Minimally Invasive Total Knee Arthroplasty: Pitfalls and Complications

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Abstract

Despite reports of complications, there has been tremendous interest in using minimally invasive surgery (MIS) for total knee arthroplasty (TKA).

Over the past 10 years, we have used an MIS approach for all TKAs. In the study described here, we examined the complications of the first 1000 of these TKAs. These cases involved a minimal incision (mean, 10 cm), a quadriceps muscle–sparing approach, and a non-patellar-everting technique. The complications assessed included manipulations, reoperations, and component revisions. We also analyzed for deviations in radiographic alignment or radiographic failures.

There were 45 clinical complications—25 manipulations under anesthesia, 12 arthroscopic procedures for painful patellofemoral crepitus (mostly for an initially nonvisualized retained lateral band), and 8 operative explorations for various component problems. Radiographically, there were 3 impending component failures—2 tibial and 1 femoral. Excluding manipulations, there was a significant decrease in operative complication rate from the first 200 cases (6.0%) to the next 800 cases (1.0%), with overall complication rates similar to those of a control cohort treated with traditional surgical techniques. From this analysis, the major concern was potential tibial component loosening, which may be related to decreased exposure and possibly poor cement pressurization.

Despite the low complication rate, this study yielded insights into further potential improvements in using this MIS technique for TKAs.

Minimally invasive surgery (MIS) for unicompartmental knee arthroplasty was introduced in the early 1990s. Since then, there have been reports of more rapid recovery and earlier return to normal function than with use of standard techniques.[1] Recently, MIS has been applied to total knee arthroplasty (TKA), and claims of advantages over standard techniques have been made, including less perioperative pain, shorter hospitalization, greater range of motion (ROM), and lower overall costs.[2-7]

Some of these advantages may result from the techniques used in MIS-TKA. These techniques include use of smaller incisions, reduction in quadriceps muscle trauma, avoidance of patellar eversion, use of downsized instrumentation, and use of a mobile soft-tissue window that enhances exposure through flexion and extension.[7-11] Unfortunately, these techniques make knee arthroplasty more difficult, as smaller incisions afford fewer visual clues, which can impair a surgeon's ability to assess proper component positioning and lead to component malalignment.[7,12,13] Smaller incisions also make it difficult to visualize the lateral tibial plateau and to remove loose bony fragments, uncapped bone, or retained cement.[14] In addition, the need for aggressive retraction to compensate for smaller incisions can lead to problems with wound healing[1,9,15] and may create the potential for avulsion of the extensor mechanism and posterior cruciate ligament.[16] Last, prosthetic components are not always compatible with the MIS approach. For all these reasons, there is the potential for a higher rate of complications for the average surgeon beginning to use this technique.[17]

In most of the literature, MIS-TKA complication rates are similar to those of standard approach TKAs,[6-11] but follow-ups are less than 1 year, and clinical results are reported anecdotally. Only a few reports describe a minimum 2-year follow-up.[1,8,9,12]

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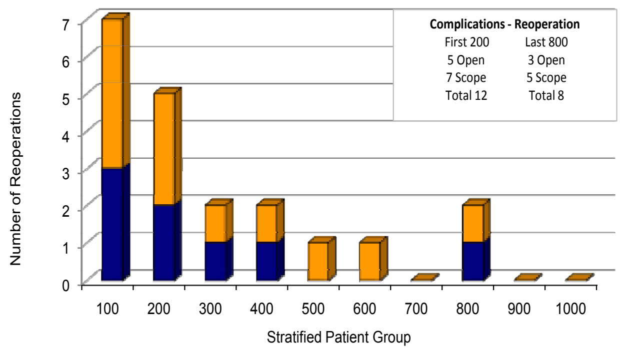

Figure. Incidence of complications requiring reoperation stratified into groups of 100 patients.

