Objective clinical performance outcome of total knee prostheses. A study of mobile bearing knees using fluoroscopy, electromyography and roentgenstereophotogrammetry

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Chapter 2

Knee anatomy, function and disorder

2.1   Anatomy of the knee joint

The bony skeleton of the lower limb consists of the femur, tibia, fibula, patella and the bones of the foot (Figure 1). Each bone consists of relatively hard cortical bone externally and spongy bone internally. Posterior of the distal femoral bone end, there are two condyles. Each is roughly spherical in shape and one is medial and the other lateral of the central notch. The femoral condyles touch or articulate on the proximal tibial bone end. The tibial surface is mostly a plateau with a slightly concave medial depression and a slightly convex lateral surface, separated by central area prominences.

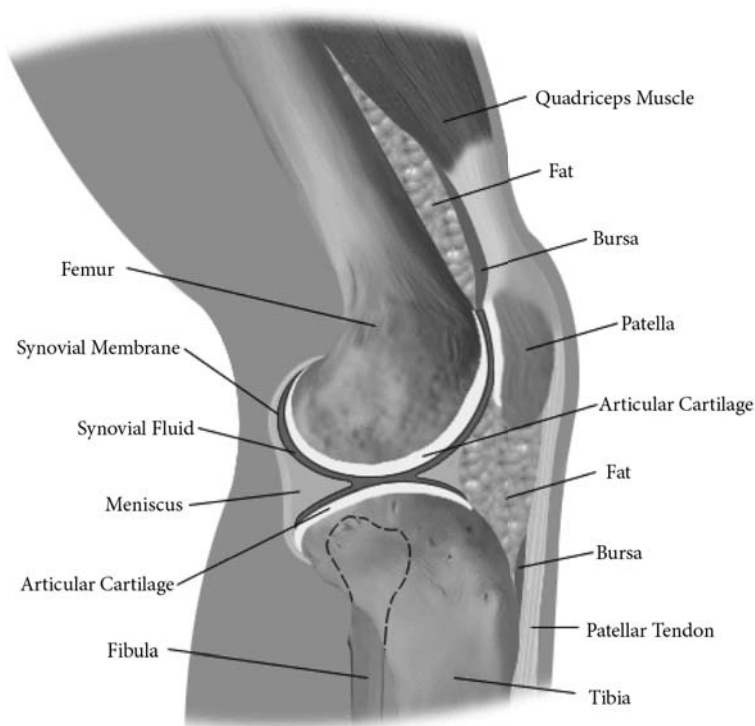**Figure 1.** Anatomy of the knee. *Source: www.rush.edu/rumc/images/ei_0276.gif*

The knee joint consists of a patello-femoral articulation and a tibio-femoral articulation. In this joint, the areas of inter-bone contact of the femur, tibia and patella

are covered in cartilage. Cartilage has a very low coefficient of friction and secrets a water lubricant under pressure. Menisci in the medial and lateral compartments of the knee provide a cushion between the articulating surfaces of the femur and the tibia.

The quadriceps tendon inserts into the proximal border of the patella and the distal apex of the patella is connected to the anterior aspect of the proximal tibia at the tibial tuberosity by the patellar ligament. The patella tracks in the trochlear groove of the femur during knee flexion and extension. The synovial membrane regulates and contains the lubricating synovial fluid of the knee and the tibia and femur are connected by ligaments.

The ligaments maintain knee stability and guide the motion of the femur relative to the tibia. They connect the tibia to the femur and transfer load across the joint space and protect the knee. The four primary ligaments of the knee are the cruciate or 'crossing' ligament pair in the mid-sagittal plane of the joint and the collateral ligament pair (medial and lateral).

Fibres of the anterior cruciate ligament (ACL) pass postero-laterally from its distal end attachment on the anterior aspect of the proximal tibia to its proximal end attachment on the medial aspect of the lateral femoral condyle (Figure 2). The posterior cruciate ligament (PCL) links the posterior of the tibial plateau to the antero-lateral aspect of the medial femoral condyle.

The anterior muscles of the knee act primarily as knee extensors. The quadriceps femoris muscle is the principle muscle involved in knee extension. This muscle can be divided into four distinct parts: the rectus femoris, vastus medialis, vastus lateralis, and the vastus intermedius. All four parts of this muscle come together to insert on the proximal edge of the patella, which then transfers their action, by way of the patellar tendon, to the tibia.

