Analysis of learning curve of minimally invasive total knee arthroplasty: A single surgeon's experience with 4017 cases over a 9-year period

Yu-Chi Cheng[a,b,c], Po-Kuei Wu[b,d,e,f], Cheng-Fong Chen[b,d,e], Chao-Ming Chen[d,e,f], Shang-Wen Tsai[d,e,f], Ming-Chau Chang[b,d,e,f], Wei-Ming Chen[b,d,e,f,*]

[a]Department of Radiology, Taichung Veterans General Hospital, Taichung, Taiwan, ROC; [b]Orthopaedic Department School of Medicine, National Yang-Ming University, Taipei, Taiwan, ROC; [c]Department of Radiology, Taipei Veterans General Hospital, Taipei, Taiwan, ROC; [d]Department of Orthopaedics and Traumatology, Taipei Veterans General Hospital, Taipei, Taiwan, ROC; [e]Department of Orthopaedics, Therapeutical and Research Center of Musculoskeletal Tumor, Taipei Veterans General Hospital, Taipei, Taiwan, ROC; [f]Institute of Clinical Medicine, School of Medicine, National Yang-Ming University, Taipei, Taiwan, ROC

Abstract

Background: To evaluate a single surgeon's experience with minimally invasive total knee arthroplasty (MIS-TKA) and report the 9-year learning curve and trends in clinical outcomes based on assessment of surgical skills, radiographic alignments, and patient's function scores.

Methods: This retrospective study included a total of 4107 knees from 3403 patients undergoing bilateral or unilateral MIS-TKA between March 2004 and February 2013. MIS-TKA was performed through a modified mini-midvastus approach. Postsurgical care regime was standardized for all patients. Data of consecutive 3-month intervals were collected and compared for changes of trends in outcomes over time, including tourniquet time, intraoperative complications, radiographic alignment, the Knee Society Score (KSS), and functional scores.

Results: Significant increase in the number of cases undergoing MIS-TKA per 3-month interval over the study period was observed. As surgeon's experience increased over time, tourniquet time was decreased from an average of 70 minutes to approximately 35 minutes. A total of 65 (1.68%) intraoperative complications were recorded and the frequencies were in a significant decreasing trend. The rate of malalignment was in a decreasing trend and steady desired alignment (6º) was achieved at the 15th three-month interval. KSS and function scores increased from 87.4 to 91.5 and 92.6 to 96.8, respectively.

Conclusion: Although a surgeon may become competent with MIS-TKA and achieved the preliminary learning curve within one year, experience accumulation continuously improved technical proficiency in MIS-TKA. This study confirmed significant improvements in surgical skills, postoperative alignment, and patients' function over time.

Keywords: Learning curve; Minimal invasive; Total knee replacement

1. INTRODUCTION

Total knee arthroplasty (TKA) has been used very successfully to treat patients with advanced osteoarthritis. It can alleviate pain, restore joint function, and improve quality of life.[1–3] Conventional TKA requires a larger incision, which may cause quadriceps mechanism disturbance, more soft tissue manipulation, and consequently results in higher levels of postoperative pain, longer hospital stays, and delayed functional recovery.[4–6]

To improve postoperative outcomes, minimally invasive TKA (MIS-TKA) has gained increasing popularity for both surgeons and patients in clinical practice. The advantages of MIS-TKA include minimized surgical trauma, decreased postoperative pain, and faster rehabilitation and functional recovery.[7–10] MIS-TKA is a technically demanding and challenging procedure. The success of TKA depends on proper alignment of components,[11] ligament balancing,[12] prosthetic designs, and surgeon's experience.[13,14] However, some critics have argued that MIS-TKA is associated with prolonged surgical times, higher incidence rates of tourniquet-associated ischemia and infection. Besides, it also poses higher risk for misaligned components and other complications because of poor exposure and visualization.[15,16]

Many clinical studies suggest conflicting results on the comparison between MIS-TKA and conventional TKA, and more recent randomized clinical trials (RCTs) on this subject yielded no conclusive results.[17–26] Some studies have also raised the issues over surgical experience for successful execution of MIS TKA.[15,27,28] However, currently, there is no study that compares the clinical outcomes of MIS-TKA at the early phase with the late experience phase of learning curve.

Address correspondence: Dr. Wei-Ming Chen, Department of Orthopaedics and Traumatology, Taipei Veterans General Hospital, 201, Section 2, Shi-Pai Road, Taipei 112, Taiwan, ROC. E-mail address: wmchen@vghtpe.gov.tw (W.-M. Chen).

