Computer-Assisted Minimally Invasive Total Knee Arthroplasty

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Introduction

Total knee arthroplasty has become one of the most successful procedures in orthopedic practice since its introduction in the early 1970s [1, 2]. Since its development, it has undergone many refinements, leading to good 10–15 year follow-up studies [3–5]. Correct component alignment and soft-tissue balancing have been cited as two of the most important components of successful knee-arthroplasty surgery [6, 7]. Alignment of the components is dependent on many factors including accurate pre-operative planning, normal bone morphology to which standardized instruments are applied and accurate placement of these instruments with the surgeon’s skill. Incorrect alignment caused by a variation of any of these factors can lead to abnormal wear [8, 9], premature mechanical loosening of the components [10, 11], and patellofemoral problems [12, 13].

Since the inception of total knee arthroplasty, many refinements in technique and instrumentation have been made. However, the majority of surgeries performed today, throughout the world, still involve the use of a large incision, intra-medullary instrumentation and fixed mechanical guides, whose aim is to produce consistent resections in the coronal, sagittal and axial planes in differing patient anatomy.

The orthopedic community is now faced with two new advancements in the field of knee arthroplasty surgery. The first is the introduction of surgeon-controlled computer-navigation systems, and the second is the increasing use of minimally invasive surgery.

Computer-navigation systems, which are widely used in mainland Europe and Australia, are now gaining popularity in the U.K. and North America. Their aim is to provide more accurate component implantation through digital mapping of standard anatomical landmarks and kinematic analysis. Surgical navigation systems can be divided into three groups: those where the information is collected pre-operatively (CT or MRI), those that use intra-operative imaging and, finally, those systems that build up a working model from the surgeon directly mapping out parts of the patient’s knee prior to starting surgery, as has already been described in a previous chapter.

A number of studies [14–16] have now shown that there is improved alignment of both the limb and the components, when this technology is used. Further advantages, including reduced blood loss and reduction of fat embolism, have been suggested as most systems are now combined with extra-medullary instrumentation.

The resurgence of unicondylar knee arthroplasty in the 1990s has been due to many factors. One has been the more rapid recovery of patients following surgery when it is combined with a minimally invasive approach. A number of authors [17–19] have now used conventional instrumentation to successfully perform total knee-arthroplasty surgery, through reduced incision sizes. All have used miniature versions of standard IM instrumentation, combined with differing surgical approaches. The results have shown improved pain scores, early ambulation and range of motion, and earlier discharge from hospital. However the positioning of components remains in question with one series [19], showing an average femoral component valgus of 6° in the coronal plane.

With the far superior accuracy of navigation systems, together with their use of extra-medullary instrumentation, it seems a logical progression to try to combine the advantages of navigation systems with mini-
minimally invasive incisions to maximize the effects of rapid recovery following surgery with increased longevity of components through more accurate placement of components and reduced wear. The marriage of these two technologies provides further exciting possibility in the use of true quadriceps-sparing lateral approaches, freehand cutting-block placement and in-situ bone cutting where minimal soft-tissue retraction and bone dislocation is performed.

Method

This method describes minimally invasive computer-assisted total knee arthroplasty using:

- either a mini-, mid-vastus or true lateral surgical approach,
- in situ bone-cutting techniques,
- specialist side-cutting instrumentation,
- the Stryker knee navigation system,
- the Scorpio CR knee-replacement system.

In developing a new method for minimally invasive knee-arthroplasty surgery, the ability to place a cutting block in space anywhere around the femoral or tibial surfaces means that there is no longer a need to displace the patella in order to resect the distal femur as the resection can take place in a medial-lateral or lateral-medial direction depending on which approach is used. This essentially leaves the patella in situ whilst the distal cut is made. More importantly, the ability to check the position of the cutting block prior to resection and then to verify the accuracy of resection means that the surgeon can confidently resect from the side and avoid varus or valgus cuts that can occur when using side-cutting techniques. A similar freehand method is used to resect the proximal tibia. The evolution of this technique has led to the development of universal cutting instruments, which result in the same resection blocks being used on the distal femur and proximal tibia. As these blocks are placed into position using a freehand technique, no extra- or intra-medially jigs are needed, which means that the resections are made entirely through captured resection blocks as opposed to the use a partially resected surface of bone to rest the blade on whilst completing the resection. The ability to localize both Whiteside axis and the trans-epicondylar axis results in the correct femoral rotation, being achieved whilst the kinematic analysis of the deformity prior to resections being made and after trial implantation of components allow accurate soft-tissue balancing to be achieved.

