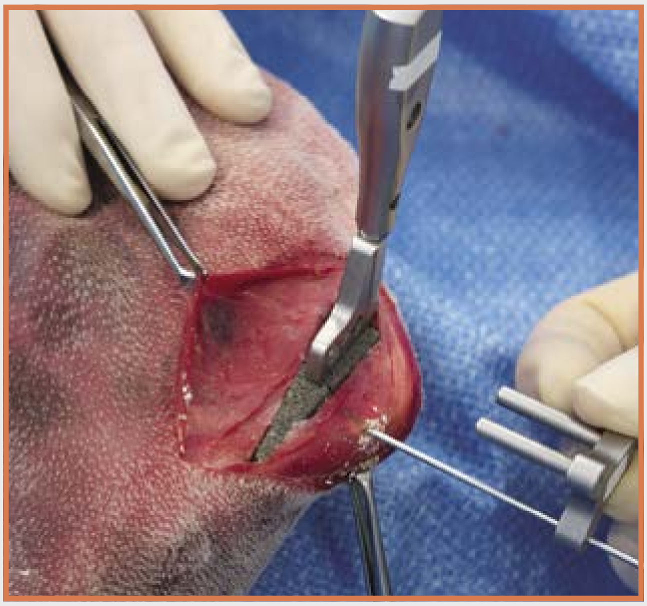
There are two butterfly drill-guides in the Standard Breed Kit which are identical but for the length of the locating pins. Cases with a thinner tibial tuberosity and a significant medial buttress will need the short-pinned guide while the butterfly drill-guide with the longer pins will be appropriate in most cases.

The butterfly drill guide in the small Small Breed kit has a different profile and can only be loaded into the saw guide in the correct orientation.

orthomed

18 The butterfly drill-guide will line up with the hole in the OrthoFoam™ wedge for a 1.6mm Kirschner wire (size critical; however, in very small dogs and cats a 1.4mm or 1.2mm K-wire may be used) to be placed through the butterfly drill guide and advanced until its trocar tip just penetrates the caudal tibial cortex. **It is essential that concurrent irrigation is used with a new, sharp-tipped K-wire inserted at high rotation speed and slow, gentle advancement.**

Pilot hole drilling with the use of 1.5mm drill bit is normally not recommended owing to difficulties with inadvertent misdirection and drill bits breaking.



19 The butterfly drill-guide is removed by gently sliding it off the K-wire after first loosening the wedge introducer a couple of turns.

20 The MMP insertion device is removed by unscrewing the handle a few turns more before gently lifting the hooked head up and over the OrthoFoam™ wedge.

Following placement of the wedge, the TT must be stabilised. Two options are available: tension band wiring or staple fixation. The original technique used a single distally placed tension wire and while this has been shown to be clinically efficacious, it is not only technically demanding but also rather technique sensitive. The staple technique is quicker, less technically sensitive and easier to master. The staple has been shown to be significantly stiffer and stronger than tension band wiring using a bone-substitute model.

Distal MMP Stapling

01 Achieving “Day 1 stability” is an essential feature of MMP surgery and to that end, before the holes are drilled for the staple, a pair of stout pointed reduction forceps is placed firmly across the proximal (and, if necessary, the distal) tibia and TT in order to pre-compress the TT and the wedge against the proximal tibial diaphysis.

02 Two holes are made to accommodate the staple; one in the TT, the second in the tibial diaphysis. The drill guide is used to ensure the drill holes are the correct distance apart and parallel to each other. This results in a well seated staple, snug to the bone.
NEVER attempt to “free-hand” the staple holes.

It is important that this second hole is made perpendicular to the tibial long axis.

It is desirable that the cranial hole is made centrally in the TT which ideally should be 6mm wide so that there is sufficient bone between the drill hole and both the osteotomy and cranial cortex of the tibial tuberosity.

03 The position of the cranial (tibial tuberosity) hole is chosen. A point is identified in the distal 1/3 of the TT; if necessary, the location may be moved slightly to find better bone stock.

Initially, the hole is "marked" by the drill without the drill guide.

Standard *and* ***Small*** *staples use 2.0mm drill whilst the* ***Mini*** *staple uses a 1.5mm drill*

The drill guide is now used and drilling through the guide, a bi-cortical hole through the tibial tuberosity is completed.

04 A 2.0mm peg (1.5mm peg for mini staple) is inserted through the drill guide, then the peg is placed into the recently drilled hole in the tuberosity.

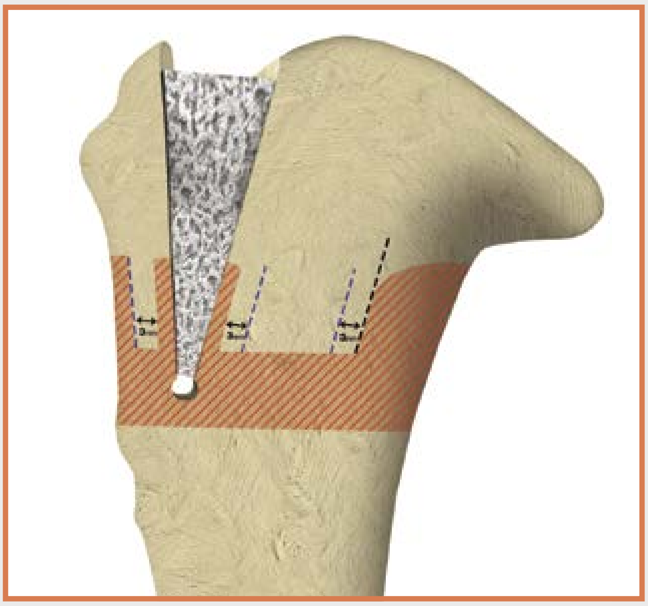
The drill guide is now carefully manipulated to choose the optimum position of the second hole, which will be made perpendicular to the tibial long axis in the tibial diaphysis. This hole is monocortical (cis cortex only) and should be drilled mid-way between the osteotomy and the caudal tibial cortex.

05 The staple is positioned gently such that each "leg" of the staple engages simultaneously with each bone hole.

The drill guide is used as a lightweight hammer to gently tap the staple home. Care is taken to advance the staple evenly.

