The Knee 22 (2015) 347–350

Contents lists available at ScienceDirect

The Knee

Lower limb alignment control: Is it more challenging in lateral compared to medial unicondylar knee arthroplasty?

Saker Khamaisy *, Brian P. Gladnick, Denis Nam, Keith R. Reinhardt, Thomas J. Heyse, Andrew D. Pearle

Sports Medicine and Shoulder Service, Department of Orthopaedic Surgery, Hospital for Special Surgery, Weill Medical College of Cornell University, New York, NY, United States

ARTICLE INFO

Article history:
Received 27 January 2014
Received in revised form 11 January 2015
Accepted 24 February 2015

Keywords:
Unicondylar
Knee arthroplasty
Alignment
Navigation
Robotic

ABSTRACT

Introduction: Limb alignment after unicondylar knee arthroplasty (UKA) has a significant impact on outcomes. The literature lacks lateral UKA alignment studies, making our understanding of this issue based on medial UKA.
Methods: We evaluated limb alignment in 241 patients who underwent medial (229 knees) or lateral (37 knees) UKA. Alignment was measured pre and postoperatively in radiographs and intra-operatively using a navigation system. We compared the percentage of over-correction and the difference between post-operative alignment and navigation measurement.
Results: Percentage of overcorrection was significantly higher in the lateral UKAs (11%) compared to the medial UKAs (4%). In medial UKAs, the mean difference between the intraoperative alignment and the post-operative was 1.33°. This was significantly lower than the mean 1.86° difference in the lateral UKAs.
Conclusions: Our data demonstrated an increased risk of "overcorrection," and greater difficulty in predicting postoperative alignment using computer navigation, when performing lateral UKAs compared to medial UKAs.

1. Introduction

Unicompartmental knee arthroplasty (UKA) has been shown in previous studies to be a promising treatment for single compartment knee osteoarthritis [1–6].

Compared to total knee arthroplasty, UKA has the advantages of a shorter rehabilitation period, faster recovery [7,8] greater range of motion [9,10] and lower postoperative morbidity [11].

In contrast to the poor outcomes of UKAs in the 1970's, the increased success of modern UKAs can be attributed to improved implant designs and surgical techniques, enabling superior implant positioning and limb alignment correction with minimal bone and soft tissue damage [12–14].

Restoration of lower limb alignment during a knee arthroplasty is critical for pain relief, improved function, and implant survival [15–18]. Controversies exist regarding the optimal postoperative limb alignment. While alignment overcorrection (i.e. turning varus knee into valgus and vice versa) may increase the risk of degenerative changes in the non-operated compartment [5], "undercorrection" is associated with accelerated polyethylene wear [18], poor results, and early failures [16]. In medial UKA, some authors recommend restoration of the normal axis of the limb, which passes medial to the knee center and have shown better results with a mild, varus undercorrection [15,16,18–20]. Lateral UKA is relatively uncommon procedure with good survivorship and outcome scores [21–23]. However, and the published studies about outcomes of lateral UKA are based on small numbers, and the conclusions of these studies are typically inconsistent, and rarely discuss issues of alignment or overcorrection [24–27].

Since UKA is a resurfacing procedure with limited soft tissue intervention, restoration of limb alignment is mainly based on implant positioning. At present, computer assisted and robotic techniques are one of the most reliable available tools to control postoperative long limb alignment in UKA [15,19,28,29]. Robotic-based navigation systems control limb alignment, as preoperative planning is based on three dimensional imaging (computed tomography), and haptic technology prevents the surgeon from performing unplanned bony resections [30, 31].

The purposes of this study were to 1) determine the overall, postoperative mechanical alignment in the medial and lateral UKR cohorts and to assess the incidence of lower limb alignment "overcorrection," between the two cohorts, 2) compare the magnitude of alignment correction (in degrees) achieved between medial and lateral UKRs using a robotic surgical technique, and 3) evaluate the reliability of a navigation system in predicting the radiographically measured, postoperative, weight bearing alignment in medial versus lateral UKAs. Our hypothesis is that physiologic differences between the medial and lateral knee compartments may contribute to increased difficulty in achieving optimal alignment correction in lateral UKRs compared to medial UKRs when using a robotic surgical technique.