Since 1996, Dr. Bonutti and Dr. Mont have used an MIS approach in more than 2000 TKAs. In this article, we describe the clinical and radiographic complications of this technique as used in 1000 consecutive MIS-TKAs performed by 1 of these surgeons.

Methods

We reviewed the data on patients who underwent MIS-TKAs performed by Dr. Bonutti at a single center between January 1, 2001, and May 31, 2005. This surgeon has exclusively used MIS techniques for all TKAs beginning with the patients included in this report, and the reported series included his early experience with this approach. This review included 1000 consecutive TKAs (642 unilateral, 179 bilateral) in 820 patients (554 women, 266 men). Mean age at time of surgery was 69 years (range, 36 to 94 years), and mean body mass index was 31.2 kg/m^2 (range, 18 to 62 kg/m^2).

Minimum follow-up was 2 years (range, 2 to 7 years). All patients underwent annual clinical and radiographic evaluations starting 1 year after the index surgery. Most patients were seen in clinic for these assessments. Eight patients (0.1%) declined to be seen in clinic because of a prohibitive travel distance from home. These patients were followed annually with radiographs that were taken at a remote facility and forwarded to the authors, and clinical follow-up performed by telephone. Nine patients (10 knees) were lost to follow-up less than 2 years after surgery and were not included in this study, leaving 990 knees (99%, 811 patients) in this report. Eleven patients in the reviewed cohort died, but only those who passed away before the 2-year follow-up were excluded. Extensive chart reviews and clinical follow-ups were performed to identify all of the surgical complications of the procedure. In addition, an analysis was made to further identify radiographic failures. Institutional review board approval was obtained to analyze the patients.

An MIS mid–vastus medialis approach was used. Incision length was no more than 2.5 times the height of the patella (proximal to distal). This limited approach was facilitated with new, smaller instrumentation. Specifically, the cutting blocks were approximately 40% smaller than traditional cutting blocks. No specialized retractors were used, but the approach used knee flexion and extension as well as relaxation of the medial and lateral retractors to facilitate exposure of the front and the back. The techniques for this MIS were described in more detail elsewhere.[7,8,18] None of the patellae were everted prior to making the tibial and femoral bone cuts to avoid excessive tension on the extensor mechanism. After the bone cuts were made, some patellae were partially everted (up to 135°) to help with prosthesis placement. This was done only in extension, and for no more than 20 minutes, again to avoid excessive extensor strain. The exact number of patellae everted was not recorded. Mean incision length, measured in extension in all cases, was 10 cm (range, 6 to 13 cm).

Complications were assessed from a critical review of charts, hospital data, and office follow-up notes. Specifically, we looked for manipulations and any further invasive surgical procedures. In addition, we looked for skin or wound problems. Complications were stratified by blocks of 100 cases each to analyze the effects of the learning curve. Clinical complication rates were compared with those of a series of 50 consecutive TKAs performed by the same surgeon, Dr. Bonutti, using conventional techniques over a 6-month period in 2002. These procedures, the last to be performed by this surgeon before he exclusively adopted MIS techniques, were previously described and served as a control group in 2 reports.[19,20]

Annual postoperative radiographs were used to assess component alignment, position, and any progressive radiolucencies or impending radiographic failures. Radiographs were used to assess tibiofemoral angle, distal femoral angle, and proximal tibial angle to evaluate any coronal plane deformities. Lateral radiographs were analyzed for degree of flexion and extension of all components. On follow-up radiographs, a zonal analysis was performed to assess for any progressive radiolucencies.

Results

Forty-five clinical complications (4.5%) were identified. Excluding manipulations under anesthesia left 20 complications (2.0%). These complications included arthroscopic procedures and reoperations.

Twenty-five manipulations under anesthesia were performed (2.5% of knees). Manipulations were performed for patients with ROM of less than 100° by 6 weeks after surgery. Mean premanipulation ROM was 90° (range, 5° to 100°), and postmanipulation ROM at final follow-up was 115° (range, 100° to 120°). One patient later underwent open revision for decreased ROM. At 2-year follow-up, this patient had ROM of 0° to 118° and a Knee Society Clinical Rating System (KSS) score of 98 points.

