Chapter 1

General introduction
1.1 Development of total knee prostheses

In the late 1960's and early 1970's the first modern total knee prostheses were developed based on hinged and unicondylar implants which were already available (Freeman et al., 1977; Insall et al., 1979a,b; Yamamoto, 1979). Current total knee prostheses are directly derived from these first prostheses and represent variations of the basic concepts introduced. Intrinsic constraints, including the shapes of the articular surfaces, post-cam mechanisms and insert mobility, have been altered to reproduce the form and function of the healthy knee (Banks and Hodge, 2004b; Pandit et al., 2005). The importance of the development in prosthetic design relates directly to the fact that the aspiration of total knee arthroplasty moved from that of a salvage operation for pain control, only performed in extreme cases, to an intervention to improve the quality of life and functionality. Pain and loss of function due to osteoarthritis and rheumatoid arthritis are nowadays the main indicators for replacement of the knee joint. The objective one hopes to achieve with total knee arthroplasty are long-lasting pain relief and restoration of functionality of the knee joint in terms of stability, mobility and load-bearing capacity (Banks et al., 2003b; Catani et al., 2006; Kim et al., 2001).

The maximum lifespan of total knee prostheses is limited; survival rates between 78% to 98% at twenty years have been reported (Buechel, 2002, 2004; Gill et al., 1999; Keating et al., 2002; Rand et al., 2003; Stiehl, 2002). Survival rates are dependent on gender, age and diagnosis of the patient, as well as, prosthetic design and fixation method (Rand et al., 2003). Reasons for revision are septic loosening (infection), aseptic loosening (associated with component malalignment and soft tissue imbalance) and wear of the polyethylene insert.

Total knee prostheses consist of a femoral component, a tibial component, an insert and in some cases also a patellar button. The first total knee prostheses had J-curved or multi-radius femoral components which means that the components had a variable sagittal curvature. This results in artificial joints with multiple axes of rotation through the arc of flexion. In these so-called multi-radius knees, the motion
of the knee is mainly guided by the shape of the articulating surfaces.

The first post-operative kinematic problems that were encountered in the mid 1970’s with total knee prostheses were limited flexion and the lack of posterior roll-back of the femoral component on the tibial component, resulting in paradoxical anterior translations. Posterior-stabilized prostheses were developed to prevent these paradoxical anterior translations during flexion. The post-cam mechanism in posterior-stabilized knee prostheses replaces the function of the posterior cruciate ligament and induces posterior displacement of the femoral component on the tibial component during flexion. This posterior displacement will avoid impingement and thereby improves the range of motion of the knee (Insall et al., 1982).

Mechanical loosening and wear of the polyethylene insert are the primary complications in knee replacement. In the late 1970’s and early 1980’s, mobile-bearing prostheses were introduced to prevent these complications. The mobility of the mobile insert allows a higher congruency between the femoral component and the polyethylene insert, which results in an increased contact area and subsequent lower contact stresses in the insert compared to non-congruent fixed-bearings (Andriacchi, 1994; Blunn et al., 1997; Dennis et al., 2005; Stiehl et al., 1997; Uvehammer et al., 2007).

Joint instability in mid-flexion and the belief that there is only one flexion-extension axis fixed in the femur led to the latest large adaptation made in total knee implants. Single-radius prostheses have been developed in the mid 1980’s as an alternative for the multi-radius prostheses. A single-radius design allows the ligaments to guide the motion of the knee on the articulating surfaces. The single axis of rotation is aligned with the transepicondylar axis providing ligament isometry and a substantial contact area throughout the entire range of motion. This provides a more uniform motion, lower contact stresses on the insert, improved mid-flexion stability and more efficient muscle activity (Kessler et al., 2007; Wang et al., 2006).
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1.2 Theoretical considerations for mobile-bearing total knee prostheses

There are numerous mobile-bearing knee prostheses on the market worldwide, most of them based on the mobile-bearing concept of the LCS-prosthesis. Mobile-bearing knees vary in type of bearing surface (single platform, separate meniscal bearings or an unicompartmental meniscal bearing), type of motion constraint (cone-in-cone, tibial tray post, stops or unconstrained bearing) and type of mobility (rotating platform or multidirectional mobility). The models with rotating platforms are often based on a conventional prosthesis and share the same femoral components with the fixed-bearing prosthesis.

Mobile-bearing knee prostheses were designed to mimic the function of the human meniscus by accommodating the natural combination of rolling and sliding movements (Goodfellow and O’Connor, 1978). The intact meniscus is relatively free to distort and can be displaced forwards and backwards upon the tibial condyles in order to take up and distributes the stresses between the non-conforming surfaces of the tibial and femoral joint surfaces.

The essential point of the mobile-bearing knee prosthesis is that the polyethylene insert can move with respect to the underlying tibial component and does not restricts the natural movements of the femoral component. The mobility of the insert allows a higher congruency between the insert and the femoral component, which leads to an increased contact area and thus lower contact stresses and wear in comparison with non-conforming fixed inserts (Andriacchi, 1994; Blunn et al., 1997; Buechel, 2004; Dennis et al., 2005; Matsuda et al., 1998; Li et al., 2006; Stiehl et al., 1997; Uvehammer et al., 2007). Furthermore, the unrestricted movement of the insert unouples the forces generated at the articulation from the prosthesis-bone interface. This could have a positive effect on the fixation of the prosthesis to the bone and thereby decreases the risk for loosening (Garling et al., 2005b; Henricson et al., 2006; Huang et al., 2007). Another potential advantage of a mobile-bearing over the fixed-bearing knee, stated in literature, is self-adjustment of the insert to accommodate
surgical malalignment. This self-adjustment might improve patellar tracking and maximal knee flexion (Cheng et al., 2003; Huang et al., 2007; Matsuda et al., 1998; Pagnano et al., 2004). However, surgeons should not select a mobile-bearing knee prosthesis based on the assumption that their surgery does not need to be as accurate as that of a surgery using a fixed-bearing knee prosthesis.

