Effect of surgeon fatigue on hip and knee arthroplasty

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Background: There is growing support in the literature that patient outcomes are adversely affected by physician fatigue in operator-dependent cognitive and technical tasks. Recent increases in total joint arthroplasty caseloads have resulted in longer operative days and increased surgeon fatigue. We sought to determine if time of day predicts perioperative complications and outcomes in total joint arthroplasty.

Methods: The records of all total hip and knee arthroplasties (THA; TKA) performed for primary osteoarthritis in one calendar year at one large university hospital were retrospectively reviewed. Demographic data, surgery start time and duration, intraoperative complications, radiographic component alignment and functional outcome scores (SF-12 and Western Ontario and McMaster Universities Osteoarthritis Index) were collected and analyzed using linear and nonparametric rank correlation statistics. Data were corrected for sex, body mass index, surgeon and postcall operating days.

Results: In the THA cohort (n = 341), a later surgery start time was significantly related to duration of surgery (p = 0.004, mean difference –7.1 min). There was a trend toward significance between a later surgery start time and intraoperative femur fracture (p = 0.05). Postoperative complications, component alignment and functional outcome scores were not significantly affected by surgery start time. There were no significant findings for any of the intraoperative or postoperative outcomes in the TKA cohort (n = 292).

Conclusion: Duration of surgery and incidence of intraoperative complications for THA may increase with later surgery start time; however, the relatively small statistical differences observed imply that they likely are not clinically significant.

Contexte : On reconnaît de plus en plus dans les publications scientifiques que dans l'exécution de tâches cognitives et techniques tributaires de l'intervenant, la fatigue des médecins a un effet indésirable sur les résultats des patients. Des augmentations récentes du nombre de cas d'arthroplastie totale d'une articulation ont allongé les journées en salle d'opération et aggravé la fatigue des chirurgiens. Nous avons cherché à déterminer si l'heure du jour est un prédicteur de complications peropératoires et des résultats d'une arthroplastie totale d'une articulation.

Méthodes : Nous avons effectué une analyse rétrospective des dossiers de toutes les arthroplasties de la hanche et du genou (ATH; ATG) pratiquées à cause d'une arthrose primitive au cours d'une année civile dans un grand hôpital universitaire. Nous avons recueilli les données démographiques, l'heure du début de l'intervention chirurgicale et sa durée, les complications intraopératoires, l'alignement radiographique des pièces et les résultats fonctionnels (SF-12 et les données sur l'indice de l'arthrose des universités Western Ontario et McMaster) et nous les avons analysées en établissant des statistiques de corrélation linéaire et non paramétrique. Nous avons corrigé les données en fonction du sexe, de l'indice de masse corporelle, du chirurgien et du nombre de jours de chirugie après l'appel.

Résultats : Dans la cohorte des ATH (n = 341), on a établi un lien important entre l'heure plus tardive du début de l'intervention chirurgicale et sa durée (p = 0,004, différence moyenne –7,1 min). On a constaté une tendance à l'importance du lien entre le début de l'intervention chirurgicale à une heure plus tardive et une fracture intraopératoire du fémur (p = 0,05). L'heure du début de la chirurgie n'a pas eu d'effet significatif sur les complications postopératoires, l'alignement des pièces et le résultat fonctionnel. Il n'y a eu aucune constatation significative dans le cas d'aucun des résultats intraopératoires ou postopératoires dans la cohorte des ATG (n = 292).

Conclusion : La durée de l'intervention chirurgicale et l'incidence de complications intraopératoires dans les cas d'ATH peuvent augmenter en fonction de l'heure plus tardive du début de l'intervention chirurgicale. Les différences statistiques relativement faibles observées indiquent toutefois qu'elles ne sont probablement pas cliniquement significatives.

In an effort to reduce wait times associated with joint replacement surgery, the overall arthroplasty caseload in the province in Ontario has increased by more than 50% in the past 5 years.[1,2] As a result, the number of total joint arthroplasties being performed during a surgical day has also increased. Many surgeons now perform 5 or 6 total joint operations in a single day, with operative working hours approaching 10. There is no doubt that this increased caseload has led to increased surgeon fatigue, particularly for cases performed at the end of the operating day compared with those performed at the beginning.

