Normal knee joint kinematics with regard to total knee replacement

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Every knee has its individal envelope of motion. The joint surfaces, the ligaments and the articular capsule determine the range of motion. In walking, stability is mainly provided by the muscles. Malalignment is the usual reason for failure in knee replacement with PCA prostheses. Preoperative planning is essential for operative success

I. R. Huiskes, Ann Arbor, USA, opened his talk with the question: What are the normal kinematics of the knee joint? The region in which the knee normally functions is a region of laxity. Within that region the knee has very little resistance against forces, so a relatively small force can produce a large displacement. It is the muscles in particular that mostly determine the stability of the joint. This is even more common in rotation.

"Every knee joint has its own envelope of motion." I. R. Huiskes, Ann Arbor

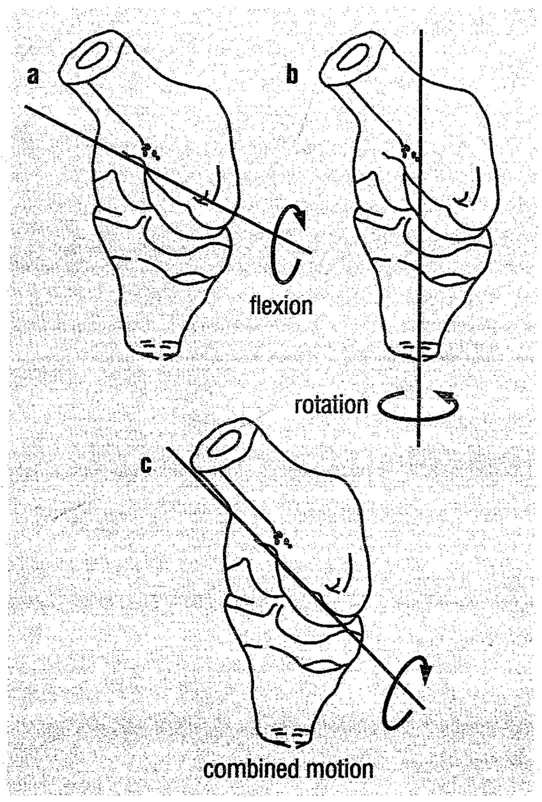
On the other hand the envelope of motion is limited by the ligaments. Motion is really only possible up to a certain point, because after that the ligaments would fail. Within this envelope there are several motions possible *(Fig. 2)*. A motion purely along a horizontal line would be pure flexion. If the knee is rotated, pure rotation takes place, and if the knee is moved in any other direction the movement is a combination of rotation and flexion. So the knee joint is actually a joint with two degrees of freedom.

The terms "the centre of rotation" of the knee joint, "the motion axis" of the knee joint are often used because it is a two-degree-of-freedom joint. In fact, there is no such thing as "*the* motion axis", Huiskes stressed. In actual motions infinitely many different axes are possible: flexion, rotation, and anything in between. It is this region of motion within regional freedom, within the envelope of motion, that is actually used during function. So, in his opinion two things are important to take into account: first of all, *laxity*, even in a relatively stiff direction, which is anterior or posterior, and then a *two-degree freedom of motion* of the joint in which the actual stability and position within this region are taken care of by the muscles.

Motion of the knee: a complex interplay of forces

It is very important, Huiskes said, to appreciate that this whole play of the knee joint is motion play along the envelopes of motion, the function as an effect of an interplay between the soft tissues and the joint surfaces *(Fig. 3)*.

In fact, as in any mechanical system, the motion is a result of the



Possibilities of knee joint motion. a: Flexion/ extension; b: rotation; c: combined motion (Fig. 2)