2. Methods and materials

We retrospectively reviewed the IRB-approved, prospective surgical database of the senior author (ADP) for all consecutive patients

* Corresponding author at: Hospital for Special Surgery, 535 E. 70th Street, New York, NY 10021, United States. Tel.: +1 646 714 6251; fax: +1 646 797–8222.
E-mail addresses: khamaisys@hss.edu, saker@hadassah.org.il (S. Khamaisy).

http://dx.doi.org/10.1016/j.knee.2015.02.018
0968-0160/

who underwent UKA for isolated compartment osteoarthritis (OA) between the first of January, 2008, and 30th June, 2010. Indications for performing a UKA were the presence of isolated compartment osteoarthritis, a flexion contracture of less than 10°, flexion to greater than 90°, and an intact anterior cruciate ligament based on clinical and intraoperative assessments. Contraindications for performing a UKA were the presence of an inflammatory arthropathy, Kellgren Lawrence grade 3–4 changes in the non-operated compartment or the patellofemoral compartment on preoperative radiograph, or suspected pain originating from the patellofemoral compartment on preoperative clinical examination.

Inclusion criteria were patients who had a preoperative overall mechanical valgus alignment with isolated lateral compartment OA, or a preoperative overall mechanical varus alignment with isolated medial compartment OA, and had undergone a robotic-assisted fixed bearing UKA (MAKO Tactile Guidance System [TGS], MAKO Surgical Corporation, Fort Lauderdale, Florida). Application of our inclusion and exclusion criteria yielded 205 patients with 229 medial UKAs and 36 patients with 37 lateral UKAs for final analysis. All patients had preoperative and postoperative anteroposterior (AP), standing, hip-to-ankle radiographs. Postoperative radiographs were typically performed at each patient's first, postoperative clinic visit (approximately six weeks after the date of surgery). To control for limb rotation, we utilized a previously described protocol in which the limb is internally rotated approximately 5° until a line between the femoral epicondyles is parallel to the cassette, and the tibial eminence is seen in the center of the intercondylar fossa. Patients who did not possess these radiographs were excluded.

Electronic medical records and charts of the patients who met our inclusion criteria were reviewed. Patient demographic data, including gender, age, and body mass index (BMI), as well as intraoperative patient data, were collected and are displayed in Table 1. The overall, mechanical alignment of the lower extremity was digitally measured by two, independent observers, for both the preoperative and postoperative radiographs. Measurements were performed using a picture archiving and communication system (PACS, Sectra Imtec AB, Linkoping, Sweden). The overall, mechanical axis was defined as the angle formed by a line drawn from the center of the femoral head to the center of the femoral notch, and a second line from the center of the tibial plateau to the center of the tibial plafond. These measurements were used to determine the mean preoperative mechanical alignment, postoperative mechanical alignment, degree of correction of the mechanical axis, and the percentage of patients who were "overcorrected" into relative varus or valgus. In addition, the radiographic measurement for postoperative alignment was compared to the intraoperative alignment provided by the MAKO system. The intraoperative value provided by the MAKO system is referred to as the "virtual" alignment, which was measured after the final components have been implanted, and an axial load is applied to the extremity in full extension. For convention, a neutral mechanical axis was considered to be 1180°, values less than this represented varus angles, while values greater than this represented valgus angles.

Table 1
Table demonstrating patients' demographics and limb alignment measurements of medial UKAs comparing to lateral UKAs.

