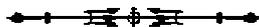




TOTAL KNEE REPLACEMENT

TECHNICAL ASPECTS - THE WHAT, HOW, & WHY
NAVIGATED AND ROBOTIC SURGERY INCLUDED



Dr Keith Holt

Knee Replacement is a demanding procedure that requires a good working knowledge of knee kinematics combined with experience. It requires prostheses that mimic normal kinematics as close as possible: but also, implantation in good alignment, with acceptable ligamentous tension and balance. This is not an easy task, as the knee is far from being just a hinge. It's motion is very 3 dimensional.

This brochure contains technical information for those that are interested. It explains in some detail how the surgery is done, what sort of replacements are available and for what purpose, and why current replacement still only has 80-85% satisfaction rates in all joint registries. It is not intended to be read as a whole. Rather, you should select the portions that you think are relevant and read those first.

Types of replacement

There are many types of knee replacement available today, with most of these resembling each other very closely. With this design coalition between manufacturers occurring, it is becoming clear that we have come close to stabilising a design, and that we are not searching for radical changes anymore. It suggests some consensus between all the companies who research and design these products. It also suggests that the product is quite good, and therefore, it is likely that future improvements will probably be small.

Total knee replacement - is the most common of the replacement operations, with partial replacements being less often used. This is not only because it is more predictable in its outcome and survival, but also because most people have wear in more than one part of the knee, and hence need more than one part of the knee replacing. In this procedure, both ends of the bone are replaced with metal, and a plastic

tray is inserted between these to keep the friction low, and to absorb impact. The kneecap (patella) may also be re-lined with a plastic (or a metal and plastic) button.

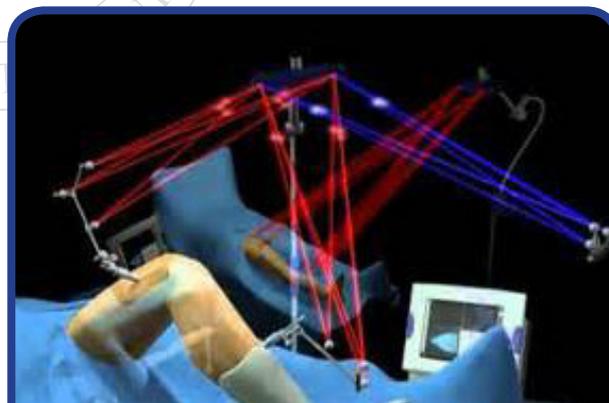
Over the years many designs have been tried. It has been found however, that the best designs, are those that recreate the normal knee most precisely. In general, the nearer the design approaches the normal knee, the better the results; both in the short and in the long term. For this reason, all the old style hinge type designs are no longer used. A replacement nowadays is really just a resurfacing of each of the bone ends. This, unfortunately, does not mean that we can entirely duplicate normal knee anatomy yet. Indeed, because of some altered ligament function that occurs during insertion of the prosthesis (the ACL or anterior cruciate ligament is lost), it is still not yet possible to totally simulate the normal joint. There are however, prosthetic designs that now come very close to this ideal.

Knee replacement - the procedure

The surgery is carried out using computer navigation to



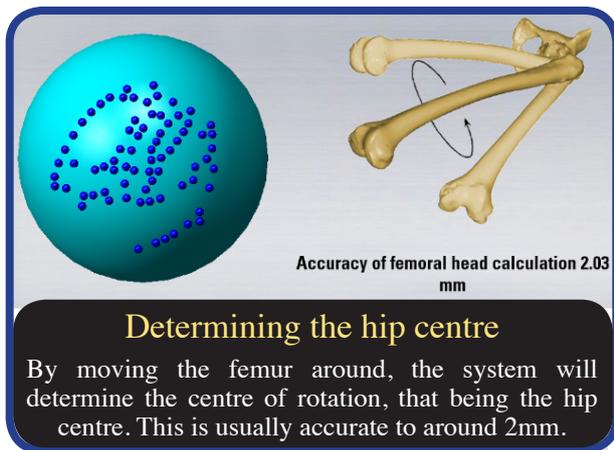
Total Knee Replacement



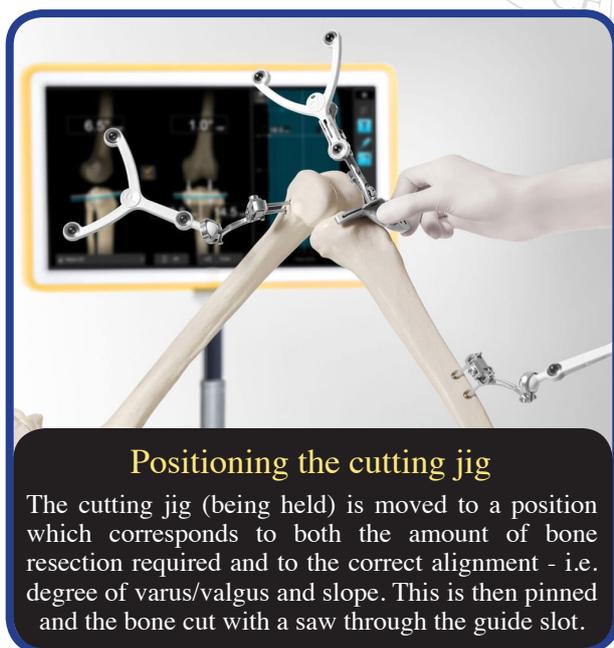
Computer Navigation at work

Note infrared beams are generated and reflected off the balls and back to the camera. This then sends information to the computer to determine both the position and the alignment of the bones.

optimize alignment correction. This involves putting 2 pins in the femur (within the incision), and 2 pins in the tibia (through separate holes). On each pair of pins is placed a tracking array which can be followed by a camera. By moving the thigh around, the centre of rotation of the hip can then be worked out, usually to within 2mm. Once this is done, the knee and ankle are plotted out with a pointing tool that also contains a tracking array. Using this information, the position of the individual bones, and the leg as a whole, can be worked out and depicted on a computer monitor, providing a 3D model of the knee, including a model of the femur and the tibia. This can then be used for the surgery.

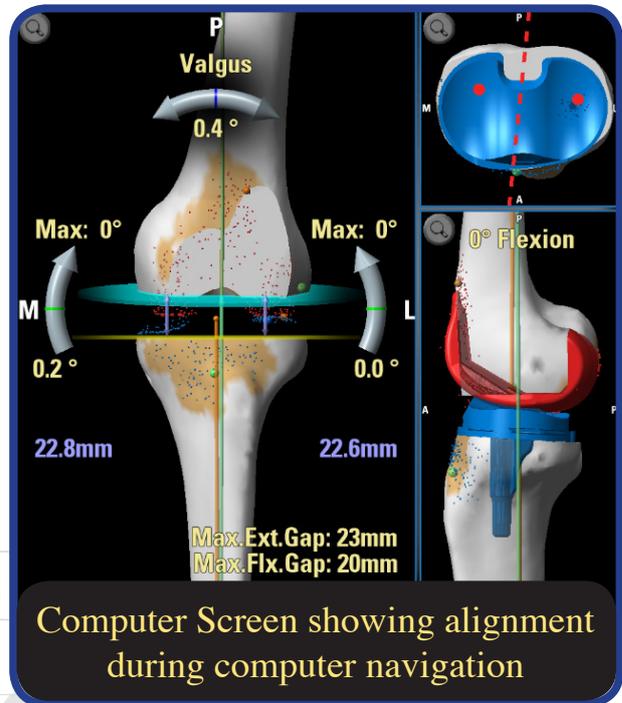


In addition to the above, the cutting guides that are used can also have arrays placed on them, thus allowing them to be tracked simultaneously with the bones. This information then allows us to move the cutting guides (seen in real time on the animation), and to accurately pin them to the bones, ready to make the cuts for the prosthesis. This process is theoretically degree and millimetre accurate, and is done by following the distances and angles that are displayed on the screen (all calculated by the computer). By doing this, the amount of bone that is to be resected, and the angle at which the cut will be made (in both planes), can be determined.

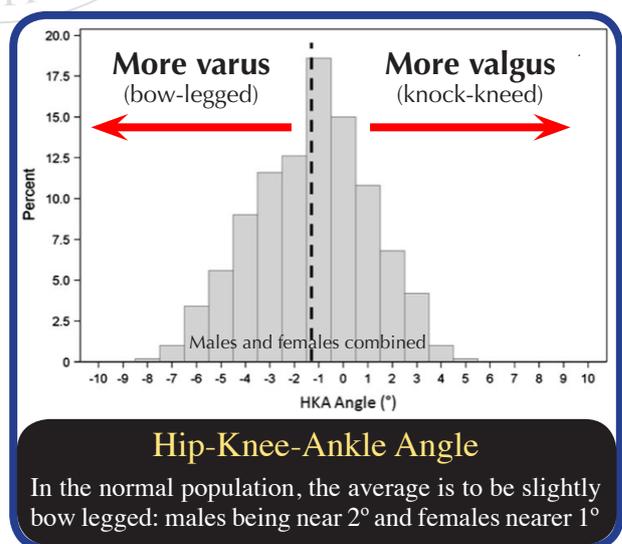


At the end of the procedure, the computer will also tell us what the final alignment of the leg will be: something that

can be adjusted during cementation of the prosthesis by varying the thickness of the cement. This then is a critical final stage, during which, we can make final adjustments to the position of the prosthesis using real time feedback from the computer. This final adjustment under computer guidance makes this an accurate procedure, providing the best possible likelihood of optimal alignment at the finish.