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Comparing to the initial phase of learning curve, we therefore sought to ask the following questions: (1) Could surgeons gain MIS-TKA proficiency in the latter phase? (2) Was the variation of postoperative alignment improved in the latter phase? (3) Was patients' functional outcome improved in the latter phase?

2. METHODS

2.1. Patients

Patients who received MIS-TKA performed by a single surgeon between March 2004 and February 2013 were enrolled to the study. The definition of MIS-TKA in the study included both the following criteria: first, the size of wound incision measured in knee extension was <12 cm; second, the approach for TKA of knee joints was through a modified mini-midvastus incision. The exclusion criteria included revision TKA (n = 105), conventional TKA (n = 43), and multipurpose surgery. Patients who received conventional TKAs included the knees with severe rheumatoid arthritis (n = 16), severe trauma (n = 6), hemophilia (n = 10), human immunodeficiency virus (n = 8), and other immune disease (n = 3). Multipurpose surgery was undertaken for TKA in combination with tumor resection, or removal of implant in the same incision with TKA, so that the patients were not included. A total of 4107 MIS-TKAs were finally used for analysis (Fig. 1). Patient characteristics are shown in Table. Female patients represented the majority (n = 2632, 77.3%). Mean age of the entire patients was 71 years and was similar between genders. Mean body mass index (BMI) values of both genders were 27.2 and 29.7 Kg/m^2 for male and female patients, respectively, giving 52.2% of male and 65.4% of female patients were obese (BMI ≥ 27 Kg/m^2) according to the cutoffs defined by the Department of Health in Taiwan. The indication for surgery was predominantly osteoarthritis (n = 3858, 94%), followed by rheumatoid arthritis (n = 91, 2.2%), and others (n = 158, 3.8%). Preoperatively, the mean range of motion (ROM) was 131.1° ± 11.4°. Of those, 704 patients (34.3%) received bilateral TKA (1408 knees) and 2699 (65.9%) underwent unilateral TKA, giving a total of 4107 knees with similar numbers of right and left knees. Data were collected with ongoing Institutional Review Board approval of Taipei Veterans General Hospital, Taiwan.

2.2. Evaluation of surgical skill

Surgical skills were evaluated based on three parameters, which includes tourniquet time, patella tracking, and intraoperative complications. Considering the duration of wound closure that