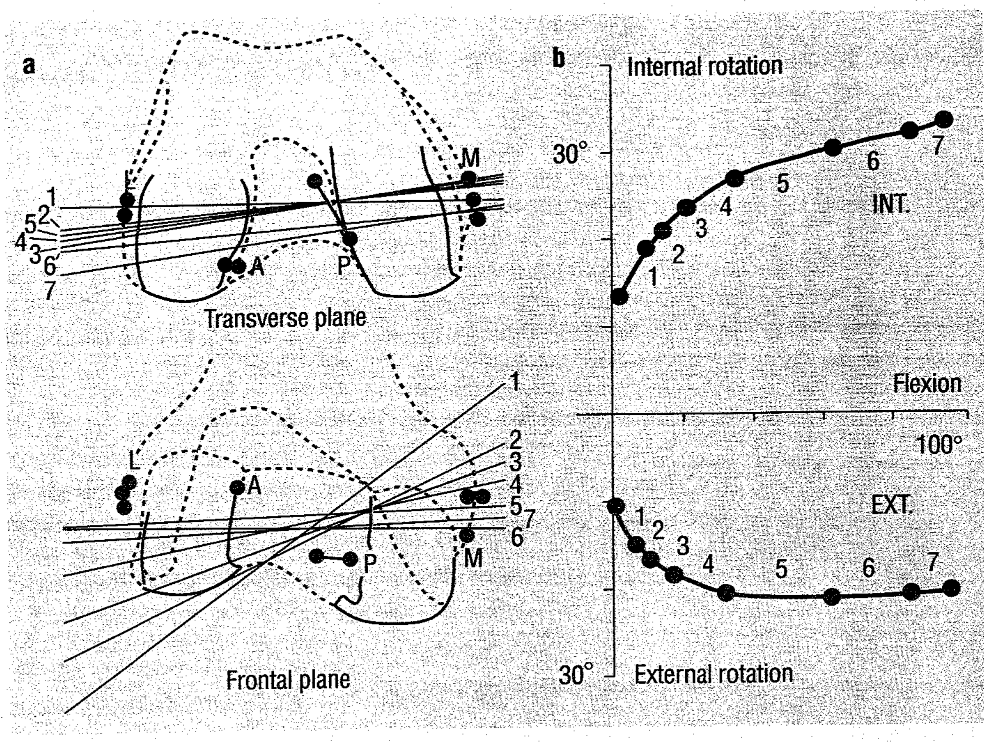
dynamic forces that are exerted on the joint. There are external forces from many sources – muscles, gravity, etc. – and due to the bounds of forces we have a particular motion. However, the system is much more complicated then just a simple relationship, because the motions in their turn again influence the forces. This is a feedback system.

Thus, if there is a particular external force, giving a particular motion, the effect is that a force in the ligament develops (ligament force). Ligament forces are dependent on changes in the length of the ligament, and also on where the ligaments are. The articular contact forces also come into play in determining the dynamic equilibrium of the joint in any given moment of time. There is also a feedback mechanism, known as screwing out of the joints. Ligament forces can increase the contact forces and within the play use the subtle relationships between ligaments, their positions, their properties and the joint surfaces.

In any given particular joint the association between joint surface geometry, joint surface mechanical properties and the ligament structure is a marriage. They belong together. One cannot take the geometrical surface configuration of one person and the ligament properties and geometrical configuration of another and think that one has a functional joint. They are very much interrelated and of course adapted to the particular situation *(Fig. 4)*.

Problems of joint replacements

It is then possible at all, Huiskes asked, to replace a joint surface without influencing ligament tension and joint kinematics? The answer is simply "No". If it is not possible, can a solution be sought? Of course that was always worth



▲ ***The amount of internal/external motion depends on flexion/extension of the knee: flexion increases the rotational freedom (Fig. 3 a, b)***

asking. If it is impossible to avoid changing ligament tension, perhaps it would be possible to influence it only a little? It is possible, of course, but technically very demanding, Huiskes concluded.

The second question was: What are the essentials of biomechanics in endoprostheses that must not be neglected? There are two of these.

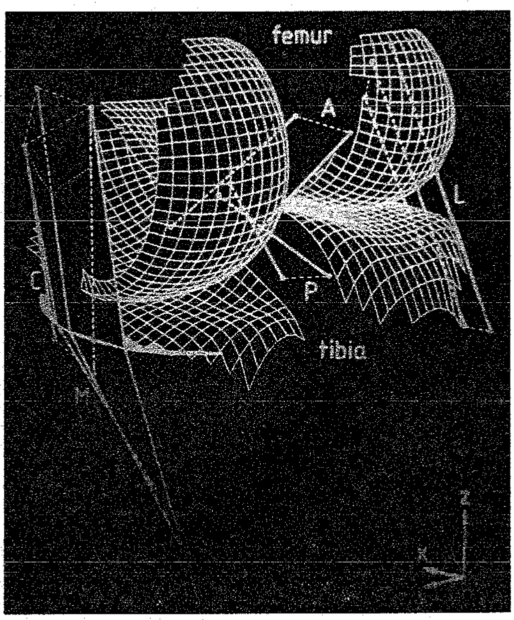
Preoperative planning essential for success