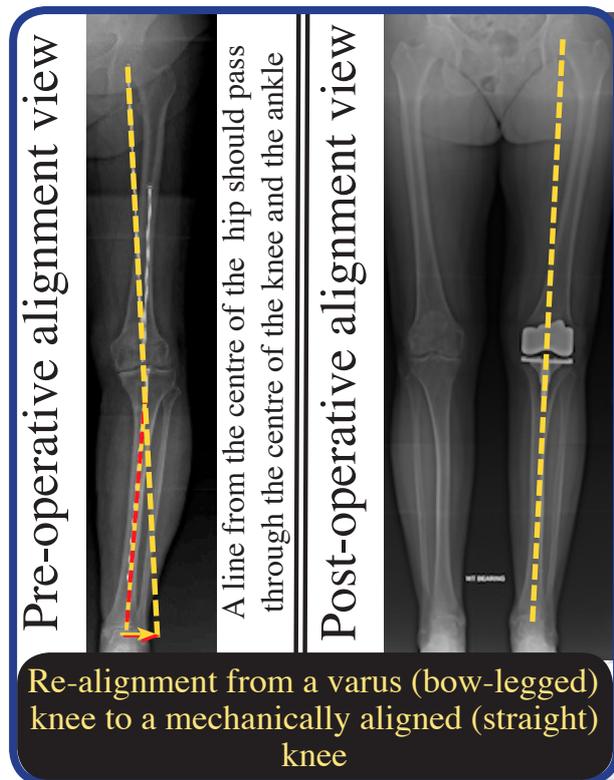


Mechanical versus Kinematic Alignment. Ideal alignment used to be thought of as a straight leg, with the tibial component being at 90° to the tibial axis, and therefore, parallel to the floor. This is known as Mechanical Alignment, and is depicted in the diagram below. The problem with this is that most people do not grow up with perfectly straight legs. Indeed, the majority are slightly varus (bow legged), but with a good number being valgus (knock kneed); and there is a whole range in between.

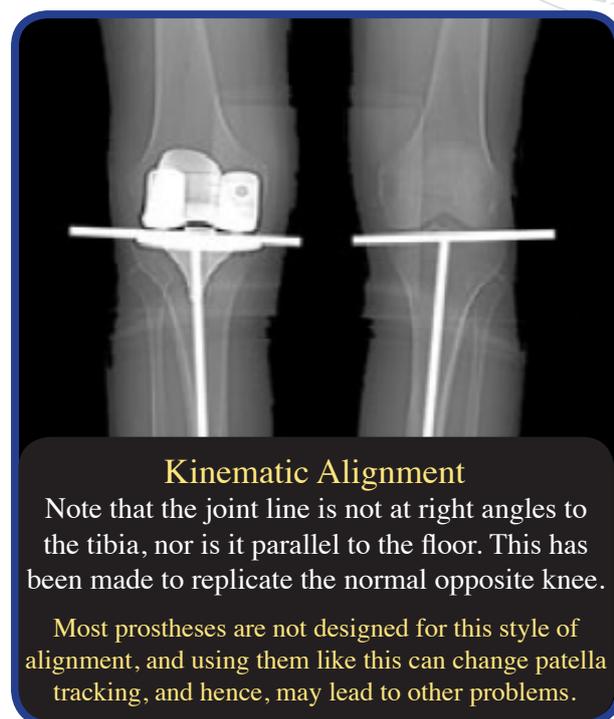


If significant mal-alignment is corrected to re-establish the mechanical axis, which is what the prostheses were originally designed for, then in some instances the ligaments on one or other side of the knee will be too tight, and may therefore require some sort of release. The problem here,

is that the leg is trying to be brought into an alignment that it has never been in: and while we know that Mechanical Alignment provides good wear characteristics, it does not always provide, either the best function, or the best pain relief.



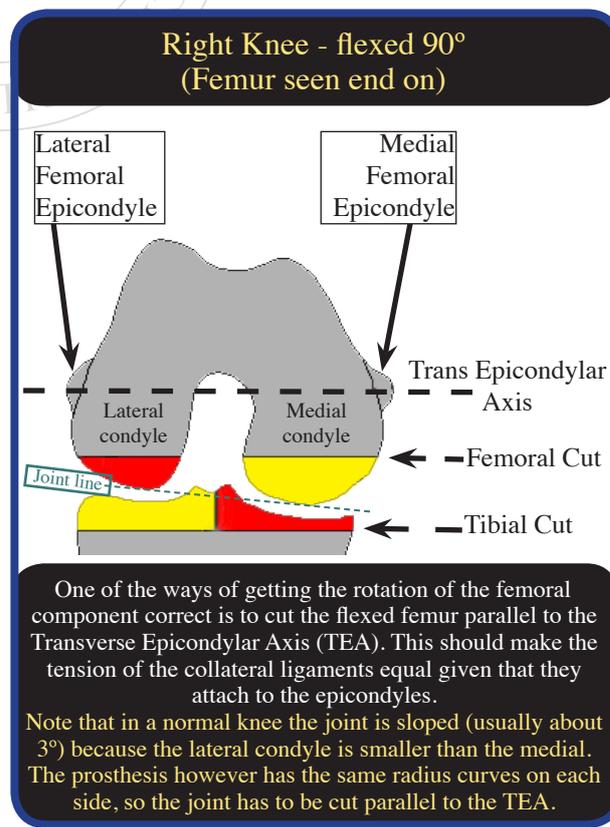
With the above in mind, and with the availability of computer technology to evaluate 3D CT scans of the knee, some people have been trying to work out where the axes of rotation of an individual's knee is, thereby leading to computer derived cutting jigs to insert the prosthesis more anatomically. That is, to try and reproduce the leg alignment that existed prior to the arthritis, and before any subsequent deformity, set in. This is called Kinematic Alignment.

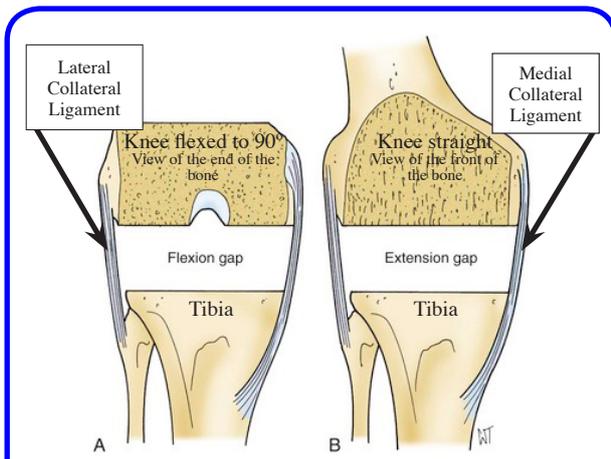


The results of kinematically aligned knees have been mostly good, albeit in many cases excellent; but it has also produced some significant outliers: patients with knees that end up well outside the 0° - 3° varus range that is thought to provide the best compromise between function and cosmesis, with optimal wear characteristics. Accordingly, current thought is that the knee should be somewhere within that range if possible, yet still trying to make the knee well balanced, with minimal releasing of any ligamentous structures being undertaken. Clearly however, there are legs where the deformity is so great that some releases will need to be performed to get them close to the ideal range, and not every knee will be able to be corrected into that range. Where this occurs, a best compromise may be taken whereby, the problems of releases are balanced against what is sometimes a slightly sub-optimal cosmetic result.

Achieving balance. The above talks about correcting the leg alignment to provide optimal varus or valgus for function and optimal wear characteristics: that is a measurement of the knee alignment when it is straight. What it does not discuss, is the ligament tension balance through the flexion range. This is determined by the rotation of the femoral component on the femur, something that is achieved by attempting to make the surface of the prosthesis parallel to the hinge line of the collateral ligaments. Mostly this is still done by using the points of attachment of the ligaments to the femur, the so-called femoral epicondylar axis. Hence, it is like getting a swing to be parallel to the ground by making the ropes on each side the same length. The problem however, is that the points of attachment and the relative lengths of the ligaments can sometimes be difficult to determine.

The skill of replacement is to insert the prosthesis such that it has the right tension (not too loose and not too tight), both with the knee in full extension (straight), and throughout the flexion range - yet within an acceptable alignment range [not too varus (bow legged), and preferably not valgus (knock knee)].





A - shows the knee flexed to 90° after cuts have been made as per the diagram on previous page
 B - shows the cuts with the knee straight
 If the knee is balanced the gap should be the same throughout the 0° - 90° range of motion.

The latest generation computer navigation systems can define what is known as the 'knee envelope'. That is, the range of alignments and balances that the knee can be put through without lengthening or releasing any of the collateral ligamentous structures. This can now be done through a nearly full range of knee motion; for the first time determining balance, not only in extension (the knee straight), but also in flexion (the knee bent).