Staple holders are available to aid staple placement.

06 The pointed reduction forceps that were used to pre-compress are removed.



07 This image depicts the “NO-GO” staple leg hole drilling areas:

- within 2mm of cranial and caudal tibial cortices
- within 2mm of osteotomy/wedge-bone interface
- immediately above the Maquet hole
- in line with the Maquet hole
- immediately distal to the Maquet hole

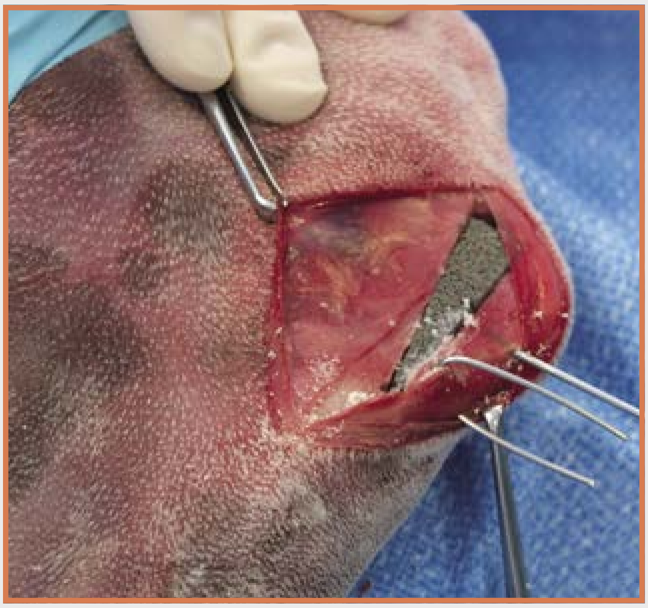
Distal MMP Tension Band Wire Fixation

01 Preparing the holes for the figure-of-eight wire: Using a 1.5mm drill bit, the distal drill hole is started 7-10mm distal to the Maquet hole and 5- 7mm caudal to the cranial tibial cortex. Start the hole perpendicular to the bone. **Drill no more than 0.5mm deep in this direction.**

At this stage, re-direct the drill at an angle between 30° and 45° to the vertical and continue drilling craniolaterally such that the hole exits just caudal to the cranial cortex.

02 Start the proximal hole as shown using a 1.5mm drill bit; locate the starting point approximately halfway between the K-wire and the Maquet hole and start the hole perpendicularly near the central thickness of the TT or slightly cranial to the osteotomy. Again start the hole perpendicular and then re-direct the drill at an angle between 30° and 45° to the vertical and continue drilling craniolaterally such that the hole exits the lateral aspect of the TT just caudal to the cranial cortex.

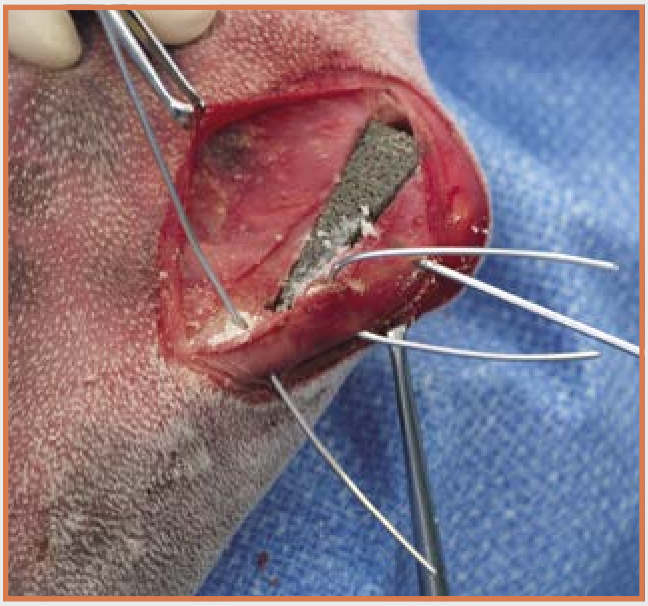
Ensure that there is enough bone stock at the level of the drill hole so the hole is not too close to the cranial cortex.



03 For tension band wiring, orthopaedic wire of 1.2mm to 1.5mm diameter is chosen. In small dogs <8kg it may be possible to use 1.0mm diameter wire. **The size of wire is critical, the commonly used "20G" orthopaedic wire is only 0.8mm diameter and is NOT SUITABLE for use in MMP, even in small dogs.**

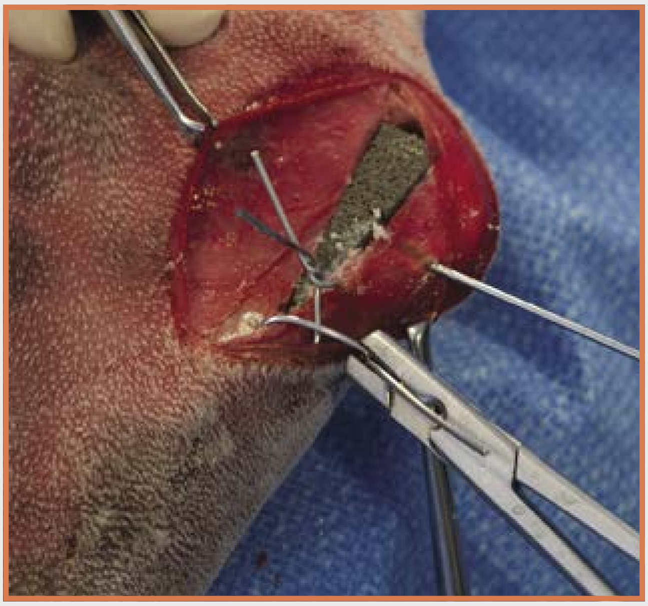
A length of the appropriate orthopaedic wire is pushed from medial to lateral. **Avoid all dissection** – the cranial tibialis muscle is pushed caudally and the wire is pushed through the tissue without the need to do any dissection.

Preservation of the distal soft tissue bridge is essential.



