OrthoFoam MMP Wedge
For Canine Cruciate Disease

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The Modified Maquet Procedure (MMP)

The Modified Maquet Procedure (MMP) is so named to acknowledge the instigator of these operations, Dr P Maquet, a human orthopaedic surgeon working in Belgium during the 1960s.

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 gives control and ensures an osteotomy of the correct length, precisely directed and positioned to ensure an appropriately “thick” tibial tuberosity while at the same time protecting adjacent structures from iatrogenic injury.

The Orthofoam wedge provides a robust early fixation without the need for support bandages or a lengthy period of rest. The potentially disruptive forces that act to displace the distal end of the tibial tuberosity cranially following advancement are controlled using either a wire tension band, a titanium staple or a plate and screws.

The open porous structure and sympathetic mechanical characteristics of the Orthofoam implant encourages early and sustained ingrowth of bone removing the need for bone grafting or similar.

Mechanics-modifying osteotomies

Tibial plateau levelling osteotomy (TPLO), developed and popularised by Dr Barclay Slocum during the 1980s, represented a paradigm shift in the treatment of the lameness caused by functional failure of the cranial cruciate ligament (CCL) in dogs.

Instead of trying to repair or replace the failed CCL, TPLO addressed the problem by altering the biomechanics of the stifle joint.

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

During the early 2000s, Professors Montavon and Tepic developed and commercialised another mechanics-modifying osteotomy; tibial tuberosity advancement (TTA).

The biomechanical theory underpinning each of these procedures remains rather speculative and controversial but despite that, there has developed a widespread agreement that currently the mechanics-modifying osteotomies offer the best chance for a dog to return to normal or near-normal function following CCL failure. 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 recognised that if mechanics-modifying cruciate surgery could be made less costly and less complex then it would become more accessible and widely available.

MMP is an evolution of the osteotomy techniques described first by Maquet for humans and then later by Montavon and Tepic in dogs: it is the result of a project to re-engineer mechanics modifying cruciate surgery with the intention of making it simpler, more cost-effective and therefore more widely available.

The design and development targets, 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 hundred surgeons worldwide who have adopted the technique and used it on 20,000 cases to date (2014) but also by the efforts of others following our lead in their attempts to simplify and popularise these operations.

That 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 recently and independently by the works of Millet and others (2013) and Cadmus and others (2014).

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 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 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.

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 an excellent starting point for the enormous amount of research that has gone into developing a

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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-sturcture); 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 the majority 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, catastrophic complications following MMP are extremely uncommon and it seems that there is a strong tendency for MMP surgery to "fail-safe" inasmuch as many complications are minor and can be effectively managed without revision surgery.

Major complications occur infrequently, typically a fracture of the tibial diaphysis, and though disconcerting, many of these fractures have been 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 derives 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 have the ability to perform extra-capsular cruciate repair surgery competently will usually find MMP within their grasp. However, attention to detail is an important part of surgical success and attendance at an MMP training course is considered 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 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 dorsal recumbency and the limb draped to allow flexion and extension both of the stifle joint and of the hock.

This shows the 'surgeons 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 saggital plane of the limb parallel to the tabletop.

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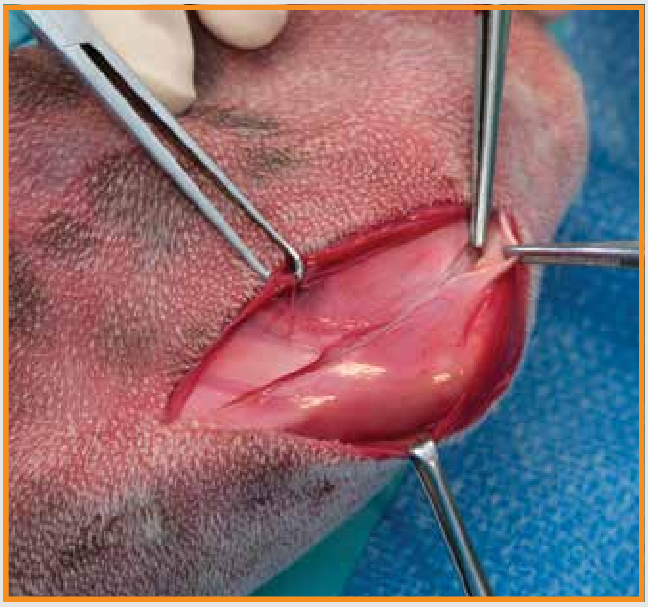
03 A skin incision is made on the medial aspect starting proximally at the level of the mid-point of the straight patellar ligament and extending distally for eight to ten centimeters.