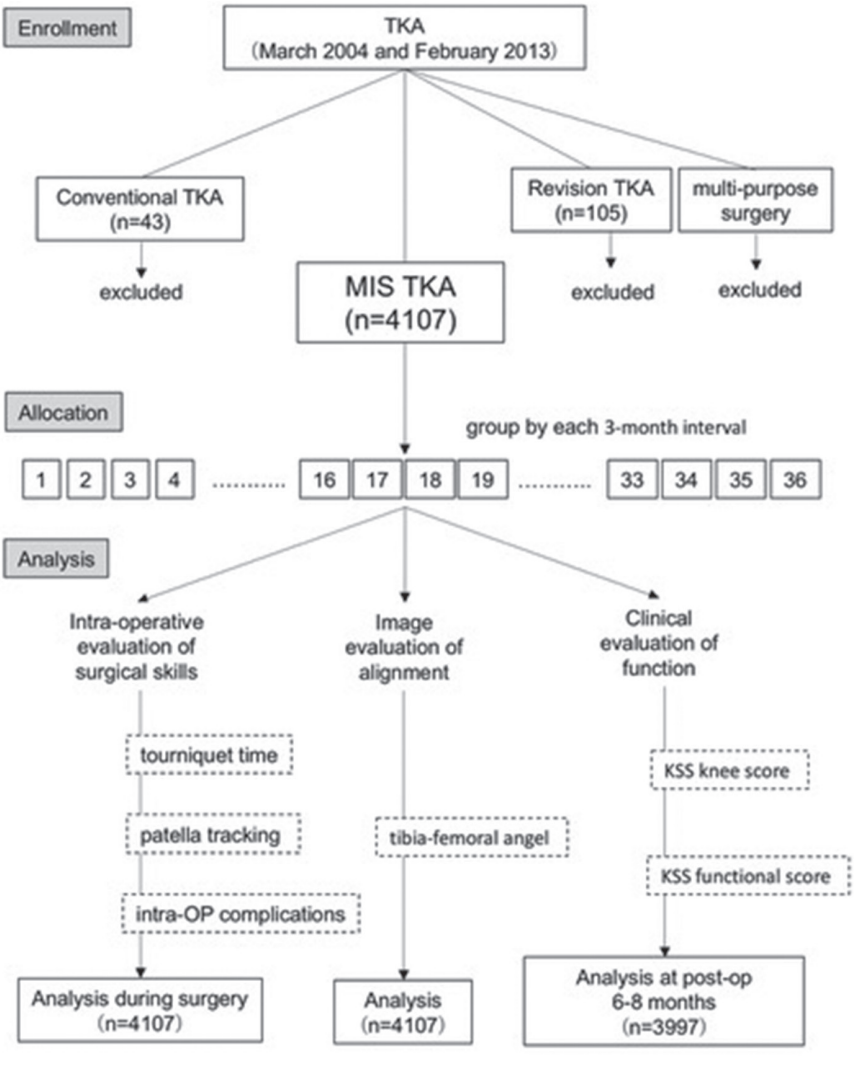

Fig. 1 Study flow chart.

Table

Characteristic of cases undergoing MIS-TKA during March 2004 to February 2013

Variables	N	%	Mean ± SD
Gender			
Male	771	22.7	
Female	2632	77.3	
Age, y			
Male			72.5 ± 9.8
Female			70.6 ± 8.5
BMI, kg/m^2			
Male			27.2 ± 6.1
Female			29.7 ± 6.1
Diagnosis			
Osteoarthritis	3858	94.0	
Rheumatoid arthritis	91	2.2	
Other	158	3.8	
Unilateral/bilateral knees			
Unilateral	2699	65.7	
Bilateral (n = 704)	1408	34.3	
Knee			
Right	1992	48.5	
Left	2115	51.5	
Incision length, cm			9.1 ± 0.5
Cuff pressure, mmHg			270.4 ± 22.9
Tourniquet time, min			46.9 ± 22.9

BMI = body mass index; MIS-TKA = minimally invasive total knee arthroplasty; ROM = range of motion.

varied among junior surgeons, "tourniquet" time was used to present the changes of proficiency instead for "surgical" time. Tourniquet was inflated during the time of skin incision, with the pressure set as systolic blood pressure (SBP) plus 110 mmHg and a minimum pressure of 260 mmHg. Tourniquet was deflated while the prosthesis was well cemented–implanted. After tourniquet was deflated, the knee was kept in full extension till entering hardening phase of bone cement, followed by wound closure performed by junior surgeons. All patella were resurfaced to reduce the risks of anterior knee pain and reoperation.[29] A modified "towel clip" technique[30] was used to assess patellar tracking and classified as "excellent," "good," or "concerned." Intraoperative complications such as soft tissue injury, iatrogenic fracture, malposition of the implant (overhanging of the prosthesis), less bone cutting lead postoperative flexion contracture, over bone cutting, which needs thicker polyethylene insert (>14 mm) to maintain the stability, over patella bone cutting (the remained patella thickness <11 mm) were all recorded.

2.3. Evaluation of image alignment

Patients with bipedal standing anterior–posterior radiographs were taken in knee full extension. Angular measurements were performed independently using SmartIris software by a senior radiologist at the other hospital. The tibia-femoral angle was defined as the angle between the femoral anatomical axis and the tibial anatomical axis in the coronal plane. As it has been recommended that normal anatomic alignment of the tibiofemoral joint is approximately 5° to 7° of valgus,[31] we defined anatomical alignment at 6° as "neutral", and the alignment deviations >3° as varus malalignment (<3.0°) or valgus malalignment (>9.0°).

2.4. Evaluation of patient's function

Postoperative knee function was evaluated using the Knee Society Score (KSS) and functional scores[32] at the sixth to eighth month after surgery. Functional results of 110 patients were not available during that period.

2.5. MIS-TKA procedures

The procedure was modified to about 20° of horizontal incision than the traditional midvastus approach. The distal femoral cut was performed by intramedullary guide in the alignment at 6° of valgus. Whiteside's line and posterior condyle axis (PCA) were used as guides to adjust position for the optimal femoral external rotation. The proximal tibia was cut perpendicular to the mechanical axis using an extramedullary alignment guide. Two types of TKA prosthesis were used, including the former half of duration (18 × 3 months) with Scorpio NRG (Stryker Orthopaedics, USA) and the latter half of duration with NexGen High Flex (Zimmer Inc., USA). After components were cemented–implanted, joint stability and implant position were rechecked. After the surgery, the cutting thickness of each bone fragments was recorded.