Mobile-bearing total knee prostheses have also potential disadvantages. First, mobile-bearing implants are less forgiving for imbalance in soft tissue compared with fixed-bearing implants. An accurate surgical technique is essential for a good result since the knee stability depends on well balanced ligaments and soft tissues around the new knee joint. Soft tissue instability might also lead to dislocation of the polyethylene insert (Callaghan, 2001).

A second disadvantage is that the polyethylene insert has two potential wearing surfaces: the upper surface in contact with the femoral component and the lower surface in contact with the tibial component. No evidence exists whether this two sided polyethylene wear is less than the one sided polyethylene wear of fixed-bearing knee prostheses. In vitro simulator studies show reduced wear rates in mobile-bearing knee prostheses compared to fixed-bearing knees due to redistribution of knee motion to two articulating interfaces with more linear motions at each interface (Haider and Garvin, 2008; McEwen et al., 2005). However, it is not clear if this also applies in vivo. Polyethylene debris (wear particles) has been implicated as the cause of osteolysis and subsequent implant failure. As the body attempts to clean up these wear particles it triggers an autoimmune reaction which causes resorption of living bone. Osteolysis seems to be dependent on the size of wear particles. The particles in mobile-bearing knees are claimed to be smaller, inducing more bone resorption compared to fixed-bearing knees (Huang et al., 2002).

A third disadvantage concerns mechanical failures of mobile-bearing knee prostheses like (partial) dislocation and even breakage of the polyethylene insert (Callaghan, 2001).
1.3 Clinical considerations for mobile-bearing total knee prostheses

The concept of mobility in total knee prostheses is attractive. Most orthopaedic surgeons and researchers have an explicit preference for one or the other but this is mainly based on eminence based knowledge in stead of on strong evidence based medicine. There has been no convincing evidence that the theoretical advantages of mobile-bearing knee prostheses translate into a benefit for the patient and deliver a better clinical outcome in the short (i.e. better functionality) or long-term (i.e. less wear). Better long-term survivorship and better clinical function compared to the fixed-bearing designs, have not yet been demonstrated in any outcome studies (Hamai et al., 2008; Hansson et al., 2005; Hanusch et al., 2010).

The reasoning behind mobile-bearing knee prostheses is that the mobility permits increased articular congruency between the femoral component and the insert, reducing contact stresses and thus reducing polyethylene wear compared to fixed-bearing knees. Therefore, for mobile-bearing knee prostheses to be considered successful, the polyethylene bearing should accommodate rotation during frequently encountered daily activities. Only a few studies are performed to evaluate the in vivo three-dimensional motion of the insert (Fantozzi et al., 2004; Garling et al., 2007b). In those studies a relatively small motion of the bearing was observed during various activities which questions the benefit of the mobile-bearing. When there is no or minimal rotation at the tibial-insert interface, the theoretical advantages which should lead to reduced contact stresses and polyethylene wear will not be accomplished and could even lead to longevity problems. However, if mobile-bearing knee prostheses are inserted with the same precision as fixed-bearing knee prostheses, the clinical outcome should be at least comparable (Callaghan, 2001).

Each total knee prosthesis has its own theoretical advantages and disadvantages. However, it is no exception that knee implants do not show in vivo the advantages they are designed for. Better understanding the influence of design parameters on in vivo kinematics, stability and muscle activation is fundamental for improving current
total knee prostheses to reach the objectives of long-lasting pain relief and restoration of knee joint stability, mobility and load-bearing capacity (Andriacchi et al., 1982; Banks and Hodge, 2004a; Taylor and Barrett, 2003; Wang et al., 2006). This is of importance because of the growing population of younger patients who will require not only an implant to function for at least two decades, but also one that is adapted to the higher physical demands of the younger patient.

1.4 Aim of this thesis

The aim of this study is twofold. First, to study if the *in vivo* kinematics of mobile-bearing total knee prostheses was consistent with the kinematics intended by the design and second to determine the additional value of insert mobility and thus ‘the sense or nonsense’ of mobile-bearing total knee prostheses.

1.5 Outline of this thesis

In Chapter 2 a short introduction of normal knee joint kinematics and knee prosthesis kinematics is given.

In Chapter 3 gait analysis was used to identify differences in muscle activity levels and co-activation patterns between patients with a mobile-bearing prosthesis or a fixed-bearing prosthesis and healthy controls.

The goal of Chapter 4 was to develop and test an integrated method to assess kinematics, kinetics and muscle activation of total knee prostheses during dynamic activities. This multi-instrumental analysis was then used to assess the relationship between kinematics, kinetics and muscle activation and early migration of the tibial component of total knee prostheses.

In Chapter 5 and 6 the tibiofemoral kinematics, including the *in vivo* axial rotation of the polyethylene insert, of two mobile-bearing total knee prostheses was assessed using fluoroscopy. The purpose of these studies was to determine the change in
tibiofemoral kinematics over time and to show the importance of re-evaluating knee kinematics.

In Chapter 7 a prospective randomized study was performed to compare a fixed-bearing and mobile-bearing single-radius total knee prosthesis and study the effect of a mobile-bearing on early migration of the tibial component and knee kinematics.

In Chapter 8 different total knee prostheses were compared to determine if in vivo kinematics was consistent with the kinematics intended by design.

Chapter 9 provides a general discussion and conclusion of the work presented in this thesis.