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



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

The caudally angled, 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.

06 An instrument (in this case a closed pair of Metzenbaum scissors) is pushed firmly behind the straight patella ligament to puncture the lateral joint capsule.

This is done to facilitate placement of the proximal (longer) pin of the saw guide. The limb is held in the standard reference position (see 2 above) and the instrument is driven perpendicular to the tabletop.

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

07 The proximal (longer) pin of the MMP saw guide is placed behind the straight 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 cranial aspect of the tibial tuberosity/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 tibia behind the straight patellar ligament is maintained) and second, by selecting a thinner, or fatter, distal pin thereby moving the distal end of the osteotomy (and the 3.5mm hole) more caudally or cranially within the tibial diaphysis. The aim is to harvest a tibial tuberosity of 8-12mm thick, which is adequate in even the biggest dog.

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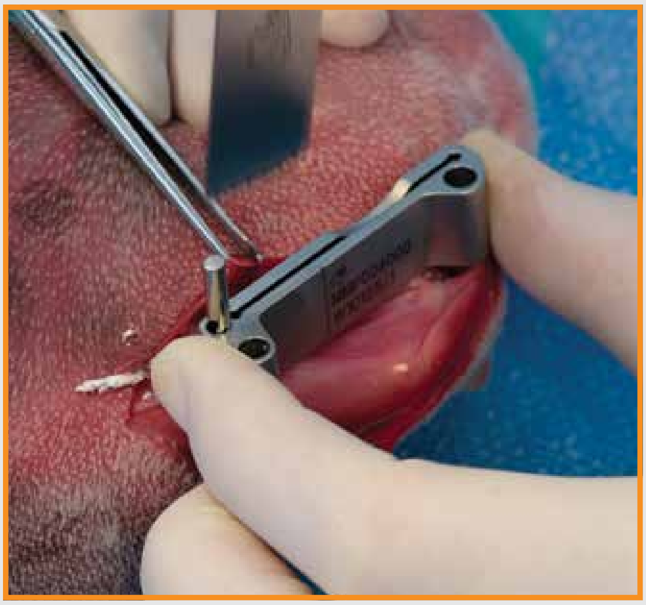
08 Having inspected the anticipated size of the tibial tuberosity fragment with reference to the position of the saw guide, the guide is fixed using the short 3.5mm drill bit, which is advanced through both tibial cortices. Prior to drilling, the limb is returned to the standard reference position, (see 2 above) and the drill is placed perpendicular to the tabletop.

The chuck is removed leaving the drill in place thereby fixing the MMP saw-guide in place.



09 The osteotomy is made: a saw blade with a thickness of approximately 0.7mm 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.