After TKA, 12 arthroscopic procedures (1.2% of knees) were performed for painful patellofemoral crepitus. These procedures were performed in cases in which the indication was present for more than 12 weeks after TKA. Specific findings on arthroscopy included lateral adhesions (all 12 patients), patellar maltracking necessitating lateral release (5 patients), retained cement (4 patients), fibrosis in the femoral notch or cyclops lesion (2 patients), and loose fragments (2 patients).

Eight knees (0.8% of knees) required reoperation. Four component revisions were performed (0.4%), and 3 polyethylene component changes were made (0.3%). One patient had a lateral release performed for patellar subluxation. Of the 2 patients who presented with late hematogenous deep infections, 1 underwent 2-stage reimplantation for clinical signs of infection, though all intraoperative cultures were negative (at 2-year follow-up, ROM was 0° to 100°, and KSS score was 90 points), and the other underwent a colonoscopy with resulting septicemia, which eventually seeded her joint and required

2-stage reimplantation (at 2-year follow-up, ROM was 0° to 110°, and KSS score was 90 points).

Two tibial components were revised for chronic pain. One of these patients had a loose tibial component (at 3-year follow-up, ROM was 0° to 115°, and KSS score was 90 points), and the other had the tibial component downsized from 9 to 7 because of a radiculopathy and reduced ROM (at 3-year follow-up, ROM was 0° to 100° and KSS score was 85 points).

Three polyethylene spacers were revised for either laxity or reduced ROM. One patient in this group experienced a traumatic posterior cruciate ligament and medial collateral ligament rupture and had the spacer revised after surgical ligament repair (ROM was 2° to 118° and KSS score was 90 points at 1-year follow-up; patient died after a motor vehicle accident before 2-year follow-up). Another patient was diagnosed with medial ligamentous laxity after a fall, though it is not clear whether the laxity developed after the fall or resulted from inadequate ligamentous balancing at the time of the primary arthroplasty (at 3-year follow-up, ROM was 0° to 120°, and KSS score was 95 points). The third patient had the spacer downsized after decreased ROM refractory to manipulation under anesthesia (at 2-year follow-up, ROM was 5° to 100°, and KSS score was 85 points).

Two patients had local postsurgical wound blistering, but neither had a wound infection, and in both cases the lesion was allowed to heal by secondary intention, with no residual scarring visible at final follow-up.

Stratification of results into 100 patient groups showed a decrease in complications requiring arthroscopic or open surgical intervention, particularly between the first 200 patients and the next 800 patients (Figure). There were 5 open surgical and 7 arthroscopic reoperations (2.5% and 3.5%, respectively; 6% overall) performed over the first 200 TKAs, representing 57% of all complications requiring reoperation. There were 3 open surgical and 5 arthroscopic reoperations (0.4% and 0.6% respectively, 1.0% overall) performed over the next 800 TKAs.

The conventional TKA cohort described earlier included 2 complications at a mean follow-up of 3 years (range, 2 to 4 years). One surgical revision and 1 arthroscopic contracture release were performed, for a total complication rate of 4%—similar to the overall complication rate for the MIS cohort and higher than the rate for the stratified population that excludes the first 200 knees.

Analysis of Radiographic Failures

Radiographic analysis of component alignment revealed 6 tibial components with varus alignment of more than 3° (0.6% of knees), with 3 of those having varus alignment of more than 5° (0.3% of knees). One tibia had an anterior slope of more than 3° (0.1% of knees). Five femoral components were in flexion of more than 5° relative to the femoral shaft (0.5% of knees), with all 5 having flexion of less than 10°. Nine patellar components had a slight tilt. All these patients were asymptomatic and doing well.