	Medial UKAs (n = 229)	Lateral UKAs (n = 37)	*p*-Value
Age (years)	65 (±10.6)	63 (±13.6)	0.24
Gender			
Male	123	14	
Female	106	23	
BMI	28.8 (±6.2)	27.9 (±5.1)	0.39
Alignment (degrees)			
Preoperative	172.5 (±3.6)	186.3 (±3.8)	
Postoperative	177.1 (±2.38)	182.7 (±2.45)	
Correction	4.45 (±3)	3.6 (±3.2)	0.09
"Virtual"–"Actual" difference	1.33 (±1.2)	1.86 (±1.33)	0.019
Overcorrections	9 (4%)	4 (11%)	0.0001
Range of overcorrection	1°–2.2° (valgus)	1°–3.6° (varus)	

*All values presented as mean ± standard deviation.

2.1. Surgical technique

All surgeries were performed by the senior author using a previously described technique [32]. A preoperative plan was created from a 3D reconstruction of a CT scan of the patient's leg and CAD models of the implanted components. Standard surgical navigation markers were placed in the femur and the tibia and were also mounted on the robotic arm. The virtual modeling of the patient's knee and intra-operative long leg mechanical alignment tracking allowed real time adjustments to control lower limb alignment and soft tissue balance. For each case, the target lower limb alignment was between 1–5° of undercorrection (i.e. target lower limb alignment was 1–5° of varus for medial UKA) depending of soft tissue tension. Release of the collateral ligaments was not performed in any case. Robotic instrumentation was used to prepare the femur and the tibia. After cement fixation of the implants, the mechanical alignment was rechecked using the navigation system with an axial load applied to the lower limb. Polyethylene thickness was adjusted to achieve the pre-burring target alignment within 1°. Overcorrection of the lower limb alignment (ie valgus long leg alignment after medial UKA) was not accepted and appropriate undercorrection by at least 0.5° was documented by the navigation system in all cases.

2.2. Statistical analysis

Interclass correlation coefficients (ICC) were calculated to evaluate interobserver reliability for radiographic measurements. ICCs were also used to determine the relationship between the postoperative radiographic measurements, and the intraoperative alignment provided by the computer navigation system. Interclass correlation coefficients were graded using previously described semi-quantitative criteria: excellent for $0.9 < p < 1.0$, good for $0.7 < p < 0.89$, fair/moderate for $0.5 < p < 0.69$, low for $0.25 < p < 0.49$, and poor for $0.0 < p < 0.24$ [33]. To evaluate the difference between the medial and lateral UKA cohorts regarding demographic data, alignment correction and "virtual"-postoperative alignment difference, student's t-test was used, and Chi square test was used to compare the percentage of overcorrection between the study groups. A p-value <0.05 was considered statistically significant.

3. Results

There was no significant different regarding age, gender and BMI between the medial and lateral UKA cohorts. Patient demographics are depicted in Table 1. In the medial UKA cohort, the mean preoperative alignment was 172.5° (+3.6°), the mean postoperative alignment was 177.1° (+2.38°), corresponding to a mean alignment correction of 4.54° (+3°).

While In the lateral UKA cohort, the mean preoperative alignment was 186.3° (+3.8°), the mean postoperative alignment was 182.7° (+2.45°), corresponding to a mean alignment correction of 3.6° (+3.32°). There was no significant difference between medial and lateral cohorts in the degree of alignment correction achieved ($p = 0.092$).

In medial UKA group, the intraclass correlation coefficients between the two examiners for the preoperative and postoperative mechanical axis measurements were 0.93 and 0.94, respectively and in the lateral UKAs 0.99 and 0.97, respectively.

The percentage of overcorrection was significantly higher in the lateral UKA group (11%), when compared to the medial UKA group (4%), ($p = 0.0001$). The chance of overcorrection in both cohorts did not correlate with the patient's age, sex, BMI, or preoperative alignment.

The mean difference between the intraoperative "virtual" alignment provided by the MAKO system, and the postoperative, radiographically measured mechanical axis, was 1.33° (±1.2°) in the medial UKA group. This was significantly lower than in the lateral UKA group 1.86° (±1.33°) ($p = 0.019$). The difference between these two measurements was less than 2° in 81% of the medial, and 62% of the lateral UKAs.

