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

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Chapter 6

Increased muscle activity to stabilise mobile bearing knees in patients with Rheumatoid Arthritis

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Abstract

The aim of this study was to assess the differences in muscle activity (surface EMG) between a posterior stabilised (PS) total knee design and a mobile bearing (MB) posterior cruciate ligament retaining design in rheumatoid arthritis (RA) patients during a step-up task.

Four patients with a PS total knee prosthesis and three patients with a MB total knee prosthesis were selected based on pain score, knee function, range of motion and joint stability.

Clinical scores and functional scores were comparable between the two groups preoperatively and at the one-year follow-up. Visual analysis of the EMG activity of the main flexor and extensor muscles showed that the activity of both extensor and flexor muscles of the MB group was on average higher compared to the PS group. When the maximum activities of the muscles were compared, the patients in the MB group showed a significant higher maximum peak activity ($p < 0.05$) of the Vastus Medialis, Vastus Lateralis and Semitendinosus during step-up than the patients in the PS group. Also the instance of activation of the Vastus Medialis and the Vastus Lateralis was significant earlier in the MB group compared to the PS group.

Since the differences between the PS and the MB group didn't only show an increase of muscle activity but also an earlier activation of the flexor muscles, this may express compensation by coordination. Rehabilitation programs for RA patients should include besides muscle strength training, elements of muscle-coordination training.

6.1 Introduction

The success of total knee arthroplasty (TKA) is influenced by a complex interaction between the geometry of the implant and the active and passive soft-tissue structures that surround the articulation (Callaghan et al., 2000). Knee joint kinematics after TKA influence the performance and lifespan of the prosthesis. Several studies have related variations in the abnormal gait patterns after TKA to the design of articulating surfaces (Dennis et al., 1998; Kärrholm et al., 1994; Nilsson et al., 1991) and the aetiology of prosthetic loosening (Hilding et al., 1995).

PS total knee prostheses substitute for the posterior cruciate ligament by a post-and-cam mechanism, which causes rollback when the knee is flexed, translating the femorotibial contact area posterior and thereby increasing the quadriceps extension moment. However, this central cam also imposes some restrictions towards the kinematics. The PS total knee is designed to provide passive stability and therefore improves postoperative function and prevents posterior subluxation of the tibia (Stern and Insall, 1992).

MB total knee prostheses have polyethylene inserts that can translate and rotate with respect to the tibial plateau. The MB knee is designed to allow the kinematic advantages of large and highly congruent surface contact and low contact pressures, while preserving flexion, extension and rotation in knee motion (Kaper et al., 1999). In the mobile bearing knee design, there is an increased dependence upon preserved ligaments and active structures to provide stability. Therefore, it is hypothesized that the muscle groups surrounding the knee should show more active stabilisation in patients with a MB prosthesis, whereas in patients with a PS prosthesis the knee joint is stabilised primarily by the intrinsic constraint of the design and thus would need less muscle activation.

The aim of this study was to assess the differences in muscle activity between RA patients with either a PS total knee design or a MB posterior cruciate ligament retaining design during a step-up task.

6.2 Methods

Four patients with a PS total knee prosthesis and three patients with a MB total knee prosthesis were selected based on pain score, knee function, range of motion and joint stability (Table 1), from a larger group of patients included in a previous study comparing MB and PS total knees (Garling et al., 2005). All the patients included in this study suffered from rheumatoid arthritis. The patients were included at one year postoperatively, and they had to be able to perform a step-up movement. Furthermore, they had to have a unilateral total knee replacement, the ability to walk more than one kilometre, and not use walking aids and/or a functional impairment of any other lower extremity joint besides the operated knee. All recorded data was coded.

Table 1. Clinical data and functional scores at the one-year follow-up evaluation.