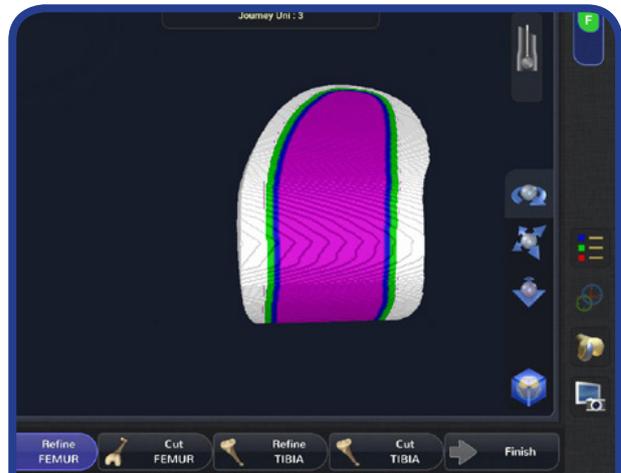
Theoretically, this should allow perfect placement of the prosthesis in accordance with a plan based on that information. The problem however, is that that decision is made on that plan and can only be adjusted after the bone has been cut and trialling of the prosthesis had occurred. Generally however, this works quite well and it seems to be quite accurate. The limiting factor however, is the femoral rotation which is often taken off the trans epicondylar axis (TEA). The epicondyles are often hard to accurately locate, and in addition, they do not always represent the isometric point of the collateral ligaments. To better delineate this, and to plan the alignment and balance before the cuts are actually made requires the next level of alignment system and on screen modeling. This is the world of robotically assisted surgery.

Robotic Knee Surgery

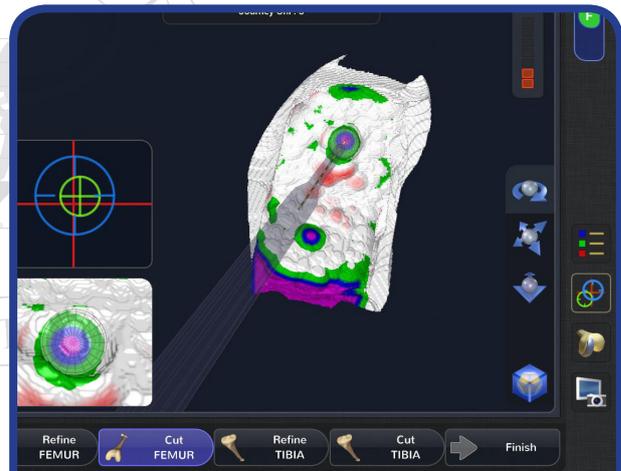
Robotic surgery is now starting to be available. What this offers is a more sophisticated navigation system to plan the placement of the prostheses and to balance the ligaments. The robots themselves (at least the ones currently licensed for use in Australia) do not actually do any of the cutting of the bone, hence perhaps, it is a bit of a misnomer to call the process 'Robotic Surgery'. Nevertheless, they do incorporate safeguards so that they prevent operation outside the designated limits of the surgery area.

For partial knee, or patello-femoral joint replacement, these being the operations where it is hardest to get the component positioning right (and more so than in total knee replacement), robotically navigated surgery can be helpful to accurately define the area that needs to be burred out for the implant. It does this by modeling the knee on the computer based on data that is input at the time of surgery. As it also knows where the tip of the burr is, the system

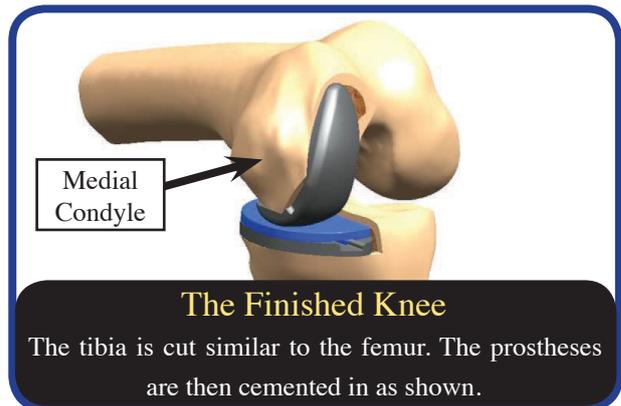
can allow the surgery to be performed on screen, where it demarcates the area to be burred by colouring it in. The coloured area is actually layers of colour, each colour representing a 1mm thick layer. Essentially, each colour is then successively removed until the underlying white, representing the bottom of the resection area, is exposed.



The medial condyle ready for surgery to begin for a partial replacement
 The burr is used to remove all the coloured layers. Each layer represents 1mm of thickness.



The medial condyle - burring nearly finished
 Once all the coloured area has been removed, the two pilot holes for the prosthetic stems are made.



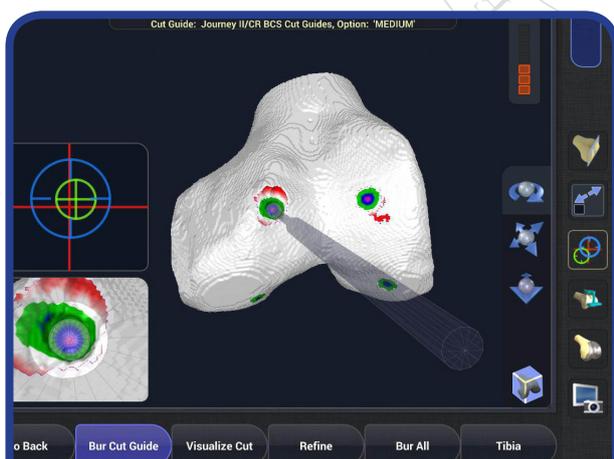
The Finished Knee
 The tibia is cut similar to the femur. The prostheses are then cemented in as shown.

In addition to defining the area to be burred, the computer can actually restrict what bone is removed. It does this by turning off, or retracting, the burr when it is outside the coloured area. As such, it prevents excessive removal of bone, leaving a well defined area on which to sit and cement the prosthesis.



The Navio burr is controlled by the computer using the navigation array that is attached to it. The burr will retract into its sheath, or will stop rotating, if it is used outside the planned area.

For total knee replacement, whilst this can be done in a similar manner, it is too slow to be useful in that format. The volume of bone to be removed is too much for a burr to do alone, and thus it would take too long to make this a viable method of bony resection. For a total knee replacement therefore, the plan is different. Here, the aim is to use standard type cutting blocks that will allow the use of a saw; this being much faster and almost as accurate as using a burr throughout. The upgraded navigation system that comes with the robot allows the positioning of some tapered holes, which then accept the blocks similar to those shown below. Once in place, the position is checked with the system, fine adjustments are made (to within 1mm and 1° of angulation), and further pins are inserted to definitively fix the block ready for the bone cuts to be made. The femur is cut first, and then the tibia.



Creating the tapered holes for the cutting block
There are two at the top of the bone and two at the end. These are defined and then burred out.

The reason to consider using the robotic system is not just to determine the position of the components on each bone (something that can be done well with standard computer navigation that we have been using for nearly 10 years) but



The cutting block locks into the holes
The block position is then finely adjusted using the navigation tools, and then pinned into place ready for the saw to be used.

to try and define the balance of the components on each other throughout the range of motion. Essentially, the aim is to have ligamentous tension that is roughly equal throughout the range of motion, being neither too tight, nor too loose, at any one point of the flexion arc. So what the system does is to define what is referred to as the ligamentous envelope of the knee. By taking the knee through a range of motion when stressed into valgus (knock knee angulation with the medial collateral ligament tightly resisting) and then in varus (bow legged angulation with the lateral collateral ligament tightly resisting) the natural tension of each ligament can be determined for all angles of motion from full extension to over 100° of flexion.



Defining the Knee Envelope
The knee is taken through a range of motion stressing it into both varus and valgus. This creates an envelope of laxity of the collateral ligaments. Orange is varus (MCL) and purple is valgus (LCL). What is created is a view of the knee throughout the motion range. This then allows us to plan what alignment might work without making those ligaments too tight or too loose.

Once the envelope has been established, the computer can overlay the prosthesis with best size and fit algorithms, and then display them on screen as it expects the knee to look

after completion. Each individual prosthetic component is then manipulated on the model, altering the size of components, angles of bone cuts, position of bone cuts, and whatever else seems necessary, until an acceptable balance is achieved throughout the range of motion.

Place Femur Implant

Component Varus 3°
Component Flexion 3°
Internal Rotation 1°

SmithNephew Journey II CR
Femur Size SIZE 4

View Mode
Solid Surface
Cross Section

Collect Tibia Free Points Place Tibia Implant

Adjusting the component position

This picture shows the femoral component position in relation to the mapped out surfaces of the original bone (yellow areas). It shows alignment, rotation and so on. The prosthesis can be moved in every direction to improve the position by using the controls (+/->..). The tibial component is then adjusted the same way.

it was before the arthritis set in. For most people this is a reasonable position, and the average knee angle for normal knees is 1-2° varus. That is, slightly bow legged. There is however quite a range of 'normal' and there are concerns with leaving the alignment out side a certain range - the so called 'Outliers' that we have tried to avoid producing over the last few decades.

From most surgeons perspective, excessive valgus (knock knee deformity) is seen as cosmetically unacceptable: and also, it can lead to a compromised gate because the knees can rub against each other during walking. Excessive varus (bow legged deformity) on the other hand is less noticeable: but, if it exceeds 3° or 4°, it may lead to premature prosthetic wear because it over stresses the medial (inside) half of the tibial polyethylene tray.

When adjusting the position of the prostheses on the model therefore, it is not just as simple as balancing the gaps throughout the flexion range. One also has to take into account the overall leg alignment to try and keep the majority of knees within an optimal range of say 0° - 3° varus. Because there is some laxity in the ligaments, and because a millimeter or two gap is normal, there is some room for this adjustment. Hence, for example, if the knee has a range of laxity encompassing 2° varus to 7° varus when the knee is in near full extension (fully straight) before surgery, then the ideal final alignment to be aimed for may be in the range of 2° and 3° varus. On the other hand, if the knee cannot be brought into the acceptable range, being out by a degree or more, then some sort of ligamentous release may have to be done to achieve that final aim. Where possible however, current thinking is that we should consider less releases than previously, even if they are only partial releases: and this is achievable because we no longer go for a mechanical alignment of 0° varus / valgus with every knee.

