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Total knee arthroplasty: Techniques and results

Providing a patient with a pain-free, stable knee joint that will last a long time can be achieved by focusing on five surgical goals.

ABSTRACT: While osteoarthritis remains the most common indication for total knee replacement, the number of primary total knee arthroplasties performed annually has increased exponentially over the last 55 years. Outcomes have improved with the use of careful preoperative assessment, a range of component options, and operative technique guided by clear surgical goals. Informed consent of any patient contemplating total knee arthroplasty must be obtained by discussing the risks and benefits and explaining that between 80% and 85% of patients are satisfied after the procedure.

Major joint arthroplasty is undoubtedly one of the surgical success stories of modern times. The number of primary knee arthroplasties performed annually increased exponentially over the last half of the 20th century and increased between 16% and 44% during the first 5 years of the 21st century.[1,2] The history of total knee arthroplasty began back in 1860, when the German surgeon Themistocles Gluck implanted the first primitive hinge joints made of ivory. Development really took off following the introduction of the Walldius hinge joint in 1951: initially manufactured from acrylic and later, in 1958, from cobalt and chrome.[3] Unfortunately, this hinge joint suffered from early failure.

In the early1960s, John Charnley's cemented metal-on-polyethylene total hip arthroplasty inspired the development of the modern total knee replacement.[4] Gunston, from the same centre as Charnley, went on to design an unhinged knee that replaced both the medial and lateral sides of the joint with separate condylar components. Improved biomechanics resulted from the preserved intact cruciate and collateral ligaments, which maintained the stability of unlinked femoral and tibial components, and a design that allowed the centre of rotation to change with flexion of the knee.[5] The metal-on-polyethylene condylar design—completely replacing the femoral and tibial articulating surfaces—was pursued throughout the early 1970s at centres across the world.[6-11] The result was an implant relying on component geometry and soft tissue balance to provide stability, with a large articulating surface area to spread load and minimize polyethylene wear. Incremental improvements in component materials, geometry, and fixation continued throughout the 1970s and 1980s. More accurate sizing, the option of patellafemoral replacement, better instrumentation, and components that allowed an increased range of motion and a lower wear rate have since been developed.

Unicompartmental knee arthroplasty developed in parallel with total knee replacement from the early efforts

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of McKeever and Elliott in 1952.[12] However, because the unicompartmental procedure replaces only the diseased part of the joint with more natural kinematics or joint movement,[13,14] the indications for its use are more limited.

Radiographs should always be performed before MRI is ordered; in many cases, the plain radiographic findings will make MRI unnecessary.

Indications and preoperative assessment

Osteoarthritis, whether primary, post-traumatic, or secondary to avascular necrosis, osteochondritis, or sepsis, is by far the most common indication for total knee replacement. Inflammatory arthritides make up the bulk of the remaining indications. Diagnosis of the underlying condition allows application of appropriate nonoperative treatment, while the functional impact of disease upon the everyday life of the patient determines the appropriate timing of surgery. Mechanical symptoms—locking or giving way—may be amenable to arthroscopic assessment and treatment. The severity of symptoms are assessed by noting reduced walking distance, analgesic use, and sleep disturbance. Ability to climb stairs or inclines, use of walking aids or other orthotics, and exacerbating or relieving factors all build a more detailed picture of disability.

Knee examination should include assessment of gait, surgical scars, localized tenderness, active and passive range of motion, limb alignment, coronal and sagittal plane ligament stability, and neurovascular status of the limb. Other pathology contributing to symptoms should be excluded by examination of the back, hip, foot, and ankle of the same limb.

Up-to-date and serial (if available) radiographs of the knee should include an anteroposterior view as well as true lateral and skyline patellofemoral views of the involved knee together with full long leg views if there is significant deformity, previous fracture, or previous osteotomy of the femur or tibia. An anteroposterior pelvis and lateral radiograph of the ipsilateral hip should be sought if there are symptoms of groin pain or signs of stiffness or pain on rotation of the hip. Magnetic resonance imaging can be used to assess for meniscal or ligamentous injury in appropriate cases, but is generally not required for the routine assessment of the painful arthritic knee. Radiographs should always be performed before MRI is ordered; in many cases, the plain radiographic findings will make MRI unnecessary.