Radiographic analysis of tibial components revealed 9 patients with 1-mm nonprogressive lucencies in zone 1. Six patients had 1-mm nonprogressive lucencies in the lateral plateau. Four of the 6 had nonprogressive lucencies in zones 1 and 5, and 2 had progressive lucencies in zones 1 and 5. The latter 2 patients, members of the group with more than 3° varus alignment of the tibial component, were clinically asymptomatic as of this writing.

Radiographic analysis of femoral components revealed 18 patients with 1-mm stable lucent lines in zone 1, 10 patients with 1-mm stable lucent lines in zone 5, and 1 patient with progressive radiolucent lines appearing first in zone 1 and then in zone 5. Two patients had 1-mm notching of the anterior femur. Two patients had 1-mm lucent lines under the lateral patella. All these patients were clinically asymptomatic as of this writing.

Radiographically, there were 3 impending component failures, 2 tibial and 1 femoral. Of the 2 patients with impending tibial component failure, one had zone 1 and zone 5 lucencies noted before 2-year follow-up, and the other had zone 1 and zone 5 lucencies noted at 3-year follow-up. Both were asymptomatic as of this writing and were to be monitored annually. The patient with impending femoral component failure had a progressive lucency noted at 2-year follow-up. This patient was also being monitored with radiographs.

Discussion

With new surgical techniques come new risks and complications. MIS techniques have risks associated with reduced visualization, and a learning curve is involved, as is the case with any new procedure. In this article, we describe the complications of MIS-TKAs so that surgeons might be able to avoid such problems or reduce their learning curve.

In this large review of TKAs, we found a complication rate similar to the low rates reported by other investigators. Schroer and colleagues[21] described 5 complications (excluding knee manipulations) in a cohort of 146 patients followed to 2 years; Kolisek and colleagues[7] reported that, of 40 patients followed over 12 weeks, 4 developed wound infections; Berger and colleagues[15] reported only 2 complications in a cohort of 50 patients followed over 3 months; and Laskin and colleagues[9] found only 1 minor case of skin necrosis among 32 patients after 3 months. Although these complications are minimal, they need to be reported so that other surgeons can try to prevent them.

In the present study, 2.3% of knees required manipulation under anesthesia—a rate comparable with that reported for standard knee arthroplasty and for MIS techniques. Keating and colleagues[22] reported a rate of 1.8% in a retrospective review of more than 1600 standard knee arthroplasties. Several smaller studies of MIS techniques have reported no cases of manipulations under anesthesia being required,[5,9-11,23] and Berger and colleagues[15] reported only 1 manipulation among 50 patients.

In the present study, several patients developed painful crepitus weeks to months after surgery. Arthroscopically, this was identified as lateral soft-tissue hypertrophy along the anterolateral aspect of the knee. In standard TKA, the patella is everted, which makes it easier to evaluate this area during surgery and to remove any excess tissue if necessary. With MIS techniques, the patella may not be everted, and in some instances the soft tissue in this blind corner (fat pad and possible lateral meniscal attachments) may not be adequately removed, resulting in impingement through flexion and extension of the lateral femoral condyle. In addition, arthroscopic examination of this blind corner revealed retained osteophytes or cement in some cases, which may have contributed to the development of lateral fibrosis. Howe and colleagues[14] described a similar complication, 4 cases of retained cement after knee arthroplasty using MIS techniques.

To prevent complications of retained soft tissue, inadequate removal of cement or bone, and postoperative lateral fibrosis, it is essential that this blind corner be evaluated thoroughly. This should be done both visually in flexion and extension and by using manual digital palpation to make sure that all osteophytes, soft tissue, and cement have been removed. We perform checks at many stages of the procedure.[18] Howe and colleagues[14] reported using a small dental mirror to examine poorly visualized regions after unicompartmental knee arthroplasty—a technique that also may be helpful in MIS-TKA. Surgeons who are relatively inexperienced with MIS techniques should not hesitate to evert the patella briefly before closure or to extend the incision to gain enough exposure to reliably ensure that these potential hazards are not present. This might be particularly appropriate in more obese patients or in patients with possible deformities not initially thought present during preoperative planning or at the start of surgery, as these conditions can further complicate intra-articular visualization.

