Discussion and conclusion
9.1 Introduction

The focus of this thesis was if the in vivo kinematics of total knee prostheses was consistent with the kinematics intended by design and to determine the additional value of insert mobility and thus 'the sense or nonsense' of mobile-bearing knee prostheses. The added value of this thesis to the current literature is the integration of different measurement techniques. The majority of studies exploring differences in total knee prostheses include only questionnaires and radiological examinations or just knee kinematics using fluoroscopy or motion analysis. Questionnaires like the WOMAC\(^1\), KSS\(^2\) and SF-36\(^3\) are not objective and accurate enough to detect potentially functional differences in total knee prostheses and therefore more objective and accurate measurement tools to detect subtle functional differences should be developed (Harrington et al., 2009). Better understanding the influence of design parameters on in vivo kinematics, stability and muscle activation is fundamental for improving current knee implant designs (Andriacchi et al., 1982; Banks and Hodge, 2004b; Taylor and Barrett, 2003; Wang et al., 2006). In this thesis, fluoroscopy is combined with RSA and motion analysis techniques to fully understand the in vivo knee kinematics beyond which can be obtained by either technique alone. In this chapter the major conclusions of this thesis are discussed and some limitations and recommendations for future research are describes.

Worldwide, there is a wide diversity of total knee prosthesis designs, including numerous mobile-bearing implants. Each implant is developed with specific properties and with a specific patient group in mind and therefore has its own theoretical advantages and disadvantages. There is a long-standing controversy on which type of total knee prosthesis provides better kinematics and clinical outcome. A huge number of kinematic studies have been performed to evaluate the performance of total knee prostheses. Total knee arthroplasty has proven to be a successful and durable solution; however, it is still not clear if the restoration of normal knee

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\(^1\)Westren Ontario and McMaster Universities index
\(^2\)Knee Society Score
\(^3\)Short-Form Health Survey
kinematics is possible or necessary. The fundamental goal of total knee arthroplasty is to give the patients what they need for their everyday activities: pain relief, a good post-operative range of motion and stability (Costigan et al., 2002).

9.2 Fluoroscopy

In vivo functional testing seems extremely useful in optimizing knee implant designs for better function, better fixation and improved long-term results (Andriacchi et al., 1982; Banks and Hodge, 2004b; Taylor and Barrett, 2003). Three-dimensional (3D) fluoroscopic analyses is the most accurate measurement technique to examine the in vivo kinematics of total knee prostheses under weight-bearing activities (Banks et al., 1997b; Dennis et al., 1996; Garling et al., 2005a; Stiehl et al., 1999). Besides the big advantage of the high accuracy of fluoroscopy, there are also a few drawbacks. Firstly, the small field of view confines the analysis to only a single joint. Secondly, a major difficulty is to measure weight-bearing knee kinematics other than stair ascent and descent due to the rigid fluoroscopic equipment. Activities such as gait cannot be performed easily because the knee moves out of the field of view. Gait is the most performed every day activity and therefore to study knee kinematics, fluoroscopy studies evaluating gait would be preferred. In our measurement set-up it was not possible to study gait because of the rigid c-arm. Currently, the University of Florida and the University of Zurich are developing movable c-arms by which the number of activities can be enlarged and gait can also be studied. Thirdly, a drawback of fluoroscopy is the patient exposure to radiation. Despite the exposure being very low, patients often experience problems with other joints, and are also under medical treatment for additional disorders, getting multiple radiological examinations a year.

Despite the high accuracy of fluoroscopy, in clinical studies large enough patient groups have to be included to reach sufficient statistical power. Unfortunately, the number of patients receiving total knee prostheses in our hospital was too small to create large patient groups. Approximately 40 patients a year are considered for total knee arthroplasty and not all patients are suited to participate in a clinical study.
Furthermore, the excessive post-processing of the fluoroscopic images per patient (3 days per patient) discourages large patient groups. Further automating the post-processing software would solve this problem (A.H. Prins, thesis 2012). Another software and measurement improvement would be to know the starting orientation of the mobile insert. Using the tantalum markers inserted in the polyethylene, change in orientation of the insert with respect to the orientation of the insert in the reference image can be calculated. Knowing the starting orientation would make it possible to model the insert between the tibial and femoral component and calculate contact points, impingement points and the accurate anterior-posterior translation patterns of the femoral component on the insert.