2.6. Postoperative care

Standard postsurgical care regime was given to all patients. Continuous passive motion (CPM) rehabilitation was started immediately following surgery and patients were allowed full weight bearing. There was no change in the rehabilitation protocols during the different time phase. First-line antibiotics were given intravenously for only one day in most cases. Prophylactic thromboprophylaxis was prescribed to patients with high risk for venous thromboembolism or BMI > 35. All drains were removed within 1 to 2 days after surgery.

2.7. Statistical analysis

Data descriptive statistics are presented as mean ± SD. Variables and outcomes were analyzed for consecutive intervals. Procedures were categorized into 3-month calendar intervals, based on the date of surgery. Changes over time were analyzed using linear regression with a best-fit linear equation ($y = mx + b$), where m (the slope) represents the rates of decrease or increase in time. Statistical analyses were performed using SPSS (version 16.0, SPSS Inc., IL, USA). A p value ≤0.05 was considered statistically significant.

3. RESULTS

3.1. Improved surgical skills in the late experience phase of learning curve of MIS-TKA

The number of MIS-TKA performed was in an overall significant increasing trend ($p < 0.001$) during the study period, with a growth rate of 1.3% per 3 months (Fig. 2). The mean tourniquet time was 46.9 ± 22.3 minutes (minimum 23 minutes and maximum 137 minutes). The tourniquet time significantly decreased with increasing experience, from an average of 70.0 minutes during the first year (4 × 3-month intervals), followed by 60-50 minutes in the following 4 years, and dipped to about 35 minutes at the 30th interval and thereafter (Fig. 2, $p < 0.001$). The results of intraoperative assessment of patellar balancing revealed a significant increasing trend in the percentage of knees with excellent outcomes ($p < 0.001$) (Fig. 3).

There were a total of 65 (1.58%) intraoperative complications in the case series (Fig. 4A). Complications of the soft tissue included superficial medial collateral ligament (MCL) injury (n = 2) and total popliteal tendon tear (n = 1). Complications of the bone consisted of inappropriate bone cutting of posterior femur (n = 10), distal femur (n = 10), lateral tibia (n = 9), and patella (n = 9). The occurrence of iatrogenic fractures were identified in femoral lateral condyle (n = 10), medial condyle (n = 6), femur shaft fracture (n = 2), and tibia plateau (n = 2). Others

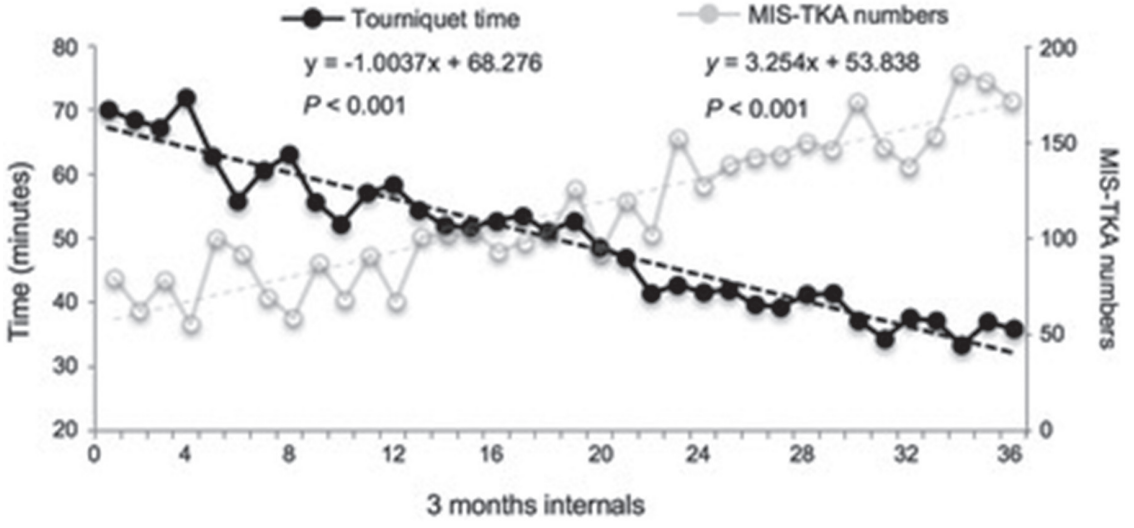

Fig. 2 The number of knees undergoing minimally invasive total knee arthroplasty (MIS-TKA) and the trends of tourniquet time required at 3-month intervals over the study period (2004 to 2013). Individual data points are connected by a straight line to represent a linear increasing trend curve.