Ancillary arthroscopic techniques recently reported by Dr. Bonutti and Dr. Mont (unpublished data) may help surgeons avoid leaving the source of impairment during the initial procedure. Their recent study may shed light on the incidence of this potential problem in MIS arthroplasty. They performed 21 MIS arthroplasties and arthroscopically evaluated the knees for 4 potential contributors to postoperative complications: (1) retained bone fragments larger than 3 mm in any dimension, (2) retained cement fragments larger than 3 mm in any dimension, (3) soft-tissue impingement either under the patella or between the femoral and tibial components, and (4) evidence of patellar maltracking. One or more of these findings was present in 13 (62%) of the 21 knees—retained cement in 9 knees, bone fragments in 2, soft-tissue impingement in 11, and patellar maltracking in 2. Although the incidence of these findings was reasonably high, we believe that careful, systematic palpation of the poorly visualized portions of the knee before closure, as described earlier, allows reliable identification and removal of these potential hazards during the initial procedure.

The smaller incision might make a full examination of the posterior aspect of the knee and the posterior portions of the prosthesis more difficult. In addition, use of an all-polyethylene tibial component further diminishes visualization of the posterior compartment. As instruments cannot pass through this small area, it can be difficult to clean the posterior margins of the implant.[6,14] Using a modular metal-backed tibial component allows improved visualization and can facilitate cement removal.[6,14] As with the lateral gutter, the posterior region should be evaluated carefully and cleaned to ensure optimal surgical outcome.

Malalignment may be a leading cause of TKA failure.[6,13,24] Significant varus of the tibial component may reduce implant longevity. Dalury and Dennis[13] hypothesized that tibial malalignments in MIS result from difficulty visualizing the lateral tibial plateau. When the implant is not seated properly, when it impinges against the lateral femoral condyle or soft tissue during impaction, or when it is cemented with a thicker mantle on the lateral side, it is possible to tilt the component into varus position. Four of the patients in their study had tibial component malalignment—a finding similar to those reported by Kolisek and colleagues,[7] Laskin and colleagues,[9] and Chen and colleagues.[12]

In the present study, 6 tibial components had more than 3° varus alignment. Kolisek and colleagues[7] found 30 varus knees (>3° varus deformity) and 5 valgus knees using MIS techniques. Tria and Coon[23] described postoperative radiographs showing a mean distal femoral valgus of 6°, a tibial varus of 2.5°, and overall alignment of 4° of valgus. Laskin and colleagues[9] described 1 patient who had a body mass index of 40 kg/m^2 and in whom the tibial component was placed in 4° of varus in the coronal plane. To reduce the incidence of malalignment, the authors recommend using an external tibial alignment guide to confirm component orientation after fixing the implant, in addition to the measurements performed prior to and during component trialing. Results from the present study underscore the need for and importance of new instrumentation specifically designed for MIS-TKAs. Also, further investigation should explore use of computer-assisted navigation, as it may help in reducing component malalignment.

The small incision makes exposure of the femur difficult and may result in internal rotation of the femoral cutting guide secondary to difficulties identifying the transepicondylar axis.[6,24] Furthermore, in the present study, 5 femoral components from the first 200 TKAs were found to be in flexion, which we hypothesized was the result of a lack of familiarity with the instrumentation and subsequent failure to properly align the femoral cutting block. All 3 patients were doing well and had no clinical complications, but this finding underscores the importance of ensuring proper alignment of all instrumentation before cutting bone and of checking for proper seating of the implant.