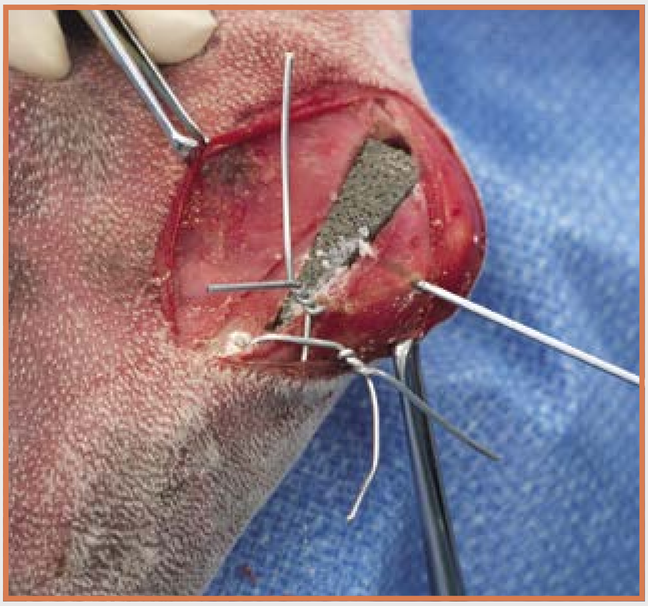
04 A second short length of orthopaedic wire, same size, is passed through the distal hole in similar fashion. **Again, it is important that all dissection is avoided.**

Note: The size of orthopaedic wire is rather larger than many surgeons will be used to selecting for similar applications. However, the magnitude and direction of forces acting here after advancing the tibial tuberosity requires that a substantial tension band wire is used.



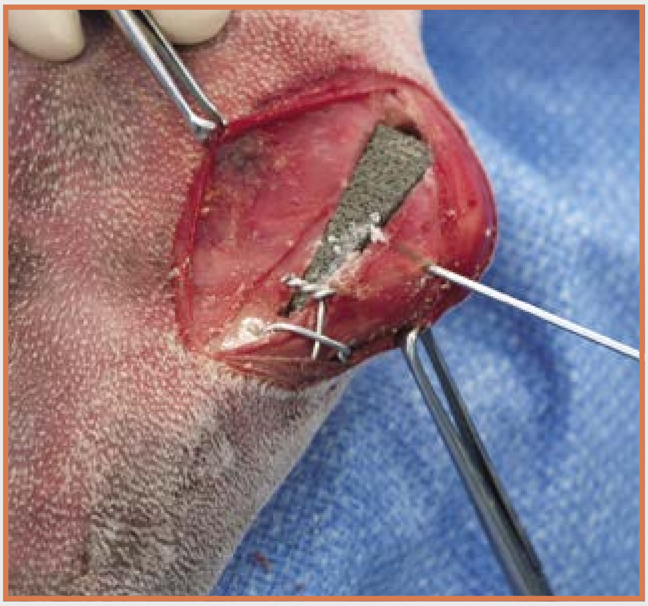
05 The figure-of-eight pattern is laid in routine fashion and great care is taken to ensure that the twists are made evenly and neatly.

It is essential that a perfect tension band wire is created. If there is any doubt the wire should be removed and start afresh.



06 Two symmetrical twists are needed to provide even tightening of this relatively thick wire. Each “arm” of the figure-of-eight is tightened in turn to achieve and maintain adequate, even tension.

Each arm is cut leaving three twists which are bent over flush with the surrounding tissue.



07 The K-wire is cut leaving approximately 5-10mm protruding

08 The protruding K-wire is bent medially to a right angle using the MMP K-wire bender (staple drill guide).

09 The wound is irrigated and suctioned clear prior to closure in ideally 3 layers (fascia/fat, subcutaneous and skin) using appropriately sized monofilament sutures in simple continuous patterns.

A light dressing with Primapore™ or similar is maintained for a few days thereafter with usage of devices to prevent patient licking and chewing for at least the first 2 weeks postoperatively.

Examples

Small breed surgery
with mini staple

Small breed surgery
with tension band wire

Small breed surgery
with small staple

Medium breed
with small staple

Large breed
with double stapling

Giant breed
with double stapling

Surgical Technique – Summary and Key Technical Points

A medial approach to the proximal tibia is made avoiding all unnecessary dissection.

The MMP can be performed with remarkably little exposure and the preservation of soft tissues is an essential component of this technique. Soft tissues are essential first to provide a blood supply for the healing TT, but also to limit displacement of the TT if distal fixation fails.

A small incision is made caudal to the patella ligament to identify the sloping bone of the proximal tibia.

If exploration of the stifle joint is appropriate, this medial parapatellar incision is extended proximally to expose the medial joint compartment including the medical meniscus. After intra-articular surgery, the MMP surgery is completed but full joint closure is often not possible following TT advancement.

A saw guide is placed in contact with both the proximal tibia and the cranial tibial cortex and held perpendicular to the weight-bearing axis of the tibia.

The limb is held such that hip, stifle, hock and paw are in simultaneous contact with the operating table. With the limb slightly flexed, the saw guide is held perpendicular and fixed with a drill. This method ensures that the osteotomy is made perpendicular to the weight-bearing axis of the tibia.

The position of the planned osteotomy is reviewed before the drill is placed and before any bone is cut.

A tibial tuberosity of 6-10 mm proximal thickness is appropriate, with a maximum of 12mm in even the largest dog. The osteotomy is made parallel to the tibial long axis (i.e. not angled cranially or caudally) and involves only the tibial tuberosity, without extending into the tibial diaphysis. In smaller dogs, care is needed to avoid placing the Maquet drill bit, or making the osteotomy, too caudally along the weight bearing axis of the tibia.

The saw guide is retained in place using a drill bit and the osteotomy is made using an oscillating saw with extreme attention to tissue irrigation to avoid thermal injury. The drill and saw guide are removed and the osteotomy is completed.

Using the size-guide, an appropriate wedge is selected.

The use of templating and surgical planning based on the crossover-point theory and relying on a 90° patella tendon angle (PTA) is unreliable and biologically implausible. The size of wedge is chosen according to the size of the patient as listed in the size-guide chart. (Appendix 3).

