Contemporary femoral designs in total knee arthroplasty: effects on the patello-femoral congruence

Pier Francesco Indelli • Massimiliano Marcucci •
Donatella Cariello • Paolo Poli • Massimo Innocenti

Received: 1 August 2011 / Accepted: 29 November 2011 / Published online: 28 December 2011
© Springer-Verlag 2011

Abstract

Purpose The objective of this study was to evaluate the radiological and clinical correlations between implant design and patellar positioning in patients who underwent TKA utilizing femoral implants with modern designs.

Methods Thirty consecutive PFC PS Sigma TKAs, characterized by a new prolonged anterior flange and a “smoother” trochlea, were prospectively reviewed. All patellae were replaced. All patients were evaluated pre-operatively and prospectively at two years follow-up both clinically according to the Knee Society score as well as radiographically. This included computed tomography (CT); patellar tilt, patellar conformity angle, patellar lateralization, and femoral component external-rotation in relation to the clinical trans-epicondylar axis.

Results Average patellar tilt at follow-up was 3° ($\pm 7.5^\circ$) with respect to a pre-operative 18.5° ($\pm 8.5^\circ$). Average patellar congruence angle at follow-up was -3° (range, -11° to $+9^\circ$) with respect to a pre-operative 10.3° (range, $+1.5^\circ$ to 25.5°). Average lateralization index at follow-up was 2.7 mm (range,

-3.4 mm to $+7.1$ mm) with respect to a pre-operative 12.2 mm (± 4.8 mm). Femoral component positioning related to the trans-epicondylar axis showed an external rotation of 2.80° ($\pm 2.10^\circ$) at follow-up with respect to 5.7° ($\pm 1.80^\circ$). Clinically, two (6.6%) patients reported patello-femoral complications related to imperfections in the surgical technique more than the implant's design.

Conclusions This study highlighted that modern femoral designs in TKA allow for a correct reproducibility of a normal patello-femoral conformity. Strict surgical principles are paramount to avoid patello-femoral complications even when modern implants are used.

Introduction

Patello-femoral complications after total knee arthroplasty (TKA) still represent the most cited cause of pain and the most often reported reason for revision surgery [1–3]. Many factors have been intensively studied as causes of patello-femoral complications after TKA, including pre-operative, intra-operative and rehabilitation issues. Pre-operative factors include the Q angle, the patellar tilt, the patello-femoral conformity angle, the patellar lateralization and the degree of external rotation of the distal femur. Intra-operative issues involve the use of different surgical approaches, the soft tissue balancing of the patello-femoral articulation, resurfacing or not the patella, the accuracy in the patellar osteotomy when resurfaced, the degree of elevation of the joint line and the degree of internal rotation of the femoral component. Postoperative issues involve the rehabilitative protocol and a correct patient's information on the appropriate activities compatible with a TKA.

Many radiological evaluations have been described as a method to highlight pre-operative risk factors for patello-

P. F. Indelli (✉) • M. Marcucci
CESAT, Università degli Studi di Firenze,
Piazza Lavagnini 1, Fucecchio,
Florence, Italy
e-mail: pindellimd@hotmail.com

D. Cariello • P. Poli
CESAT,
Piazza Lavagnini 1, Fucecchio,
Florence, Italy

M. Innocenti
Clinica Ortopedica, Università degli Studi di Firenze,
Largo P. Palagi 1,
Florence, Italy

femoral complications after TKA. Laurin et al. [4, 5] first introduced the concept of patellar tilt as a form of malalignment. Other tilt measurement methods have been developed on plain radiography, CT, and MRI [6–10]. The patello-femoral congruence angle was first described by Merchant et al. [11] and later by others [12, 13]. The femoral component positioning and its effect on the patellar tracking have been intensely studied [14–17] through the measurement of the posterior condylar angle (PCA).

Different femoral designs in TKA have shown multiple effects on the conformity of the patello-femoral joint. Historically, this anatomical relationship may interfere with clinical results. In fact, there is little information in regards to how the complex anatomy of the normal trochlea compares to that of the femoral component.

The objective of this study was to evaluate the radiological and clinical correlations between implant design and patellar positioning in patients who underwent TKA utilizing modern femoral implants.

Material and method

In 2009 the authors randomly selected, after obtaining the institution's IRB and patients' approval, 30 consecutive patients affected by knee osteoarthritis from the operative schedule for TKA. The study group was composed of 22 females and eight males. The average age was 69 years (range, 52–83 years). The knee deformity was varus in 25 knees (range 6–17°) and valgus in five (range 5–14°). The right knee was involved in 23 cases and the left in seven. All patients were evaluated pre-operatively and at two years minimum follow-up both clinically according to the Knee Society score as well as radiographically. Bilateral standing 30×90 cm. view, bilateral Merchant view, and bilateral standard lateral view have been performed. A pre-operative and a two-year CT evaluation were done in each knee with a standard GE Medical Systems Scanner, whereby the patient assumed a supine position on the radiological table with the knee bent at 20°; CT images were 2 mm in thickness and with 2 mm in reconstructive increments starting at the distal metaphysis and finishing at the tibial tubercle. Particular attention was paid to the following CT measurements: patellar tilt according to Fulkerson et al. [7], patellar congruence angle according to Aglietti et al. [13], patellar lateralization measuring the lateral patellar displacement according to Brossman et al. [18] and femoral component external rotation in relation to the patellar sitting measuring the PCA according to Boissard et al. [16]. The patella tilt angle (PTA) was calculated drawing an angle made by a line parallel to the posterior condyles and a line joining the edges of the patella: this index is normally <5° (Fig. 1). It is a measure of tilting of the patella. The congruence angle (CA)