The problems found with these techniques can be amplified when the amount of cement is reduced or poor cement pressurization techniques are used, which can lead to premature component loosening. There have been in vivo and in vitro studies documenting different cementing techniques that affect the stability of the components in knee arthroplasty,[25,26] with decreased visualization and access to the bony surfaces to pressurize the cement possibly contributing to early loosening of the components. In addition, during knee MIS, some surgeons intentionally minimize the amount of cement placed on the components at time of cementation to limit the cement debris extrusion that leads to retained cement foreign bodies.[6] Recognizing the importance of good cementing technique in ensuring the stability of tibial implants, we know that the amount of cement used should not be reduced to the point where the depth of penetration of cement into tibial bone will be compromised.

The consensus of several investigators is that there is an MIS-TKA learning curve. In contrast to learning curve estimates being based on operative time in smaller patient groups,[27,28] we based our estimate on differences in complication rates for stratified groups of 100 knees using a large number of patients and a long follow-up. With an 80% decrease in rates of complications requiring arthroscopic or open surgical intervention between the first 200 and the next 800 patients, it is possible that high-volume knee surgeons may require as many as 200 MIS-TKAs before achieving optimum proficiency with the technique. A results comparison between the current cohort and the last 50 consecutive TKAs performed by the same surgeon shows a similar overall clinical complication rate—and a lower complication rate in the MIS group when the first 200 procedures are excluded, suggesting that, even with the learning curve, complication rates need not increase.

The limitations of this study include differences in follow-up time between the stratified patient cohorts. Follow-up was longer for the first 200 knees than for the next 800. With most of our patients' complications occurring during the early follow-up period, however, we do not believe that having equal follow-up times would markedly affect our finding that there is a learning curve associated with MIS-TKA adoption that may encompass as many as 200 cases.

As mentioned earlier, most MIS-TKA cases have follow-ups of only 1 year. We believe that our large series with its minimum 2-year follow-up offers the unique advantage of describing many of the long-term complications of this technique. Knowledge of potential problems may prevent, or lessen the incidence of, MIS-TKA complications.

Authors' Disclosure Statement

Dr. Bonutti wishes to note that he is a paid consultant and a member of the speakers' bureau for Stryker Orthopaedics, and receives royalties from ArthroCare, Stryker Orthopaedics, Synthes, Biomet, and Joint Active Systems Inc. Dr. Mont wishes to note that he is a paid consultant for Stryker Orthopaedics and Wright Medical Technology Inc., receives royalties from Stryker Orthopaedics, and receives research support from the National Institutes of Health (NIAMS & NICHD), Stryker Orthopaedics, Tissue Gene, and Wright Medical Technology Inc. The other authors report no actual or potential conflict of interest in relation to this article.