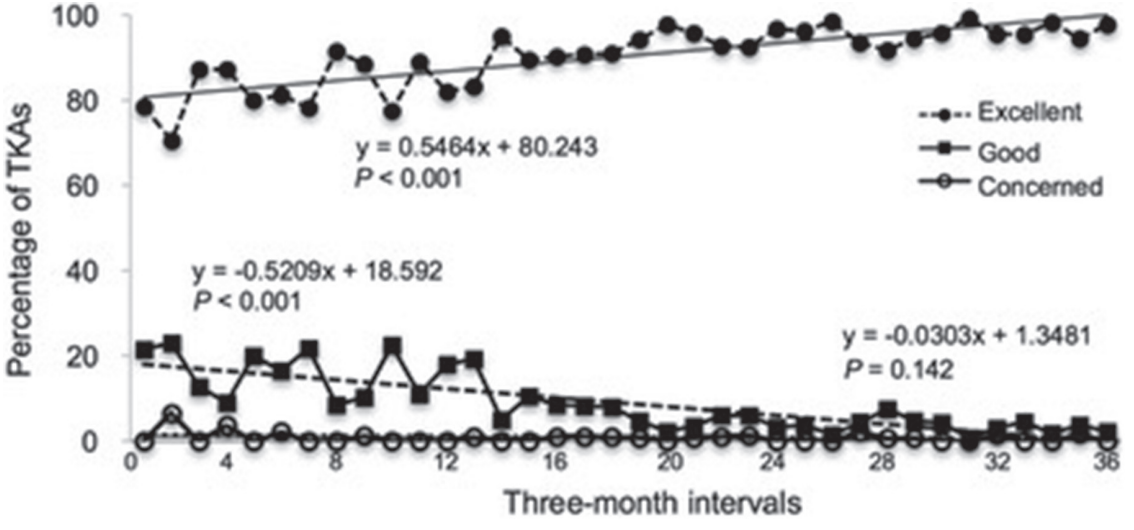

Fig. 3 The percentages of knees undergoing minimally invasive total knee arthroplasty (MIS-TKA) with concerned, good, and excellent patellofemoral kinematics in intraoperative assessment of patellar tracking per 3-month interval over the study period (2004 to 2013).

were malposition of the prosthesis of femur (n = 3) and tibia (n = 1). The frequencies of complications decreased with operative experience and time were noted (Fig. 4B).

3.2. Steady alignment in radiographic assessment at the late experience phase of learning curve

The mean of tibia-femoral angle in the coronal plane was 6.5° ± 0.1°; of which, 89.0% of knees were within 5.0° to 8.0°. There were relatively widespread variations in the overall tibia-femoral angles until the 15th three-month interval (Fig. 5A). Despite the means of alignment angles remained very similar across all measurement at 3-month intervals, the percentage of malalignment being different, with a trend noticed in a tighter range over time. The percentage of malalignment was shown in Fig. 5B. Steady desired alignment (6°) was achieved at the 15th three-month interval, followed by a slight elevation of alignment deviations due to the change of components (from Stryker to Zimmer).

3.3. Improvement of knee function in the late experience phase of learning curve of MIS TKA

Statistically significant improvement in the trends were observed in the KSS knee and functional scores among the measurements at 3-month intervals (Fig. 6). The initial mean KSS knee score was 87.4 and gradually increased to 91.5 at 3-month follow-ups and KSS function score improved from 92.6 to 96.8, which was a significant improvement compared with the early stage of learning curve.

4. DISCUSSION

4.1. Limitations

There are limitations to this study. First, it represents the learning curve of a single surgeon, and as expected, it can change from surgeon to surgeon, depending on previous training and inherent skills. However, a learning curve analysis including