4. Discussion

In our study, we used a robotic-assisted technique to control and dynamically assess lower limb alignment. This type of technique has been shown to be more reliable than conventional techniques for optimizing lower limb alignment after UKA [29,34–36]. Even with the use of this navigation system, we have shown a significantly increased risk of alignment overcorrection in the lateral UKA cohort, with a rate of 11%, versus 4% in the medial UKA cohort ($p = 0.0001$). In the lateral UKA cohort, overcorrection ranged between 1 to 3.6°, i.e. 4 to 7° more than the "mild undercorrection" targeted. Therefore, these "outliers" potentially have an increased risk for OA development in the medial compartment. Another significant difference between the medial and lateral cohorts was related to the ability of the navigation system in predicting the final, weight bearing postoperative alignment. Interestingly, the robot based navigation system was highly accurate in predicting the postoperative alignment in the medial UKAs, where the mean difference between the "virtual" and the "actual" (postoperative) alignment was 1.33°, and in more than 81% of the cases, the difference was within 2°. In contrast, in the lateral UKAs, the robotic system was significantly less precise, with mean difference of 1.86°, and only 62% of the cases with "virtual"-"actual" difference within 2°, as demonstrated in Fig. 1.

As opposed to total knee arthroplasty, when performing a UKA, the ability to balance the knee is limited. Soft tissue re-tensioning (for both medial and lateral UKAs) gives a reference point for limb alignment, and takes an important role when defining the knee axis and implant sizing. Studies evaluating the physiologic coronal laxity of normal knees with different stages of osteoarthritis [37–39] have shown an increased degree of laxity of the lateral compartment stabilizers and increased stiffness of the soft tissues in the medial compartment compared to the lateral. This inherent laxity of the lateral soft tissue structures may be a mechanistic explanation for the increased risk of overcorrection with lateral UKA. To re-tension the compressed medial side during medial UKA, the medial collateral ligament (MCL) may serve as a relatively rigid strut that helps guide the lower limb correction. However, with lateral UKA, the inherent laxity of lateral ligaments, particularly at higher flexion angles, may not guide the lateral UKA realignment as reliably. Alternative mechanisms to explain our findings include a possible increased inflammatory nature of lateral compartment degenerative joint disease that may result in subtle laxity in the collateral ligaments making the reference point for "re-tensioning" of these structures more difficult in lateral UKAs. This concept of increased coronal plane laxity in isolated lateral versus medial compartment OA also explains why the navigation system is not as reliable in predicting standing postoperative long leg alignment; namely weight bearing forces, which are difficult to reproduce with application of axial load intra-operatively, may shift long leg alignment in the setting of increased coronal plane laxity.

There are a few limitations to our study. First, the study was a retrospective review of data which was collected intra-operatively, prior to the study design, therefore our conclusions regarding limb aligning during UKA are limited, in addition, the study did not possess a control group, as our results were not compared to those achieved using a conventional, mechanical alignment method. Second, the study was a single surgeon case series with extensive experience in performing UKAs, and thus these results may not be reproducible at other centers. A third limitation is that our measurements were performed using AP, standing, hip-to-ankle radiographs based on a previously described protocol controlling for limb rotation. However, rotational errors may still exist and may affect the accuracy of our measurements. To control for limb rotation, we utilized a previously described protocol in which the limb is internally rotated approximately 5° until a line between the femoral epicondyles is parallel to the cassette, and the tibial eminence is seen in the center of the intercondylar fossa. Use of standing hip-to-ankle radiographs is arguably the gold standard of measuring knee alignment and the mechanical axis of the lower limb as it incorporates weight-bearing versus a supine film such as a CT [40,41]. Our ICC values of between 0.93 and 0.99 demonstrate the repeatability of measurements made using this method.