Surgical Technique

The patient is placed supine on a standard operating table. A tourniquet is applied and standard skin preparation and draping is undertaken. The surgeon’s usual preference of supports is used; however, closely placed lateral supports may interfere with the initial navigation hip registration. Two distal foot supports are used to allow the knee to be flexed to 45° or 90°, as the surgeon will develop flexion, mid-flexion and extension surgical windows to operate in.

The patient’s patella, patella tendon, medial tibial plateau and distal femur are marked out using a surgical marker pen. With the knee flexed, a 10–12 cm incision is marked out medial to the patella and patella tendon. The skin and underlying subcutaneous tissue is then incised to show the underlying knee retinaculum. At the superior end of the wound, the fibers of the vastus medialis muscle (VMO) are seen to insert into the medial side of the patella. A 2-cm stab wound is made in the VMO fibers at the edge of the patella in a 10 or 2 o’clock position, depending on which knee is being operated on. The incision is then continued down along the side of the patella to the inferior aspect of the wound.

Through the medial arthrotomy wound, the fat pad is partly excised together with the anterior horn of the medial meniscus. An interval is created on the medial side by releasing the antero-medial knee capsule/retinaculum from the anterior surface of the tibia. This further aids visualization of the medial side of the knee and creates also a pocket for the dedicated cutting blocks to be placed in.

With the knee in mid-flexion/extension, a soft-tissue retractor (e.g. Langenbeck) is placed under the patella tendon close to its insertion into the tibia. A small segment (no more then 1 cm) of the patella tendon can be released from the tibial surface to aid exposure. With the retractor in position, the surgeon can visualize the antero-lateral surface of the tibia and anterior horn of the lateral meniscus. This can be removed under direct vision.

The surgeon’s attention is now focused on the superior aspect of the wound. The leg is held in extension
and two soft-tissue retractors are placed under the fibers of the VMO and quadriceps expansion. Both retractors are lifted up to visualize the supra-patellar pouch. In the interval below the VMO/quadriceps mechanism, the anterior capsule is visible to the surgeon as a fine white fibrous layer. This is often attached to the undersurface of the VMO/quadriceps mechanism and needs to be dissected free with Metztabaum scissors. Once free, it is divided longitudinally. The fat and synovial tissue over the anterior surface of the distal femur is next removed and finally any plical bands attaching the medial capsular layer to the medial side of the femur are divided to create a free medial gutter.

Once the proximal and distal releases have been performed, the patella can be easily displaced across the lateral side if required. Next, the surgeon’s attention is turned to the insertion of the navigation pins. Due to the desire not to tether the quadriceps mechanism, the interval between the IT band and quadriceps mechanism is identified and a percutaneous stab wound made. A tracker pin is inserted in an antero-lateral to postero-medial direction. A further percutaneous stab wound is made over the anterior tibial surface at least 2 cm below the tibial tuberosity. A tibial tracker pin is then inserted.

The center of the femoral head, distal femoral landmarks, proximal tibial landmarks and ankle landmarks are then registered, using the surgical navigation system. Once this information has been registered, the knee can be analyzed from a kinematic viewpoint to assess the varus/valgus of the knee and the degree of flexion contracture. This can be done not only at 0° and 90°, as with traditional tensioning devices, but through a dynamic arc of movement. The deformity can also be gently stressed to assess how much is easily correctable and how much is fixed. With this simple maneuver, the surgeon can build up a picture of possible soft-tissue contractures and the possible remedial solutions.

The distal femoral resection requires the surgeon to position the block in relation to the three axes of freedom, varus/valgus, flexion/extension and distal resection depth, solely by positioning the block in space. The tibial tracker is attached to the resection-plane probe which in turn is placed into the captured slot of the cutting block. The cutting block/tracker construct is then held by the surgeon with a tripod grip. The cutting block/tracker construct is now an active tool whose virtual position can be monitored on the computer-navigation screen (Fig. 16.1).