9.3 Kinematics

This thesis showed that in vivo kinematics of most included total knee prostheses were consistent with the kinematics intended by their design. However, some prostheses showed reversed or paradoxical kinematics in parts of their functional range of motion. If the theoretical kinematics is not in accordance with the in vivo kinematics, the manufacture should optimize the new prosthetic design to prevent excessive polyethylene wear with subsequent prosthesis loosening. This is of importance because of the growing population of younger patients who will require an implant to function for at least two decades (Chapter 8).

The variability in kinematics, seen in the literature as well as in this thesis, could be explained by patient diversity (osteoarthritis and rheumatoid arthritis), pre-operative deformities, muscle adaptations and the different surgeons (Banks et al., 2003a). It is known that surgeons are still the largest variable in outcome after total knee arthroplasty. Factors that play a major role in dysfunction of any knee, and are related to the surgical procedure, are frontal plane malalignment, axial malrotation, sagittal overstuffing of the knee, inappropriate level of joint space, inappropriate constraint or ligamentous imbalance and poor initial fixation of the implant (Banks et al., 2003b; Callaghan, 2001; Nozaki et al., 2002; Rousseau et al., 2008).
9.4 Muscle activations

Knowledge of the muscular control of knee prosthesis provides insight into the integration of the prosthesis within the musculo-skeletal system. After total knee arthroplasty, rheumatoid arthritis patients showed lower net knee joint moment and higher co-contraction than healthy controls indicating avoidance of net joint load and an active stabilization of the knee joint (Chapter 3). Anticipatory stabilization and co-activation are mechanisms to protect the soft tissue from external loads by increasing the stiffness of the knee (Andriacchi, 1994). However, moving with excessive muscle activations and co-activations is inefficient and large forces are transmitted to the bone-implant interface which could lead to micromotion of the tibial component (Grewal et al., 1992) (Chapter 4).

The extra degree of freedom in mobile-bearing knees might require higher muscle activity levels of the extensor (quadriceps) and flexor (hamstrings) muscles to stabilize the knee. However, in this thesis, mobile-bearing and fixed-bearing groups had the same co-contraction levels, although coordination in patients with a fixed-bearing was closer to healthy controls than patients with mobile-bearing total knee prostheses (Chapter 3). Muscle activity timing which was different for the mobile-bearing and fixed-bearing groups, may express compensation by coordination (Chapter 3). Furthermore, muscle activation did not change in the first two post-operative years (Chapter 5 and 6). Therefore, to prevent problems caused by excessive muscle activations and co-activations, rehabilitation programs for patients with total knee prostheses should include besides muscle strength training, elements of muscle-coordination training.

9.5 Patella

Despite the patella being an important part of the knee joint, the patella was not included in this thesis due to practical issues with the fluoroscopic set-up. The out-of-plane inaccuracy and visualisation problems of the patella in the fluoroscopic
images made it impossible to include the patella in the measurements performed. Osteoarthritis and rheumatoid arthritis cause changes not only in the knee joint but also on the back of the patella. If the patella is damaged, it needs to be resurfaced during total knee arthroplasty. The patella (resurfaced or not) interacts with the patellar groove of the femoral component. Malalignment of the femoral component in a more internally or externally rotated position will have an effect on patellar tracking and knee kinematics. Furthermore, reversed axial rotations seen after total knee arthroplasty can cause patellofemoral instability and maltracking of the patella (Dennis et al., 2004, 2005; Most et al., 2003). In turn, this will cause increased contact pressure at the lateral aspect of the patella and influences the quadriceps moment arm (Andriacchi et al., 1997; Andriacchi and Hurwitz, 1997; Most et al., 2003). Therefore, in future studies evaluating kinematics and clinical outcome of total knee prostheses, it is recommended to also take the patella into account.