References

1. Tashiro Y, Miura H, Matsuda S, Okazaki K, Iwamoto Y. Minimally invasive versus standard approach in total knee arthroplasty. *Clin Orthop.* 2007;(463):144-150.
2. Bozic KJ, Hansen E. The economics of minimally invasive total knee arthroplasty. *J Knee Surg.* 2006;19(2):149-152.
3. Coon TM. The economic impact of minimally invasive total knee arthroplasty. *Am J Orthop.* 2006;35(7 suppl):33-35.
4. Cuckler J. The ugly underbelly of the MIS movement: in the affirmative. *J Arthroplasty.* 2007;22(4 suppl 1):99-101.
5. Haas SB, Cook S, Beksac B. Minimally invasive total knee replacement through a mini midvastus approach. A comparative study. *Clin Orthop.* 2004;(428):68-73.
6. Hamilton WG, Collier MB, Tarabee E, McAuley JP, Engh CA Jr, Engh GA. Incidence and reasons for reoperation after minimally invasive unicompartmental knee arthroplasty. *J Arthroplasty.* 2006;21(6 suppl 2):98-107.
7. Kolisek FR, Bonutti PM, Hozack WJ, et al. 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(1):8-13.
8. 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.
9. Laskin RS, Beksac B, Phongjunakorn A, et al. Minimally invasive total knee replacement through a mini-midvastus incision: an outcome study. *Clin Orthop.* 2004;(428):74-81.
10. Lonner JH. Minimally invasive approaches to total knee arthroplasty: results. *Am J Orthop.* 2006;35(7 suppl):27-29.
11. Tenholder M, Clarke HD, Scuderi GR. Minimal-incision total knee arthroplasty: the early clinical experience. *Clin Orthop.* 2005;(440):67-76.
12. Chen AF, Alan RK, Redziniak DE, Tria AJ Jr. Quadriceps sparing total knee replacement. The initial experience with results at two to four years. *J Bone Joint Surg Br.* 2006;88(11):1448-1453.
13. Dalury DF, Dennis DA. Mini-incision total knee arthroplasty can increase risk of component malalignment. *Clin Orthop.* 2005;(440):77-81.
14. Howe DJ, Taunton OD Jr, Engh GA. Retained cement after unicondylar knee arthroplasty. A report of four cases. *J Bone Joint Surg Am.* 2004;86(10):2283-2286.
15. Berger RA, Sander S, Gerlinger T, Della Valle C, Jacobs JJ, Rosenberg AG. Outpatient total knee arthroplasty with a minimally invasive technique. *J Arthroplasty.* 2005;20(7 suppl 3):33-38.
16. Scuderi GR, Tenholder M, Capeci C. Surgical approaches in mini-incision total knee arthroplasty. *Clin Orthop.* 2004;(428):61-67.
17. Tria AJ Jr. Minimally invasive total knee arthroplasty: the importance of instrumentation. *Orthop Clin North Am.* 2004;35(2):227-234.
18. Bonutti PM, Mont MA, Kester MA. Minimally invasive total knee arthroplasty: a 10-feature evolutionary approach. *Orthop Clin North Am.* 2004;35(2):217-226.
19. Bonutti PM, Dethmers DA, McGrath MS, Ulrich SD, Mont MA. Navigation did not improve the precision of minimally invasive knee arthroplasty. *Clin Orthop.* 2008;466(11):2730-2735.
20. Bonutti PM, Dethmers DA, Ulrich SD, Seyler TM, Mont MA. Computer navigation–assisted versus minimally invasive TKA: benefits and drawbacks. *Clin Orthop.* 2008;466(11):2756-2762.
21. Schroer WC, Diesfeld PJ, Reedy ME, LeMarr AR. Mini-subvastus approach for total knee arthroplasty. *J Arthroplasty.* 2008;23(1):19-25.
22. Keating EM, Ritter MA, Harty LD, et al. Manipulation after total knee arthroplasty. *J Bone Joint Surg Am.* 2007;89(2):282-286.
23. Tria AJ Jr, Coon TM. Minimal incision total knee arthroplasty: early experience. *Clin Orthop.* 2003;(416):185-190.
24. Jenny JY, Ciobanu E, Boeri C. The rationale for navigated minimally invasive unicompartmental knee replacement. *Clin Orthop.* 2007;(463):58-62.
25. Bert JM, McShane M. Is it necessary to cement the tibial stem in cemented total knee arthroplasty? *Clin Orthop.* 1998;(356):73-78.
26. Ritter MA, Herbst SA, Keating EM, Faris PM. Radiolucency at the bone–cement interface in total knee replacement. The effects of bone-surface preparation and cement technique. *J Bone Joint Surg Am.* 1994;76(1):60-65.
27. King J, Stamper DL, Schaad DC, Leopold SS. Minimally invasive total knee arthroplasty compared with traditional total knee arthroplasty. Assessment of the learning curve and the postoperative recuperative period. *J Bone Joint Surg Am.* 2007;89(7):1497-1503.
28. Lubowitz JH, Sahasrabudhe A, Appleby D. Minimally invasive surgery in total knee arthroplasty: the learning curve. *Orthopedics.* 2007;30(8 suppl):80-82.