The first essential is that, relative to the design of the prosthesis, it must be appreciated that in order to provide the knee in the condylar type prostheses with the laxity that the normal knee has, a small contact region must be accepted. A small contact region means high forces, polyethylene is a weak material, and polyethylene damage is the most important problem. So that is the first essential problem – *polyethylene destruction.*

The second essential, which is badly neglected, is *alignment*. An investigation in a multi-centre study of a large number of PCA prostheses found that in over 50% the joint was malaligned. "Malalignment" was taken as a displacement of the mechanical axis from the centre of more than 2 cm. The cause of malalignment was also investigated, and it turned out that in 80% of the cases the preplanning procedure had not been used. The preplanning procedure is necessary for most prostheses to determine how the instruments should be set, how the particular anatomy of the person to be operated on should be considered. In regard to the hip joint, at least in the Netherlands, Huiskes remarked, only 20% of surgeons ever use the preplanning procedure. Malalignment means that there is more load on one of the plateaux, more wear, interface loosening, subsidence, etc.

The final question was: What are the results if the freedom of motion is reduced by a prosthesis? According to Huiskes, there are two consequences. One is functional. It is generally agreed that if the prosthesis reduces freedom of motion to pure flexion/extension, the patient's motion freedom is limited. Whether that is a great problem is open to doubt. Quite a few people walk around with joints like that; they are usually elderly and appear to be quite happy with the freedom of motion that they have.

A much more important consequence is that every force put to the leg is directly transmitted to the interfaces of the prosthesis and is not resisted by the muscle forces. That means that, for constrained prostheses, the consequences are high interface pressures and a high risk of interface loosening. Those are the preliminary answers to those questions. ■



▲ ***The envelope of motion is limited by the joint congruity and the ligaments (Fig. 4)***

Discussion

➔ *If 50% of the replacements are malaligned, this is not so bad as might be imagined, because only a percentage of knee joints that are malaligned fail. It is very difficult to find any positive evidence in the literature that malalignment is a common cause of failure in knee replacement. If 50% of knee joints are placed in a malaligned position, a very large proportion of them still continue to function in spite of that malalignment.*

Huiskes: That is a very good point. In the aforementioned recent study with PCA knees a correlation was found between results of wear and malalignments. Of course this is very difficult to measure. In very many instances it is even impossible to measure malalignment because no long-standing X-rays are taken. In the same study, the precision of alignment measurements without long-standing X-rays was also investigated. The precision of that procedure, taking the tibial axis and the femoral axis and trying to reconstruct the position of the joint relative to these axes, is terribly poor.

Experiments looking at wear have also been done in a joint simulator, and showed clearly that wear increased progressively with malalignment – so theoretically, from an experimental point of view, it is evident that malalignment is bad.

➔ *How much disarrangement between surface geometry and ligament length may be tolerated in the long run without getting the leg's becoming unstable?*

Huiskes: That is a question which is very difficult to answer. The response of the ligaments to the placement of the prosthesis is very nonlinear in a certain region. It is just like the placement of an anterior cruciate. In one particular region, if there is a little bit of mismatch the consequences are not grave. However, there certainly is a spot – this is further and reached very progressively – where high tension develops with flexion and extension. In clinical practice quite often the objective of retaining ligaments is abandoned, because it turns out that while working on the joint the ligaments have to be sectioned.

➔ *The mechanical axis is a line joining the hip to the ankle and passing through the knee. It does this only when the knee is straight. Most arthritic patients have some degree of flexion deformity and so for most of them the mechanical axis – whatever that is – lies behind the knee joint. They bend their knees and go up and down stairs and nobody worries about the direction of the line of action of the load in relation to the tibial plateau when the knee is bent. But a couple of degrees of variation of the line of action of the knee when seen in the frontal plane are worried about a great deal. What is the difference?*

Huiskes: That is quite right, but it is not the point. The point is really that alignment is the position of the prosthesis *relative to* the bound and that is measured in a frontal X-ray. It is also important to put each of the two components in correct relation to each other.