Our data suggest that the realignment process of the lower extremity may be prone to overcorrection in lateral UKAs more than the medial UKAs. The soft tissue differences (between the medial and lateral

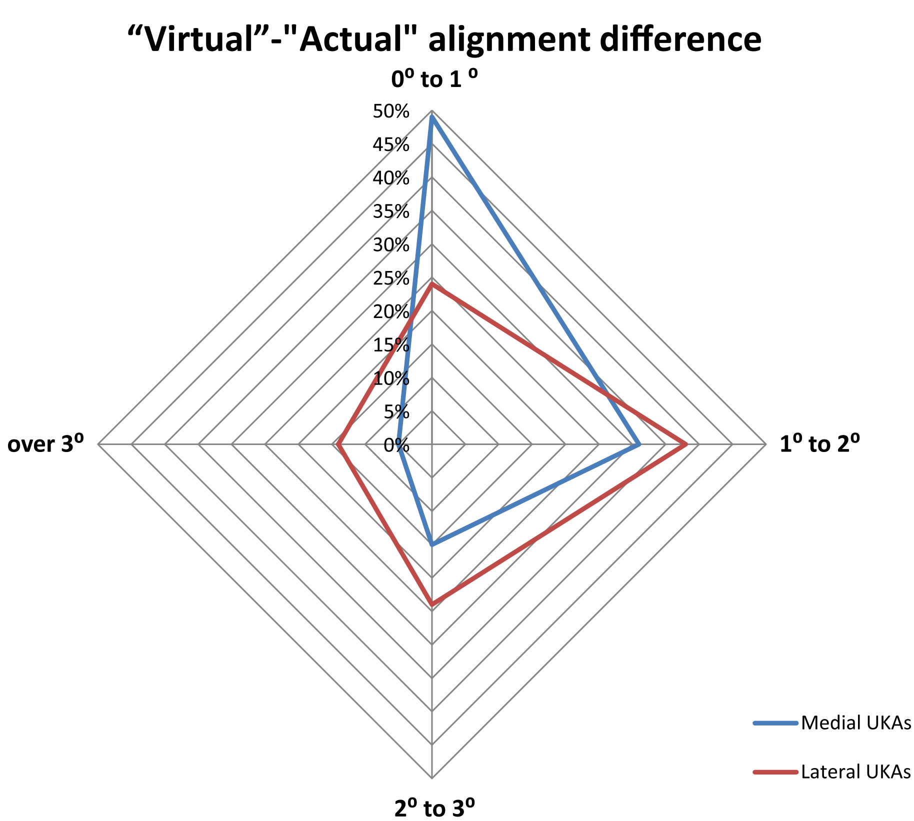

Fig. 1. Figure demonstrates the difference between "virtual" alignment measured by the navigation system and the "Actual" alignment measured in the postoperative weight bearing radiographs divided to ranges: 0^0 to 1^0, 1^0 to 2^0, 2^0 to 3^0 and more than 3^0 and the percentage of knees falling in each range.

compartments) should be taken into consideration when performing a lateral compartment UKA independent of the surgical technique used. In conclusion, this study demonstrates an increased degree of "overcorrection" and greater difficulty in predicting postoperative alignment when performing lateral UKAs compared to medial UKAs. To our knowledge, this is the first study directly comparing the alignment results of medial and lateral UKAs. Future studies must focus on the exact cause of these findings, in order to modify surgical techniques that may improve the alignment results of lateral UKAs.

Conflict of interest

The authors declare that there are no conflicts of interest.