There is growing support in the literature that patient outcomes are adversely affected by fatigue in operator-dependent cognitive and technical tasks. Adverse events and medical errors have been shown to occur more frequently in sleep-deprived physicians, and technical skills have also been shown to be negatively influenced by physician fatigue.[3–9] More specifically, laparoscopic procedures,[10] cardiac interventions,[11] endotracheal intubation[12] and colonoscopies[13,14] have been shown to have inferior outcomes when performed later in the day. These findings potentially have implications for physician productivity, procedural outcome and, most importantly, patient safety.

There are many factors that contribute to the outcome of total joint arthroplasty, including preoperative, intraoperative and postoperative variables. It is well established that preoperative variables, such as unrealistic patient expectations,[15–18] diabetic control[19,20] and obesity,[21–23] can have a negative effect on radiologic and functional outcomes. Fortunately, these variables are modifiable and therefore have the potential to be optimized preoperatively. Postoperative variables, such as participation in rehabilitation and avoidance of limb positions that may predispose to hip dislocation, are also modifiable variables that have been shown to affect outcome.[24,25] The influence of intraoperative variables on outcomes in total joint arthroplasty have been less extensively studied. Duration of the surgical procedure,[26,27] blood loss[28] and component alignment[29–33] are modifiable intraoperative variables that influence patient outcomes and may be adversely affected by surgeon fatigue. To our knowledge, the extent to which fatigue affects the technical and cognitive skills of the surgeon and overall patient outcomes in total joint arthroplasty has not previously been studied.

The purpose of this retrospective study was to determine whether there is a difference, in terms of perioperative and postoperative complications, between patients undergoing total hip arthroplasty (THA) or total knee arthroplasty (TKA) at different times during the operative day.

Methods

All patients treated with primary THA or TKA during the 2007 calendar year at a single academic university hospital were identified using hospital medical records. Patients with inflammatory arthritis, hip dysplasia, posttraumatic deformity, bilateral single-stage procedures or resurfacing procedures were excluded from the THA cohort. Patients with inflammatory arthritis, previous intra-articular fracture, posttraumatic deformity or bilateral single-stage procedures were excluded from the TKA cohort. Review of hospital database records was undertaken to verify diagnosis and operative procedure.

After obtaining institutional research ethics board approval, we reviewed the hospital charts for each study participant. A data abstraction form was used to gather information regarding age, sex, body mass index (BMI), attending surgeon, date of surgery, surgeon postcall days, anesthetic type (general v. spinal), start time of surgery, duration of surgery, intraoperative complications (arterial injury, nerve injury, periprosthetic fracture, medical complication), length of stay in hospital, number of days in the intensive care unit (ICU), units of blood products transfused, postoperative complications (myocardial infarction, pulmonary embolus, infection, intestinal ileus, urinary tract infection), need for revision surgery, readmission within 30 days, SF-12[34] scores, Western Ontario and McMaster Universities Osteoarthritis Index (WOMAC)[35] scores and radiographic component alignment. The surgeon postcall days variable was used to indicate the days on which a surgeon performed total joint arthroplasty surgery after a night of being on call. Data acquisition was reviewed and verified in duplicate before statistical analysis.

All patients in the THA cohort had uncemented femoral and acetabular components placed through either a posterior or direct lateral approach. Two surgeons used a posterior approach exclusively, and 1 surgeon used a lateral approach exclusively. All patients in the TKA cohort had cemented femoral and tibial components with intramedullary femoral alignment and extramedullary tibial alignment. All patients participated in a physiotherapy program postoperatively. Deep vein thrombosis (DVT) prophylaxis was used until the time of discharge from hospital.

Patient-centered functional outcome data (SF-12 physical health component, SF-12 mental health component and WOMAC scores) were recorded preoperatively and at 3 months postoperatively. Radiographic analysis was performed 3 months postoperatively to record the acetabular component inclination angle and femoral component varus/valgus angle in the THA cohort. In the TKA cohort, the tibial component varus/valgus angle was recorded.