Using small pointed reduction forceps, the tibial tuberosity is manipulated first to accommodate trial wedges then the OrthoFoam™ wedge.

The wedge is positioned such that it contacts the medial cortex of the tibia along its length - this ensures that the implant is supported on stiffer cortical bone and not exclusively on softer cancellous bone which, especially in larger dogs, is not stiff or strong enough to counter the imposed forces. A poorly positioned wedge in a large dog may subside or fracture.

The butterfly drill guide is used to accurately place a K- wire through the TT coincident with the centre of the wedge.

If the K-wire is placed without pre-drilling, irrigation must be used to avoid bone injury through frictional heat generation.

The tibial tuberosity and wedge are pre-compressed against the tibial metaphysis using large pointed reduction forceps.

Day-1 stability is an essential part of this technique. Do not rely on the staple or tension-band wire to create interfragmentary compression, but rather “pre- compress” the wedge-bone interfaces using large pointed reduction forceps applied across the tibial tuberosity to the caudal tibial cortex. Once the forceps are in place with pre- compression generated, the staple or tension band wire can be applied to retain the compression and optimise day- 1 stability.

The distal tibial tuberosity is fixed using either staple(s) or a figure-8 tension band wire.

Staples are stiffer, stronger and simpler to place than wire. If wire is used it must be at least 1.0-1.2mm thick and properly laid and tensioned. In small dogs <8kg 1.0mm wire is appropriate. Both implants must be applied with care to minimise creation of multiple adjacent stress-riser holes in proximity to each other, the cranial and caudal tibial cortices, the osteotomy or the Maquet-hole.

The wound is closed in 3 layers (fascia/fat, subcutaneous and skin) using monofilament sutures in simple continuous patterns.

After-care information for clients

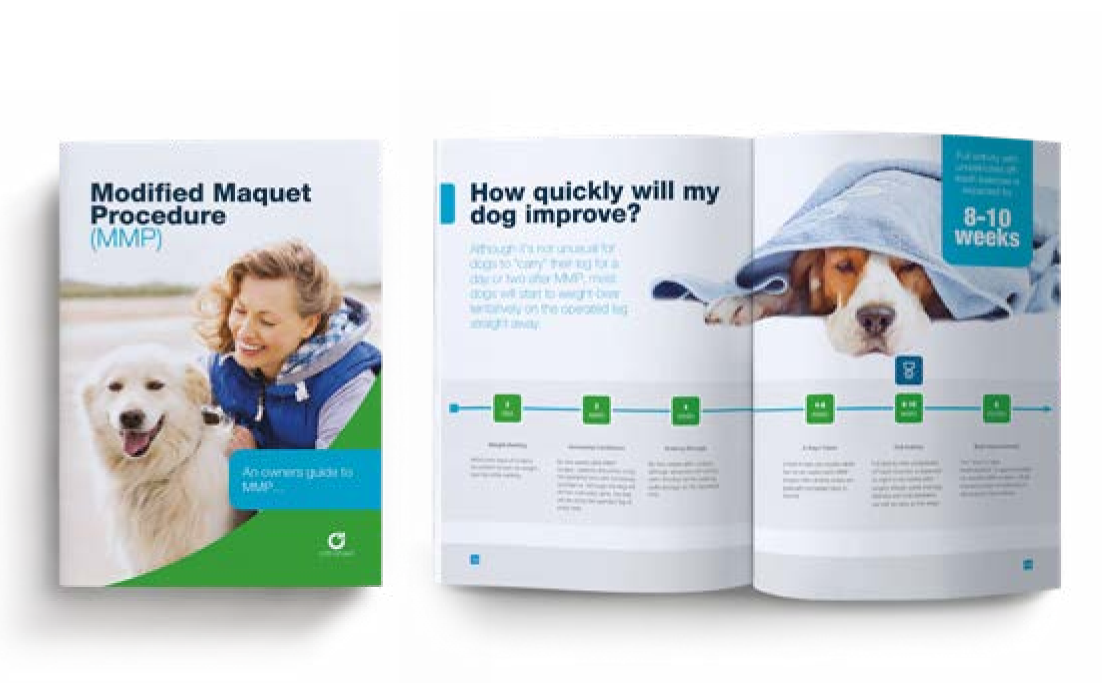
Dogs can normally be discharged the day after surgery or even the same day in certain cases. If strict aseptic technique is adhered to then no post operative antibiotics are indicated. Dogs should be discharged with NSAIDs to continue for 6-8 weeks in most cases.

Dogs are allowed leash-controlled exercise only for the first eight weeks after surgery. This can start with 5-10 minutes up to four times daily until the wound has healed. After suture removal the exercise can be increased by 3-5 minutes per walk per week. There must be no running, jumping, playing or stair use.

Clinical and radiographic assessment is recommended at 4-6 weeks, after which the dog is gradually returned to full activity over a further 4-6 weeks, assuming documented radiographic stability of all implants and bone. Best resolution of lameness may not be expected until 6+ months after surgery.

Early confident weight bearing is not uncommon following MMP surgery and that can encourage owners to disregard aftercare advice and allow their dog free-running exercise very soon after surgery. Tibial diaphyseal fractures are the most significant major complication of MMP surgery and it occurs almost exclusively during the first 4 weeks after surgery, especially in dogs that are allowed to exercise off the leash, contrary to aftercare instructions.

Full after-care guide for clients is available to download from www.orthomed.co.uk or by contacting the office.



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Appendix 1

At the start of the MMP project accepted wisdom and established practice were relied upon as far as possible.

The beneficial effect of TTA was said to derive from a biomechanical phenomenon, the “crossover point”. The crossover point is that point during the motion of the stifle joint where there is no tension in either the cranial, or the caudal cruciate ligaments and which is claimed to occur coincident with a patellar tendon angle (PTA) of ninety degrees (Nissel 1984 and 1985). Consequently, the notion of advancing the TT to achieve a PTA of ninety degrees became widely accepted as the end point of TTA surgery.
The rationale was to replicate the biomechanical condition which featured a lack of tension in the CCL and therefore, by inference, stability due to abolition of tibial shear force.