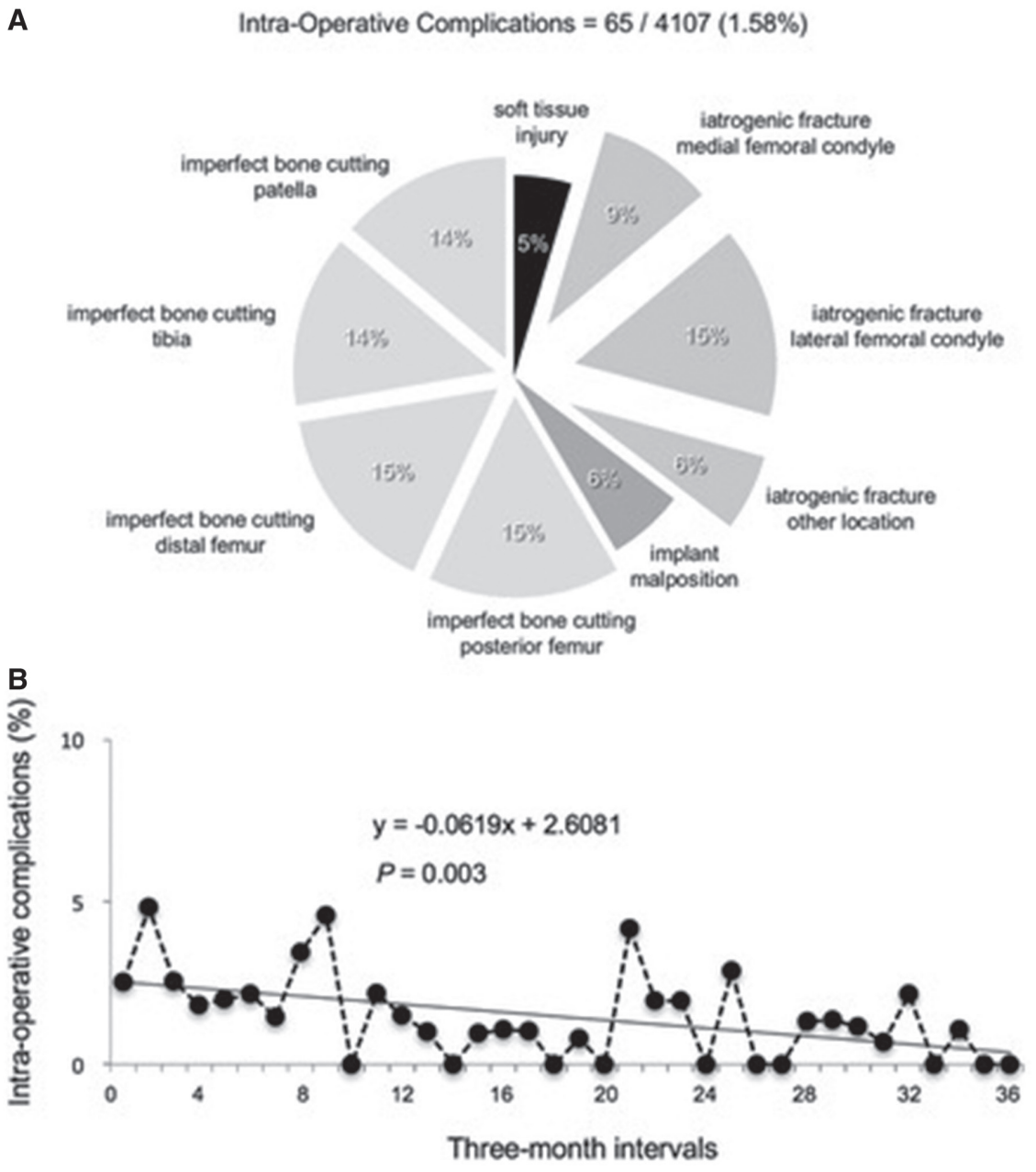

Fig. 4 The distribution of intraoperative complications in the case series (A) and the changes in trend over time (B).

multiple surgeons with variations in skills, preferences, personalities, and surgical volumes may lead to difficulties in drawing conclusions. Second, this was a retrospective study. Although the study was based at the same institution, the population was large, patients were included with uncontrolled variables, and data of long-term follow-up were incomplete or unavailable, leading to the analyses of many clinical outcomes or the survivorship of knee components impossible. Third, the learning curve described herein might not only be just representative of an individual surgeon, but also a coordinated team. Improvements in anesthesia, ancillary staffs in surgical room, critical care, nursing, and others involved in the care of patients receiving MIS-TKA are inseparable from the surgical performance. Therefore, results of this study might not be extrapolated in a different setting. However, by this 4107 MIS-TKA cases series, we compare the changes in surgical skills, patients' image results, and functional outcome through a 9-year period, the results would be meaningful for both surgeons' approval and disapproval of MIS-TKA.