		Age [years]	**BMI** [kg/m^2]	**Knee Score** [pts]	**Function Score** [pts]	**Flexion** [°]	**M-L instability** [°]	**A-P instability** [mm]	**Fem-Tib Angle** [°]
	1	74	32.2	85	100	130	< 5	10-14	183
MB	**2**	74	27.7	94	100	120	< 5	< 5	178
	3	63	31.2	88	15	90	5-10	< 5	179
	1	62	24.8	85	80	90	< 5	6-9	183
PS	**2**	63	23.6	87	100	100	< 5	< 5	183
	3	57	32.1	97	30	110	< 5	< 5	183
	4	76	31.2	89	70	125	< 5	< 5	188

In the PS group the patients had received the Interax Posterior Stabilised total knee prosthesis (Stryker-Howmedica, Rutherford, New Jersey, USA). In the MB knee group, the Interax Integrated Secure Asymmetric (ISA) total knee prosthesis was used. This mobile bearing total knee design is only conforming in extension and permits anterior/posterior sliding and rotation of the inlay on the tibial tray. The maximum possible movement of the inlay center is 8.5 mm anterior/posterior and 18 degrees of axial rotation relative to the tibial tray.

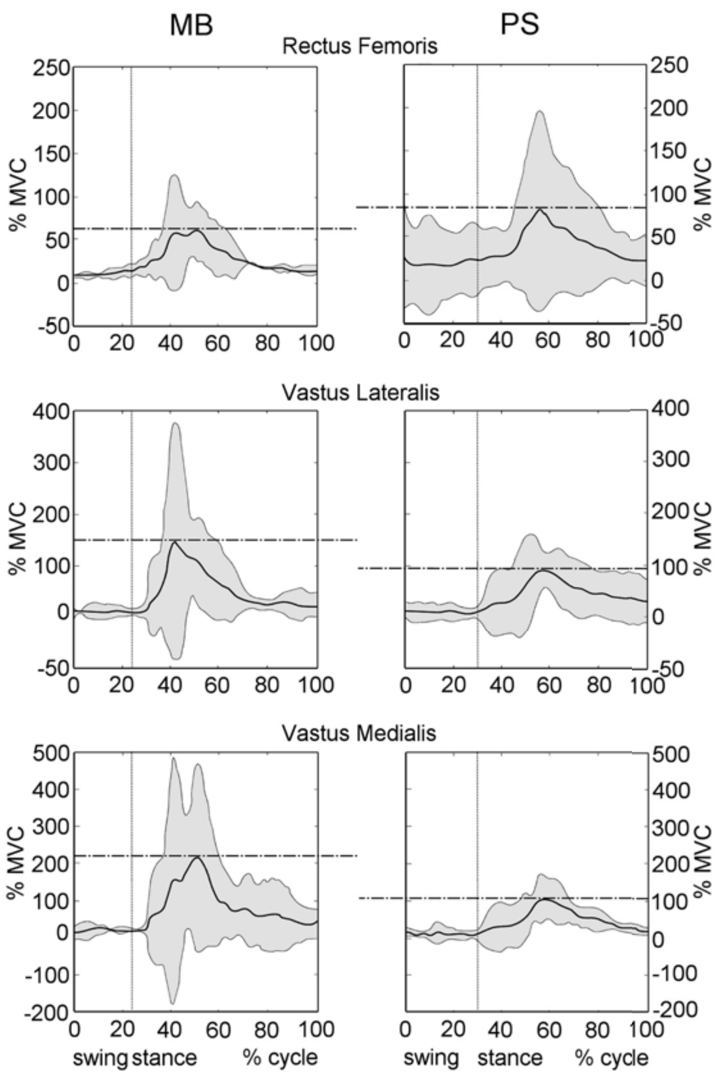

Figure 1. Smoothed rectified EMG of the extensors around the knee during step-up. The EMG signal is averaged and normalised to the MVC for all subjects in each group (MB: n=3; PS: n=4). The greyed area indicates the 95% confidence interval. The start of the stance phase is visualised by the dotted vertical line