At least two methods of estimating the required TT advancement were proposed - the radiograph overlay template method and later the “Common Tangent” method. For both, the starting point was a 135° extended stifle radiograph collimated to allow determination both of the femoral and tibial long axes.

At a very early stage, we recognised an inherent variability related to the reliance upon a radiograph extended to exactly 135°, especially when radiographing a cruciate deficient, and therefore often grossly unstable stifle.

DeRooster and VanBree demonstrated as long ago as 1999 that the amount of femorotibial subluxation apparent radiographically varies considerably and unpredictably in cruciate deficient stifles so any technique relying on a normal femorotibial relationship must be unreliable and similarly, Bush and others (2011) demonstrated that different methods of estimating the femoral long axis lead to different TT advancements.

Two recent papers Millet and others (2013) and Cadmus, Palmer and Duncan (2014) investigated the reliability/repeatability of these methods of TTA advancement and found significant shortcomings.

Before we fully appreciated the shortcomings with the current methods of estimating TTA, we developed and tested a modified method specifically for MMP. This was illustrated in some detail in the MMP User Guide Vers 1.

This technique was evaluated carefully for inter-estimator and intra-estimator error and found to perform very well and by measuring angles accurately and using only tibial landmarks, the variability and inaccuracy of the earlier estimating methods was largely eliminated. However, the method remained imperfect and that observation led to a critical review and re-evaluation of the theory that underpinned tibial tuberosity surgery in dogs and the evidence that supports that theory.

The review revealed that evidence to support a crossover point in humans is weak, and suggests that a crossover point probably doesn’t occur at all in quadrupeds.

That TTA procedures actually work in terms of bringing about a useful clinical improvement seems beyond reasonable doubt and while some surgeons state that clinical efficacy is evidence of the validity of the “crossover point” theory that is a logical non sequitur.

The crossover point theory is referenced back to a monograph, Nissel (1985) and an earlier thesis written by the same author (1984). The crossover point is not a main theme of either the monograph or the thesis. While there are diagrams to show a crossover point coincident with a PTA of ninety degrees it is difficult to discern an obvious, direct causal relationship. Furthermore, the thesis is relatively lightly referenced, and remarkably little supportive or corroborative data is offered.

Importantly, it seems that the theory has not been considered or tested in quadrupeds and it has not been validated in dogs.

In contrast, Shahar and various colleagues published a series of papers, over a number of years, culminating in the description of a relatively complex mathematical model of the dog’s pelvic limb. (Shahar and Banks-Sills 2004) One aspect of this work looked specifically at the tension in the cruciate ligaments and the Shahar model indicated that the CCL was under tension throughout the stance phase. An important finding, which suggests that there isn't a crossover point in dogs at all.

Furthermore, the Shahar data was compared with in vivo data collected in goats by Holden and colleagues (1994) who found similarly that the CCL remains under tension throughout the stance phase. Other indirect evidence can be found. For example, Appelt and Kowaleski (2007), working with a cadaver limb model of TTA in dogs, showed that advancing the TT abolished cranial tibial shear force. However, the PTA at which the force was abolished was surprisingly variable with mean +/- 2 SDs extending to a range of 36 degrees. In any given dog, it was not predictably close to ninety degrees.

It seems that the accepted wisdom is, at best, controversial and the established practice for pre-operative planning is uncontrollably variable and inherently unreliable. If the crossover point doesn't exist or is not properly understood in dogs then the use of a TPA of ninety degrees as a surrogate end-point for TTA surgery is not valid. Consequently, the current recommendation is that wedge size selection for MMP is based on patient size (see Appendix 3). This information is based upon internal review of several hundred cases operated successfully over many years.

Appendix 2 - Complications

Complications are an inevitable consequence of performing surgery and the MMP is no exception. All surgeons performing the MMP surgery are asked to submit their complications, for advice if required, but primarily so that a continual review of complications takes place. This continual review consistently concludes that complications are normally the result of technical error. If we as surgeons, can avoid technical errors then the complication rate is reassuringly low and compares to other tibial osteotomy procedures used to treat cranial cruciate ligament disease.

As with any surgery there is a learning curve and when a surgeon has performed about 20 MMPs a decrease in complication rate can be expected.

Significant complications that can be encountered are listed below. The rate of incidence of each is estimated from reviews of procedures performed by some of our surgeons

- Tibial diaphyseal fractures (2.1%)
- Broken wedges (2.8%)
- Significant loss of reduction of the distal tibial tuberosity
- Implant associated Infection
- Late meniscal Injury (8.4%)

Tibial diaphyseal fractures

Tibial diaphyseal fractures are the single most significant serious complication of MMP surgery. Technical errors (an osteotomy too caudally positioned or extending into the tibial diaphysis; poorly positioned staple or wire holes, multiple drill holes or osteotomies created) and owner non-compliance with post-operative instructions regarding exercise lead to this complication.

Often, although initial lameness is profound, radiographic and clinical examinations reveal minimal displacement and the fibula to be intact. The fracture pattern is consistent, being a shallow spiral morphology, likely arising from the stress-risers created during surgery – this is suggestive of torsional forces applied to the tibia. A few cases have been more severely comminuted and displaced. It should be noted that in almost all fractures the tibial tuberosity, the wedge and the tibial metaphysis remain in place, fixed together.

Cases with minimal displacement and an intact fibula may be managed conservatively to good effect. Confinement and analgesia with follow up radiography to confirm that the fracture remained stable and was healing, has proven effective in many cases. There is no indication for any form of external co-aptation.

However, conservative management will significantly increase recovery time compared to that expected with internal fixation. Internal fixation leads to a rapid return to function and optimises recovery from the CCL disease. Stabilisation can normally be achieved effectively using a single, medially applied bone plate placed caudal to the wedge and staple. In most cases a cranial plate is not required but if the tibial tuberosity has been displaced then orthogonal plating may be required.

Following treatment of this complication, dogs can be expected to return to full function.