The surgeon first places the cutting block against the medial surface of the femur. Then, in a similar method to arthroscopy, he watches the navigation screen as he moves the block into the desired position with one hand, leaving the second hand free to hold the pin driver. Depth of resection is achieved by moving the block in a proximal/distal direction. Flexion/extension of the block is achieved by rotating the block in the appropriate flexion/extension direction. Finally, varus/valgus positioning of the cutting block is achieved by tilting the block in a medial or lateral direction relative to the long axis of the femur (Fig. 16.2).

A blunt curved retractor is placed under the patella/patella tendon, with its tip in the lateral gutter of the knee. This retractor acts as a tissue protector rather than a true retractor, as it separates the quads/patella mechanism from the saw blade.

With the knee in mid-flexion, a saw is then used to cut from a medial to lateral direction through the flat surface of the block. The curved portion of the block can be used to cut the medial femoral condyle in an anteroposterior direction (Fig. 16.3). The resected part of the condyle is removed and the resection-plane probe placed on the distal cut surface to verify the depth and accuracy of the cut. This is then recorded on the femoral cut-verification screen.

Fig. 16.1. The Universal J Block with attached resection plane probe are seen in the medial mid vastus pocket.
The proximal tibial cut is performed with the same cutting block, and a similar freehand technique of cutting-block placement is also used as for the distal femur. The cutting block is first placed into the wound and medial soft-tissue envelope, created during the initial dissection. The surgeon then orientates the block so that the correct depth, varus/valgus and slope are achieved. The depth is achieved by proximal/distal movement of the block, whilst varus/valgus is achieved by tilting the block in medial/lateral direction about the long axis of the tibia. The desired slope for resection is achieved by tilting the block forward or backward. Once again the block is held with a tripod grip, and the virtual movements of the block can be monitored in real time on the navigation screen.

A retractor is placed under the patella ligament and another placed to protect the MCL. With the knee at 90° of flexion, a saw blade is then introduced into the captured slot and the medial part of the tibial plateau cut through the anterior portion of the cutting block (Fig. 16.4). The saw blade is then turned obliquely through the curved portion of the cutting block and the anterior portion of the lateral tibial plateau is cut. Next a curved retractor is placed behind the central tibial plateau, to protect the PCL, and the central and posterior parts of the proximal tibia are cut. Finally, a malleable retractor is inserted between the LCL and lateral tibial plateau, and the posterior-lateral tibial plateau is cut. This latter cut needs to be performed carefully to avoid damage to the LCL.
The knee is then placed into extension, where the previously resected distal femur provides space. An osteotome is used to free the cut proximal plateau, and graspers are the utilized to remove the resected piece of bone. Soft-tissue attachment to the resected bone is removed from medial side, then the posterior aspect and finally the lateral side. The resected piece of bone is then removed and the resection level checked with navigation.

During the resection of both distal femur and proximal tibia, the tibio-femoral articulation has not been dislocated, and, as such, true in-situ cutting has occurred.

During the initial anatomical landmark navigation registration, the lateral epicondyle was approximated. With the distal femur resected, the rotational landmarks of the femur are remapped, using a special referencing guide shown below. This guide is based on the 90° relationship between Whitside's AP axis and the transepicondylar axis (Fig. 16.5).

An anterior skim guide is then used to produce an anterior skim cut, which has the correct rotational alignment, as calculated by the navigation system. A miniature 4-in-1 resection block is then used to finish the femoral cuts (Fig. 16.6).

The tibial baseplate is then inserted and the correct rotation achieved with the navigation unit (Fig. 16.7).

The trial femur is the inserted together with a trial poly insert, and the kinematics of the knee are assessed again. A direct comparison can then be made with the pre-surgery kinematic data, and appropriate changes to
the size of the tibial insert or soft-tissue releases can be performed with instant bio-feedback.

Once the surgeon is satisfied with the limb alignment and soft-tissue balance, the real components can be cemented into place (Figs. 16.8, 16.9).

By utilizing the flexion, mid-flexion and extension windows, the components can be inserted safely and any excess cement can be removed.

The wound is then closed in a standard fashion (Figs. 16.10, 16.11).
Anesthesia and Pain Relief

All patients have spinal anesthesia, the effects of which wear off within 4 h of surgery. Once the patients have sensations in the sole of the foot, they are allowed to mobilize freely. Their pain relief consists of either a PCA pump or a combination of opioids and NSAIDs.

