Does Minimally Invasive Total Knee Arthroplasty Improve Isokinetic Torque?

Michael C. Liebensteiner MD, PhD,
Martin Krismer MD, Arnold Koller PhD,
Barbara Semnitz MD, Eckart Mayr MD

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Abstract

Background Less invasive dissection of the extensor apparatus, one of the aspects of minimally invasive surgical (MIS) TKA, might result in less reduction of postoperative quadriceps strength. However, it is unclear whether MIS is associated with less strength reduction.

Questions/purposes We asked whether knee strength (extensor or flexor torque) would be greater in patients having a MIS TKA compared with patients having a standard TKA and whether knee scores, alignment, ROM,

tourniquet and operating times, and hospital length of stay were improved.

Methods We prospectively recruited 52 patients awaiting MIS or standard TKA, matched for age, weight, height, BMI, sex, and surgically treated side, but not randomized. Isokinetic tests were performed preoperatively and postoperatively to obtain peak values of extensor and flexor torque. Postoperative-to-preoperative ratios and the extensor-flexor torque ratio also were calculated.

Results Mean baseline extensor torques were 57 Nm and 53 Nm for MIS and standard TKAs, respectively. At 8 weeks postoperatively, absolute values of the mean postoperative knee extensor torque also were similar: 47 and 45 Nm for patients with MIS and standard TKAs, respectively. The postoperative-to-preoperative ratios were 0.8 for extensor and flexor torque in both groups. The extensor-flexor torque ratios were similar between groups.

Conclusions Our data suggest a less invasive dissection of the extensor apparatus involved in MIS TKA does not enhance postoperative quadriceps strength.

Level of Evidence Level III, therapeutic study. See Guidelines for Authors for a complete description of levels of evidence.

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All ICMJE Conflict of Interest Forms for authors and *Clinical Orthopaedics and Related Research* editors and board members are on file with the publication and can be viewed on request. Each author certifies that his or her institution approved the human protocol for this investigation, that all investigations were conducted in conformity with ethical principles of research, and that informed consent for participation in the study was obtained. This work was performed at Innsbruck Medical University, Innsbruck, Austria.

M. C. Liebensteiner (✉), M. Krismer, E. Mayr
Department of Orthopaedic Surgery, Innsbruck Medical
University, Anichstrasse 35, 6020 Innsbruck, Austria
e-mail: michael.liebensteiner@i-med.ac.at

A. Koller
Institute for Sports Medicine, Alpine Medicine
and Health Tourism, Natters, Austria

B. Semnitz
Department of Internal Medicine, Innsbruck
Medical University, Innsbruck, Austria

Introduction

Minimally invasive surgical (MIS) TKA was developed to facilitate early and intermediate-term rehabilitation. MIS generally includes reduced length of skin incision, less invasive arthrotomy, avoidance of tibiofemoral dislocation or hyperflexion, and use of special cutting blocks and retractors [4, 12].

The literature contains inconsistent findings regarding whether MIS achieves its stated goals. Typical knee scores for MIS TKA as compared with standard TKA have been

reported as improved in the long term [4, 11, 21], improved only in the short term [15, 18, 27], or similar [24, 25, 30, 37]. The same has been observed with respect to radiographic findings (leg alignment and/or component alignment). Some authors reported inferior radiographic alignment [7, 19, 44], whereas others reported similar alignment [11, 13, 15] for MIS and standard TKAs. There is some consensus in the literature regarding the rate of improvement in ROM; many authors have reported a faster gain in ROM for patients having MIS TKA, at least during the first few weeks postoperatively [8, 11–13, 18, 19, 21, 27].