Statistical analysis

We performed all statistical analyses using Minitab (State College, Pennsylvania) software. Descriptive statistical methods were used to calculate frequencies, means and standard deviations. Nonparametric rank-correlation statistics were used to compare data within the THA and TKA cohorts. We used the Spearman rank order test to compare continuous outcome variables, and we used the point biserial test to compare binary outcome variables. Time of day was chosen as the independent predictor variable for both the Spearman and point biserial tests. The outcome variables included duration of surgery, intraoperative complications, postoperative complications, functional outcome scores and radiographic parameters. We considered results to be significant at $p < 0.05$.

We constructed a multivariate regression analysis model to correct for the effects of confounding variables. The predictor variables for the model were age, sex, BMI, attending surgeon, surgeon postcall days and surgery start time. The outcome variables were intraoperative complications, duration of surgery, component alignment and functional outcome scores.

Results

Patient identification

A search of the hospital database records identified 341 patients treated with THA and 292 patients treated with TKA by 3 surgeons during the 2007 calendar year. The baseline demographic and clinical characteristics are summarized in Table 1.

Total hip arthroplasty cohort

In the THA cohort, 133 (39.0%) patients were male, with an average age of 60.7 (range 14–90) years and a mean BMI of 29.2 (15.4–57.8). The distribution of cases among the 3 surgeons were 153, 57 and 131, respectively. There were 51 postcall operating days for the 3 surgeons combined. The mean number of cases per operating day was 3.1 (range 1–7). The mean duration of surgery was 76.1 (range 45–170) minutes.

The outcomes of patients are summarized in Table 2. There were 10 intraoperative complications (9 periprosthetic fractures and 1 cardiac arrest). There were 9 cases of superficial infection and 2 cases of deep prosthetic infection requiring 2-stage revision procedures. The average difference between preoperative and 3-month postoperative functional outcome scores were 8.4 on the SF-12 physical health component, 3.9 on the SF-12 mental health component and 29.6 on the WOMAC. The average inclination angle for the acetabular component was 43.9° (range 20°–66°). The total number of acetabular components exceeding an inclination angle of 45° was 29 (8.5%). The average deviation from anatomically neutral alignment for the femoral component was 1.3° of valgus (3° valgus to 8° varus). The total number of femoral components positioned in greater than 3° of anatomic varus or valgus was 30 (8.8%).

The Spearman rank order test identified a significant association between duration of surgery and later surgery start time ($p = 0.004$, rs = 0.145, $t = 2.69$; Table 3). However, the mean difference in duration between the first and

Table 1. Baseline characteristics of patients who underwent THA or TKA at a single centre in 2007

Characteristic	Cohort; mean (SD)*	
	THA	TKA
No.	341	292
Age, yr	60.7 (16.3)	65.7 (10.6)
Male sex, no. (%)	133 (39.0)	84 (28.8)
Weight, kg	80.1 (19.9)	87.8 (23.4)
Height, cm	165.6 (9.8)	162.2 (10.5)
BMI	29.2 (6.9)	33.4 (9.1)
Preoperative survey score		
SF-12 physical	33.7 (6.7)	33.2 (6.7)
SF-12 mental	45.7 (10.7)	47.6 (10.4)
WOMAC	44.9 (17.4)	45.7 (16.7)

BMI = body mass index; SD = standard deviation; SF-12 = Short Form-12 health survey;[34] THA = total hip arthroplasty; TKA = total knee arthroplasty; WOMAC = Western Ontario and McMaster Universities Osteoarthritis Index.[35]
*Unless indicated otherwise.