Broken wedges

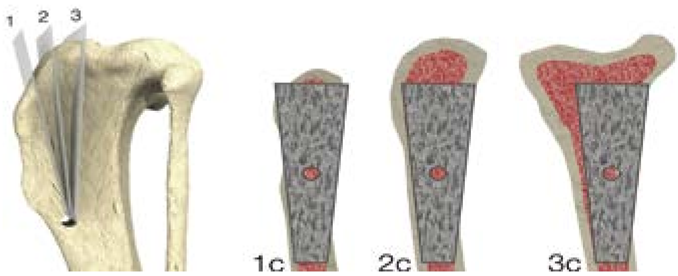
The incidence of broken wedges remains reportedly low among MMP surgeons. In more than half the reported cases, the broken wedge was an incidental finding on the four weeks postoperative radiograph of a dog that was otherwise progressing satisfactorily.

In most cases where progress was slowed in association with a broken wedge, a period of controlled activity and extended NSAID treatment was enough to achieve an excellent functional outcome. Attempted removal of the broken wedge is not advisable or advantageous in most cases with up to moderate loss of reduction.

Review of case details and radiographs showed that this complication was occurring in larger dogs in association with a rather caudal osteotomy and in some cases an obviously "centralised" wedge. When the osteotomy is made caudally, a "thick" tibial tuberosity is created, and this is tempting in larger dogs because of a fear of tibial tuberosity fracture. However, the risk of tibial tuberosity fracture with MMP is very low and a tibial tuberosity of 8- 12mm is all that is needed, even in the largest dog.

An unwanted consequence of the caudal osteotomy relates to the triangular cross-section of the tibia – a caudal osteotomy exposes a wider area of cancellous bone. If the wedge is centralised then its proximal end will lie exclusively supported on cancellous bone. Cancellous bone is neither stiff enough nor strong enough to resist the loads applied through the wedge by larger, stronger dogs and proximal subsidence ensues. At the same time, the distal portion of the wedge by virtue of its shape is supported on the stiffer, stronger bone of the medial and lateral tibial cortices. In many cases, the ingrowth of bone will occur and stabilise the situation before complication, but in a few cases, the bending forces lead to breakage of the wedge through the K wire hole.

This complication is prevented first by avoiding the error of making the osteotomy too caudal but more importantly, by first ensuring that the wedge is placed in contact, along its length, with the medial tibial cortex, and the TT and wedge are pre-compressed in combination with well-positioned distal construct fixation.



Significant loss of tibial tuberosity reduction

To date, there have been only a few reports of significant proximal migration of the tibial tuberosity following MMP surgery. This is probably related to the original surgical technique that emphasises and reiterates the importance of preserving all soft tissues and ensuring pre-compression is achieved prior to placement of well-positioned, rigid distal construct stabilisation implants.

The bone bridge at the distal osteotomy between the maquet drill hole and the cranial cortex will often 'snap' during surgery and is not a complication. Displacement is avoided by minimal soft tissue dissection and pre- compression with pointed reduction forceps followed by well-placed distal fixation (a staple or tension band wire).

Loss of reduction of advanced tibial tuberosity is a common minor complication. The loss of reduction is a cranial displacement of the distal end of the tibial tuberosity and is a consequence of the increased caudal force acting on the proximal end of the tibial tuberosity which is due to the re- directed quadriceps pull and which is key to MMP surgery. The staple or tension band wire is intended to control this force and a loss of tibial tuberosity reduction implies a degree of failure of this part of the surgery.

Analysis of feedback and first-hand experience showed that in many cases, the loss of reduction went un-noticed until radiography. In those cases, no specific treatment was provided, and the dogs typically progressed to full function. It seems that in those cases, despite the loss of reduction, the bone went on to heal and remodel without further ado. In a few cases, the loss of reduction was more marked (5- 15mm of cranial displacement distally) to the extent that revision surgery was contemplated. In fact, all such cases were managed conservatively with bone filling the void and healing, with subsequent remodelling occurring without the need for revision surgery. Although the radiographic appearance was ugly, the functional outcomes, though delayed, were typically excellent.

Review of case details and radiographs revealed that poor wiring technique was a consistent feature of these cases. Technical errors included the use of under-size tension wire and inadequate tensioning of the wires. Slightly loose or under-size wires will not impose day-1 stability and as the dog uses the limb, any potential "slack" will be exacerbated under load and result in failure with cranial displacement of the distal tibial tuberosity. In most cases, it seems that the bone will "catch up" with the imperfection and normal healing will ensue.

While good wiring technique will prove effective in almost every case, tension band wiring is very technically sensitive and even relatively minor technical errors or imperfections can pre-dispose to this complication.

With increased usage of the titanium staple over tension band wiring, the reported incidence of this complication has diminished significantly. This is due, in part, to the fact that the staples are simpler to insert than wire, and therefore less prone to technical error, but also to the fact that following properly achieved pre-compression across the wedge-bone interfaces, well-positioned titanium staples, fully seated in good quality bone, will usually prevent significant loss of TT reduction. However it must be remembered that the increase in force of the pull of the quadriceps is significant and poor staple placement can still result in significant loss of reduction of the tibial tuberosity.

Displacement that may be managed conservatively

Displacement that requires revision surgery

Infection

Implant associated infection is not uncommon, especially when MMP has been used in an already infected site – for example in revision of failed, infected extra-capsular cruciate surgeries. In such cases, the advanced tibial tuberosity will heal onto the wedge in the face of infection and though the infection will persist while K wires, staples, tension wire etc. remain in place, once these are removed the infection appears to resolve with the wedge in situ.

Titanium is remarkably biocompatible, and the “infection- resisting” property of the material is optimised by the specific structure of OrthoFoam™. The open porosity permits through flow of tissue fluids and supports the development of vasculature deep into the implant leaving little, if any potential space for bacterial colonisation.

Similarly, the mechanical properties of the implant, specifically its Young’s modulus close to that of the parent bone minimises the risk of stress-protection making the mechanical environment unsuitable for unhealthy bone.

Nevertheless, there are a few instances when an infected wedge may need to be removed, especially when there is radiographic evidence of a loose wedge surrounded by infected bone, or if persistent sinus drainage is linked to the wedge itself. Staged initial explantation of the K-wire, tension band wire or staples is done and submitted with or without debrided tissue for bacteriology testing to direct an appropriate antibiotic course for 6-8 weeks. Closed suction drainage may also be needed. If sinus drainage recurs, wedge explantation is performed gently using an oscillating saw or osteotome and mallet along the cranial and caudal wedge-bone interfaces.