Given the less invasive dissection of the extensor apparatus with MIS TKA, the latter might be associated with better postoperative quadriceps strength. Many authors assessed quadriceps function in terms of rehabilitation milestones (eg, straight leg raise) after MIS and standard TKAs [8, 16, 20, 25, 33]. The findings in those studies are consistent, in that quadriceps function was superior with a MIS TKA during the first postoperative week [8, 16, 33]. Only a few studies reported on quadriceps function in terms of rehabilitation milestones beyond the first postoperative week; Kolisek et al. [25] reported no strength differences 12 weeks after surgery, and the strength findings observed by Karpman and Smith [20] 2 weeks postoperative were dependent on the type of MIS approach (quadriceps-sparing superior, but mini-midvastus not superior as compared with medial parapatellar). Quadriceps outcome in terms of rehabilitation milestones might be dependent on the subjective interpretation of the observer. Other authors investigated knee extensor (and partly flexor) torque as an objective parameter of quadriceps function after MIS and standard TKAs [5, 23, 33, 37, 44]. The findings from those studies are inconsistent. Some reported better extensor torque during the first 4 weeks postoperative in patients who had MIS, which no longer was present in the following months [33, 37, 44]. Others found equal extensor torque during the first postoperative measurements among patients who had MIS and standard TKAs, but better torque after 1 year in patients who had MIS [23]. Others reported better results for 3 and 12 months postoperative among patients who had MIS [5]. In addition to the incongruent findings, most of the mentioned studies did not assess the torque ratio between knee extension and flexion [5, 33, 37, 44], although it was reported as a parameter indicating quadriceps-hamstrings imbalance [21, 26, 35, 36].

Given the contradictory information in the literature, we asked whether (1) postoperative knee torque (extensor and flexor) was greater, (2) scoring on a typical knee questionnaire was improved, (3) alignment was equal, and (4) ROM, (5) length of hospital stay, (6) tourniquet use, and (7) operating times were reduced in patients after MIS TKA compared with after standard TKA.

Patients and Methods

We prospectively recruited 52 patients awaiting either standard or MIS TKA between 2007 and 2010. Exclusion criteria were (1) age younger than 55 years and older than 80 years, (2) neuromuscular or neurodegenerative disease, (3) BMI of 35 or greater, (4) prior arthrodesis in any joint of the lower limbs (except for Toes II–V), (5) prior TKA on the contralateral side, (6) prior arthroplasty of the ipsilateral hip or ankle, and (7) constant need for walking aids. There were 24 and 28 patients in the MIS and standard TKA groups, respectively. In each group, 19 patients completed the measurements (Fig. 1). The study protocol was approved by the ethics committee of our institution, and written informed consent was obtained from all patients before inclusion in the study.

A clinically meaningful difference between groups was defined as 20 Nm difference in extensor torque. This was because previous studies reporting 10 to 15 Nm differences did not find accompanying differences in several knee scores [23, 37]. With a 20-Nm difference in means and $\alpha = 0.05$ and $\beta = 0.8$, we determined an effect size of 0.98 and a sample size of 18 per group. To compensate for potential loss of participants, 20 to 30 patients were included in each group. The groups were similar with respect to demographics and preoperative clinical, radiographic, and torque parameters (Table 1).

Patient positioning, antibiotic- and deep vein thrombosis prophylaxis, draping, and tourniquet control were standardized, and identical cruciate-retaining TKAs were performed in both groups (Scorpio™; Stryker Corp, Kalamazoo, MI, USA) using intramedullary referencing in the femur (rigid IM rod) and extramedullary referencing in the tibia. In accordance with the clinical routine at our institution, the patella was left unresurfaced. All operations were performed by experienced orthopaedic surgeons specializing in knee arthroplasty or under the supervision of one of these surgeons.

In the standard TKA group, a midline skin incision and a standard medial parapatellar arthrotomy were performed, and the patella was everted. The prosthesis was implanted according to the manufacturer's instructions using a measured resection technique and standard cutting blocks and instruments.

In the MIS TKA group, a midline skin incision was followed by a medial mini-midvastus arthrotomy (1–3 cm) [12]. The patella was subluxated instead of being everted. Special downsized retractors and cutting jigs [4] were used in accordance with the operation manual for the Scorpio™ MIS procedure as provided by the manufacturer. The major differences compared with standard TKA were less invasive arthrotomy, absence of patellar eversion, use of special instruments, and the tibiofemoral articulation was dislocated or hyperflexed only during cementing of the tibia [4, 12].

Fig. 1 This flowchart shows patient recruitment and dropouts.