The option of total knee arthroplasty is typically discussed with patients at the point in their lives when knee pain from arthritis is significantly interfering with activities of daily living. Informed consent requires a full discussion of the risks and benefits of surgery to ensure that patient expectations are realistic. Generally, between 80% and 85% of patients are satisfied with their knee arthroplasty. The most significant complication is deep infection, which complicates between 1% and 2% of operations and may require further and repeated major joint surgery. Arterial injury complicates between 0.03% and 0.17% of cases[15] and peroneal nerve injury has been reported in between 0.3% and 2.0% of patients.[16] The 20-day postoperative mortality rate of 0.2% is increased above the age-matched population and is the same as that measured for total hip arthroplasty. The mortality rate normalizes with the age-matched population after the 70th postoperative day.[17] Mortality at 1 year following knee arthroplasty is 1.6%, which is half the mortality rate of the age-matched population, demonstrating that total knee arthroplasty patients are a highly select group.[18]

Operative technique

Preoperative radiographic templating for knee arthroplasty, while not as crucial as for hip arthroplasty, does indicate the size and shape of the tibial bone to be removed and the component type and size that is likely to be required. It is particularly important in cases requiring the extremes of implant size to ensure that all likely sizes are available, in cases of severe deformity, and in cases where there is severe bone loss.

Components

Most orthopaedic supply companies manufacture a range of implant designs, from cruciate ligament retaining (Figure 1) and posterior stabilized (Figure 2) implants that usually provide sufficient stability in the primary setting, through to megaprotheses for replacing tumor or bone.

The level of built-in constraint, or stability, required by a knee prostheses depends upon whether the posterior cruciate and collateral ligaments are intact. If the posterior cruciate ligament is compromised, as it is in most rheumatoid knees, or there is fixed coronal plane or significant flexion deformity, then the PCL is replaced by a cam and post, the design of which controls sagittal plane kinematics. A larger post can provide additional side-to-side/coronal plane stability (Figure 3). If the medial collateral ligament is compromised, a hinged prosthesis is chosen to further improve coronal plane stability (Figure 4). Inevitably this puts greater strain upon the hinge itself and produces increased shear stresses at the implant interface with the bone. A rotating hinge allows movement in the axial plane between the polyethylene and tibial surface, decreasing these stresses but producing a secondary surface for the generation of wear debris. Modular femoral and tibial stems are added to the resurfacing implants in this scenario to increase the area of fixation, spreading load and decreasing stresses at the implant bone interface.

Femoral or tibial stems of varying lengths may also be added if there are significant uncontained bone defects. Generally, a contained bony defect with an intact cortical rim or an uncontained defect of less than 5 mm can be filled with cement upon implantation. Contained defects greater than 5 mm with an intact cortical rim can be treated with morcelized impaction bone allografting. Uncontained defects require shaping to accommodate the metal wedges that are added to the implant. Larger defects are not commonly encountered in the primary setting, but when present may require bulk bone allograft. The addition of a femoral or tibial stem provides additional stability and protects supplemented defects, minimizing the risk of long-term implant subsidence.

Surgical goals

The clinical aims of knee arthroplasty are to provide the patient with a pain-free, stable joint that will last a long

Figure 1. Cruciate ligament retaining implant.