Continued antibacterial therapy and temporary bone plate stabilisation of the advanced TT may be achieved until there is documented radiographic healing across the osteotomy gap. If there is recurrence of the sinus drainage tract plate and screw removal may eventually be necessary.

Meniscal injury

The literature is replete with articles in favour of meniscal integrity evaluation to identify and treat meniscal injuries secondary to cranial cruciate ligament disease at the time of CCL surgery. The need for this has been recently questioned and entering the joint is not a benign procedure; unpredictable clinical morbidity of varying degrees results in the individual patient. Whether to evaluate the meniscus pre-operatively by ultrasonography, CT arthrograms or MRI or intra-operatively by arthroscopy or arthrotomy with meniscal probing is a clinical decision made by the surgeon. Pre-operative imaging is either operator dependant in the case of ultrasonography or cost prohibitive in the case of CT and MRI. Whether or not the surgeon evaluates the meniscus, MMP surgery can be performed.

Late meniscal injury is a complication of all cranial cruciate surgeries and can result in pain and lameness. Clinical signs include severe lameness, pain on stifle flexion and stifle effusion with or without a meniscal click.

> *Latent Mensical Injury is a tear that was missed at the sentinel CCL surgery and has progressed.*
>
> *Postliminary Meniscal injury is where the meniscus was intact at the time of CCL surgery and has developed later.*

Late meniscal injury can occur up to two to three years following CCL surgery. A recent audit revealed late meniscal injury in 8.4% of cases following MMP surgery.

With years of experience some of these cases can be treated medically with aggressive analgesia and a rapid increase in exercise. If this does not resolve the lameness over a 2-4 week period and the clinical and radiographic examinations do not find an alternative cause then inspection of the menisci can be achieved by arthroscopy or arthrotomy with meniscal probing. Arthroscopy is more sensitive than arthrotomy for visualising small meniscal tears. Often the most significant meniscal tear is one in which there is a large bucket handle tear of the caudal horn of the medial meniscus. The menisci can be treated by partial meniscectomy or hemimeniscectomy.

Appendix 3 - MMP wedge sizing

Having carefully reviewed the literature and theory that underpins the 90° patella tendon angle as an end point for TTA surgery, and examined the experience of several thousand successful MMP cases we concluded, as others have, that the existing methods to estimate tibial tuberosity advancement are unreliable. [Millet and others (2013) and Cadmus, Palmer and Duncan (2014)].

Furthermore, their theoretical basis is clinically implausible – this is discussed in more detail in Appendix 1. Extensive clinical experience with MMP has shown that selection of wedge size, and therefore amount of tibial tuberosity advancement, can be made confidently based on patient breed and stature rather than weight, according to the guidelines in the charts below:

Adv.	Breed						
3mm	Small Yorkie	Chihuahua	Small Shih Tzu				
4mm	Large Yorkie	Large Shih Tzu	Miniature Poodle	Bichone Frise	Maltese Terrier		
5mm	West Highland Terrier	Boarder Terrier	Cairn	Small Tibetan Terrier	Fox Terrier	French Bulldog	Jack Russell
6mm	Large West Highland Terrier	Large Boarder Terrier	Large Cairn	Large Tibetan Terrier	Miniature Schnauzer	Small Cavalier King Charles Spainiel	Small Shiba Inu
7mm	Small Corgie	Large Cavalier King Charles Spainiel	Small Beagle	Small Cocker Spaniel	Basset Hound	Cypriot Poodle	Minature Labradoodle
8mm	Large Corgi	Large Cocker Spaniel					
7.5mm	Springer Spaniel	Staffordshire Bull Terrier	Large Cocker Spanie	Large Beagle	Large Corgi		
Medium or Standard Breed wedge							
7.5mm	Border Collie	Chow Chow	Shar Pei	English Bulldog			
9.0mm	Large Bulldog	Bull Terrier	American Bulldog	English Bulldog			
Medium or Standard Breed wedge							
9.0mm	Small Labrador	Boxer	Golden retriever	Dalmatian	Standard Poodle	English Setter	Airedale Terrier
10.5mm	Large Labrador	Large Boxer	Large Dalmatian	Akita	Small Rottweiler	GSD	Bernese Mountain Dog
12mm	Large Rottweiler	Malamute	Large GSD	Dogue de Bordeaux	Perro de Presa	Malinois	
13.5mm	Mastiffs	Newfoundland	Large Dog de Bordeaux	Great Dane			
15.0mm	Large New Foundland	Large Saint Bernard	Large Great Dane	Large Mastiff			

While this does not appear to be very "scientific" it has the advantage of being simple and has been shown to be effective over many clinical cases.

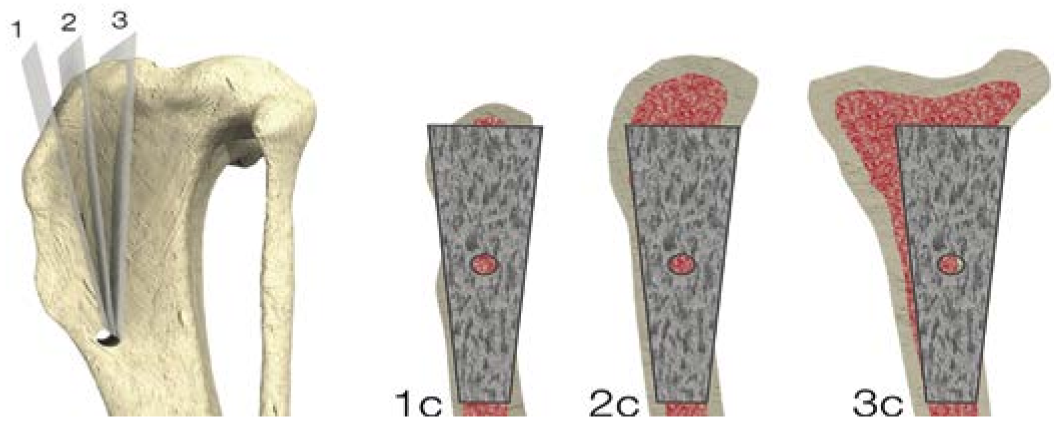
Existing methods are much more complex and, more worryingly they are based on a theory and assumptions that do not stand up well to critical review and intellectual scrutiny.