References

[1] Berger RA, Meneghini RM, Jacobs JJ, Sheinkop MB, Della Valle CJ, Rosenberg AG, et al. Results of unicompartmental knee arthroplasty at a minimum of ten years of follow-up. J Bone Joint Surg Am 2005;87:999–1006.
[2] Berger RA, Della Valle CJ. Unicompartmental knee arthroplasty: indications, techniques, and results. Instr Course Lect 2010;59:47–56.
[3] Deshmukh RV, Scott RD. Unicompartmental knee arthroplasty: long-term results. Clin Orthop Relat Res 2001:272–8.
[4] Heck DA, Marmor L, Gibson A, Rougraff BT. Unicompartmental knee arthroplasty. A multicenter investigation with long-term follow-up evaluation. Clin Orthop Relat Res 1993:154–9.
[5] Murray DW, Goodfellow JW, O'Connor JJ. The Oxford medial unicompartmental arthroplasty: a ten-year survival study. J Bone Joint Surg 1998;80:983–9.
[6] Price AJ, Waite JC, Svard U. Long-term clinical results of the medial Oxford unicompartmental knee arthroplasty. Clin Orthop Relat Res 2005:171–80.
[7] Fisher DA, Dalury DF, Adams MJ, Shipps MR, Davis K. Unicompartmental and total knee arthroplasty in the over 70 population. Orthopedics 2010;33:668.
[8] Berend KR, Lombardi Jr AV. Liberal indications for minimally invasive oxford unicondylar arthroplasty provide rapid functional recovery and pain relief. Surg Technol Int 2007;16:193–7.
[9] Amin AK, Patton JT, Cook RE, Gaston M, Brenkel IJ. Unicompartmental or total knee arthroplasty?: results from a matched study. Clin Orthop Relat Res 2006;451:101–6.
[10] Laurencin CT, Zelicof SB, Scott RD, Ewald FC. Unicompartmental versus total knee arthroplasty in the same patient. A comparative study. Clin Orthop Relat Res 1991: 151–6.
[11] Brown NM, Sheth NP, Davis K, Berend ME, Lombardi AV, Berend KR, et al. Total knee arthroplasty has higher postoperative morbidity than unicompartmental knee arthroplasty: a multicenter analysis. J Arthroplasty 2012;27:86–90.
[12] Naal FD, Fischer M, Preuss A, Goldhahn J, von Knoch F, Preiss S, et al. Return to sports and recreational activity after unicompartmental knee arthroplasty. Am J Sports Med 2007;35:1688–95.
[13] Swienckowski JJ, Pennington DW. Unicompartmental knee arthroplasty in patients sixty years of age or younger. J Bone Joint Surg Am 2004;86-A(Suppl. 1):131–42.
[14] Tabor Jr OB, Tabor OB, Bernard M, Wan JY. Unicompartmental knee arthroplasty: long-term success in middle-age and obese patients. J Surg Orthop Adv 2005;14: 59–63.
[15] Keene G, Simpson D, Kalairajah Y. Limb alignment in computer-assisted minimally-invasive unicompartmental knee replacement. J Bone Joint Surg 2006;88:44–8.
[16] Ridgeway SR, McAuley JP, Ammeen DJ, Engh GA. The effect of alignment of the knee on the outcome of unicompartmental knee replacement. J Bone Joint Surg 2002;84:351–5.
[17] Emerson Jr RH. Preoperative and postoperative limb alignment after Oxford unicompartmental knee arthroplasty. Orthopedics 2007;30:32–4.
[18] Hernigou P, Deschamps G. Alignment influences wear in the knee after medial unicompartmental arthroplasty. Clin Orthop Relat Res 2004:161–5.
[19] Kennedy WR, White RP. Unicompartmental arthroplasty of the knee. Postoperative alignment and its influence on overall results. Clin Orthop Relat Res 1987:278–85.
[20] Cartier P, Sanouiller JL, Grelsamer RP. Unicompartmental knee arthroplasty surgery. 10-year minimum follow-up period. J Arthroplasty 1996;11:782–8.