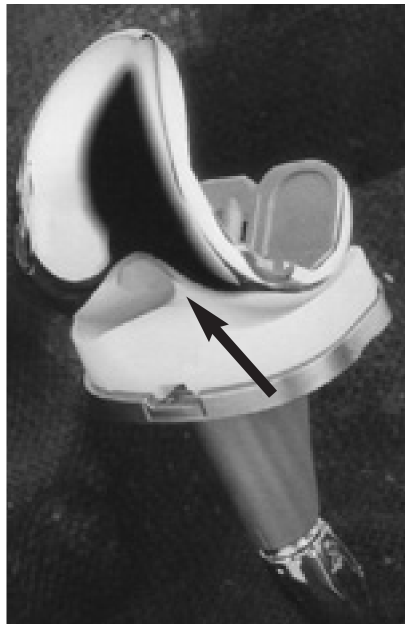

Figure 2. Posterior stabilized implant. The presence of a post (arrow) distinguishes this design from the cruciate ligament retaining design in Figure 1, which has no such post.

Figure 3. Posterior stabilized implant with larger post (arrow) for improving coronal plane stability.

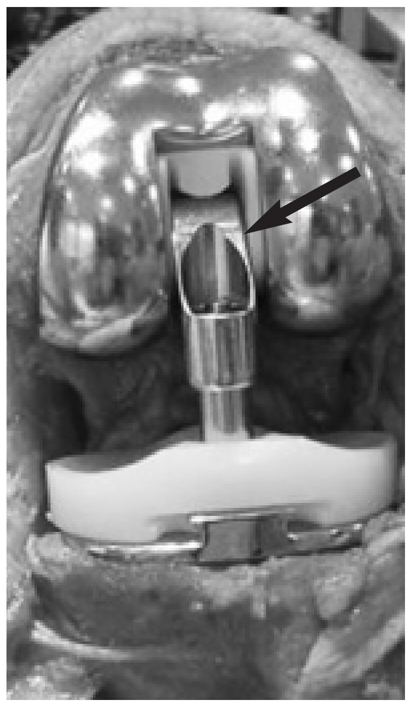

Figure 4. Hinged implant for improving coronal plane stability. The hinge is linked into the femoral component as indicated by the arrow.

time. To achieve this, the surgical team focuses on five surgical goals:

- Mechanical alignment of the limb. The proximal tibia and the distal femur are cut so that the mechanical axis of the limb—from the centre of the hip to the centre of the ankle joint—passes through the centre of the knee arthroplasty. This ensures that forces are transmitted equally through each side of the new joint, optimizing the lifetime of the joint.[19] Aligning the limb correctly also provides the correct starting platform for achieving subsequent surgical goals.
- Joint line preservation. The depth of bone removed from the tibia and the femur should be equal to the height of the respective components that are implanted. By taking out what is to be put back in, the position of the original joint line is preserved. This optimizes the function of the ligaments and muscles acting upon the knee.
- Soft tissue balance in the coronal plane. Balancing the knee to varus and valgus stress maintains equal load transmission through each side of the knee. Following many years of disease, deformity in the coronal plane can become fixed by contracture of soft tissues. Osteoarthritis most commonly leads to a varus deformity and tight medial soft tissues, which are released in the following order to attain satisfactory balance:
  1. Medial osteophyte removal.
  2. Proximal subperiosteal stripping of the deep medial collateral ligament.
  3. Posteromedial capsular release.
  4. PCL sacrifice requiring the use of a posterior stabilized component.
  5. Distal tibial periosteal stripping of the MCL (avoiding complete release and subsequent valgus instability).

  Rheumatoid arthritis or lateral femoral condyle hypoplasia can lead to a valgus deformity that requires the following releases to attain satisfactory balance:
  1. Lateral osteophyte removal.
  2. Subperiosteal dissection of the lateral joint capsule.
  3. Lateral patellofemoral ligament release.
  4. "Pie crusting" of the iliotibial band if tight in extension.
  5. Popliteus release if tight in flexion.
  6. PCL sacrifice requiring the use of a posterior stabilized component.
  7. Lateral collateral ligament release from its femoral insertion (avoiding complete release and subsequent varus instability).
- Balance of the flexion and extension gaps in the sagittal plane. This results in the knee maintaining stability throughout its full range of motion. Flexion instability occurs when the gap between the tibia and the femur is wider in flexion than in extension and must be corrected to ensure the patient is asymptomatic. Recurvatum or extension beyond 0 degrees may result from a "loose" extension gap. A "tight" flexion or extension gap may restrict the full range of flexion or extension. Loss of full range of motion at either extreme can be disabling. Loss of full flexion can make stair and hill climbing difficult. Loss of full extension makes complete lockout of the knee impossible and requires prolonged quadriceps muscle engagement—which is tiring for the patient—when standing in one spot. A tibiofemoral gap consistent throughout a full range of motion can be achieved by using an appropriately sized tibial insert combined with a femoral component implanted in the correct position.
- Q angle correction. This is the angle between the quadriceps and the patella tendon and is a function of the positioning of the tibial, femoral, and, if used, patella component. In particular the femoral component requires appropriate positioning in all three planes to allow the patella to track correctly.