Table 1. Patient demographics and preoperative characteristics

Parameter	MIS TKA	Standard TKA	p value
Age (years)*	66.7 ± 4.9	67.6 ± 6.9	0.65
Height (m)*	1.65 ± 0.08	1.65 ± 0.08	0.93
Weight (kg)*	82.8 ± 12.7	85.9 ± 12.24	0.44
BMI (kg/m ²)*	30.2 ± 3.8	31.5 ± 4.2	0.32
Left side (number of patients)	9	7	0.51
Right side (number of patients)	10	12	
Male (number of patients)	8	9	0.74
Female (number of patients)	11	10	
mFTA (°)*	2.7 ± 6.9	2.3 ± 6.8	0.869
Extensor torque (Nm)*	57 ± 30	53 ± 28	0.687
Flexor torque (Nm)*	36 ± 20	41 ± 19	0.477
Extensor-flexor torque ratio*	1.72 ± 0.82	1.34 ± 0.55	0.100
WOMAC pain (%)*	49.6 ± 19.2	53.4 ± 20.8	0.567
WOMAC stiffness (%)*	56.7 ± 30.4	60.8 ± 20.7	0.628
WOMAC function (%)*	54.6 ± 19.3	52.0 ± 18.1	0.665
WOMAC global (%)*	53.8 ± 19.1	53.0 ± 17.6	0.900

* Values are expressed as mean ± SD; mFTA = mechanical femoro-tibial angle (positive values = varus; negative values = valgus); MIS = minimally invasive surgery.

All patients underwent the same standardized rehabilitation program after surgery. Patients were mobilized from the second postoperative day under supervision of our

physiotherapists. Exercises included continuous passive motion, assisted and unassisted knee extension, walking and stair climbing with two crutches, and progression as tolerated.

Preoperative data were collected 1 month before surgery and postoperative data were collected 8 weeks postoperatively. The clinical outcome was assessed using the WOMAC index [2], which was completed by the patients on a self-administered basis. The WOMAC score consists of the subscales of pain (five items), stiffness (two items), and physical function (17 items), which were calculated and expressed as percentages of the maximum score of the subscales. Additionally, the three subscales were summed and expressed as a percentage (WOMAC global score).

The preoperative and postoperative mechanical femoro-tibial angles (mFTA) were taken from weightbearing whole-leg radiographs to determine the patient's leg axis. One investigator (MCL) who was not a treating surgeon made all radiographic measurements. Component alignment was determined postoperatively according to The Knee Society total knee arthroplasty roentgenographic evaluation and scoring system [10]. Alpha and beta angles were assessed to quantify frontal alignment of the femoral and tibial implants, respectively. Gamma and delta angles were assessed from lateral radiographs to determine sagittal alignment of the femoral and tibial implants, respectively.

One observer (AK) performed peak extensor and flexor torque measurements preoperatively and postoperatively in a standardized manner using an isokinetic dynamometer (Con-Trex® MJ; CMV AG, Zurich, Switzerland). Patients were seated on the dynamometer with their hip flexed to approximately 90° and their trunk secured with dual crossover straps and a waist strap. The ROM at the knee was set at 110° and was modified according to available passive motion and the subject's tolerance. The angle was 0° when the leg was fully extended at the knee and 110° when it was fully flexed. A thigh strap on the test leg was used to restrict any lateral movement at the knee, allowing only flexion and extension. The testing protocol consisted of concentric quadriceps and hamstrings contractions after familiarization with the equipment (2 minutes; submaximal trials at an angular velocity of 60°/second). The patients performed four repetitions at an angular velocity of 60°/second. Peak extensor and flexor torques were recorded for the surgically treated leg and used for statistical analysis. To directly compare the effect of surgery between groups, we determined postoperative-to-preoperative ratios of extensor and flexor torques [37, 44]. Additionally, the extensor-flexor torque ratio was determined to identify a potential imbalance of quadriceps and hamstrings [22, 25, 35, 36].

All but one parameter (interval-scaled data) were normally distributed as determined by Kolmogorov-Smirnov tests and analyzed for group differences using t-tests. Descriptive statistics were determined as means and SDs. Only the postoperative-to-preoperative ratios of extensor and flexor torque data sets were determined as not normally distributed and further analyzed using Mann-Whitney U tests. Descriptive statistics included medians and interquartile ranges. We compared the two groups by chi-square tests regarding proportions of sexes and surgically treated sides (nominal-scaled data). Statistical tests always were performed in a two-tailed manner using the Statistical Package for Social Sciences (SPSS-Norasis/SPSS Inc, Chicago, IL, USA).