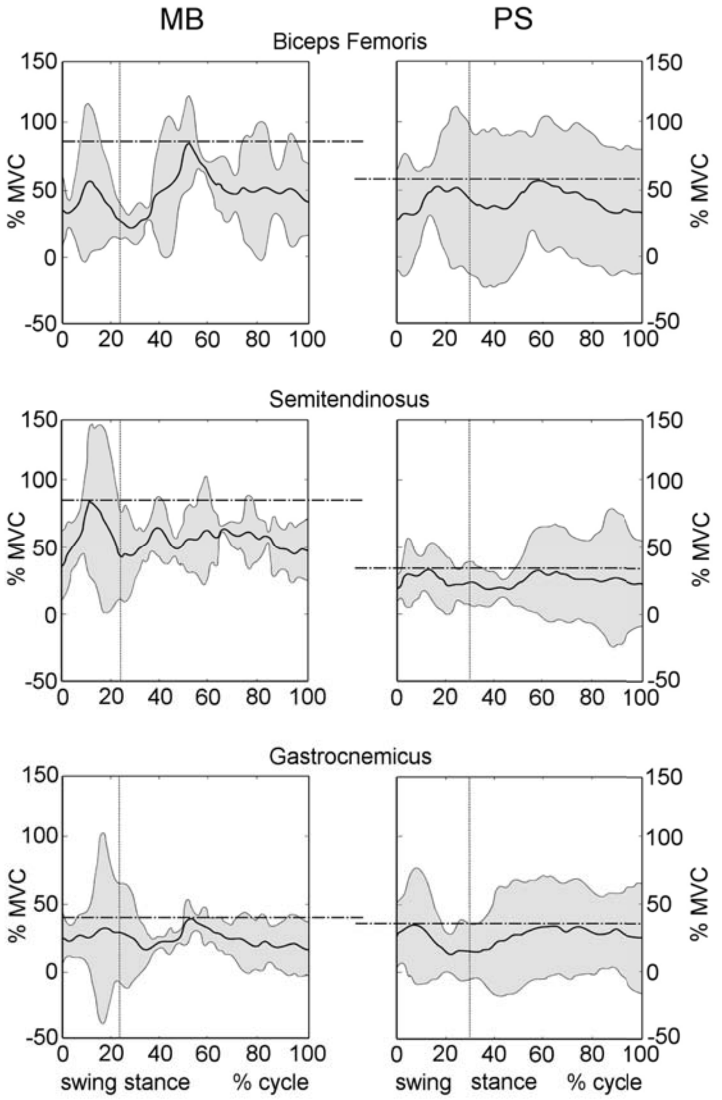

Figure 2. Smoothed rectified EMG of the flexors around the knee during step-up. The EMG signal is averaged and normalised to the MVC for all subjects in each group (MB: n=3; PS: n=4). The greyed area indicates the 95% confidence interval. The start of the stance phase is visualised by the dotted vertical line. The dashed-dotted line indicates the difference between the two groups of the EMG signal for each muscle.

External movement registration (Optotrak: Northern Digital inc., Canada) was used to determine the beginning and the end of the step-up cycle. A force plate was used to determine the onset of the stance phase during the step-up. All measurement systems were time-synchronised. The activity was performed barefoot without the aid of bars. Prior to the recordings, functional and anthropometrical measurements were taken. Patients were assessed clinically by an orthopaedic surgeon using radiographic and functional evaluation using the Knee Society Score (Ewald, 1989).

Surface EMG of the most important stabilising muscles of the knee was recorded at a sample frequency of 1000 Hz. The muscles recorded were the Rectus Femoris (RF), Vastus Lateralis (VL), Vastus Medialis (VM) as the major extensor muscles; the Biceps Femoris (BF) and Semitendinosus (ST) as two major flexor muscles; and the Gastrocnemius Medialis (GM). Electrode placement for the different muscles used in this study was similar as described by Nelissen et al. (1995). Before placing the electrodes, the skin was shaved, slightly braided and cleaned with alcohol to reduce skin resistance. EMG data were processed with Matlab (The Mathworks Inc., Natick, USA). After removing movement artefacts the raw data was high-pass filtered (Butterworth, 10 Hz) and full-wave rectified. This full-wave rectified signal was filtered with a low-pass filter using a second-order recursive Butterworth filter with a cut off frequency of 2 Hz. The recorded EMG was normalised to the Maximum Voluntary Contraction (MVC). This MVC was determined by an isometric contraction of each muscle prior to the experiment. The average of three isolated MVC's of each muscle was used to normalise the recorded EMG.

Telemetric Light Emitting Diodes (LED's) were placed on the operated leg of each patient, located at anatomical landmarks, and were recorded with a frame rate of 100 Hz. The LED's were attached at the anterior superior iliac spines, the lateral malleolus, the lateral side of the fifth metatarsal and the lateral aspect of the calcaneus. Two cameras of the Optotrak system were positioned lateral-frontal and lateral-dorsal of the patients operated side. When markers were occluded during the measurements the missing values were replaced by means of interpolation.