Each of these goals may not necessarily be addressed in strict order during surgery. Indeed, some of the steps involved during the procedure may address more than one goal at the same time. For instance, sizing and positioning the femur ensures balance of the flexion and extension gaps as well as creating a Q angle that affords correct patella tracking. What is vital is that every goal be considered in order to produce a pain-free, stable joint that will last a long time.

The operation

Following complete preoperative assessment and planning to ensure correct implant availability, a typical total knee arthroplasty would proceed as follows:

- Intravenous antibiotics are given well before inflation of a proximal thigh tourniquet to 300 mm Hg.
- The skin is prepped and draped to allow an adequate midline longitudinal incision to access the knee joint, usually via a medial parapatellar approach.
- Part of the anterior fat pad, remnants of the medial and lateral menisci, the anterior cruciate ligament and the PCL (if a posterior stabilized implant is to be used) are excised. Osteophytes are excised and the proximal medial soft tissues are released to allow visualization of the edge of the medial tibial plateau and forward subluxation of the tibia in full flexion and external rotation. Further preliminary soft tissue releases are performed at this stage as appropriate.
- The tibia is cut at 90 degrees to its

mechanical axis using an extramedullary or intramedullary jig. Tibial bone is removed from the normal side of the joint to the same depth—usually 10 mm—as the height of the tibial component to be implanted, with the aim of preserving the position of the original joint line.

- The femoral intrameduallary canal is entered and the appropriate jig is used to cut the distal femur in between 5 and 7 degrees of valgus relative to the anatomical axis. This ensures the bone is cut at 90 degrees to the mechanical axis of the femur, thus satisfying the first surgical goal of knee arthroplasty. Femoral bone is removed to the same depth—again, usually 10 mm—as the height of the femoral component to be implanted, with the aim of preserving the position of the original joint line.
- The extension gap is checked to ensure a 10-mm spacer can be inserted. If it cannot, the tibia or femur, as appropriate, are recut by an appropriate amount—usually 2 to 4 mm. Overall alignment of the bony cuts is checked to ensure the limb is straight and the soft tissues balance to varus and valgus stress. Further adjustments of the bony cuts and further soft tissue releases proceed if required.
- The femoral size is measured (in the anteroposterior and mediolateral plane) and correct position of the femoral cutting block in the sagittal (anteroposterior translation), the coronal (mediolateral translation), and axial plane (rotation) is ensured.
- The posterior femoral condylar cut is made to enable trialing of the 10-mm spacer block at 90 degrees of flexion to confirm that the flexion gap matches the extension gap between the tibia and the femur.
- The remaining femoral bony cuts are made to match the inside of the femoral component, and a drill hole is made in each condyle to accommodate the two femoral pegs.The trial components are inserted with the appropriate tibial spacer. The patella is prepared if it requires replacement, and is rechecked prior to final implantation. The optimum position of the tibial component is marked and preparation of the tibial keel is completed.
- The cancellous bone surface is cleaned and the real components cemented with antibiotic-loaded cement. Compression is applied with the knee in extension through a trial insert. Once the cement has hardened any loose cement is removed and the appropriate real polyethylene insert is implanted.
- The tourniquet is released to confirm hemostasis. A single drain is used and the retinacular-tendinous layer is closed with interrupted sutures. The subdermal tissues and skin are closed and dressings applied.