Results

All mean torque measures were similar in both groups (Table 2). Absolute values of postoperative mean knee extensor torque were similar ($p = 0.757$) for patients with MIS and standard TKAs, 47 and 45 Nm, respectively. The mean postoperative knee flexor torques were 30 and 32 Nm for MIS and standard TKAs, respectively ($p = 0.677$). Median postoperative-to-preoperative ratios of flexor and extensor torques were similar (median for both, 0.8). Likewise, no differences were seen between groups regarding the extensor-flexor ratio. The postoperative mean subscale and

Table 2. Major outcome parameters after MIS and standard TKAs

Parameter	MIS TKA	Standard TKA	p value
Extensor torque (Nm)*	47 ± 15	45 ± 19	0.757
Flexor torque (Nm)*	30 ± 14	32 ± 15	0.677
Extensor-flexor torque ratio*	1.73 ± 0.51	1.49 ± 0.46	0.145
Extensor-flexor torque ratio (preoperative-to-postoperative difference)*	0.00 ± 0.75	0.15 ± 0.53	0.478
Extensor torque (postoperative-to-preoperative ratio)†	0.8 ± 0.3	0.8 ± 0.4	0.988
Flexor torque (postoperative-to-preoperative ratio)†	0.8 ± 0.4	0.8 ± 0.5	0.544

* Values are expressed as mean ± SD; †values are expressed as median ± interquartile range; MIS = minimally invasive surgery.

Table 3. Minor outcome parameters after MIS and standard TKAs

Parameter	MIS TKA	Standard TKA	p value
mFTA (°)	-1.9 ± 2.6	0.1 ± 3.2	0.036
Alpha angle (°) (femur component frontal)	95.8 ± 1.7	96.5 ± 2.1	0.243
Beta angle (°) (tibia component frontal)	90.0 ± 1.4	89.1 ± 2.1	0.139
Gamma angle (°) (femur component sagittal)	2.2 ± 2.3	0.6 ± 1.5	0.019
Delta angle (°) (tibia component sagittal)	85.6 ± 2.4	86.3 ± 2.2	0.365
ROM (preoperative-to-postoperative difference) (°)	1.63 ± 11.1	-3.2 ± 15.7	0.285
WOMAC pain (%)	21.2 ± 17.0	17.1 ± 13.7	0.415
WOMAC stiffness (%)	25.3 ± 14.3	32.6 ± 21.3	0.223
WOMAC function (%)	18.5 ± 8.2	18.4 ± 14.0	0.982
WOMAC global (%)	19.6 ± 8.8	19.3 ± 13.4	0.933
Hospital stay (postoperative days)	11.3 ± 2.3	11.5 ± 2.2	0.774
Tourniquet time (minutes)	92.8 ± 21.5	77.5 ± 12.1	0.010
Operation time (minutes)	107.2 ± 27.9	88.3 ± 28.7	0.048

Values are expressed as mean ± SD; MIS = minimally invasive surgery; mFTA = mechanical femorotibial angle (positive values = varus; negative values = valgus).

global values of the WOMAC questionnaire revealed no differences ($p = 0.223$ – 0.982) between groups (Table 3).

The gamma angle was greater in the MIS group ($p = 0.019$), indicating the femoral components had been implanted in greater flexion in MIS TKAs (Table 3). The other mean parameters of component alignment were similar. The mean postoperative leg axis (mFTA) was in greater ($p = 0.036$) valgus in patients with MIS TKAs than in patients with standard TKAs.

The preoperative-to-postoperative change in ROM was similar between the two groups.

The mean durations of hospital stay were similar ($p = 0.774$) between groups: 11.3 versus 11.5 days (Table 3).

Mean tourniquet times and operating times were longer ($p = 0.01$ and 0.048 , respectively) in the MIS TKA group than in the standard TKA group (Table 3).