A strain gauge force plate with a surface area of 1 m^2 was used to measure at a frame rate of 500 Hz the ground reaction forces in all directions. The force plate was calibrated prior to the measurements (Pijnappels et al., 2001).

At the beginning of the step-up the patient was asked to stand, feet together, at a distance of 15 cm in front of the 18-cm-high force plate platform, and step onto the platform using the limb with the implant under investigation. The start of the movement cycle (0%) was defined as the first change in position (movement speed > 0.01 m/s) of one of the foot markers. The end of the movement cycle (100%) was defined as the maximum height of the Spina Iliaca Anterior Superior (end of single limb support). The movement cycle was divided into a swing phase and a stance phase. The swing phase was defined as the first part of the movement cycle until the instant of support (force on platform > 10 N). The stance phase was defined from the moment of support until the end of the movement cycle. After a brief orientation session, the patient performed the step-up three times, with a rest period of 2 minutes between trials.

Non-parametric tests were used to determine the differences in maximum activity of the recorded muscles between the two groups. Statistical differences were defined as significant at an alpha level of 0.05.

6.3 Results

The preoperative and one year follow-up clinical scores and functional scores were comparable between the two groups (Table 1). Patient 3 of the MB group had a poor function score. The Knee Function Score showed that this patient was unable to walk more than one kilometre at the time of the measurements and used a rail to step-down from the stairs. However, the patient was pain free and had no impairments when climbing stairs. Two patients had a limited flexion of 90 degrees of the knee joint. These patients had no flexion contracture but a small lateral femoral component flexion angle (0-1 degree). When this angle is (too) small, high flexion of the knee will result in early impingement of the femoral component with the tibia.

No difference in co-contraction was observed between the two groups. In Figure 1, the mean EMG data of the extensor muscles is presented as a percentage of the MVC, of all patients in each group during the step-up task. For the BF and ST – as the flexor muscles – the data is presented in Figure 2. Visual analysis shows that the

activity of both extensor and flexor muscles of the MB group is on average higher compared to the PS group. Only the RF showed on visual basis a higher activity in the PS group compared to the MB group. However, this difference was not significant. When the maximum activities of the muscles were compared, the patients in the MB group showed a higher maximum peak activity of the VM ($p = 0.023$), VL ($p = 0.029$) and ST ($p = 0.011$) during step-up than the patients in the PS-group. Also the instance of activation of the VM and the VL was significant earlier in the MB group compared to the PS group (respectively $p=0.043$ and $p=0.049$). The VM and VL in the MB group and the RF in the PS group showed a large 95% confidence interval, showing not only the inter-individual differences but also intra-individual differences.

Two patients of the MB group reported a subjective unstable feeling in the knee. The EMG data of these two patients showed also a high maximum activity of VM and VL.

6.4 Discussion

Differences in kinematics between the PS and the MB group were analysed during a step-up movement. Stairs and steps are frequently encountered during the course of daily activity and are important aspects in functional assessment. In comparison to normal walking stair climbing is a more stressful activity, which requires a greater flexion of the knee. Therefore, during this activity it is possible to stress differences between different knee replacement designs more clearly (Andriacchi et al., 1982).

Although the study population was a homogeneous group, the inclusion criteria bias the outcome of the study since the selected patients represent the 'best' patients of the original knee prostheses cohort (Garling et al., 2005). Patients with MB total knees will benefit from well functioning active and passive soft-tissue structures surrounding the knee joint preoperatively, since preoperative function and general condition of the patient are important factors determining the postoperative function after TKA (Nelissen, 1995). However, no significant differences in clinical and function scores between the two groups were observed preoperatively. Only 7 patients in this rheumatoid group sufficed the inclusion criteria. This emphasises that a prerequisite for patients after TKA is a good muscle function to be able to perform a step-up at all. Statistical analysis showed a low power i.e. more false negative outcome, because of this small number of patients and the large observed confidence intervals in the EMG data. Nevertheless, the EMG data supported our hypothesis.