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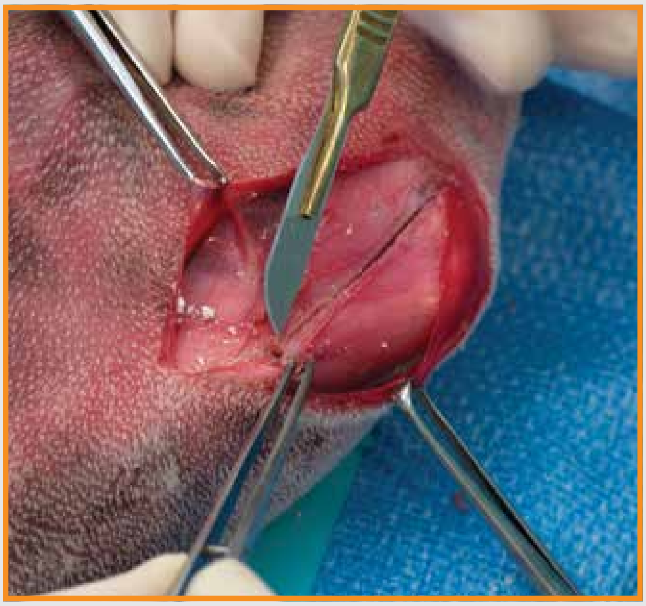
10 On completion of the osteotomy, the 3.5mm drill bit is removed.

11 The MMP saw-guide is removed.



12 A bony bridge between the distal end of the saw slot and the 3.5mm drill hole persists. This is identified and cleared of any overlying fascia. Avoid excessive dissection – it is essential that all soft tissue distal to the end of the osteotomy is preserved untouched.

13 Removing the small bony bridge using the same oscillating saw completes the osteotomy.

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

14 A pair of small pointed reduction forceps is placed across the proximal end of the osteotomised tibial tuberosity. Gentle traction confirms that the osteotomy has been completed successfully.

Occassionally, further use of the bone saw will be required to complete the osteotomy proximally and in that case the saw guide must be replaced. An important function of the saw guide is to protect the straight patella ligament and other, intra-articular structures from iatrogenic damage.

15 The smallest trial wedge is offered up to the osteotomy – the small pointed reduction forceps facilitate this process.

Extending the stifle at this point will facilitate advancement of the tibial tuberosity – even in the anaesthetised dog there is considerable Quadriceps muscle tone working against the cranialisation of the tibial tuberosity.

16 Increasingly large trial wedges are placed until the desired size is reached.

17 Note the position of the distal tip of the wedge relative to the 3.5mm drill hole – this position should be replicated when the Orthofoam wedge is placed. Similarly, it is essential that the medial aspect of the 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.

The saw-guide is longer than the wedge so the proximal end of the wedge will lie safely “behind” the proximal extremity of the tibial tuberosity.

18 Ensure that there is no tendency for soft tissue to be “dragged ” in between the trial wedge and the bone.

19 The final trial wedge is placed - in this case 12mm

20 The appropriate Orthofoam MMP wedge is loaded into MMP insertion device and placed exactly as predicted by the trial wedge .

21 Positioning of the wedge is reviewed: the distal tip of the wedge should lie exactly as predicted by the trial wedge and the medial aspect of the wedge must lie very slightly proud, of the medial tibial cortex.

Verify that the proximal end of the wedge is lying safely behind the bone at the proximal extremity of the tibial tuberosity. Finally, check that there is no soft-tissue entrapment.

22 The butterfly drill-guide is placed onto the MMP insertion device. Two butterfly drill-guides are provided, 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.

23 A 1.5mm drill bit is used to make a hole through the tibial tuberosity only. The butterfly drill-guide will line up this drilling with the hole in the Orthofoam wedge. Avoid drilling beyond the wedge – specifically, do not drill the tibial diaphysis. Careful attention to technique is required as this is a small-diameter drill cutting hard bone at an angle – use a sharp drill bit, high rotation speed and slow, gentle advancement.

24 A 1.6mm Kirschner wire (size critical) is placed through the butterfly drill guide and advanced until firmly seated in, but not penetrating, the caudal tibial cortex .

Some surgeons omit the pre-drilling (step 23) and direct drill with a 1.6mm K wire. This has the advantages of being quicker, technically easier and omitting the need for a 1.5mm drill. However, the trochar point on the K wire is a relatively inefficient cutter of the very hard bone of the tibial tuberosity so there is potential, with poor technique, to generate considerable frictional heat – enough to cause localised bone damage. Performed carefully, using a good quality, sharp K wire and with copious fluid to cool and irrigate the K wire during placement, this is a valid modification to the technique.