Gap Planning

Component Varus 3°
Internal Rotation 4°
Component Varus 1°
Internal Rotation 12°

SmithNephew Journey II BCS
Femur Size SIZE 4
Tibia Size SIZE 4
Thickness 9 mm

Preoperative 1° Varus Postoperative 1° Varus

Place Tibia Implant Place Femoral Cut Guide

Adjusting the component position

The graph at the bottom of the picture shows the gaps on each side of the knee for each degree of motion. With this information, final changes can be made to component positioning to ensure that the knee goes through to full extension and that it is neither too tight nor too loose at any point in the range.

Postop Stressed Gap Assessment

Manufacturer/Design SmithNephew / Journey II BCS
Femur Implant Size SIZE 4
Tibia Implant Size/Thickness SIZE 4 / 9 mm
Preoperative Alignment 7° Varus
Planned Alignment 8° Varus

Flexion 43°
Internal Rotation 2°
Valgus 1°

Reset Collect ROM (HOLD)

The final Assessment

The graphs here represent the end result of a knee plan. What it shows is the gaps on each side of the knee during a range of motion from 0° through to about 120°. You will see here that the final alignment suggested to achieve those gaps is 8° varus (that is: quite bowed). Some may accept that as being just kinematic alignment, but it probably means that the Medial Collateral Ligament is too tight, so a release should probably be made to get the knee into a less varus position (say 2-3°).

If the above procedure is carried out as is, then what you end up with is kinematic alignment. That is to say that; the knee ends up being balanced, but no specific account of overall alignment (varus or valgus) is taken. Essentially, this methodology just restores the knee alignment back to where

Why should you consider robotically aided surgery?

The overall satisfaction rate for total knee replacement, in almost every registry in the world, is only about 80-85% good to excellent. The remainder are less happy with their new knee, and often for reasons that are hard to define. The advent of computer navigation to improve alignment was thought to be the harbinger of better results, but that did not happen. Results in the Australian joint registry are showing some early benefits of this, but the improvement is small.

Changing away from mechanical alignment to more natural alignment (like a modified kinematic alignment as discussed above), is thought to be bringing better results, but it is still too early to know that. To now move to a system of not only modified kinetic alignment, but also to one that incorporates ligament tension balance throughout the range of motion, is logical, but the evidence for it will be some years away; and perhaps 10 - 20 years away. Nevertheless, we think that the slightly increased accuracy over standard computer navigation, plus the ability to better plan component position before the bones are cut, will lead to better results. If so, then the additional cost of these techniques may become justified. Certainly, as Robotic systems become more user friendly, more helpful, and cheaper, we expect them to become the instrument of choice for this sort of procedure.



The 'Navio' Orthopaedic Robot

This one, designed by Blue Belt Technologies, and now owned by Smith & Nephew, comes with the upgraded Navio computer alignment system. This is optimised for implantation of S & N prostheses.

More advanced robotic systems are already on trial. Some of these have the robot doing all the cutting of the bone based on a plan designed along the same lines as the current systems with the surgeon making the plan before any cuts are made. There are various reasons why this sort of system will be not only more accurate (it doesn't need to use cutting blocks for one thing), but also quicker. It is likely therefore that these systems will eventually become used, albeit that they will require legislative change to allow this. For now, all such machines require the surgeon to be in control throughout the procedure. In time however, as the machines get better, it is likely that they will be approved to actually do the bone cuts based on the surgically approved plan. This means that the knee will be exposed, the bone ends mapped out for the navigation system to recognise, and then the robot will make all the cuts. Components will then be placed in the knee by the surgeon and the alignment and balance checked to see if it matches that plan. Any adjustments required can then be made.

Further into the near future we think that navigation systems will not require pins being put into the bones to hold the navigation arrays. Indeed, there are systems under development which have implantable devices that are very small but very accurate. These merely need to be placed into the bone and can stay there to provide information on wear and other parameters for the life of the prosthesis. Also, instead of hand mapping the ends of the bone to register that information onto the computer, there are cameras and laser devices which will do all this for us in seconds rather than minutes, and will be more accurate. Over the next 5 years therefore, we expect that there will be quite a lot of changes which will make this sort of procedure more accurate and quicker, and hopefully this will lead to better satisfaction rates in the registries.

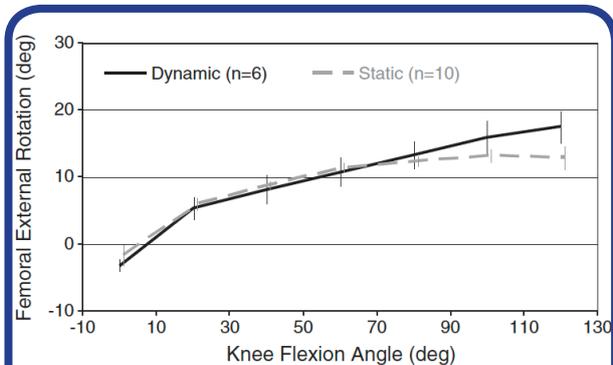


Robots with surgical arms

This robot is part of the newer series of robots in development. These have arms that can not only be controlled, but can actually carry out the surgery based on the same navigation systems that are described above. It is likely that these will be approved for use in the not too distant future.

The patello-femoral joint has not yet been mentioned, but is a major cause of problems following total knee replacement. Indeed, it may actually be the largest cause of problems following this sort of surgery. The reason for this is that the current replacement types that are available in this country do not actually work like a normal knee. The ones that are available mostly work more like a hinge than a normal knee, and the difference is important.

In the normal knee, the femur rotates externally (turns outwards) about 15° as it bends.

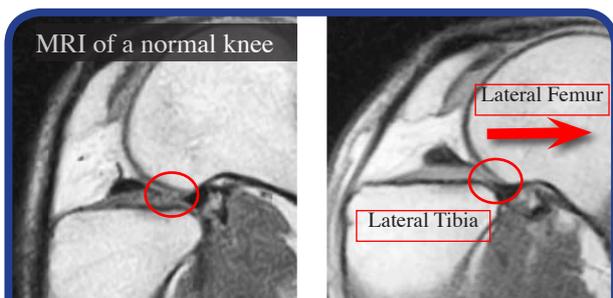


Femoral external rotation with flexion

This shows that as the knee is flexed (bent), the femur rotates about 15° with respect to the tibia. Some of this actually occurs in the tibia because the act of pushing the foot up (dorsi-flexion) causes this bone to internally rotate. The cause of this effect is the crooked hinge phenomenon made by the sub-talar joint (the joint just below the ankle joint).

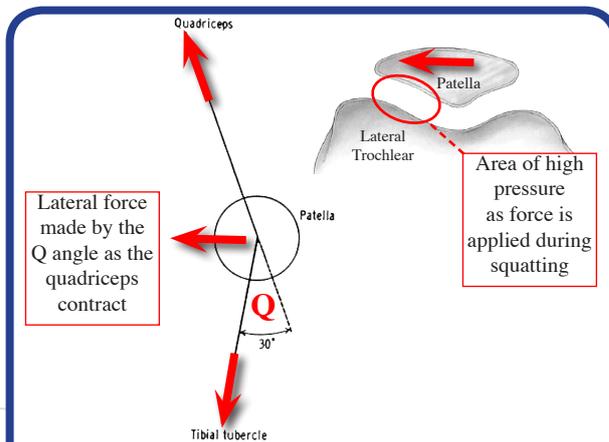
For this to occur in a knee replacement requires a number of changes to prosthetic design which may include:

1. The femoral condyle on the lateral side has to be smaller than the medial - with a slightly smaller radius of curvature
2. As a consequence the lateral joint line will be 3mm above that on the medial side (i.e. sloped)
3. The backward slope of the lateral joint line will be more than the medial
4. The lateral tibial surface will be flat or convex and not concave so that as the knee bends, the lateral condyle will slide posteriorly down the slope. Because of that slope the lateral ligament becomes looser as the lateral condyle moves posteriorly and, in turn, it is that looseness that allows it to move more posteriorly.



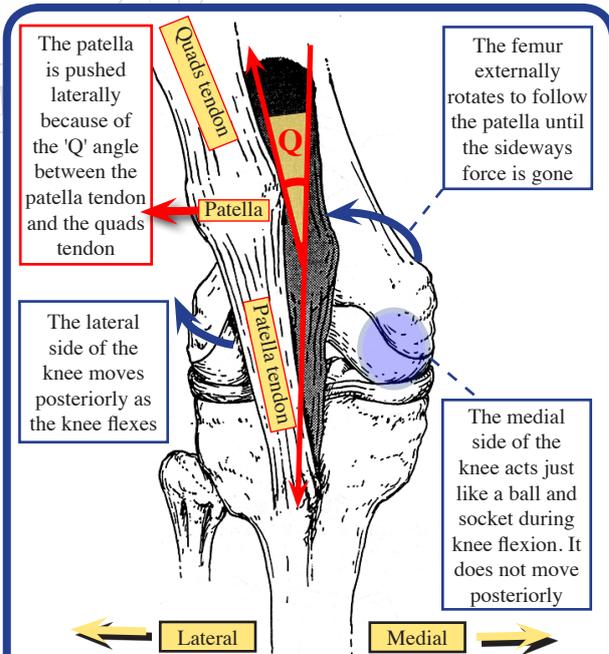
With flexion, the lateral condyle moves right off the back of the tibia

The driving force for this is the pressure under the lateral patella which pushes the lateral side of the femur into external rotation. This is aided by what is called the 'Q' angle, which describes the extensor mechanism (patella tendon, patella, and quadriceps tendon) as going round a corner at the patella. The patella tendon comes up from the tibia to reach the patella. The patella is held in a groove on the femur (the trochlear) and the quadriceps tendon angles outwards towards the hip area. As the quadriceps applies force to the tibia via the extensor mechanism, that angle pushes on the lateral trochlear to force it into external rotation.