The maximum voluntary contraction (MVC) was used in this study to normalise the muscle activity. The EMG data of the MB group showed activity of the VM and VL larger than 100%. This might be explained by a sub maximal contraction of the patients during the MVC measurements due to improper activation of the isolated muscle. Another explanation could be avoidance for pain during contraction, however the patients reported no pain during the measurements. Furthermore, enforced tasks during daily activities may often require higher activation levels of the muscles than patients are willing to give during a MVC measurement. Recently, a different method of normalising EMG data was published (Doorenbosch and Harlaar, 2003). The EMG data was normalised using a limited number of isokinetic contractions of the knee during the entire range of motion. The normalised data showed a high discriminating power. It is advised to normalise EMG data for TKA patients by means of this method in the future.

In vivo fluoroscopic studies have shown an abnormal anteroposterior translation during flexion and extension of the knee in both mobile and fixed bearing designs (Callaghan et al., 2000; Dennnis et al., 1998; Stiehl et al., 1997). This paradoxical movement is responsible for unfavorable kinematics of the extensor mechanism. The predominant shear force during gait and stair climbing is directed posterior on the tibia, which normally is resisted by the posterior cruciate ligament, preventing an anterior movement of the femorotibial contact point (Andriacchi and Hurwitz, 1997). At lesser degrees of flexion, the direction of the patellar ligament pull is anterior on the tibia. The anterior cruciate ligament normally resists this anterior directed shear force on the tibia. Since the anterior cruciate ligament is absent in both the PS and MB designs, the femorotibial contact point will shift to anterior especially in a MB design where there is no central cam preventing anterior translation. As a consequence of this anterior movement of the tibia, the quadriceps efficiency is reduced by a

decrease of the moment arm about the condylar contact point (Andriacchi et al., 1982). Higher levels of activity of the quadriceps are expected in patients who have this anterior translation of the tibia at the beginning of extension. In this study we also found more activity in the VM and VL muscles. Fluoroscopy could be the appropriate technique to confirm the anterior translation of the femorotibial contact point in patients with high EMG activity of the quadriceps (Dennis et al., 1998; Stiehl et al., 1997; Banks et al., 1997).

Since the cruciate ligaments are disrupted after TKA, normal physiological knee joint kinematics cannot occur (O'Connor et al., 1996). Soft tissue and muscles acting on the knee substitute for the absence of the anterior cruciate ligament and or the posterior cruciate ligament. One of the difficulties described in PCL-retaining designs is tensioning of the posterior cruciate ligament. If the tension of the PCL is not restored properly, the ligament will lose its stabilising function (Dennis et al., 1998; Nelissen, 1995). The importance of the PCL is higher with larger flexion angles. Inadequate tension could also be an explanation for the higher compensatory activity of the quadriceps during extension in the MB group. The EMG data of the MB group showed a statistically significant higher maximum activity of the VM and VL during the stance phase of step-up. In normal subjects the VL is also an important stabiliser of the knee during stair ascent (McFayden and Winter, 1988).

The early onset of hamstring activity, especially the lateral hamstrings (BF), is due to the dynamic stabilisation of the knee in preparation for foot contact with the ground (Lass et al., 1991). In the MB group the BF showed a higher activity than in the PS group before the stance phase. This anticipation before contact with the ground was further emphasized in the total movement time of the step-up. The BF pulls the tibia into a position so that the knee joint is stable during extension.

Higher EMG levels of the main stabilisers of the knee (i.e. quadriceps and hamstrings) in the MB group indicate that compensatory muscle activity is used to stabilise the femur with respect to the tibia. It has been shown that simultaneous contraction of the knee muscles increase the stiffness of the joint and reduces anterior-posterior laxity up to 50 percent of the normal value (Markolf et al., 1987). This kind of protective knee stabilisation in MB knees has also been observed in a study comparing a MB and a fixed bearing TKA design (Catani et al., 2003). In that study a decrease in the frontal external knee moments in the MB group was observed suggesting that compensatory mechanism seemed to be adopted especially during stair ascending.

The mobile bearing design is more forgiving during surgery, self-correcting the slight axial mal-rotations between the actual anatomy and the total knee prosthesis. Furthermore, slight mal-rotations between the femoral and tibial component will be adjusted as well. However it seems that a MB design is more demanding for the RA patient requiring a better preoperative and postoperative status of the ligaments and the muscles consuming more energy.

Since the differences between the PS and the MB group didn't only show an increase of muscle activity but also an earlier activation of the flexor muscles, this may express compensation by coordination (Rutherford, 1988). Rehabilitation programs for RA patients should include besides muscle strength training, elements of muscle-coordination training.

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