Table 2. Surgical outcomes of patients who underwent THA or TKA at a single centre in 2007

Outcome	Cohort; no. (%)*	
	THA	TKA
Duration of surgery, mean (SD) min	76.1 (21.8)	79.8 (28.1)
Survey score change, mean (SD)		
SF-12 physical	8.4 (6.6)	5.1 (7.1)
SF-12 mental	3.9 (8.3)	0.2 (9.0)
WOMAC	29.6 (14.7)	28.2 (11.8)
Acetabular angle, > 45°	29 (8.5)	—
Femoral angle, > 3°	30 (8.8)	—
Tibial angle, > 3°	—	23 (7.9)
Intraoperative fracture/notch	9 (2.6)	6 (2.1)
Superficial infection	9 (2.6)	18 (6.2)
Deep infection	2 (0.6)	0 (0.0)
Dislocation	5 (1.5)	—

SD = standard deviation; SF-12 = Short Form-12 health survey;[34] THA = total hip arthroplasty; TKA = total knee arthroplasty; WOMAC = Western Ontario and McMaster Universities Osteoarthritis Index.[35]
*Unless indicated otherwise.

fourth quartiles of surgery start time was 7.1 minutes. The point biserial test revealed a trend toward significance between intraoperative periprosthetic femur fracture and a later surgery start time ($p = 0.05$, pb = 0.09, $t = 1.61$). There were no postoperative complications associated with surgery start time, and there were no significant relations between surgery start time and any of the functional outcome measures.

Multivariate regression analysis using a combined continuous and binomial variable model was used to control for possible simultaneous confounding effects of predictor variables (age, sex, BMI, surgeon and surgeon postcall days). After correcting for all confounding variables, surgery start time remained a significant predictor of duration of surgery ($p = 0.029$). No other predictor variable was found to be significantly related to any outcome variable.

Total knee arthroplasty cohort

In the TKA cohort, 84 (28.8%) patients were male, with an average age of 65.7 (27–91) years and average BMI of 33.4 (17.4–81.6). The distribution of cases among the 3 surgeons was 79, 120 and 93, respectively. There were 51 postcall operating days for the 3 surgeons combined. The mean number of cases per operating day was 3.1 (range 1–7). The mean duration of surgery was 79.8 (range 40–180) minutes.

The outcomes of patients are summarized in Table 2. There were 7 intraoperative complications (6 periprosthetic fractures/femoral notches and 1 popliteal artery injury). There were 18 cases of superficial infection and no cases of deep prosthetic infection. The average change between preoperative and 3-month postoperative functional outcome scores was 5.1 on the SF-12 physical health component, 0.2 on the SF-12 mental health component and 28.2 on the WOMAC. The average deviation from mechanically neutral alignment for the tibial component was 1.7° of varus (3° valgus to 6° varus). The total number of tibial components positioned in greater than 3° of anatomic varus or valgus was 23 (7.9%).

There were no significant findings in the TKA cohort with respect to surgery start time when using either the Spearman rank order test or the point biserial test for all continuous and binomial outcome variables (Table 3).

Discussion

There are numerous variables that determine the radiographic and functional outcomes of total joint arthroplasty. These variables may be temporally stratified into preoperative, intraoperative and postoperative categories, and they also can be stratified based on whether or not they are modifiable. The identification and optimization of modifiable variables may ultimately lead to improved patient outcomes. Surgeon fatigue may be an underappreciated modifiable variable that has widespread effects across multiple intraoperative domains.

Our study population had similar baseline characteristics to those reported in recent studies examining outcomes of primary THA and TKA.[36,37] In addition, values for mean duration of surgery, intraoperative complications and functional outcome scores were comparable. These studies validate our results with respect to patient demographic and clinical characteristics, operative complications and functional outcomes.