➔ *In unconstrained prostheses with polyethylene components, the wear rate is becoming very high, because load transmission to the polyethylene is not possible to that extent. This is one region of risk in an unconstrained model. You also pointed out the other dangerous interface between prosthesis and bone where a higher load transmission has to be brought about in constrained prostheses. Might there be constructional features in the anchorage of prostheses which might allow load transmission from the bone to the prosthesis and back again?*

Huiskes: The load depends on the kinematic arrangement. If, for instance, there is internal/external laxity in the prosthesis, then there will be no internal/external torque to the interfaces. Today in unconstrained prostheses the interface is not a major problem. The major problems in unconstrained prostheses are wear and patellar problems. So the problem of interfaces occurs only in constrained prostheses. Particularly in the hinged prostheses, the loading of the interface is very high. There does not appear to be an adequate solution for this.

➜ *Nevertheless, within the envelope of motion special types of motion are theoretically possible provided that the constraint and the forces generated by that constraint are transferred to the surrounding bone sufficiently. A prosthesis which has more constraint must not be condemned as nonbiological or nonphysiological.*

Huiskes: No, that is so. It all depends on the demands of the patient really. As was mentioned, most patients are quite happy with a constrained flexion-extension motion only. Of course, many younger patients demand more mobility.

➜ *The envelope of motion in a severely arthritic knee is reduced by the congruity of the joint surfaces, osteophytes, and everything to a nearly pure flexion/extension.*

Huiskes: Every knee has an envelope of motion. Old knees with osteophytes in the intercondylar space have not much rotation. Most older patients have been operated on without this envelope, without this movement of rotation in the knee. That does make a difference between theory and practice. In practice, an old person who has a very narrow envelope of motion and a very small range of motion will be happy postoperatively with a constrained prosthesis, because there is not much difference in function. The difference for any patient with constrained motion is that the forces formerly taken by the joint structures will now be taken by an interface. ■

Characterization of the different prosthesis models

Polyethylene is always exposed to wear. The more punctual and asymmetric the force on the surfaces, the stronger the wear. Thus, fatigue wear is more often found in unconstrained prostheses. In regard to wear problems, a prosthesis should have an axis that avoids fatigue wear and two polyethylene parts on the tibial plateau

***"Fatigue wear is more frequent in unconstrained prostheses."* W. Plitz, Biomechanics Laboratory, Orthopaedic Clinic, Munich**

In 1985 an international standard was designed for prostheses used to replace some or all of the bearing surfaces of the knee joint. Many courses have been held on the definition, introduction, scope and field of application of this standard, began *W. Plitz, Munich.*

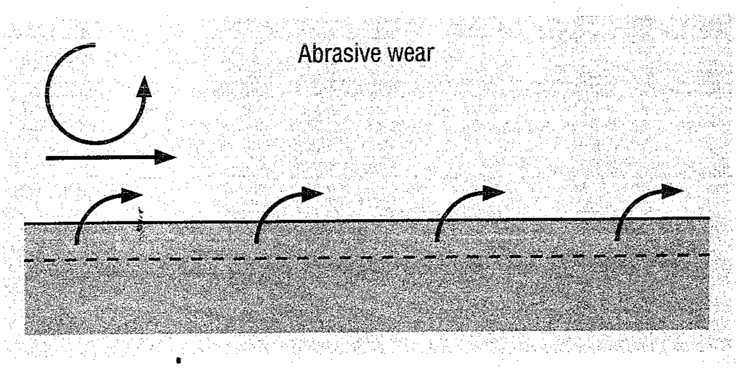
The prostheses are classified as follows:

a Unicondylar (femoral, tibial)
b Bicondylar (femoral, tibial)
c Partial joint replacement (unicondylar, unicompartmental)
d Total joint replacement (non-, partially or fully constrained)

It is difficult to fit all the existing models into these four classifications. Plitz described some special problems of all these types. He reported on the analysis by his group of 155 removed knee prostheses and how they tried to classify the type and degree of wear and the wear problems in the components. Different wear mechanisms exist, he confirmed.

Types of wear

In the smooth type a polished surface is seen. This phenomenon is normally found 1-2 years after surgery. The next step is abrasive wear.



▶ ***Pathway of abrasive wear (Fig. 5)***