Discussion

Less invasive dissection of the extensor apparatus, one of the aspects of MIS TKA, might exert a favorable effect on postoperative knee strength. Given the contradictory information in the literature we asked whether (1) postoperative knee torque (extensor and flexor) was greater, (2) scoring on a typical knee questionnaire was improved, (3) alignment was equal, and (4) ROM, (5) length of hospital stay, (6) tourniquet use, and (7) operating times were reduced in patients after MIS TKA compared with after standard TKA.

The following limitations to our study are worth mentioning. First, we did not randomize the patients because of the impracticality of persuading surgeons to modify the routines with which they were comfortable. A randomized trial would have reduced the risk of bias between the groups, but we suspect would not modify the findings. Second, we performed torque measurements on only two occasions. More postoperative measurement would have provided additional information on the course of torque recovery and also would have facilitated comparability with other studies. Third, MIS TKAs always were performed by one of two experienced knee surgeons whereas standard TKAs were performed by a larger pool of surgeons with varying degrees of experience. However, all operations were performed under the direct supervision of a consultant. We suspect these differences would have exerted a favorable impact on the observed parameters in patients who underwent MIS although we found no differences.

We found no differences in mean extensor torque between MIS and standard TKAs at 8 weeks postoperatively; this was true for absolute extensor torque and preoperative-to-postoperative changes in torque. Of the studies reporting on quadriceps function in terms of achievement of rehabilitation milestones [8, 16, 20, 25, 33], the majority reported superior quadriceps function for MIS TKA in the first postoperative week [8, 16, 33]. Only a few studies reported on quadriceps function in terms of rehabilitation milestones beyond the first postoperative week; Kolisek et al. [25] found no strength differences 12 weeks after surgery. Karpman and Smith [20] reported 2-week results dependent on the type of MIS approach

(quadriceps-sparing superior, but mini-midvastus not superior as compared with medial parapatellar) and no group differences at 3 and 6 months. The findings of studies that compared the more objective parameter knee extensor torque between MIS and standard TKAs [5, 23, 33, 37, 44] were incongruent. Some reported better extensor torque in patients who had MIS during the first 4 weeks postoperative that no longer was present in the following months [33, 37, 44]. Others found equal extensor torque among patients who had MIS and standard TKAs 3 and 6 months postoperatively, but better torque in patients who had MIS after 1 year [23], or they reported better results at 3 and 6 months postoperatively among patients who had MIS [5]. Summarizing the above-mentioned studies and including our findings, we believe the evidence shows better quadriceps function with MIS TKA for the first postoperative month [8, 16, 33, 37, 44], and scant evidence for any differences in quadriceps strength in the longer term [5, 20, 23, 25, 37]. It is unclear to what extent the different types of MIS approach used in the above-mentioned studies might have contributed to discrepancies. Moreover, in this regard the literature is incongruent. Some authors reported strength differences between different types of MIS TKAs [1, 20], whereas others reported similar strength [6, 29]. Our preoperative knee extensor torque of 53 to 57 Nm is approximately 30% to 50% of that reported for healthy volunteers [14, 40]. Some authors reported a postoperative decrease in quadriceps strength [20, 23, 33], with recovery thereafter. However, reports on the course of recovery are contradictory. Kim et al. reported a return to the preoperative strength after 6 months [23]. The patients studied by Karpman and Smith returned to preoperative values between 6 and 12 weeks after surgery (dependent on the type of approach) [20]. Majima et al. used the strength of the untreated limb as a reference and found recovery to that value between 4 weeks and 12 months, depending on the type of approach [33]. Although the preoperative reference or the strength of the untreated limb can be reached after a time, we are not aware of studies reporting complete recovery to the values of healthy controls [14]. Knee flexor torque or extensor-flexor ratios were assessed less frequently in the context of MIS versus standard TKA [23, 37, 44]. Those studies reported no effect of MIS in TKA, which is supported by our findings in the current study.

At 8 weeks postoperatively, we found no difference between groups regarding the WOMAC questionnaire. Several studies have reported conflicting knee scores for MIS TKA [15, 18–21, 24, 25, 27, 30, 37, 44–46].