The principle muscles involved in knee flexion are the hamstring muscle group. This group is comprised of the biceps femoris, semitendinosus, and the semimembranosus muscles. Their insertion occurs on the proximal tibia and head of the fibula. The biceps femoris muscle has an additional action of externally rotating the tibia. While the semitendinosus and semimembranosus muscles also have an additional role of internally rotating the tibia. Other muscles participating in knee flexion and internal rotation are the sartorius, and gracilis muscles. The popliteus

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muscle also serves to internally rotate the knee in a non-weight bearing position. Additional muscles involved in isolated knee flexion include the gastrocnemius and plantaris muscles.
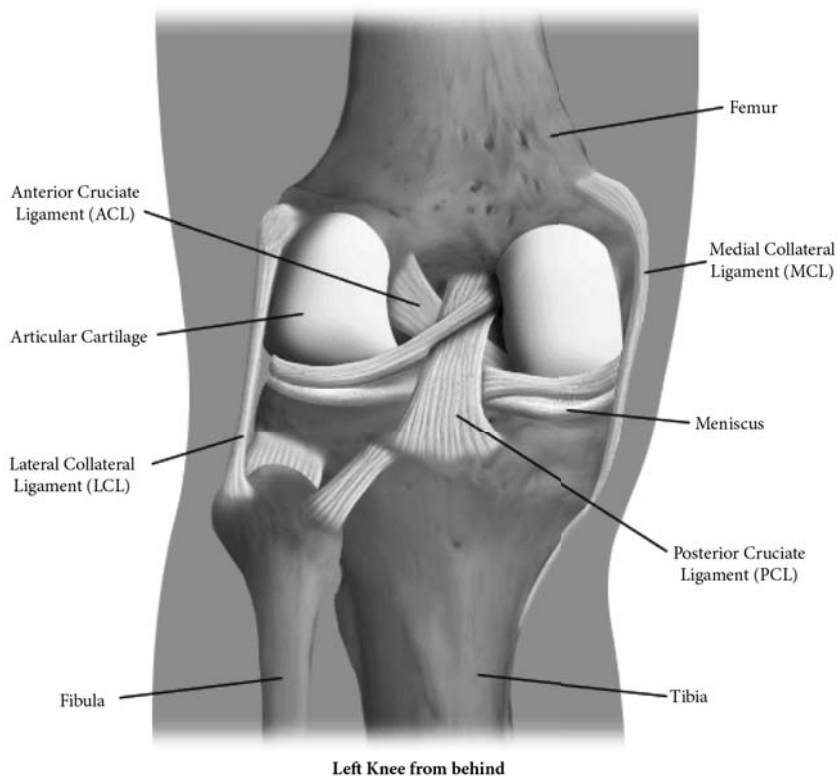

Figure 2. Knee joint ligaments. *Source: www.summithealth.org/greystone_images/es_0277.gif*

2.2   Knee joint kinematics

Movement of the knee joint can be classified as having six degrees of freedom – three translations: anterior/posterior, medial/lateral, and inferior/superior and three rotations: flexion/extension, internal/external, and abduction/adduction. The movements of the knee joint are determined by the shape of the articulating

surfaces of the tibia and femur and the orientation of the four major ligaments of the knee joint: the anterior and posterior cruciate ligaments and the medial and lateral collateral ligaments functioning as a four bar linkage system.

Knee flexion/extension involves a combination of rolling and sliding called 'femoral roll back' which is an ingenious way of allowing increased ranges of flexion. Because of asymmetry between the lateral and medial femoral condyles the lateral condyle rolls a greater distance than the medial condyle during the first 20 degrees of knee flexion. This causes coupled external rotation of the tibia which has been described as the 'screw-home mechanism' of the knee which locks the knee into extension (Blankevoort et al., 1988; Lafortune et al., 1992).

The primary function of the medial collateral ligament is to restrain valgus rotation of the knee joint with its secondary function being control of external rotation. The lateral collateral ligament restrains against varus rotation as well as resisting internal rotation.

The primary function of the ACL is to resist anterior displacement of the tibia on the femur when the knee is flexed and control the 'screw home mechanism' of the tibia in terminal extension of the knee. A secondary function of the ACL is to resist varus or valgus rotation of the tibia, especially in the absence of the collateral ligaments. The ACL also resists internal rotation of the tibia.

The main function of the PCL is to allow femoral rollback in flexion and resist posterior translation of the tibia relative to the femur. This is also important for improving the lever arm of the quadriceps mechanism with flexion of the knee. The PCL also controls external rotation of the tibia with increasing knee flexion.

The movement of the patello-femoral joint can be characterized as gliding and sliding. During flexion of the knee the patella moves distally on the femur. This movement is governed by its attachments to the quadriceps tendon, ligamentum patellae and the anterior aspects of the femoral condyles. The muscles and ligaments of the patello-femoral joint are responsible for producing extension of the knee. The patella acts as a pulley in transmitting the force developed by the quadriceps muscles to the femur and the patellar ligament. It also increases the mechanical advantage of the quadriceps muscle relative to the instant centre of rotation of the knee.