In the present study, duration of surgery in the THA cohort was significantly associated with a later surgery start time. This finding may be partially explained by increasing surgeon fatigue throughout the operative day leading to longer procedures, although other factors, including BMI, sex, proportion of the case performed by a trainee and difficulty of the case, likely contributed.[38] In our analysis, BMI and sex were not found to be significantly associated with duration of surgery. In addition, at the study institution, there is no standardized difference in the proportion of the case performed by a trainee based on time of day. Increasing case difficulty would likely result in longer durations;

Table 3. Rank order correlation statistics

Outcome	THA			TKA		
	p value	rs	*t*	*p* value	rs	*t*
Duration of surgery, min	0.004	0.145	2.690	0.44	0.009	0.140
SF-12 physical	0.25	0.076	0.680	0.13	0.067	1.140
SF-12 mental	0.07	0.099	1.830	0.27	0.035	0.600
WOMAC	0.41	0.012	0.230	0.49	0.002	0.890
Acetabular angle	0.26	0.040	0.650			
Femoral angle	0.23	0.040	0.740			
Tibial angle				0.19	0.051	0.870
Intraoperative fracture	0.05	0.090	1.640	0.35	0.020	0.310
Superficial infection	0.22	0.040	0.760	0.23	0.040	0.730
Dislocation	0.29	0.030	0.550			

SF-12 = Short Form-12 health survey;[34] THA = total hip arthroplasty; TKA = total knee arthroplasty; WOMAC = Western Ontario and McMaster Universities Osteoarthritis Index.[35]

however, the exclusion criteria ensured that only routine primary THAs were included in the analysis.

There are several benefits to shorter duration of surgery for THA, including a decreased infection rate[27,39] and increased residual operating room resources. Presumably, the decreased infection rate is based on the fact that the operative wound is exposed to the outside environment longer with prolonged surgery, although there is no universally accepted threshold value for which the risk of infection increases. The duration of surgery in our study ranged from 45 to 170 minutes; however, the mean difference in duration between the first and fourth quartiles of surgery start time was only 7.1 minutes. This difference is likely too small to result in clinically important outcomes. In addition, in this study there were only 2 cases of deep prosthetic infection; therefore, no statistical association between infection rate and surgery start time could be demonstrated.

There was a trend toward significance between a later surgery start time and intraoperative periprosthetic femur fracture. Increasing surgeon fatigue later in the operative day may contribute to decreased vigilance with respect to protecting the femur against intraoperative fracture; however, other factors likely contributed to this finding. Previous studies have identified age, sex and osteoporosis as risk factors for intraoperative periprosthetic fracture.[40,41] Our analysis showed no differences with respect to age, sex and osteoporosis in patients who experienced a periprosthetic fracture. The difference in incidence between the first and fourth quartiles of surgery start time was 3 fractures (1 v. 4). Although these complications did not ultimately result in functionally compromised outcomes, they did cause inconvenience for the patient owing to an alteration in postoperative weight-bearing status and physiotherapy protocols.

There were no significant differences between surgery start time and any outcome variables in the TKA cohort, possibly because TKA is relatively resistant to fluctuations in surgical time based on fatigue because the incorporation of alignment guides and anatomic verifications standardize TKA to a greater extent than THA.[37,38] Furthermore, the intraoperative complication rate in terms of risk of intraoperative periprosthetic fracture is lower overall in TKA compared with THA.

Limitations

This retrospective cohort study has several limitations. First, the patients included in this review were not randomly allocated to a surgery start time. Rather, patients were arbitrarily scheduled for surgery by their attending surgeons. There may have been a predilection for scheduling more technically challenging cases earlier or later in the operative day based on surgeon preference. However, in an attempt to control for variability in case difficulty, we excluded patients undergoing revision procedures and those with a diagnosis of nonprimary osteoarthritis. Second, owing to the relatively low number of intraoperative complications in this study, a more definitive association with respect to surgery start time was difficult to obtain. If the number of patients studied was larger, there would be a greater potential to show a significant difference. Finally, there are numerous factors in addition to the time of day that contribute to physical and cognitive fatigue among surgeons. Despite the fact that we controlled for operating on a postcall day and the specific surgeon performing the procedure, it is reasonable to assume that other extraneous factors may have confounded the results. However, through the use of multivariate analysis, we attempted to standardize the data and control for these uncertainties.