We found differences in the mean postoperative leg axis (mFTA) between MIS and standard TKAs; the mean value in the MIS TKA group was nearly 2° valgus alignment whereas the mean value in the standard TKA group was 0° . Analogous to our study, Chin et al. [7] measured the

postoperative leg axis from whole-leg radiographs and reported inferior alignment in MIS TKA. The authors of other studies investigating the radiographic outcome of MIS TKA assessed component alignment alone [19, 27], defined the leg axis on short standard radiographs [11, 13, 21], or did not mention the method used to measure the leg axis [20]. The clinical importance of the low mean valgus leg axis in MIS TKA we observed is debatable because published data concerning the consequences of tibiofemoral malalignment on TKA survival are controversial [17, 39]. Some authors have recommended aligning a TKA in “neutral or a slight amount of valgus” [41]. In our patients who had MIS TKAs, the femoral components were implanted in greater flexion. This may have been attributable to the limited surgical exposure. Although there are adequate data to corroborate the importance of accurate femoral component alignment in the coronal plane [9, 31, 32, 38], we are not aware of equally strong evidence concerning sagittal orientation of the femoral component. We found prolonged tourniquet and operating times for MIS TKAs, which is in agreement with other publications [11, 24, 25, 27, 37]. Therefore, we assume that the published risks and disadvantages of a tourniquet [3, 28, 34, 42, 43] could be more pronounced for MIS TKA.

We found no differences in extensor or flexor torque values or extensor-flexor torque ratios between MIS and standard TKAs at 8 weeks postoperatively. Based on previous studies and our data, it appears MIS TKA leads to better quadriceps strength in the very early postoperative period but not later. We also found prolonged tourniquet and operating times for MIS TKA.

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References

1. Aglietti P, Baldini A, Sensi L. Quadriceps-sparing versus mini-subvastus approach in total knee arthroplasty. *Clin Orthop Relat Res*. 2006;452:106–111.
2. Bellamy N, Buchanan WW, Goldsmith CH, Campbell J, Stitt LW. Validation study of WOMAC: a health status instrument for measuring clinically important patient relevant outcomes to antirheumatic drug therapy in patients with osteoarthritis of the hip or knee. *J Rheumatol*. 1988;15:1833–1840.
3. Beller J, Trockel U, Lukoschek M. [Peroneal nerve palsy after total knee arthroplasty under continuous epidural anaesthesia] [in German]. *Orthopade*. 2008;37:475–480.
4. Bonutti PM, Mont MA, McMahon M, Ragland PS, Kester M. Minimally invasive total knee arthroplasty. *J Bone Joint Surg Am*. 2004;86(suppl 2):26–32.
5. Bonutti PM, Zywiell MG, Seyler TM, Lee SY, McGrath MS, Marker DR, Mont MA. Minimally invasive total knee arthroplasty using the contralateral knee as a control group: a case-control study. *Int Orthop*. 2010;34:491–495.
6. Bonutti PM, Zywiell MG, Ulrich SD, Stroh DA, Seyler TM, Mont MA. A comparison of subvastus and midvastus approaches in minimally invasive total knee arthroplasty. *J Bone Joint Surg Am*. 2010;92:575–582.