The 'Q' angle

This is the angle that the quadriceps force pulls on the patella subtended on the patella tendon below. It causes a laterally directed force that pushes the patella sideways and loads up the lateral patella groove (trochlear) on the femur. This in turn causes the femur to externally rotate as the knee bends and the force increases.

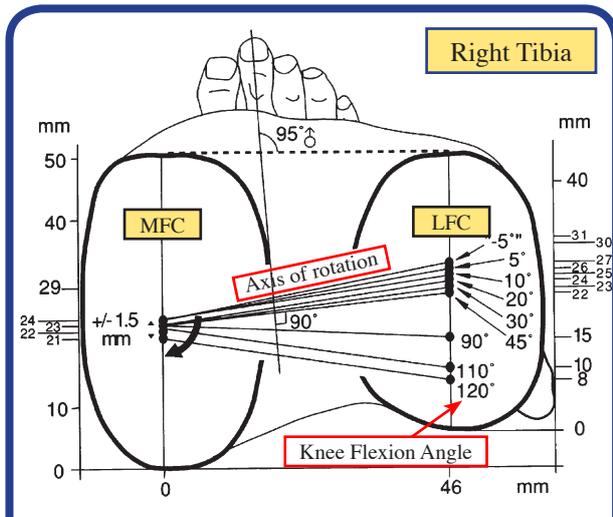


The 'Q' angle and Knee Flexion

The quadriceps force exerted during knee flexion pushes the patella laterally because of the 'Q' angle. This forces the femur to externally rotate until the angle is 0° and the lateral force is neutralised.

As a consequence, the femur rotates taking the patella with it. Hence, by about 20° of flexion, the 'Q' angle becomes neutralised such that it no longer acts to provide and external rotation force

The importance of all this is that, as the knee bends, the patella becomes much more in line with the trochlear groove and hence is not pushing it sideways. This then decreases any shearing force on the patella itself as the knee bends: and given that squatting can invoke a force of about 7 - 8 times body weight (say 500kg in a 70kg man), a force that progressively increases from standing through to full flexion, it is important to remove the associated shear force from early on in the flexion manoeuvre.

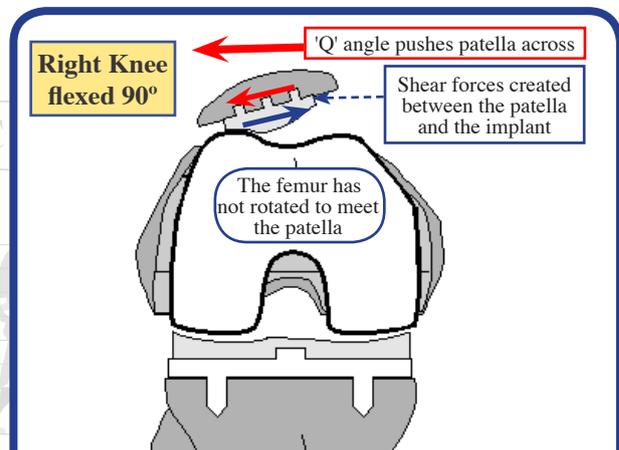


Looking down on the top of the tibia

This diagram shows how each of the femoral condyles move during flexion. Note that the Medial Femoral Condyle (MFC) just pivots around a fixed point like a ball and socket whereas the Lateral Femoral Condyle (LFC) moves posteriorly. By plotting those points, the axis of rotation is marked out and this can be seen gradually externally rotating with flexion, thus neutralising the 'Q' angle - and hence decreasing shear forces on the patella.

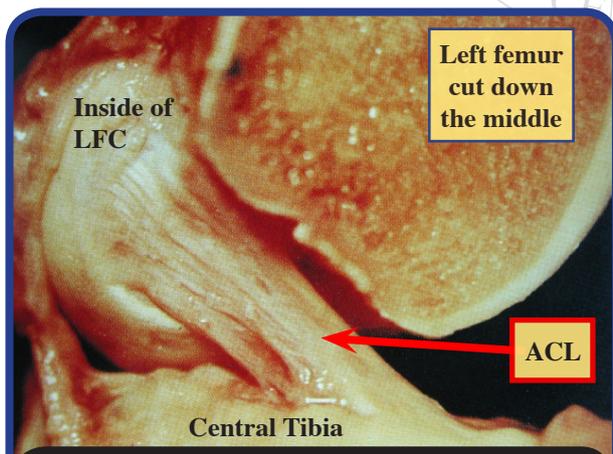
If the above could be achieved in a knee replacement design, then some feel that this would eliminate, or at least greatly reduce, the patella problems that we still see. Hence, when associated with modern robotic techniques, such a prosthetic change may further reduce the dissatisfaction rate that we currently see. Of course this remains to be proven, but bi-cruciate stabilised knees, those with both ACL and PCL function, do exist (The Journey 11 BCS Knee); and the number that have been implanted are now quite high. Although not available in this country due to regulation issues, we are starting to see encouraging data from other international centres. Further information on this, and other prosthetic types, is described below.

5. For this much freedom of movement of the lateral femoral condyle on the lateral tibia, there must be ACL function (as well as PCL function) to provide control to this so that the knee is not unstable in rotation. The ACL here prevents the femur from just sliding off the lateral tibia as it rotates out. It also rotates the femur back to its internally rotated position as it extends.



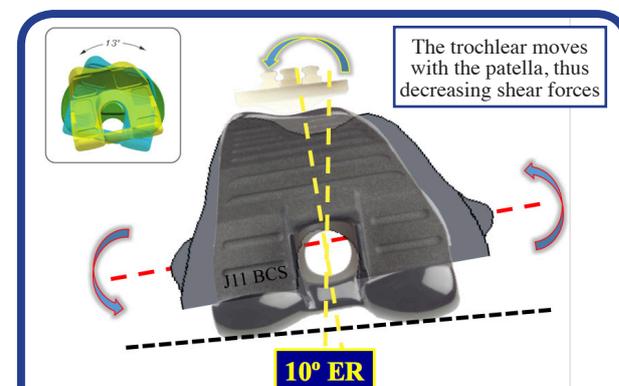
A standard Knee Replacement

Up until recently, all knee replacements acted like a hinge, not rotating as the knee goes into flexion. To cope with this, the trochlear groove is often made crooked, an improvement on the older designs. This however, is not the same as the normal knee where the femur (and trochlear) rotate to keep in line with the patella: thus decreasing shear forces.



The Anterior Cruciate Ligament

This goes from the central tibia to attach to the inside of the lateral femoral condyle. It thus prevents the condyle slipping right off the back of the lateral tibial plateau during flexion, and pulls it back as the knee is straightened again.



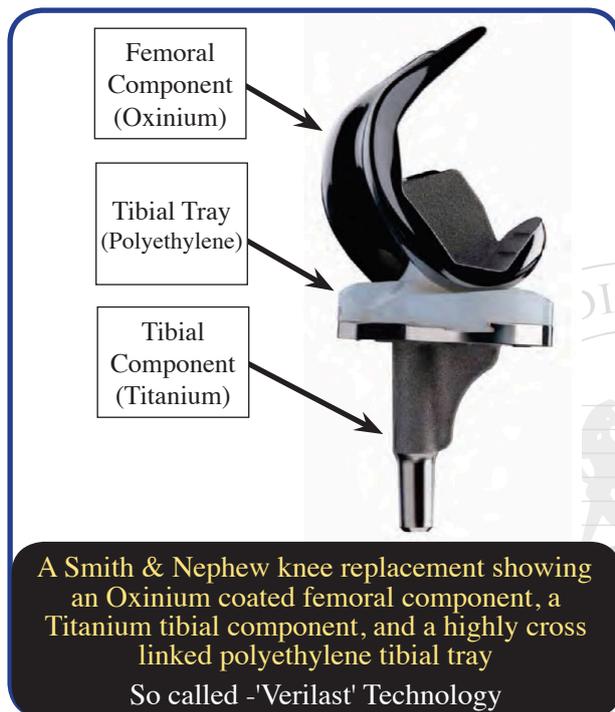
The Journey 11 BCS Knee in flexion

Bi-cruciate function lets this knee function more like the normal one and hence it rotates in flexion.

Technical Issues

The prosthesis is sized during the procedure. Each component comes in multiple sizes, all of which are available for every case. On the femoral side, there are also available, both a standard width and a narrow width component for any given size. These have been available for a few years now, recognising that most females have a narrower knee for the same depth than males. Indeed, over 90% of females will end up best suited to a narrow component.

In addition to variations on the femoral and tibial component sizes, the polyethylene tibial tray which locks into the tibial component, comes in multiple thicknesses for any given size; there being a range from 9mm through to 25mm. This then allows a good deal of adjustment for any bone loss which might otherwise leave a large gap to be filled between the cut bone ends.