Wedge sizing tips

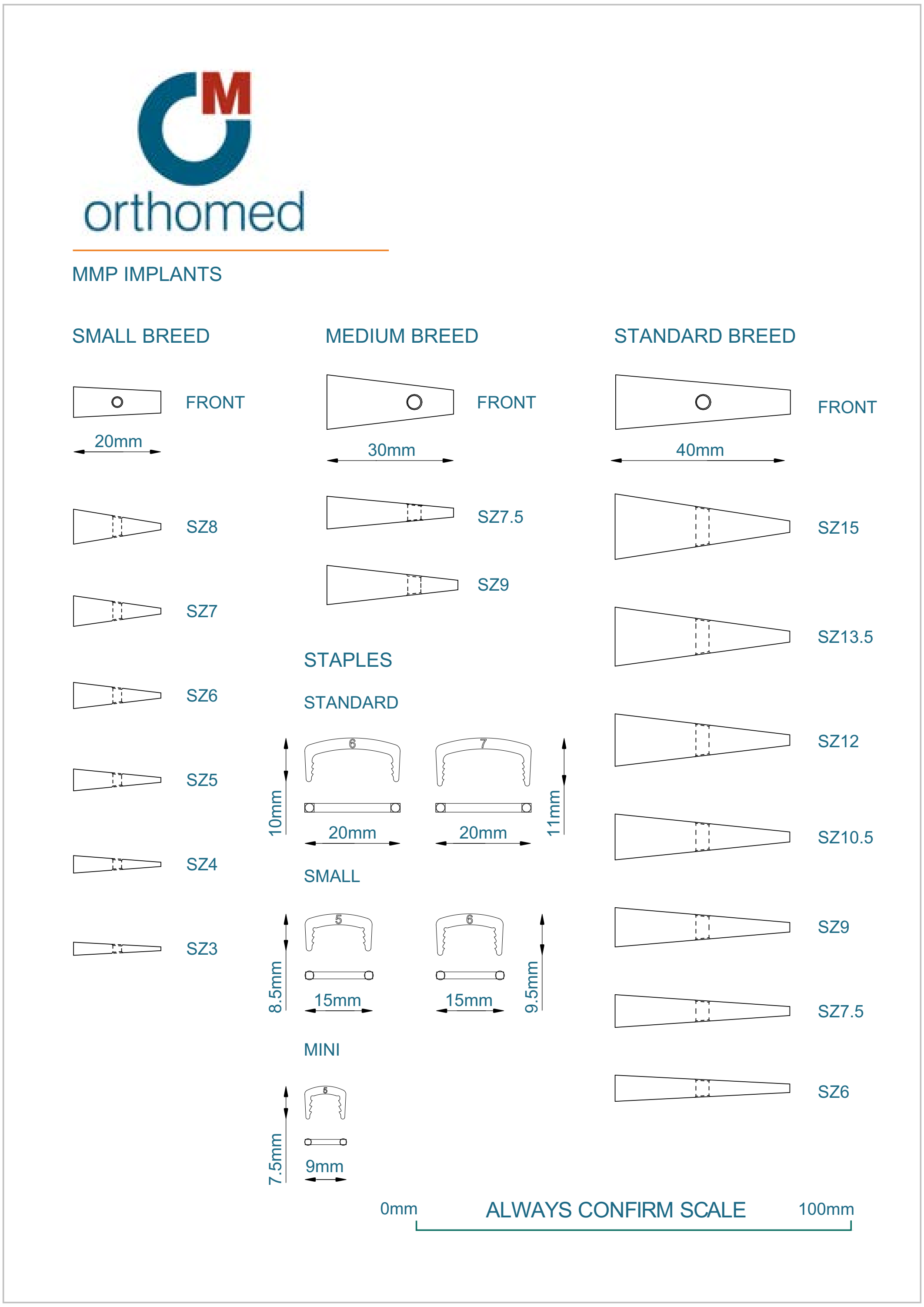
1. The desired tibial tuberosity advancement is based on the stature of the patient and not the weight.
2. If a breed is not represented on the sizing chart above or is a cross breed, look for a dog of the equivalent stature and use that size.
3. The difference in advancement between wedges is small so if in any doubt between sizes then choose the larger advancement.
4. There are three lengths of wedge:
    a) Small breed 20mm
    b) Medium breed 30mm
    c) Standard breed 40mm
5. In many circumstances it will be obvious which length of wedge to use. However, you can measure the tibial tuberosity length on pre-operative radiographs to help choose appropriate length of wedge
    a) Approximately 20mm to 30mm for small breed wedge
    b) 31 – 40mm for medium wedges
    c) >41mm for standard wedges
6. In exceptional circumstances it may be necessary to choose a wedge length that is longer than the tibial tuberosity, in which case the osteotomy made during surgery is completed through the distal tuberosity and the wedge can protrude a couple of milimetres in the cranial tibialis muscle.

Appendix 4 - Depth of wedge

Due to the triangular cross section of the proximal tibia, the more caudal the osteotomy the wider the tibia is medial to lateral. Therefore with a more caudal osteotomy the wedge may not have lateral bone contact as per image 3c.



Appendix 5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MMP IMPLANTS
SMALL BREED
FRONT
20mm
SZ8
SZ7
SZ6
SZ5
SZ4
SZ3
MEDIUM BREED
FRONT
30mm
SZ7.5
SZ9
STAPLES
STANDARD
10mm
20mm
20mm
11mm
SMALL
8.5mm
15mm
15mm
9.5mm
MINI
7.5mm
9mm
STANDARD BREED
FRONT
40mm
SZ15
SZ13.5
SZ12
SZ10.5
SZ9
SZ7.5
SZ6
0mm
ALWAYS CONFIRM SCALE
100mm

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