[21] Smith JR, Robinson JR, Porteous AJ, Murray JR, Hassaballa MA, Artz N, et al. Fixed bearing lateral unicompartmental knee arthroplasty—short to midterm survivorship and knee scores for 101 prostheses. Knee 2014;21:843–7.
[22] Ashraf T, Newman JH, Evans RL, Ackroyd CE. Lateral unicompartmental knee replacement survivorship and clinical experience over 21 years. J Bone Joint Surg 2002;84:1126–30.
[23] Argenson JN, Parratte S, Bertani A, Flecher X, Aubaniac JM. Long-term results with a lateral unicondylar replacement. Clin Orthop Relat Res 2008;466:2686–93.
[24] Scott RD, Santore RF. Unicondylar unicompartmental replacement for osteoarthritis of the knee. J Bone Joint Surg Am 1981;63:536–44.
[25] Insall J, Walker P. Unicondylar knee replacement. Clin Orthop Relat Res 1976:83–5.
[26] Marmor L. Lateral compartment arthroplasty of the knee. Clin Orthop Relat Res 1984:115–21.
[27] Lustig S, Elguindy A, Servien E, Fary C, Munini E, Demey G, et al. 5- to 16-year follow-up of 54 consecutive lateral unicondylar knee arthroplasties with a fixed-all polyethylene bearing. J Arthroplasty 2011;26:1318–25.
[28] Jenny JY, Boeri C. Unicompartmental knee prosthesis implantation with a non-image-based navigation system: rationale, technique, case–control comparative study with a conventional instrumented implantation. Knee Surg Sports Traumatol Arthrosc 2003;11:40–5.
[29] Pearle AD, Kendoff D, Stueber V, Musahl V, Repicci JA. Perioperative management of unicompartmental knee arthroplasty using the MAKO robotic arm system (MAKOplasty). Am J Orthop 2009;38:16–9.
[30] Cobb J, Henckel J, Gomes P, Harris S, Jakopec M, Rodriguez F, et al. Hands-on robotic unicompartmental knee replacement: a prospective, randomised controlled study of the acrobot system. J Bone Joint Surg 2006;88:188–97.
[31] Davies BL, Rodriguez y Baena FM, Barrett AR, Gomes MP, Harris SJ, Jakopec M, et al. Robotic control in knee joint replacement surgery. Proc Inst Mech Eng H 2007;221: 71–80.
[32] Pearle AD, O'Loughlin PF, Kendoff DO. Robot-assisted unicompartmental knee arthroplasty. J Arthroplasty 2010;25:230–7.
[33] Munro BH. Statistical methods for health care research. Philadelphia: Lippincott; 1997.
[34] Roche M, O'Loughlin PF, Kendoff D, Musahl V, Pearle AD. Robotic arm-assisted unicompartmental knee arthroplasty: preoperative planning and surgical technique. Am J Orthop 2009;38:10–5.
[35] Lonner JH, John TK, Conditt MA. Robotic arm-assisted UKA improves tibial component alignment: a pilot study. Clin Orthop Relat Res 2010;468:141–6.
[36] Sinha RK. Outcomes of robotic arm-assisted unicompartmental knee arthroplasty. Am J Orthop 2009;38:20–2.
[37] Tokuhara Y, Kadoya Y, Nakagawa S, Kobayashi A, Takaoka K. The flexion gap in normal knees. An MRI study. J Bone Joint Surg 2004;86:1133–6.
[38] Creaby MW, Wrigley TV, Lim BW, Bowles KA, Metcalf BR, Hinman RS, et al. Varus–valgus laxity and passive stiffness in medial knee osteoarthritis. Arthritis Care Res 2010;62:1237–43.
[39] Jenny JY. Coronal plane knee laxity measurement: is computer-assisted navigation useful? Orthop Traumatol Surg Res 2010;96:583–8.
[40] Hinman RS, May RL, Crossley KM. Is there an alternative to the full-leg radiograph for determining knee joint alignment in osteoarthritis? Arthritis Rheum 2006;55: 306–13.
[41] Colebatch AN, Hart DJ, Zhai G, Williams FM, Spector TD, Arden NK. Effective measurement of knee alignment using AP knee radiographs. Knee 2009;16:42–5.