The longevity of a knee replacement is probably the best of any joint that can be replaced. For most available prostheses a 90% - 95% survivorship at 15 years is expected (as the results from the Australian Joint Registry show). This means that most replacements will be functioning well at 15 years, and that some will go to 25 years or more before requiring revision. As expected, the analysis of results show that the heavier more active patients will wear out their knees earlier: and hence, the older, lighter and more sedentary patients are more likely to be in the 90% group that will go past 15 - 20 years.

Some of the current models, such as the one Dr Holt uses by preference (the Smith & Nephew Legion component with Verilast technology), are now tested to out past 30 years in the laboratory, but only time will tell if these newer knees will really last that long. The (theoretical) 50% improvement in longevity over the prostheses that were implanted 20 years ago is due to 2 factors.

1. The femoral component has been made smoother. Instead of the more traditional polished chrome cobalt prosthesis (medical grade stainless steel if you like), it is now available with a ceramic surface. This is achieved

by using zirconium as the base metal and subjecting the bearing surface to a plasma spray that oxidizes the surface to Zirconium Oxide (patented as Oxinium). This is not only significantly smoother than the metal surfaces, it is also very much harder and less easily scratched. Fortunately, this type of prosthetic construction does not contain nickel, that being the metal that most people react to. It also does not contain either cobalt or chrome.

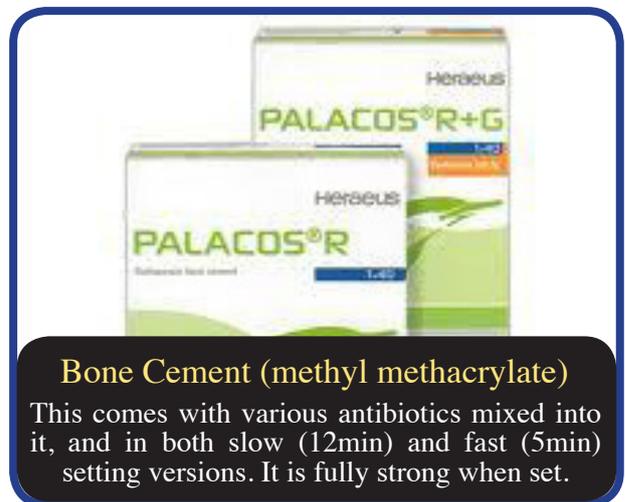
2. The polyethylene tibial tray is harder and less subject to wear. This has been achieved by 'highly cross linking' the polyethylene molecules. The polyethylene is composed of very long monomers (single molecular chains) that are fused together to create a polymer. Those molecules then line up with the direction of stress in the component which, because the knee moves hinge like in line with the direction of walking, means that they line up with the direction of motion (i.e. front to back). By doing this, it allows some splitting of the molecules under extreme loads. By fusing these together, side to side, the plastic is made stronger. In addition it is made harder which, if done cautiously, does not harm its intrinsic strength. If made too hard however, it may become brittle, so the radiation dose used for this process has to be very carefully measured.

Compared to a Chrome Cobalt Femoral component, the Oxinium coated component has been shown to be twice as hard and 49 times more abrasion resistant. This latter may be important if there are any minor (sometimes microscopic) bone or cement fragments remaining in the knee; something that may be reasonably common given how hard it is to wash out and remove all of these tiny fragments.

The figures of the Australian Joint Registry now go back over 15 years, so most of the information will pertain only to Chrome Cobalt technology. To date, no specific differences between this and Oxinium have shown up, but over the next 20 years, based on laboratory testing, it is anticipated that this will change. Unfortunately however, only time will tell.

Cement or no cement?

Traditionally joint replacements have been cemented into the bone. Theoretically this would seem to be a good idea. It means that the prosthesis is solidly glued into the bone at the outset, and that recovery should therefore be fairly quick. In addition, the cement seals the ends of the bone which cuts down the bleeding. Hence, there is less bruising and swelling after surgery, so motion should return more quickly.



The problem with this approach is that bone is living and, unlike wood, bone is constantly being removed and replaced. Whether, during this cycle of constant rejuvenation, it grows back as strong as it was depends on a number of factors, including local forces through the bone.

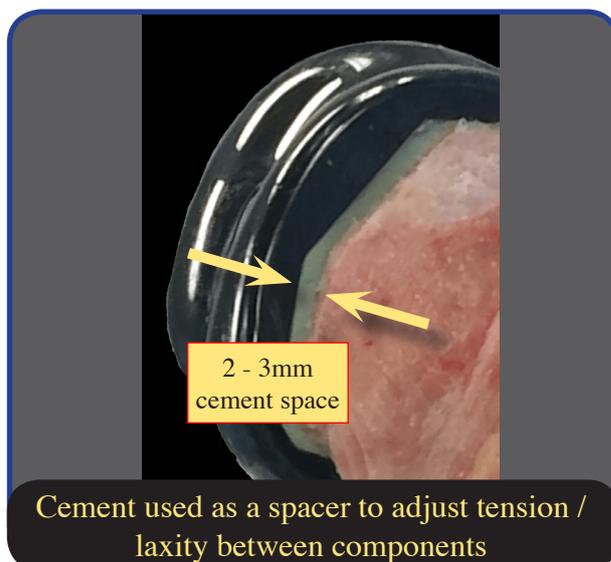
On the tibial side it is usual for a rigid base plate to be used, this being a tray for the polyethylene bearing surface. Independent of how accurate the bone cuts are and how good the cementation is, the tray will always sit on some slightly high points putting extra pressure on those areas and hence lowering pressure on other areas. This leads to high stress areas where the bone builds up to support the tray and low stress areas where the bone may just be resorbed (osteolysis). Generally, these variations of bone strength, whilst often seen on x-ray, are not a great clinical problem. Sometimes however, in high demand patients, the high stress areas can develop stress fractures and stress reactions which can be painful. The opposite effect, where bone that is shielded from stress and gets resorbed, can lead to prosthetic loosening: though this is unusual with today's prostheses.

For the above reasons, engineers continue in their quest for a reliable, cement free joint replacement. In most cases, this involves having a special porous surface on the back of the metal prosthesis which allows the bone to grow into it. If this occurs, then the stresses that go through the joint should be much more like normal, and hence, bone should theoretically build up evenly under the tibial plate, thus becoming stronger with time.

Many such surfaces have been developed, and all seem to work to a variable degree. Unfortunately however, the best ingrowth surface (tantalum) does not come with an Oxinium femoral component. This makes choosing a prosthetic knee like choosing a car: one model might look best, another may last longest, another may have the best engine, and yet another may be the nicest to drive, etc. In other words - you can't have it all in one package. Hence, this means choosing a prosthesis on the values that seem to be most important at the time. There is no one best prosthesis, just better performing ones in the Australian Joint Registry, and better performance outcomes (which are not documented in the Registry - outcome measures are not part of the data collection).

Dr Holt currently cements all his prostheses in, having had some past failures from uncemented versions of his preferred prosthesis. Different prostheses however, have different mechanics, and different ingrowth surfaces, and hence, some are more suited to being used in their uncemented versions. Accepting all this variation, the literature is still unclear as to whether the long term outlook for a cemented joint is any different from an uncemented one. At this stage therefore, the choice remains the surgeons preference, depending on his experience with the prosthesis he uses.

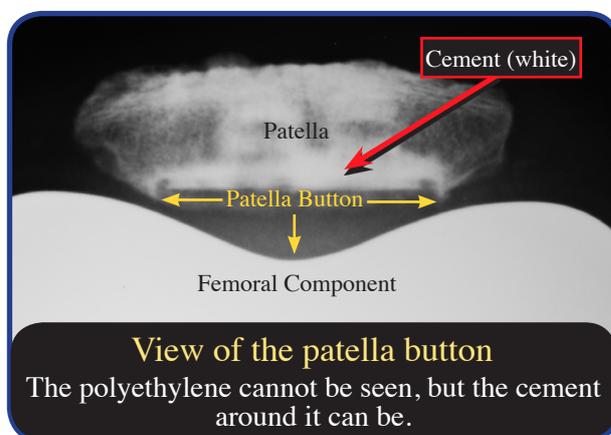
Finally, but importantly, and independent of its use to fix the prosthesis to the bone, the cement can be used in varying thicknesses to adjust the final tightness of the joint. Too tight can make it sore, too loose can make it unstable. With increasing emphasis on this balance, this seems to be one of the best ways of providing a knee with optimised balance throughout the range of motion. Again, it is one reason why Dr Holt prefers cement, given how accurate navigation systems are. This allows alignment and tension to be finely adjusted in accordance with current best practice.



Patella or no patella?

Resurfacing of the patella (kneecap) with a polyethylene button is one of the most controversial areas in knee replacement surgery. Most studies in the literature show that, at least in the first 5 years or so, there is no difference in the results whether the patella is replaced or not. In the last few years however, longer term results are starting to show that patella replacement may be advantageous. Kneecap pain is a not infrequent problem after replacement, whether or not it has been resurfaced. The incidence of this problem may be up to 25% in some designs when un-resurfaced, but in no designs is it completely avoided, even with a polyethylene button on the bearing surface.