Conclusion

Recently, the medical literature has identified physician fatigue as a risk factor for complications in operator-dependent cognitive and technical tasks. The present study demonstrates that duration of surgery and the incidence of intraoperative complications for THA may increase with later surgery start time. An appreciation of the balance between surgeon fatigue and operative caseload may allow for more efficient use of allocated operating room resources and a lower intraoperative complication rate. These findings should be taken into consideration when planning operative lists involving THA.

Competing interests: None declared.

Contributors: C. Peskun and E. Schemitsch designed the study. D. Walmsley acquired the data, which C. Peskun and J. Waddell analyzed. C. Peskun wrote the article, which all authors reviewed and approved for publication.

References

1. *Hip and Knee Replacements in Canada: Canadian Joint Replacement Registry (CJRR) 2008–2009 Annual Report*. Ottawa (ON): Canadian Institute for Health Information; 2009.
2. Ontario Wait Times. In: *Ministry of Health and Long Term Care* [website of the Ministry]. Available: www.waittimes.net/surgerydi/En/Type.aspx (accessed 2010 July 27).
3. Wesnes KA, Walker MB, Walker LG, et al. Cognitive performance and mood after a weekend on call in a surgical unit. *Br J Surg* 1997;84:493-5.
4. Weinger MB, Ancoli-Israel S. Sleep deprivation and clinical performance. *JAMA* 2002;287:955-7.
5. Leff D, Aziz O, Darzi A. Trucks, planes, and scalpels: Is there an evidence-based approach to surgeons' working hours? *Arch Surg* 2007;142:817-20.
6. Koslowsky M, Babkoff H. Meta-analysis of the relationship between total sleep deprivation and performance. *Chronobiol Int* 1992;9:132-6.

7. Kelz RR, Freeman KM, Hosokawa PW, et al. Time of day is associated with postoperative morbidity: an analysis of the national surgical quality improvement program data. *Ann Surg* 2008;247:544-52.

8. Rothschild JM, Keohane CA, Rogers S, et al. Risks of complications by attending physicians after performing nighttime procedures. *JAMA* 2009;302:1565-72.

9. Grantcharov TP, Bardram L, Funch-Jensen P, et al. Laparoscopic performance after one night on call in a surgical department: prospective study. *BMJ* 2001;323:1222-3.

10. Taffinder NJ, McManus IC, Gul Y, et al. Effect of sleep deprivation on surgeons' dexterity on laparoscopic simulator. *Lancet* 1998;352:1191.

11. Kuon E, Dahm JB, Schmitt M, et al. Time of day influences patient radiation exposure from percutaneous cardiac interventions. *Br J Radiol* 2003;76:189-91.

12. Wright MC, Phillips-Bute B, Mark JB, et al. Time of day effects on the incidence of anesthetic adverse events. *Qual Saf Health Care* 2006; 15:258-63.

13. Sanaka MR, Deepinder F, Thota PN, et al. Afternoon colonoscopies have higher failure rates than morning colonoscopies. *Am J Gastroenterol* 2006;101:2726-30.

14. Wells CD, Heigh RI, Sharma VK, et al. Comparison of morning versus afternoon cecal intubation rates. *BMC Gastroenterol* 2007;7:19-23.

15. Lingard EA, Sledge CB, Learmonth ID. Patient expectations regarding total knee arthroplasty: differences among the United States, United Kingdom, and Australia. *J Bone Joint Surg Am* 2006;88:1201-7.

16. Howell SM, Rogers SL. Method for quantifying patient expectations and early recovery after total knee arthroplasty. *Orthopedics* 2009;32: 884-90.

17. Bourne RB, Chesworth BM, Davis AM, et al. Patient satisfaction after total knee arthroplasty: Who is satisfied and who is not? *Clin Orthop Relat Res* 2010;468:57-63.

18. Mahomed NN, Liang MH, Cook EF, et al. The importance of patient expectations in predicting functional outcomes after total joint arthroplasty. *J Rheumatol* 2002;29:1273-9.

19. Schiavone Panni A, Cerciello S, Vasso M, et al. Stiffness in total knee arthroplasty. *J Orthop Traumatol* 2009;10:111-8.