25 The butterfly drill-guide is removed by gently sliding it back off the K-wire after first loosening the insertion device a couple of turns .

26 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 tibial tuberosity must be stabilised. Several options are available: tension band wiring; staple fixation or use of a custom-made bone plate and screws. 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 (Alves and Ness (2014) for Orthomed. Data on file). Some surgeons have reportedly used custom-made bone plates and screws in this application to good effect but no data is available.

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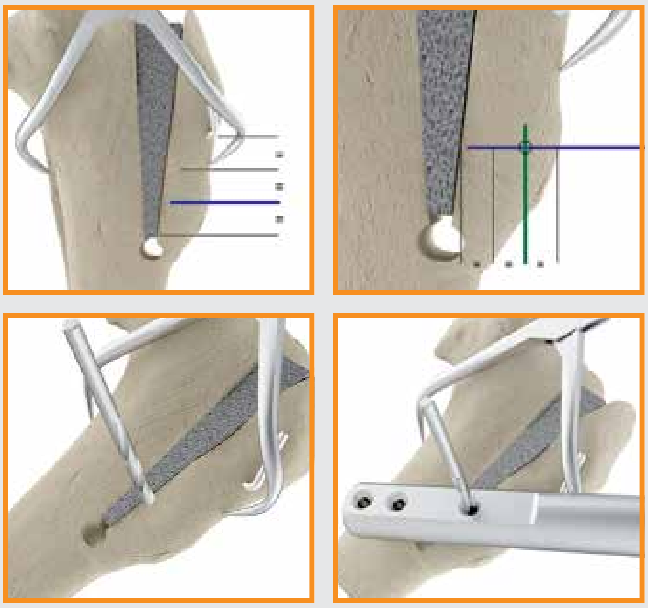
MMP Stapling

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 tibia and tibial tuberosity in order to pre-compress the tibial tuberosity and the wedge against the proximal tibial diaphysis.Two holes are made to accommodate the staple, one in the tibial tuberosity, the second in the tibial diaphysis. The drill guide is used to guide the planning and positioning of these holes. Note that the drill guide imposes both the relative position AND the relative direction of the holes as they are drilled. NEVER attempt to “free-hand” the staple holes. It is important that this second hole is made some way DISTAL to the end of the osteotomy. It is desirable that the proximal hole is made rather cranially and distally in the tibial tuberosity.



02 The position of the proximal (tibial tuberosity) hole is chosen. A “rule of thirds ” is used. A point is identified two thirds of the way distally between the position of the K wire and the end of the osteotomy and two thirds of the way cranially across the tibial tuberosity. The first staple hole is made into good bone some way distal and cranial to this point. Initially, the hole is “marked” - using the 2.0mm drill a shallow (< 1mm) hole is drilled into, but not through, the tibial tuberosity. The drill guide is now used and drilling through the guide, this hole through the tibial tuberosity is completed. When making holes for a staple, both position and direction are important – this two-step drilling process ensures that the resulting hole is optimally placed in the tibial tuberosity while at the same time appropriately directed such that the staple will lie snug against the tibia.

03 A small peg is inserted though the drill guide, then the peg is placed into the recently drilled 2.0mm hole in the tibial tuberosity. The drill guide is now carefully manipulated to choose the optimum position of the second hole, which will be made in the tibial diaphysis.

The hole must be distal to the end of the osteotomy; it must penetrate only one cortex. The angle that the staple lays relative to the axis of the tibia is not important but care should be taken to make the hole away from the caudal or the cranial cortices.