7. Chin PL, Foo LS, Yang KY, Yeo SJ, Lo NN. Randomized controlled trial comparing the radiologic outcomes of conventional and minimally invasive techniques for total knee arthroplasty. *J Arthroplasty*. 2007;22:800–806.
8. Chotaphuti T, Ongnamthip P, Karnchanalerk K, Udombuathong P. Comparative study between 2 cm limited quadriceps exposure minimal invasive surgery and conventional total knee arthroplasty in quadriceps function: prospective randomized controlled trial. *J Med Assoc Thai*. 2008;91:203–207.
9. Engh GA, Petersen TL. Comparative experience with intramedullary and extramedullary alignment in total knee arthroplasty. *J Arthroplasty*. 1990;5:1–8.
10. Ewald FC. The Knee Society total knee arthroplasty roentgenographic evaluation and scoring system. *Clin Orthop Relat Res*. 1989;248:9–12.
11. Haas SB, Cook S, Beksac B. Minimally invasive total knee replacement through a mini midvastus approach: a comparative study. *Clin Orthop Relat Res*. 2004;428:68–73.
12. Haas SB, Manitta MA, Burdick P. Minimally invasive total knee arthroplasty: the mini midvastus approach. *Clin Orthop Relat Res*. 2006;452:112–116.
13. Han I, Seong SC, Lee S, Yoo JH, Lee MC. Simultaneous bilateral MIS-TKA results in faster functional recovery. *Clin Orthop Relat Res*. 2008;466:1449–1453.
14. Harbo T, Brincks J, Andersen H. Maximal isokinetic and isometric muscle strength of major muscle groups related to age, body mass, height, and sex in 178 healthy subjects. *Eur J Appl Physiol*. 2012;112:267–275.
15. Hart R, Janacek M, Cizmar I, Stipcak V, Kucera B, Filan P. [Minimally invasive and navigated implantation for total knee arthroplasty: x-ray analysis and early clinical results] [in German]. *Orthopade*. 2006;35:552–557.
16. Huang HT, Su JY, Chang JK, Chen CH, Wang GJ. The early clinical outcome of minimally invasive quadriceps-sparing total knee arthroplasty: report of a 2-year follow-up. *J Arthroplasty*. 2007;22:1007–1012.
17. Jeffery RS, Morris RW, Denham RA. Coronal alignment after total knee replacement. *J Bone Joint Surg Br*. 1991;73:709–714.
18. Juosponis R, Tarasevicius S, Smailys A, Kalesinskas RJ. Functional and radiological outcome after total knee replacement performed with mini-midvastus or conventional arthrotomy: controlled randomised trial. *Int Orthop*. 2009;33:1233–1237.
19. Karachalios T, Giotikas D, Roidis N, Poultsides L, Bargiotas K, Malizos KN. Total knee replacement performed with either a mini-midvastus or a standard approach: a prospective randomised clinical and radiological trial. *J Bone Joint Surg Br*. 2008;90:584–591.
20. Karpman RR, Smith HL. Comparison of the early results of minimally invasive vs standard approaches to total knee arthroplasty: a prospective, randomized study. *J Arthroplasty*. 2009;24:681–688.
21. Kashyap SN, van Ommeren JW. Clinical experience with less invasive surgery techniques in total knee arthroplasty: a comparative study. *Knee Surg Sports Traumatol Arthrosc*. 2008;16:544–548.
22. Kawazoe T, Takahashi T. Recovery of muscle strength after high tibial osteotomy. *J Orthop Sci*. 2003;8:160–165.
23. Kim JG, Lee SW, Ha JK, Choi HJ, Yang SJ, Lee MY. The effectiveness of minimally invasive total knee arthroplasty to preserve quadriceps strength: a randomized controlled trial. *Knee*. 2011;18:443–447.