20. Moon HK, Han CD, Yang IH, et al. Factors affecting outcome after total knee arthroplasty in patients with diabetes mellitus. *Yonsei Med J* 2008;49:129-37.

21. Dowsey MM, Liew D, Stoney JD, et al. The impact of pre-operative obesity on weight change and outcome in total knee replacement: a prospective study of 529 consecutive patients. *J Bone Joint Surg Br* 2010;92:513-20.

22. Jackson MP, Sexton SA, Yeung E, et al. The effect of obesity on the mid-term survival and clinical outcome of cementless total hip replacement. *J Bone Joint Surg Br* 2009;91:1296-300.

23. Gillespie GN, Porteous AJ. Obesity and knee arthroplasty. *Knee* 2007;14:81-6.

24. Moffet H, Collet JP, Shapiro SH, et al. Effectiveness of intensive rehabilitation on functional ability and quality of life after first total knee arthroplasty: a single-blind randomized controlled trial. *Arch Phys Med Rehabil* 2004;85:546-56.

25. Munin MC, Rudy TE, Glynn NW, et al. Early inpatient rehabilitation after elective hip and knee arthroplasty. *JAMA* 1998;279:847-52.

26. Peersman G, Laskin R, Davis J, et al. Prolonged operative time correlates with increased infection rate after total knee arthroplasty. *HSS J* 2006;2:70-2.

27. Cordero-Ampuero J, de Dios M. What are the risk factors for infection in hemiarthroplasties and total hip arthroplasties? *Clin Orthop Relat Res* 2010;468:3268-77.

28. Moonen AF, Neal TD, Pilot P. Peri-operative blood management in elective orthopaedic surgery. A critical review of the literature. *Injury* 2006;37:S11-6.

29. Berend ME, Ritter MA, Meding JB, et al. Tibial component failure mechanisms in total knee arthroplasty. *Clin Orthop Relat Res* 2004;428:26-34.

30. Jaffe WL, Hawkins CA. Normalized and proportionalized cemented femoral stem survivorship at 15 years. *J Arthroplasty* 1999;14:708-13.

31. Munuera L, Garcia-Cimbrelo E. The femoral component in low-friction arthroplasty after ten years. *Clin Orthop Relat Res* 1992;(279): 163-75.

32. Vresilovic EJ, Hozack WJ, Rothman RH. Radiographic assessment of cementless femoral components. Correlation with intraoperative mechanical stability. *J Arthroplasty* 1994;9:137-41.

33. Perillo-Marcone A, Barrett DS, Taylor M. The importance of tibial alignment: finite element analysis of tibial malalignment. *J Arthroplasty* 2000;15:1020-7.

34. Ware J Jr, Kosinski M, Keller SD. A 12-Item Short-Form Health Survey: construction of scales and preliminary tests of reliability and validity. *Med Care* 1996;34:220-33.

35. Bellamy N, Buchanan WW, Goldsmith CH, et al. 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: 1833-40.

36. Wülker N, Lambermont JP, Sacchetti L, et al. A prospective randomized study of minimally invasive total knee arthroplasty compared with conventional surgery. *J Bone Joint Surg Am* 2010;92:1584-90.

37. Woolson ST, Kang MN. A comparison of the results of total hip and knee arthroplasty performed on a teaching service or a private practice service. *J Bone Joint Surg Am* 2007;89:601-7.

38. Kosashvili Y, Mayne IP, Trajkovski T, et al. Influence of sex on surgical time in primary total knee arthroplasty. *Can J Surg* 2010;53:256-60.

39. Willis-Owen CA, Konyves A, Martin DK. Factors affecting the incidence of infection in hip and knee replacement: an analysis of 5277 cases. *J Bone Joint Surg Br* 2010;92:1128-33.

40. Sarvilinna R, Huhtala HS, Puolakka TJ, et al. Periprosthetic fractures in total hip arthroplasty: an epidemiologic study. *Int Orthop* 2003;27:359-61.

41. Abendschein W. Periprosthetic femur fractures — a growing epidemic. *Am J Orthop* 2003;32(Suppl):34-6.