### 9.6 Motion of the mobile insert

High congruency between the insert and the femoral component in combination with free rotation of the mobile insert is assumed to be beneficent for the longevity of the prosthesis by reducing multidirectional wear on the femoral aspect of the insert and friction at the bone-implant interface. However, in Chapter 4 and 5, high congruency of the insert seems to lead to undesired restrictions of motions of the femoral component which in turn might be a disadvantage for the functioning and long-term survival of that specific total knee prosthesis design. At lower knee flexion angles, the femoral component is obstructed by the highly congruent insert and is not able to move freely. This leads to high stresses at the insert which will be transferred to the bone-implant interface.

Furthermore, this thesis shows that high congruency does not guarantee adequate insert rotation. Reversed and divergent axial rotations with increasing knee flexion were seen in patients with the ROCC total knee prosthesis. The single-radius Triathlon total knee prosthesis including a less congruent insert showed preferable
axial rotation of the insert compared to that of the high congruent ROCC total knee prosthesis (Chapter 4, 5, 8). Based on these results, an optimal level of congruency between the insert and femoral component should be found.

The inserts of two (Triathlon and ROCC) of the three mobile-bearing groups moved as predicted on theoretical grounds and remained mobile several years postoperatively. The comparable axial rotations of the insert and the femoral component supports the assumption of redistributing the knee motion to two articulating interfaces with a more linear motions at each interface leading; pure rotation at the lower surface and anterior-posterior motions at the upper surface. The absence or reduced mobility seen in one of the mobile-bearings knees makes this implant very similar to a fixed-bearing prosthesis (Chapter 6). This absence or reduced mobility will also enhance wear of the polyethylene and could induce a higher incidence of loosening by transmitting larger forces to the bone-implant interface (Andriacchi, 1994; Bottlang et al., 2006; Blunn et al., 1997; Dennis et al., 2005; Stiehl et al., 1997; Uvehammer et al., 2007; Garling et al., 2005c). In this thesis, the mobile inserts did not add additional mobility to the knee joint compared to the fixed-bearing groups. However, additional mobility was possibly not necessary during the dynamic motions performed.

Chapter 7 shows early migration in 33% of the mobile-bearing group versus 9% in the fixed-bearing group. This indicates that early migration of the tibial component is worse in the mobile-bearing group. Despite the mobile insert was following the femoral component during motion, and therefore performed as intended, no kinematic advantages of the mobile-bearing total knee prosthesis were seen. The fixed-bearing knee performed as good as the mobile-bearing knee and maybe even slightly better based on less paradox and reversed motions and less early migrations.

9.7 Final Conclusions

In this thesis, fluoroscopy was combined with RSA and motion analysis techniques to fully understand the in vivo knee kinematics beyond which can be obtained by either
technique alone. Results demonstrate that the integration of different measurement techniques was indeed of great value to comprehend the *in vivo* knee kinematics.

This thesis showed that the *in vivo* kinematics of most included total knee prostheses were consistent with the kinematics intended by their design. However, some prostheses showed reversed or paradoxical kinematics in some parts of their functional range of motion. Because of the high accuracy, it is recommended that fluoroscopy is used for evaluating the kinematics of new total knee prostheses before introducing it to the market.

Based on this thesis, it was also possible to determine the additional value of insert mobility and thus ‘the sense or nonsense’ of mobile-bearing knees. It is concluded that a mobile-bearing insert in single-radius total knee prostheses is redundant and will not lead to additional benefits. Finally, at the current time there is no compelling reason for the widespread use of mobile-bearing total knee prostheses over successful fixed-bearing total knee prostheses either in terms of improved kinematics, early migration, clinical and radiological success.