Most big surveys of knee replacements are now showing that the ability to be able to climb and descend stairs is enhanced by having the patella resurfaced. Given the low complication rate of patella replacement therefore, it would seem reasonable to carry this out at the time of the initial procedure. Certainly the advantages of this versus leaving the patella alone, are now becoming more compelling. For this reason, Dr Holt resurfaces every patella with a polyethylene bearing surface (button). This then avoids the problem of having to comeback and resurface it later if there is on-going patella pain. It does not however, guarantee that there will be no patella pain.



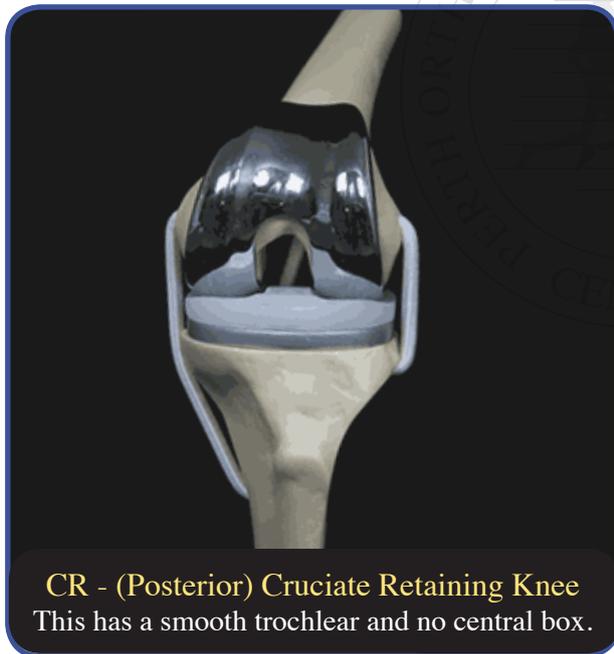
TYPES OF KNEE REPLACEMENT

CR, PS, BCS, CP, Constrained, Medial Pivot, Mobile Bearing, or Hinge?

The prostheses come in different types which are used based on surgeon preference, and the requirements of the knee concerned. Essentially there are 7 main varieties which are made, of which, 5 are currently available in Australia. In all of these, except the CP (Cruciate Preserving), the ACL (Anterior Cruciate Ligament) is removed. Whilst in a normal knee this would cause instability, in a knee replacement, the intrinsic design is such that this does not occur. The prosthesis itself is stable and therefore does not require an ACL.

1. **CR - Cruciate retaining** knees, being updated versions of the original design of almost all modern day prostheses, still remain popular worldwide. They are called Cruciate Retaining because they preserve the PCL (Posterior Cruciate Ligament) not the ACL. The advantage of these is that they have the best longevity: at least as documented in the Australian Joint Registry reviewing knee designs that were implanted 20 years ago.

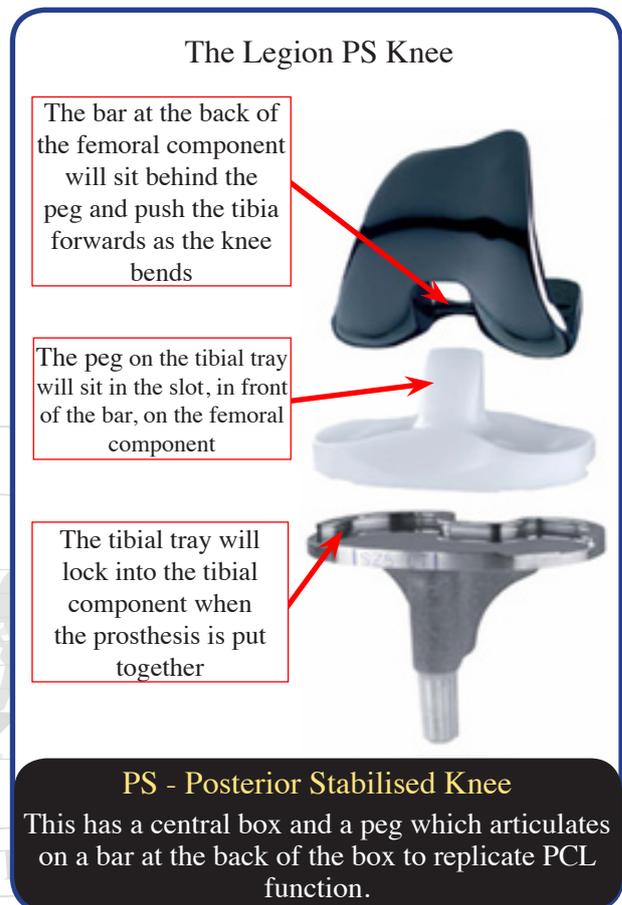
The downside is that the PCL can be hard to preserve such that it remains fully functional and, in a good many of these knees, the PCL is at least partly damaged and loses at least some of its function. This occurs because, the portion of the tibia that is removed to allow insertion of the tibial component, also contains some of the footprint of the PCL.



Loss of PCL function causes the tibia to have increased laxity, allowing it to move back and forth on the femur during motion. This forwards and backwards motion, whilst usually not noticed can, if significant, be enough to cause some instability; albeit that this may actually give rise to a feeling of pain rather than a feeling of looseness or giving way.

2. **PS - Posterior Stabilised** knees, such as the 'Legion PS', are a later development of the CR knee. In this version, the PCL is removed along with the ACL. The PCL is then

substituted for, thereby replacing the function of the PCL. This is done by having a peg in the middle of the tibial tray which sits in front of a bar on the femoral component, thus stopping the tibia from sagging backwards. The advantage of this is that full PCL function is guaranteed, thus preventing so called 'flexion instability' (instability or looseness of the knee when it is at about 45° of flexion). This, in turn, also decreases the force on the patella during bent knee activities: something that may be important given that the commonest site of residual pain in a replaced knee is the patello-femoral joint.



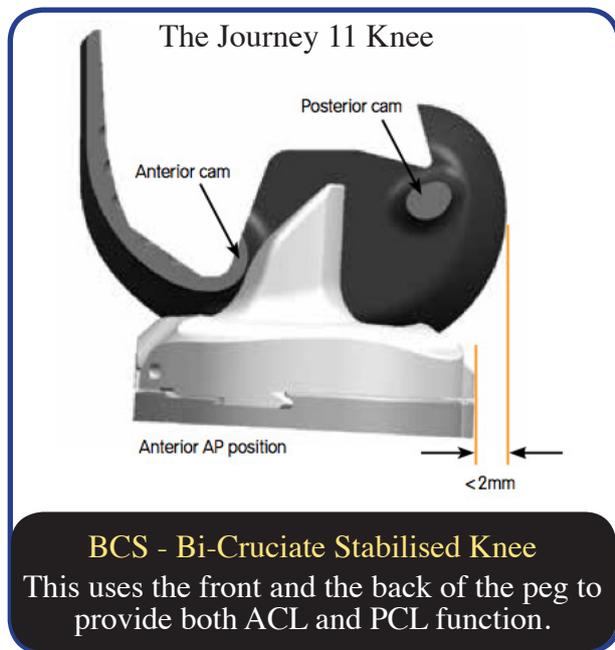
One of the downsides of the PS knee has been premature wear of the peg. Early designs caused excessive pressure on the peg, and hence, earlier than expected failure. More modern designs however, have much better designed pegs which, at least in laboratory testing, exhibit much less wear. It is therefore expected, that these more recent designs will address that problem. In addition, better joint surfaces and tougher polyethylene should also help.

Currently, the single biggest problem that is seen in the PS knee, relates to the box that is required to fit the peg and therefore to make the PCL function work. The problem is referred to as a 'patella clunk', and it seems to relate to the quadriceps tendon rubbing on the top of the box as the knee is bent past 90°. Whilst not often a problem, it can present as a painful grating of the knee during flexion, often beginning many months after surgery. If bad enough, the inflamed tissue that builds up around the patella can form a big enough lump of tissue that it can get caught between the patella and the femoral component, hence causing a clunk.

If mild it needs either no treatment, or occasionally, just a

cortisone injection to settle the inflammation. Providing it is not sore, the grating is of no consequence, and it does not do any damage to the prosthesis. If significant however, and noting that it can worsen with time, an arthroscopy can be performed to remove the offending tissue. This is generally a minor, day case procedure, and recurrence is uncommon.

3. **BCS - Bi-Cruciate Stabilised** knees are relatively new. In this design, both the ACL and the PCL are substituted for, and the prosthesis is designed to replicate normal knee function rather than that of a simple hinge. This is very important as it causes the femur to rotate outwards (externally ~ 15°) as it flexes, thus aligning the patella groove on the femoral component with the patella much better, just like the native knee. Because of this, there should be much less shear force on the patella in flexion, and it is thought that this should therefore provide not only better function, but significantly, less patella pain. If this proves to be the case, then this will solve the single biggest cause of residual problems in knee replacement: and it should significantly improve bending, squatting, climbing and so forth.



BCS - Bi-Cruciate Stabilised Knee
This uses the front and the back of the peg to provide both ACL and PCL function.