04 The staple is positioned gently such that each “leg” of the staple engages simultaneously with each bone hole.

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

06 The pointed reduction forceps that were used to pre-compress are removed. (See Surgical Technique - Summary and Key Technical Points)

MMP Wiring

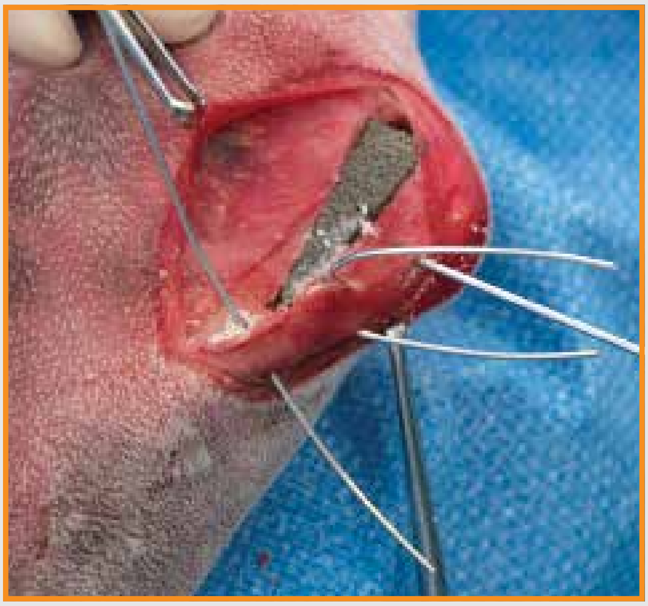
01 Achieving “Day 1 stability” is an essential feature of MMP surgery and to that end, before the holes are drilled for the tension band wire, a pair of stout pointed reduction forceps is placed firmly across the proximal tibia and tibial tuberosity in order to pre-compress the tibial tuberosity and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

Preparing the holes for the figure of eight wire. Start the proximal hole as shown using a 1.5mm drill bit: locate the starting point approximately two thirds of the distance between the K wire and the end of the osteotomy and start the hole very close to the edge of the osteotomy.
Drill no more than half a millimeter deep in this direction.

02 As soon as possible, re-direct the drill at an angle between thirty and forty five degrees to the vertical and continue drilling such that the hole exits the lateral aspect of the tibia close to its cranial extremity. Avoid any dissection – it is essential that the soft tissues in this region are preserved untouched.

03 A length of orthopaedic wire, 1.2 (minimum) – 1.5mm diameter (size critical) is pushed from medial to lateral. Avoid all dissection – the wire will find a path through the soft tissues without the need to do any dissection whatsoever. Preservation of the distal soft tissue bridge is essential.

Note: the commonly used "Eighteen Gauge" orthopaedic wire is only 0.8mm diameter and is NOT SUITABLE for use in MMP, even in small dogs.



04 A second short length of orthopaedic wire, 1.2 (minimum) – 1.5mm in diameter (size critical) 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 wire tension band 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.

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

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07 The wire must end up firm and “snug” – the aim is to prevent creep and resist the disruptive loads that will be applied as soon as the dog bears weight on the operated limb.

08 The twists are cut to length and bent over to lie flush with the underlying structures .

MMP Surgical Technique (Cont)

27 The K-wire is cut leaving approximately 10mm protruding.

28 The protruding K-wire is bent medially to a right angle using the MMP K-wire bender.

29 The bent K-wire is rotated to lie against the cranio-medial aspect of the tibial tuberosity.

30 The soft-tissues are closed using a single simple continuous suture of 3 metric vicryl or similar before the skin is closed using a single continuous suture of 2 or 3 metric monofilament nylon or similar.

31 Bandages and complex dressings are unnecessary – the wound is protected using two or three rolled sterile gauze swabs (sponges) held in place with three simple interrupted sutures of 2 or 3 metric monofilament nylon or similar.

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Surgical Technique – Summary and Key Technical Points

A medial approach to the proximal tibia is made avoiding all unnecessary dissection.
Soft tissues are essential first to provide a blood supply for the healing TT but also to limit any disruption in the event of a fracture. MMP can be performed with remarkably little exposure and the preservation of soft tissues is an essential component of this technique.

A small incision is made caudal to the straight 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 joint is closed before MMP surgery is continued.