Results

One of the most important aspects of minimally invasive surgery, is not to sacrifice shorter term gains in recovery of function for poor component positioning, which ultimately may lead to a higher number of revision procedures later. We therefore watched the first 22 patients who underwent this new procedure looking at the radiological alignment of components, blood loss, length of stay, time to straight leg raise/90° of flexion and surgery times.

On long-leg Maquet views, the majority of patients had a standing femoral-tibial angle of within 3° of neutral, as shown in Fig. 16.12.

The mean position of the femoral component was 1.5° valgus, whilst the mean position of the tibial component was 0.5° varus. The distribution of position of both components is shown in Figs. 16.13 and 16.14, where 90° indicates neutral and increasing values indicate a valgus position.
The length of patient stay in the MIS group was compared to a similar group of open computer-assisted knee replacements and their distribution is shown in Fig. 16.15. The mean length of stay for the MIS group was 3.25 days whilst it was 6.04 days for the open computer-navigated group.

Surgical OR time ranged from 180 min at the start of the learning curve to 100 min for the last cases. Patients achieved straight leg raise from 1–9 h after surgery and the majority took 3–12 h to take their first steps with a walking frame.
Conclusions

Computer-assisted minimally invasive total knee arthroplasty has, in its infancy, produced a dramatic leap forward in both surgical technique and patient recovery. The ability to cut accurately from the side, leave the joint in situ to avoid repetitive joint dislocation and produce minimal trauma to the entire soft-tissue envelope of the knee — not just the quadriceps mechanism —, is clearly producing dramatic results as shown in our short early series.

All minimally invasive surgery, including computer-assisted techniques, is technically demanding and surgeons must realize the limitations both in terms of their own surgical ability and patient selection. The technique, whilst rewarding, is technically demanding. Some previous use of computer navigation during open arthroplasty surgery is certainly an advantage, as is the progressive downsizing of the surgical incision.

Many manufacturers provide cadaveric courses, which are highly commended. In this era of patient-led decisions, the question is which patients are suitable for such a minimally invasive procedure. Clearly any patient who would be a candidate for total knee arthroplasty surgery under normal circumstances may be a candidate for an MIS TKR. In those patients who have a varus or neutral deformity, a mid-vastus procedure is applicable, whilst in those with a valgus deformity, a lateral approach is more applicable. Clearly having a universal approach with the same instrumentation has advantages in dealing with the diversity of patients in clinical practice. In obese patients, MIS surgery can be performed more easily than in heavy-muscled male patients. Significant bone loss on either tibial or femoral sides requiring bone wedges or significant flexion contractures is a contraindication to an MIS procedure.

Whilst the aims of all minimally invasive surgery techniques is to reduce soft-tissue trauma, post-operative pain and hospital stays, it is clear that this must not be at the cost of poor surgical positioning of components that will ultimately lead to early failures and revisions.

The potential for surgical inaccuracies when operating through small incisions is a reality, and errors can be frequent as the surgeon’s normal visual landmarks are not always clearly visible. This may lead to an excessive amount of retraction on a small wound, which may be more detrimental than performing the surgery through a normal incision. The use of computer navigation has provided many advantages as well as challenges. The use of entirely extra-medullary devices means that the medullary canal of either the femur or the tibia is not violated, reducing the risk of cognitive impairment from fat embolism. The lack of need for an intra-medullary rod also reduces the pressure on the patella and the need to forcibly displace it laterally when inserting such a device. The accuracy that computer navigation gives to the surgeon, both in positioning cutting blocks and verifying resection levels, is unsurpassed and has been proven in many studies to exceed the accuracy of current instrumentation. The ability of these systems to provide instant bio-feedback when performing soft-tissue releases provides the perfect platform to produce a well-balanced knee arthroplasty.

The combination of computer navigation with minimally invasive surgery has provided surgeons with an exciting opportunity. Despite navigation technology still being in its infancy, it has already surpassed conventional instrumentation and is used in many operating rooms around the world. The future of this technology will be in the development of less invasive tracker attachments, more advanced software developments which map out gap kinematics even more accurately, smart polyethylene inserts which will give the surgeon instant load readings with different sizes of inserts, and a reduction in financial cost. The future of joint replacements as a whole may be the development of specific MIS implants with installed sensors, so the surgeon can monitor a patient’s knee for any number of variables. Whilst to many surgeons some of these ideas may seem fanciful, many manufacturers aim to make them real within the next two years.
References