The number of patients undergoing MIS-TKA in 2013 was 2.5 times that during the first year (2004), suggesting that MIS-TKA is performed in an increasing demand in Taiwan as other countries, driven by socio-demographic changes, more information accessible, patient age and expectations, longer life expectancy, and health insurance policy.[33]

All new techniques require a learning curve of variable duration. Studies that specifically analyzed the learning curve for MIS-TKA were rare and reported that 10 to 100 operations could achieve optimal experience;[27,34,35] however, the authors imposed strict eligible criteria for patients undergoing MIS-TKA. On the contrary, 98.9% primary TKA patients received MIS-TKA in this study. Based on the achievement of steady postoperative

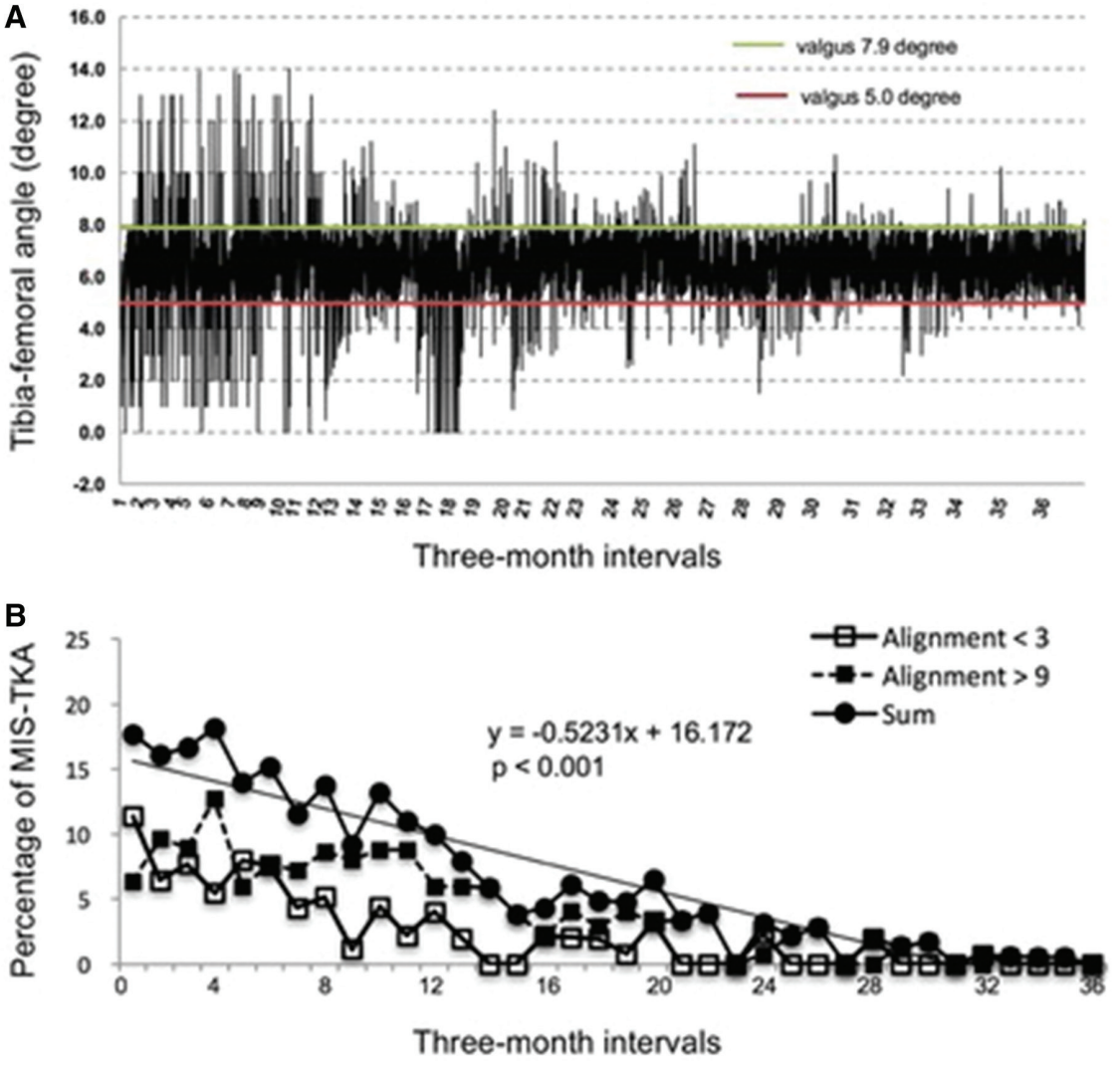

Fig. 5 The overall anatomical alignment degrees in the knees undergoing minimally invasive total knee arthroplasty (MIS-TKA) (A) and the percentage of knees with postoperative malalignment after MIS-TKA at 3-month intervals over the study period. The acceptable range of alignment was defined at within 6° ± 3° (B).