The mechanical axis of the lower limb is an imaginary line through which the weight of the body passes. It runs from the centre of the hip to the centre of the ankle through the middle of the knee. This allows normalisation of gait and protects the tibia from eccentric loading.

2.3   Knee disorder

Knee disorder can result from wear and tear, infection, trauma or disease. Osteoarthritis is the most common form of knee disorder. It is also known as degenerative joint disease. It is characterized by the breakdown of the articular cartilage within the joint. While the exact cause is unknown, there are known to be several possible causes including: injury, age, congenital predisposition, obesity, metabolic or constitutional attack and involves new tissue production in response. Part of the body's response is to produce osteophytes. The most common inflammatory type is rheumatoid arthritis. It primarily affects the synovium, which thickens and secretes chemicals damaging the cartilage and other tissue (Doherty et al., 2001). In the Netherlands, up to one quarter of all people over 55 have osteoarthritis of the knee, and a further one-seventh have rheumatoid arthritis (Schouten et al., 2003). Severe pain during daily activities and inflammation of the joints are indications for treatment. Medicines, weight loss and physiotherapy can only treat moderate forms of arthritis. When these conservative treatments fail, (total) joint replacement is the intervention for patients with pain, limitation of motion, and/or deformities.

Although in 1890 the first endoprosthesis with any success was reported (Gluck, 1890), the modern history of knee arthroplasty began in the 1940's, and is today second only to the hip as the most commonly replaced joint. World wide more than 750,000 primary and revision knee arthroplasties are performed each year.

Knee arthroplasty involves resurfacing of the condylar and tibial surfaces. There are a large number of total knee arthroplasty (TKA) designs available for the surgeon to implant, depending on the age and expected activity level of the patient, and on the preoperative deformity and stability of the knee. If the arthritis or other abnormal condition (such as avascular necrosis or fracture) affects only the medial or lateral

compartment of the knee, a unicompartmental arthroplasty may be performed, in which only the condylar and tibial surfaces of that particular compartment are replaced. If both the medial and lateral compartment are involved, a TKA is performed, which may or may not involve resurfacing of the patella (Barrack et al., 2001).

All total knee prostheses sacrifice the anterior cruciate ligament. Some also sacrifice or substitute for the posterior cruciate ligament while others retain the PCL. All of these devices are considered unconstrained or partially constrained, depending on the degree of stability they provide to the knee joint. Fully constrained devices act like simple hinges and provide complete stabilization to a knee that no longer has any inherent stability, but are used in less than 5% of the cases (Vince, 1996).

Although total knee replacements have excellent long term survival (Buechel, 2002; Gill et al., 1999; Keating et al., 2002), wear is one of the critical factors limiting the long-term success of total knee prostheses (Wimmer & Andriacchi, 1997). Retrieval studies of tibial inserts have shown that low-conformity and the thicknesses of the polyethylene insert are associated with increased wear (Bartel et al., 1986; Collier et al., 1991; Wright et al., 1992). To reduce excessive wear, one should increase the contact area between the tibial and femoral components (Sathasivam et al., 2001). Even in the most highly evolved designs of fixed bearing knees there is an intrinsic conflict between the need for dispersing contact forces over a greater range of the polyethylene tibial component in order to reduce wear, and the reduction in mobility that results from the more highly conforming polyethylene.

The introduction of mobile bearing knees in the late 1970's was intended to address this 'kinematic conflict' with designs that combined a highly conforming surface and a mobile polyethylene tibial component (Buechel and Pappas, 1990; Jordan et al., 1997). The highly conforming surface disperses contact stresses over a greater area, thus potentially reducing wear. At the same time, the mobile polyethylene bearing allows a degree of motion that has the potential to reduce implant to bone interface stresses. Such stresses have been shown to lead to implant loosening in highly conforming fixed-bearing knee designs. The defining feature of a 'mobile bearing knee' is the presence of a moving polyethylene bearing that articulates with both the femoral condyle and the tibial tray.

2.4   Mobile bearing prostheses

Today, there are nearly fifty different mobile bearing knee designs in use. They utilize a number of design variations that attempt to achieve low contact stress while maintaining near natural mobility (Callaghan et al., 2001). These design variations include:

Type of bearing surface

Platform: a single polyethylene bearing that rotates in the transverse plane, with or without anterior-posterior motion (rotating only or multidirectional platform – Figures 3A and 3B, 4 and 5).

Figure 3A. Low Contact Stress (LCS) Rotating Platform (J&J DePuy, Warsaw, Indiana, USA).

Figure 3B. TRAC Mobile Bearing Knee System (Biomet, Bridgend, UK).