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 8-12 mm maximum thickness is appropriate in even the largest dog. In smaller dogs care is needed to avoid placing the drill, or making the osteotomy too caudally into the weight bearing axis of the tibial diaphysis.

The saw guide is retained in place using a drill bit and the osteotomy is made using an oscillating saw. 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 ninety-degrees patella tendon angle is unreliable and biologically implausible. The size of wedge is chosen according to the size of the patient as listed in the size-guide. (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, in larger dogs is not stiff or strong enough to cope with the imposed forces. A poorly placed wedge in a large dog may subside or fracture.

A drill guide is used to accurately place a K wire through the tibial tuberosity coincident with the centre of the wedge.
If the K wire is placed without pre-drilling, great care must be taken 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, wire or plate to tighten things up but rather "pre-compress" using large pointed reduction forceps across the tibial tuberosity to the caudal tibial cortex. Once the forceps are in place with compression generated, the staple, wire or plate can be applied to retain the compression and optimise day-one stability.

The distal tibial tuberosity is fixed using either a staple; figure 8 tension wire or plate and screws.
Staples are stiffer, stronger and simpler to place than wire. If wire is used it must be at least 1.2mm thick and properly laid and tensioned. Plates are strong and "familiar" but must be applied with care to minimise creation of stress-riser holes.

Wounds are closed with continuous suture patterns.

After-care information for clients

Dogs are allowed leash-controlled exercise only for the first four weeks after surgery. Clinical and radiographic assessment is recommended at four weeks after which the dog is returned gradually to full activity over a further four to six weeks. Best resolution of lameness is seen several 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 diaphseal fracture is the most significant major complication of MMP surgery and it occurs almost exclusively between postoperative days 5 and 20 in dogs that are exercising 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 one hundred and thirty five degree 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** 135º, 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 femoro-tibial subluxation apparent radiographically varies considerably and unpredictably in cruciate deficient stifles so any technique relying on a normal femoro-tibial 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 confirming that our earlier concerns were well-founded.

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 on review of several hundred cases operated successfully over the last four years or so.

Appendix 2 - Complications

The initial review of complications was made on the evidence of the first 3,000 MMP cases operated. These comprised approximately 500 cases from early adopter hospitals and 2,500 cases from "new" users. These figures are important because the early adopter hospitals were known to have recorded and reported all of their complications while for the others there was voluntary reporting.

This suggested an estimated under-reporting rate of about 65%. Furthermore, while the early adopter surgeons each had accumulated an experience of more than 50 cases, surgeons with fewer than 10 MMP cases had operated almost all of the other 2,500 cases. Despite this preponderance of surgeons at the bottom end of the learning curve, there were a total of 31 significant complications recorded and none of these was catastrophic. A significant complication was defined as a complication that required or might have required, revision surgery.

Correcting for the perceived under-reporting by assuming that the reported rate of complication of new users (0.74%) was actually equivalent to the known rate of complication of early adopters (2.4%), significant complications were estimated at 73/3000 (2.4%). These included an estimated 33/3000 (1.1%) tibial diaphyseal fractures; 18/3000 (0.6%) broken wedges and 22/3000 (0.73%) cases with significant loss of reduction of the distal tibial tuberosity.

Tibial diaphyseal fracture

Tibial diaphyseal fracture is the single most significant serious complication of MMP surgery. Often, although initial lameness is profound, radiographic and clinical examinations reveal minimal displacement (the fibula is often intact) and several of these cases were managed conservatively to good effect. Confinement and medical pain control with follow up radiography to confirm that the fracture remained stable and was healing proved effective and is now the treatment of choice in cases where there is minimal or no displacement.

The fracture pattern is fairly consistent being a shallow spiral morphology 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 but in each of these, the tibial tuberosity, the wedge and the tibial metaphysis remained fixed together so repair was achieved effectively using a single, medially applied bone plate.