24. Kim YH, Kim JS, Kim DY. Clinical outcome and rate of complications after primary total knee replacement performed with quadriceps-sparing or standard arthrotomy. *J Bone Joint Surg Br.* 2007;89:467–470.
25. Kolisek FR, Bonutti PM, Hozack WJ, Purtill J, Sharkey PF, Zelicof SB, Ragland PS, Kester M, Mont MA, Rothman RH. Clinical experience using a minimally invasive surgical approach for total knee arthroplasty: early results of a prospective randomized study compared to a standard approach. *J Arthroplasty.* 2007;22:8–13.
26. Lanshammar K, Ribom EL. Differences in muscle strength in dominant and non-dominant leg in females aged 20-39 year: a population-based study. *Phys Ther Sport.* 2011;12:76–79.
27. Laskin RS, Beksac B, Phongjunakorn A, Pittors K, Davis J, Shim JC, Pavlov H, Petersen M. Minimally invasive total knee replacement through a mini-midvastus incision: an outcome study. *Clin Orthop Relat Res.* 2004;428:74–81.
28. Li B, Qian QR, Wu HS, Zhao H, Lin XB, Zhu J, Weng WF. [The use of a pneumatic tourniquet in total knee arthroplasty: a prospective, randomized study][in Chinese]. *Zhonghua Wai Ke Za Zhi.* 2008;46:1054–1057.
29. Lin WP, Lin J, Horng LC, Chang SM, Jiang CC. Quadriceps-sparing, minimal-incision total knee arthroplasty: a comparative study. *J Arthroplasty.* 2009;24:1024–1032.
30. Luring C, Beckmann J, Haibock P, Perlick L, Grifka J, Tingart M. Minimal invasive and computer assisted total knee replacement compared with the conventional technique: a prospective, randomised trial. *Knee Surg Sports Traumatol Arthrosc.* 2008;16:928–934.
31. Maestro A, Harwin SF, Sandoval MG, Vaquero DH, Murcia A. Influence of intramedullary versus extramedullary alignment guides on final total knee arthroplasty component position: a radiographic analysis. *J Arthroplasty.* 1998;13:552–558.
32. Mahaluxmivala J, Bankes MJ, Nicolai P, Aldam CH, Allen PW. The effect of surgeon experience on component positioning in 673 Press Fit Condylar posterior cruciate-sacrificing total knee arthroplasties. *J Arthroplasty.* 2001;16:635–640.
33. Majima T, Nishiike O, Sawaguchi N, Susuda K, Minami A. Patella eversion reduces early knee range of motion and muscle torque recovery after total knee arthroplasty: comparison between minimally invasive total knee arthroplasty and conventional total knee arthroplasty. *Arthritis.* 2011;2011:854651.
34. Matsuoka T, Jin E, Tachihara A, Ghazizadeh M, Nakajima A, Yoshino S, Katayama Y, Kawanami O. Induction of pulmonary thromboembolism by neutrophil elastase in collagen-induced arthritis mice and effect of recombinant human soluble thrombomodulin. *Pathobiology.* 2008;75:295–305.
35. Myer GD, Ford KR, Hewett TE. New method to identify athletes at high risk of ACL injury using clinic-based measurements and freeware computer analysis. *Br J Sports Med.* 2011;45:238–244.
36. Myer GD, Ford KR, Khoury J, Succop P, Hewett TE. Development and validation of a clinic-based prediction tool to identify female athletes at high risk for anterior cruciate ligament injury. *Am J Sports Med.* 2010;38:2025–2033.
37. Nestor BJ, Toulson CE, Backus SI, Lyman SL, Foote KL, Windsor RE. Mini-midvastus vs standard medial parapatellar approach: a prospective, randomized, double-blinded study in patients undergoing bilateral total knee arthroplasty. *J Arthroplasty.* 2010;25(6 suppl):5–11, 11.e11.
38. Novotny J, Gonzalez MH, Amirouche FM, Li YC. Geometric analysis of potential error in using femoral intramedullary guides in total knee arthroplasty. *J Arthroplasty.* 2001;16:641–647.
39. Parratte S, Pagnano MW, Trousdale RT, Berry DJ. Effect of postoperative mechanical axis alignment on the fifteen-year survival of modern, cemented total knee replacements. *J Bone Joint Surg Am.* 2010;92:2143–2149.
40. Pietrosimone BG, Park CM, Gribble PA, Pfile KR, Tevald MA. Inter-limb differences in quadriceps strength and volitional activation. *J Sports Sci.* 2012;30:471–477.
41. Ritter MA, Faris PM, Keating EM, Meding JB. Postoperative alignment of total knee replacement: its effect on survival. *Clin Orthop Relat Res.* 1994;299:153–156.
42. Smith TO, Hing CB. Is a tourniquet beneficial in total knee replacement surgery? A meta-analysis and systematic review. *Knee.* 2010;17:141–147.
43. Tai TW, Lin CJ, Jou IM, Chang CW, Lai KA, Yang CY. Tourniquet use in total knee arthroplasty: a meta-analysis. *Knee Surg Sports Traumatol Arthrosc.* 2011;19:1121–1130.
44. Tashiro Y, Miura H, Matsuda S, Okazaki K, Iwamoto Y. Minimally invasive versus standard approach in total knee arthroplasty. *Clin Orthop Relat Res.* 2007;463:144–150.
45. Varela-Egocheaga JR, Suarez-Suarez MA, Fernandez-Villan M, Gonzalez-Sastre V, Varela-Gomez JR, Rodriguez-Merchan C. Minimally invasive subvastus approach: improving the results of total knee arthroplasty: a prospective, randomized trial. *Clin Orthop Relat Res.* 2010;468:1200–1208.
46. Wohlrab D, Gutteck N, Hildebrand M, Zeh A, Hein W. [Influence of the surgical approach on postoperative rehabilitation after TKA] [in German]. *Z Orthop Unfall.* 2008;146:200–205.