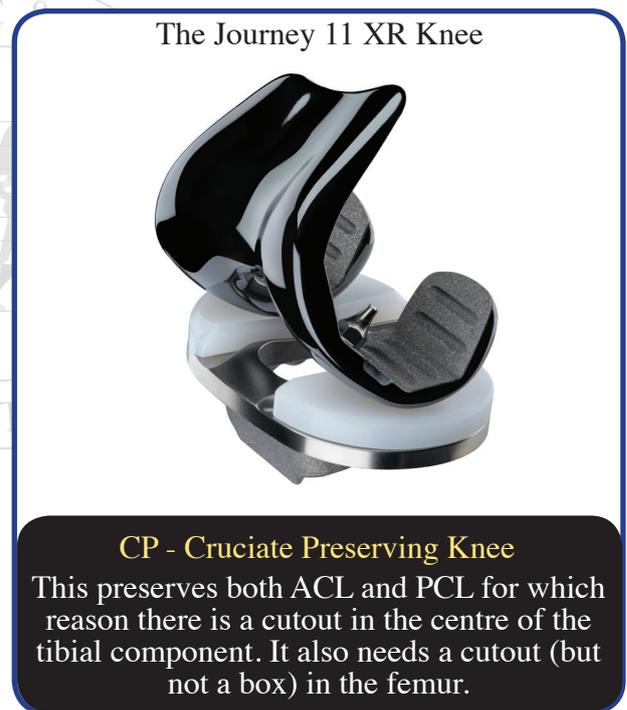
The archetypal BCS design, the Smith & Nephew 'Journey 1' knee, was introduced a decade or so ago though never released for general use in this country. It was however, used in testing centres around the country, and more widely elsewhere. Subsequently though, it was withdrawn from the market because of mixed results. It turned out that this knee produced either excellent results, or poor results, with little in between. Further research suggested that this knee, whilst functioning the nearest to a normal knee in the laboratory, was hard to put in because there was not enough tolerance engineered into the design to provide some forgiveness in the placement of the components during insertion. Trying to get the exact centres of rotation and pivot points to be exactly the same as in a normal knee was too difficult, and remains so, even with computer navigation, computer planning and robotic assistance.

Some years on, the 'Journey 11' has been released, having addressed all of the design problems that were

thought to be an issue with the original 'Journey 1' knee. The revised knee design has now been implanted since 2013 and is in widespread use elsewhere with excellent early results. Importantly, all of the problems that were associated with the 'Journey 1' seem to have been resolved. To date, the 'Journey 11' has not been approved for use in this country, but it is expected to be available soon given the good results seen elsewhere.

4. **CP - Cruciate Preserving** knees are very new, and are still being inserted in testing centres only. Essentially, these preserve both the ACL and PCL. The current model, the 'Journey XR', is identical to the 'Journey 11', but rather than substituting for the cruciate ligaments with a peg, it uses the native ligaments. Of course, for this to work, the native ligaments need to be normal: not torn, stretched or contracted. This will therefore preclude many degenerate knees from being so replaced but, as it is essentially a 'Journey 11 knee', the latter can be implanted if it is thought that the knee in question is unsuitable for this style of replacement.

Because of the difficulty in getting the joint line at the right level and getting the ligament tensions correct, it may be that advanced navigation systems, with the new robotic technology, will be required to get optimum results from this.



CP - Cruciate Preserving Knee
This preserves both ACL and PCL for which reason there is a cutout in the centre of the tibial component. It also needs a cutout (but not a box) in the femur.

5. **Constrained Prostheses** knees are a modification of PS and BCS designs. Essentially, the peg in the middle of the knee is made in square cross section instead of round. This means that it can substitute for damaged collateral ligaments (medial or lateral) where necessary. The advantage of this is that it is just a matter of inserting a different polyethylene tibial tray (constrained rather than PS) onto the tibial component, hence straight forward. It does require a central box, meaning that it can be used with either a standard PS, or BCS, femoral component. To change from a CR (or an MP) knee to a stabilised knee however, requires a change of femoral component to one with a box. This then means that, in a revision situation,



A Constrained Prosthesis
 A variation on PS and BCS. The difference is the square peg on the tibial tray which prevents varus or valgus.

the old femoral component needs to be removed: hence making this somewhat bigger surgery to do.

The downside of a stabilised knee is that it puts extra forces on the femoral component because the varus valgus (bow-legged / knock knee) stability that it exerts is provided by the peg in the femoral box. Accordingly, there is some evidence that this can occasionally produce premature loosening of one of the components. When necessary however, it provides a simple and reliable solution to what can be a difficult problem (one of medial or lateral ligament insufficiency).

6. **Medial Pivot** knees are a relatively old design but which, with newer versions now available, have become popular. What these do is to provide front to back (sagittal) stability similar to a PS design knee, except that this is done by making the medial part (inside half) of the knee a ball and socket. Although this would at first seem a strange thing to do, it turns out that that is how the normal knee works. Essentially, in the normal knee, the medial condyle of the femur stays within a socket on the medial tibia which is formed by the meniscus and its ligamentous attachments. The lateral femoral condyle on the other hand slides backwards and forwards with flexion,



A Medial Pivot Knee
 Creates a ball and socket mechanism on the medial side which is conforming and provides good stability. The lateral side rotates about this.

thereby rotating outwards (externally) as the knee bends.

Although this could theoretically replicate normal knee function, it doesn't do that all that well because there is no ACL function remaining in the knee. Clearly, if full function was restored, the knee would be unstable just like in a normal knee that has had an ACL injury. Accordingly, whilst it allows for some rotation of the femur during flexion of the knee, it is limited.

It seems that medial pivot knees are liked because of the stability they provide from the constrained ball and socket arrangement on the medial side of the knee. In addition, they do not require a box to house a peg for PCL and ACL function, which may therefore mean that they are less liable to develop a 'patella clunk' or related problem.

7. **Mobile Bearing** knees, in various incarnations, have been around since the 1980's. These were originally designed to allow some rotation of the tibia at the knee whilst increasing constraint of the tibial and femoral components. It was thought that by increasing the contact area between the femoral component and the polyethylene tibial tray, that wear would be reduced. Indeed, this proved to be the case but the mechanics were not normal and the design did not allow the femur to roll backwards on the tibia during flexion of the knee. As a consequence, these knees tended to have less flexion range than more conventional knees; that is, they do not bend as far.



A Mobile Bearing Knee
 This separates the flexion component (above the poly insert) from the rotation component (below). Note that there is complete conformity of the femoral component to try and reduce wear.

Despite this, in some hands, these knees have given very good results. As a consequence therefore, they are still in widespread use today. The main aim of the design however, was to make the polyethylene wear less and for it to therefore last longer. Interestingly though, despite the theory, the long term follow up by the Australian National Joint Replacement Registry does not show this to be the case: and in any event, the current generation polyethylene is so good that premature wear in any of the above designs is rare. Accordingly, the reason to

choose such a knee is now one of personal preference rather than one of component longevity.

8. **Hinge Knees** are the next step up in stability. Essentially, these link the femoral and tibial components by a hinge mechanism. These always require some sort of stem on each side so as to spread the forces over larger lengths of the tibia and femur. Whereas once these prostheses were prone to relatively early failure because of over-constraint, they now come with rotation available at the knee and some vertical laxity which allows slight separation of the components during flexion; all of which goes towards decreasing the stresses put on the tibia and femur, hence providing better longevity.

the knee becomes gradually looser and more hyper-extended. Only a hinge will prevent this. It is therefore indicated in arthritic knees where there is an associated muscular, or neurologic, problem which affects control of the knee.



The Legion Hinge Knee (HK)

In this knee the components are linked together by a hinge mechanism which provides ultimate stability in all directions. It is for use in knees with extensive ligament damage or bone loss.

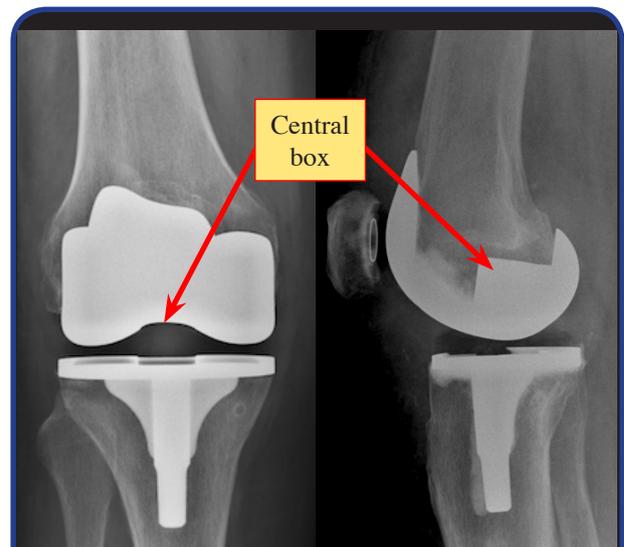
The currently available Smith & Nephew hinge that Dr Holt uses by preference, comes with knee function that is based on the 'Journey 11' design. It not only allows femoral rotation during flexion, it actually makes it happen, thus replicating normal knee function more accurately. This sort of freedom at the knee, coupled with excellent all round stability, can thus provide a very good solution to the very damaged knee with little remaining ligament function. It can also be used where there is large amounts of bone loss, including such situations as removal of bone tumours, or where there is substantial bone missing from previous failed replacement surgery.

Given that the hinge comes with stems, it can be easily augmented with extra wedges of metal to fill any bone deficiencies. Such augments, which can be used on both sides of the joint, are off the shelf components and are kept at the hospital for use as needed. The other types of prosthesis (CR, PS, BCS etc) also come as stemmed versions if augmentation is required, but these are all meant for situations where less inbuilt stability is required.

Another use of a hinge is in the knee where there is poor quads muscle control thereby requiring the knee to be hyper-extended (over straightened) to provide stability when walking. This action gradually stretches out the tissues at the back of a normal knee so, over time,



X-ray of a right CR
Total Knee Replacement



X-ray of a right PS
Total Knee Replacement