Postoperative care

Two further intravenous doses of antibiotics are given to cover the first 24 hours. Low molecular weight heparin or a similar suitable anticoagulant is prescribed—according to patient risk assessment—usually up until the 10th day postoperatively to ensure optimal thromboprophylaxis. The patient is mobilized, fully weight bearing in the majority of cases, as soon as the gross effects of the anesthetic have worn off. Patients are encouraged to maximize knee extension and flexion at every stage of their recovery to ensure optimal outcome. Exercises are commenced to ensure full recovery of quadriceps tone and strength and analgesia is provided to ensure the best possible results from physiotherapy. Discharge from hospital is allowed when the wound is dry and the patient is safe ascending and descending stairs. Sutures or skin clips are removed at 10 to 14 days. A walking aid may be required for several weeks following surgery. The literature supports driving from 8 weeks, so long as the patient is clear of opiod analgesia and can perform an emergency stop.[20] Follow-up appointments are scheduled at 6 to 8 weeks, 1 year, 5 years, and every subsequent fifth year thereafter. Earlier follow-up should be requested if there is any sign of infection or other significant concern. Over 85% of total knee arthroplasty patients will recover knee function following a general rehabilitation protocol. The remaining 15% of patients will have difficul-

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ty obtaining proper knee function secondary to significant pain, limited preoperative motion, or the development of arthrofibrosis. This subset of patients will require a more specific prolonged rehabilitation program that may involve ongoing oral analgesia, continued physical therapy, additional diagnostic studies, and occasionally manipulation. Controlling pain is the mainstay of any such treatment plan.[21]

Results

The survivorship rate is the percentage of total knee arthroplasties that have not been revised in any given series of patients. It is generally the most often quoted outcome in the joint arthroplasty literature. Survivorship is arguably the most useful outcome when distinguishing between different prosthetic designs and also helps answer the patient question, "How long will the knee last?"

The pioneers of total knee arthroplasty saw early failures that quickly led to the use of more durable materials, better fixation, and improved design.[5-11] Published longer-term results have shown markedly differing survivorship rates between more subtle differences in arthroplasty design. In a recent study looking at 3234 knee arthroplasties performed between 1969 and 1995, 89% of the condylar designs had survived 10 years and between 78% and 89% had survived 15 years.[22] Survivorship rates, however, varied considerably among different implant designs. The corresponding rates for some, now discontinued, designs in this same study were between 43% and 63% at 10 years and between 28% and 59% at 15 years.[22] Further studies have confirmed clinical survival of the total condylar knee design of 94% at 15 years[23] and between 77% and 91% at 21 to 23 years.[24,25] For this reason the total condylar design has endured. Perhaps the best long-term published results are for the Anatomic Graduated Condylar (AGC) knee arthroplasty, the success of which is attributed to a straightforward design that utilizes carefully manufactured materials. The AGC knee has a published survivorship rate of 98.9% in 4583 knees at 15 years[26] and a rate of 97.8% in 7760 knees at 20 years—quite impressive survivorship. The number of knees that reach long-term follow-up in such series are, however, often small; only 36 of the 7760 knees in this study made it to the 20-year point.[27]

Medium-term follow-up is becoming available on updated versions of the total condylar design. Improved survivorship rates of 100% at 10 years are seen with the Miller-Galante II knee, which was redesigned to solve the high rate of patellofemoral complications seen with the Miller-Galante I (which still had an 84.1% survivorship rate at 10 years).[28] Studies comparing the results of different design options manufactured by the same company are now also available: the 10-year Genesis knee results for the (posterior) cruciate retaining knee reveal 97% survival compared with the Genesis posterior stabilized knee, which has 96% survival—an insignificant difference.[29] The results of unicompartmental knee arthroplasty have been as good as total knee arthroplasty in published individual series, with survivorship rates of 98% at 10 years.[30,31]