Figure 4. Mobile Bearing Knee
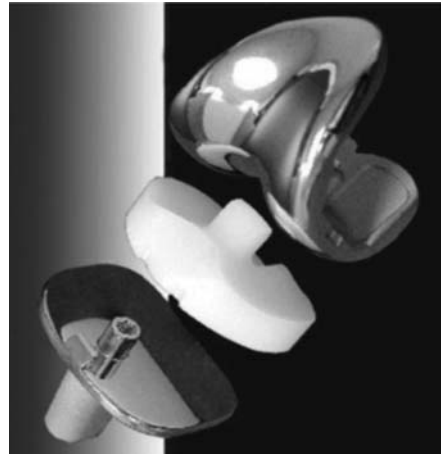(Zimmer, Warsaw, ID, USA).

Figure 5. LPS-Flex Mobile Knee
(Zimmer, Warsaw, ID, USA).

Meniscal bearing: separate medial and lateral polyethylene bearings that slide independently in arced tracks that run anteriorly and posteriorly in the fixed, metal tibial component (Figure 6).

Figure 6. Low Contact Stress (LCS) Meniscal Bearings (J&J DePuy, Warsaw, Indiana, USA).

Unicondylar meniscal bearing: an implant in which only the medial or lateral compartment of the knee is replaced. The polyethylene may run in a track as described above, or may move freely, held in place only by its reciprocal shape and the tension of the surrounding ligaments (Figure 7).

Figure 7. Oxford Unicompartmental Knee (Biomet, Bridgend UK).

Type of constraint

Cone-in-cone design: incorporates a tapered projection of the polyethylene insert that inserts into a reciprocal concavity in the tibial tray (Figure 3).

Tibial tray post: A post extending from the superior surface of the tibial tray fits into a recess on the polyethylene insert (Figure 4, 5).

Longitudinal curved sliding tracks: Movement of the platform or meniscus is limited by a track formed in the upper surface of the tibial tray (Figure 6).

Stops: Elevated rim of the tibial tray that limits excessive anterior-posterior translation or rotation (Figure 5).

Unconstrained bearing: designs that lack a mechanical limit to movement, but instead rely on the conformity of the polyethylene mobile bearing to the femoral condyle and the tension of the soft tissues (Figure 7).

Directional mobility of the bearing surfaces

The mobile polyethylene bearing has been utilized in a variety of designs that permit mobility in one or more directions. Some have only rotational mobility, which permits internal and external movement in the transverse plane. Some have multidirectional mobility, which may include anterior/posterior and medial/lateral movement in addition to rotational mobility. Designs can be characterized

as "unconstrained", "semi-constrained", and "constrained". Unconstrained are those designs characterized by very low constraint forces over the entire range of normal (physiologic) displacements. Semi-constrained are those that have near physiologic constraint that rises over the range of normal displacements. Constraint forces that exceed physiologic levels and rise sharply over the range of displacements characterize constrained designs.

Rotation in the transverse plane (internal/external rotation) is a primary requirement of normal gait (Lafortune et al., 1992; Andriacchi & Dyrby, 2005). Constrained and semi-constrained medial/lateral mobility is characteristic of both mobile and fixed bearing knee designs, and does not adversely affect clinical performance (Banks et al., 2003; Dennis et al., 1998; Stiehl et al., 1997).

Congruence

Fully congruent mobile bearing knees are those that have a high degree of conformity between the femoral condyle and the polyethylene bearing surface, over a wide range of flexion (approximately 120 degrees). The congruence is achieved over this range by providing a constant sagittal femoral radius. These prostheses have a theoretical range of flexion of 120 degrees, limited by posterior impingement of the tibial component. A fully congruent prosthesis has a large contact area between the femoral condyle and the bearing surface, which disperses contact forces. This can result in reduced polyethylene wear.

During gait congruent or partially congruent mobile bearing knees have large contact areas in the first 20 degrees of flexion. The contact area decreases with flexion due to a decreasing sagittal radius. These prostheses maximize contact areas in the more important low end of the flexion range, while decreasing the sagittal radius to improve flexion range.

PCL management

Mobile bearing knees are available in PCL-retaining, PCL-sacrificing and PCL stabilizing designs (respectively Figure 3A, 4 and 5). In general, knees with only rotating mobility utilize a PCL sacrificing or PCL-stabilizing design, while multidirectional platform knees generally are PCL-retaining. Based on the radiological knee joint destruction, one should decide to retain or sacrifice the PCL (Nelissen and Hogendoorn, 2001).

In summary, there are numerous mobile bearing knee designs on the market worldwide that are designed with two common purposes. The first is to increase contact area in order to reduce long-term wear. The second is to reduce implant-to-bone interface stresses and allow good kinematics by the mobility of the polyethylene bearing on the tibial plate. The number of variations of mobile bearing knee designs available proofs the interest in evaluating the clinical success and performance of current designs with the aim to improve the mobile bearing alternative to traditional fixed bearing knees. Since the differences between (mobile bearing) total knee designs are small, this requires objective and accurate performance assessment and evaluation tools.

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