Following treatment of this complication, dogs can be expected to return to full function. Factors that might pre-dispose to this complication include an osteotomy that is made too caudally, especially in dogs where the osteotomy extends into the tibial diaphysis; staple or wire holes made too proximally – ideally the staple or wire hole should be distal to the end of the osteotomy.

Failure to comply with post-operative instructions regarding exercise is much the most important factor. It is noteworthy that almost every case of tibial diaphyseal fracture reported to date has occurred between day 5 and day 20 after surgery in a dog that was exercising off the leash, contrary to standard post-op instructions. Furthermore, the majority of cases occurred following some additional trauma, for example being knocked over by another playing dog or jumping from a height.

It seems that tibial diaphyseal fracture, though a worrying complication can often be successfully treated conservatively but if surgery is needed, then a single medially applied bone plate is usually adequate. The risk of tibial diaphyseal fracture is extremely low in dogs restricted to leash exercise during the first four postoperative weeks.

Broken wedges

Although broken wedges were not seen at all in two of the three early adopter hospitals, they were encountered in four cases at the third early adopter hospital and reported by several other MMP surgeons. In more than half the reported cases, the broken wedge was an incidental finding on the four weeks radiograph of a dog that was otherwise progressing satisfactorily.

In the majority of cases where progress was slowed in association with the broken wedge, a period of controlled activity and extended NSAID treatment was enough to achieve an excellent functional outcome. In two cases, the surgeons elected to remove the broken wedge: in both cases the attempt was abandoned after removing only the proximal part of the wedge and in both cases the tibial tuberosity remained stable and the dogs were subsequently managed conservatively and both went on to a full functional recovery.

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 caudally but more importantly, by ensuring that the wedge is placed in contact, along its length, with the medial tibial cortex.

Significant loss of tibial tuberosity reduction

To date, there have been no reports of significant proximal migration of the tibial tuberosity following MMP surgery and that is probably related to the original surgical technique that emphasises and reiterates the importance of preserving all soft tissues.
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 the proximal end of the tibial tuberosity which is due to the re-directed quadriceps pull and which is key to MMP surgery.

The wire/staple/plate is intended to control this force and a loss of tibial tuberosity reduction implies failure of this part of the surgery. Analysis of feedback and first-hand experience showed that in the majority of cases, the loss of reduction went un-noticed until radiography. In those cases, no specific treatment was given 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 heal will ensue.

While good wiring technique will prove effective in almost every case, tension 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 wiring, the reported incidence of this complication has diminished significantly. This is due in part to the fact that the staples are simpler to use than wire, and therefore less prone to technical error, but also to the fact that materials-testing work has recently shown the 1.6mm and 2.0mm titanium staple to be substantially stiffer and stronger even than a properly placed, 1.2mm tension wire. (Orthomed, 2014. Data on file)

Infection

To date, we have neither experienced nor had reported any instance of an infected wedge needing to be removed.

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 the 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 sustaining healthy bone.

It is inevitable that an infected implant will be encountered at some stage but based on present information and experience is reasonable to assume that the risk of infection with the Orthofoam wedge is small.

Appendix 3

Having carefully reviewed the literature and theory that underpins ninety-degrees 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 at appendix 2. Extensive clinical experience with MMP has shown that selection of wedge size, and therefore amount of tibial tuberosity advancement, can be made confidently on the basis of patient size according to the guidelines written below:

Small Breed	**Gauge**
Chihuahua / Yorkshire Terrier	3mm
West Highland White Terrier / Jack Russell	5mm
Cavalier King Charles Spaniel	6mm
Small Cocker Spaniel / English Bulldog	7mm

Standard Breed	**Gauge**
Springer Spaniel / Small Border Collie / Staffordshire Bull Terrier / Weimaraner	7.5mm
Labrador / Boxer / Small Rotweiller / Standard Poodle / American Bulldog / Doberman	9mm
Malamute	10.5 - 12mm
Large Rotweiller / GSD / Newfoundland / Bull Mastiff / Dogue de Bourdeux / Giant Breeds	12mm with double staple

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.

Notes

Notes

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