It is arguably the recent registry data for newer generation knee implants that apply most readily to the average patient considering total knee arthroplasty. The 8-year survivorship rate for the eight most common knee joints in current use in Norway is between 89% and 95%[1] and the 7-year rate in Australia is 95.7%.[2] Of note, purely in terms of survival, these registries have found inferior results for even the best-performing unicompartmental knee arthroplasties when these are compared with total knee arthroplasty. The cumulative survival at 7 years for unicompartmental knees in Australia is only 88.1% compared with 95.7% for total knees.[1,2] This may relate to issues of patient selection or reflect the increased technical expertise required for this procedure. Conversion of unicompartmental knee arthroplasty to total knee replacement is relatively straightforward, so appropriate patients seeking a partial knee replacement should not be discouraged by the slightly lower long-term survivorship seen in registry data.

Several knee scores have been developed to assess outcome follow-

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Survivorship rates in obese patients were not significantly lower than in patients who were not obese at 10 years follow-up.

ing total knee arthroplasty. These tools produce numbers that correspond to excellent, good, fair, or poor outcome. For example 92% of knees were assessed as good or excellent in one study, with 1.6% fair and 6.5% poor.[23] Between 96% and 98% of knees were assessed as good or excellent in another study.[29] However, more recently it has been shown that the views of surgeons and their patients regarding the outcome of surgical interventions do not always correlate well—especially with respect to function and pain. Patient questionnaires are thought to better assess patient outcome, and in a recent study 81.8% of 8095 patients were satisfied, 11.2% (906 of 8095) were unsure, and 7.0% (566 of 8095) were not satisfied with their new knee joint.[32]

With regard to younger patients under the age of 55 years, a survivorship rate of 96% of 93 knees was observed at 10 years,[33] and of 90% of 108 knees at 18 years;[34] 94% of patients in the latter study had good or excellent function and all but two patients had improvement in their activity score postoperatively. Furthermore, 24% regularly participated in activities such as tennis, skiing, bicycling, or strenuous farm or construction work.[34] This suggests that the traditional practice of withholding knee replacement until patients are over 65 or over is not warranted, and replacement should proceed when clinically appropriate.

It was traditionally thought that obese patients do not fare as well as normal-weight patients following joint replacement. Postoperative outcome scores for obese patients, however, were found to be comparable to scores for patients who were not obese in one recent study. Furthermore, given the lower preoperative scores measured in the obese group, the overall improvement was actually greater than in the normal-weight group. Additionally, survivorship rates in obese patients were not significantly lower than in patients who were not obese at 10 years follow-up.[35] There was, however, a greater proportion of lucent lines seen on the radiographs around the implants of the obese patients[23,35] and in the morbidly obese the complication rates are higher and the implant survivorship rate is lower.

The final objective measure of outcome perhaps most relevant to the individual patient is range of flexion. This has gradually improved from a mean of 99 degrees[23] to between 114 and 117 degrees with newer generation designs.[29] Postoperative range of motion largely depends on the preoperative range of motion. Generally, what the patient has before the operation is what the patient can expect to achieve after surgery and rehabilitation.[36] Patients seeking knee replacement should be counseled that their postoperative knee will not be "normal," but it will feel and function much better than their preoperative arthritic knee.

Conclusions

Osteoarthritis remains the most common indication for total knee arthroplasty. Fortunately, technical developments over the last half century have resulted in 10-year survivorship rates of 90% and higher, and between 80% and 85% of patients have been satisfied with their total knee replacement. Further incremental improvements in knee arthroplasty engineering, implant design, and material science will continue to improve bearing surface tribology, implant fixation, and implant longevity. These advances will all help meet the main surgical goals of total knee arthroplasty: to correct limb alignment, preserve joint line position, balance the soft tissues in the coronal plane, balance the flexion/extension gap in the sagittal plan, and create a Q angle that facilitates satisfactory patella tracking. Preoperative assessment and planning will also help meet these goals by ensuring patient expectations are realistic and informed consent has been obtained after a full discussion of the risks and benefits of surgery.

Competing interests

None declared.

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