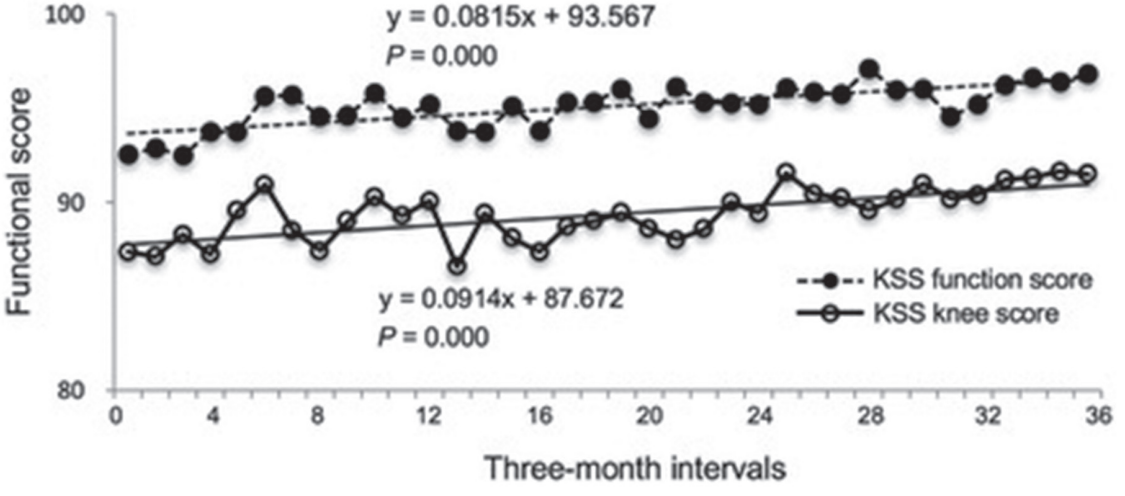

Fig. 6 Graphs showing the trends of mean Knee Society Score (KSS) and function score in patients undergoing minimally invasive total knee arthroplasty (MIS-TKA) at 3-month intervals over the study period (2004 to 2013).

alignment, the surgeon has gone through his learning curve after the fourth 3-month interval, with approximately 280 patients in the study.

The experience of MIS-TKA could be advanced by surgical volume, as well as changes in surgical approaches, instruments, and ancillary staffs. For surgical approaches and instruments, modified mini-midvastus incision was preferred to gain better restoration of extension mechanism. However, the bulky quadriceps muscle could hinder the vision field. Thus, adequate undermining of quadriceps muscle, application of a specific angled Hohmann retractor to patella, and choose MIS-specific cutting jigs were all critical to gain a better surgical field. Besides, well-controlled extension-flexion status of the knee during the whole procedure was necessary to create a mobile window for gaining a lager intra-articular working space.

A competent surgeon not only continues to improve himself to deliver effective skills but also creates a learning environment to educate ancillary staff for promoting the synergy of team members, which have a vital impact on surgical outcomes and contribute to successful MIS-TKA. For example, experienced ancillary staff would proactively inquire about the initiation of PMMA polymerization at specific time points, which contributed to decrease in tourniquet time.

In this study, the surgeon's skill was continuously improved within the period of 9 years. Not only the tourniquet time decreased to approximately half of the beginning (70 to 35 minutes) but also patella tracking was improved and intraoperative complications were decreased significantly.

Among those intraoperative complications, some events reasonably could be expectable to increase during MIS-TKA. First, inappropriate posterior femur condyle bone cutting could cause malrotation of femur component, leading to concerned patella tracking and unfavorable posterior condylar offset.[36,37] To gain the better visualization of the posterior femur condyle, surgeon might need to measure the posterior cutting in fully-flexion status. Second, overcutting of tibia bone at lateral side could cause valgus malalignment. In such case, complications might be prevented by preoperative templating. Third, unequal femur condylar bone cutting is caused by malposition of the notch chamfer, and it would cause iatrogenic femur condylar fracture consequently. However, by good surgical approaches and retractor, as well as experienced skills, could together contribute to prevent those aforementioned complications.

Surgical skill affects outcomes greatly and the extent of improvement can be reflected in the results of postoperative radiographic assessment on alignment and patients' functional scores. According to the aforementioned results, the outcomes of MIS-TKA in terms of efficiency and quality at the late experience phase of learning curve were significantly improved compared to the early phase. It is therefore suggested that the impact of learning curve should be taken into considerations while conducting MIS-TKA-related studies.

In conclusion, this study reports the experience of a single surgeon undertaking MIS-TKA over 9 years. Although the events of complications were unavoidable in MIS-TKA, with experience accumulation, significant improvements in surgical skills, postoperative alignment, and patients' function were confirmed. Furthermore, the learning curve for surgeons should be emphasized while applying MIS-TKA or investigating outcomes.

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