Fig. 1 Patellar tilt angle (PTA): angle made by a line parallel to the posterior condyles and the line joining the edges of the patella

was calculated by drawing a line perpendicular to the deepest point of the trochlea and drawing a second line from the apex of the trochlea to the most posterior point of the patella. If the patella is medial to the bisector, the CA is negative and positive if the patella moves laterally (normally <+5°). It measures patellar subluxation (Fig. 2). The lateral patellar displacement (LPD) index was measured defining first a line tangent to the posterior condyles and second a perpendicular line was projected anteriorly through the medial condyle; the distance from this line to the medial edge of patella in millimetres is the LPD index (normally <+5 mm) (Fig. 3). It is a measure of absolute patellar lateralization. PCA is an indicator of femoral external rotation: to assess pre-operative and post-operative rotational alignments, posterior condylar angles formed by the clinical transepicondylar axis and a tangent line to posterior condyles were measured (Fig. 4). Abnormality of this angle at follow-up indicates a defective rotational positioning of the femoral component.

The new fixed-bearing PFC PS Sigma System (De Puy, Warsaw, USA) was used in all the cases. This system was first introduced in 2009, having a peculiar femoral design. This new femoral component has a “J curve” shape with three different tangential radii in the sagittal profile and a single radius curve in the coronal profile; a prolonged anterior flange and a “smoother” transition from trochlea to the box are innovative to this design too.

The surgical approach included a standard midline incision and a medial peripatellar capsulotomy, avoiding standard lateral releases. The Sigma HP instrumentation was used to allow 3° of external rotation to the cemented femoral component, and the “balanced gaps technique” was the chosen surgical technique. The tibial component was cemented matching the tibial anterior cortex with its anterior side (“curve on curve technique” for rotational alignment). All patellae were replaced with a so-called “free hand technique”, and tracking of the patella was checked using the “no

Fig. 2 Congruence angle (CA). The congruence angle is measured by drawing a line perpendicular to the deepest point of the trochlea and drawing a second line from the apex of the trochlea to the most posterior point of the patella. If the patella is medial to the bisector, the CA is negative and positive if the patella moves laterally (normally $<+5^\circ$)

thumb technique”; a release of the deep lateral patello femoral ligament was performed if necessary.

All patients were evaluated at two years follow-up both clinically according to the Knee Society score as well as radiographically [19, 20], including CT evaluation. Statistical analysis was performed utilizing the *t*-test and the Wilcoxon test ($p<.0.05$).

Fig. 3 Lateral patellar displacement (LPD) index. LPD is measured defining first a line tangent to the posterior condyles and secondly a perpendicular line is projected anteriorly through the medial condyle; the distance from this line to the medial edge of the patella in millimetres is the LPD index (normal $<+5$ mm)

Fig. 4 Posterior condyles angle (PCA). PCA is formed measuring the clinical transepicondylar axis and a tangent line to the posterior condyles

Results

Radiological results

All patients were available at follow-up. The four CT measurements in each knee were performed by an independent reviewer (LM) not part of the surgical team.

Patellar tilt angle (PTA)

The average patellar tilt at follow-up was 3° ($\pm 7.5^\circ$) with respect to a pre-operative average value of 18.5° ($\pm 8.5^\circ$). This difference was statistically significant ($p<.0.05$).

Patellar congruence angle (CA)

The average patellar congruence angle at follow-up was -3° (range, -11° to $+9^\circ$) with respect to an average pre-operative value of 10.3° (range, $+1.5^\circ$ to $+25.5^\circ$). This difference was statistically significant ($p<.0.05$).

Lateral patellar displacement (LPD)

The average lateralization index at follow-up was 2.7 mm (range, -3.4 mm to $+7.1$ mm) with respect to a pre-operative value of 12.2 mm (± 4.8 mm). This difference was statistically significant ($p<.0.05$).

Posterior condyles angle (PCA)

The femoral component positioning in relation to the transepicondylar axis at follow-up showed 2.80° of external rotation ($\pm 2.10^\circ$) with respect to a pre-operative value of 5.7° ($\pm 1.80^\circ$). This difference was statistically significant

Fig. 5 The left knee of a 65-year-old female. Posterior condyles angle (PCA) at follow-up was 2.8°. The patellar position is almost parallel to the posterior condyles line

($p < 0.05$). The planned external rotation of the femoral component was 3° (Fig. 5).

Clinical results

All patients were available at follow-up. No revisions were performed in this case series. According to the KSS, average pre-operative knee score was 43, while average function score was 42 points. Average knee score at two-year follow-up was 89 points, while average function score was 76 points. Average knee flexion at follow-up was 115° (min. 97°, max. 115°). Two major patello-femoral complications (6.6%) were registered at follow-up: one patient (patient one, female, 69 years) had a mildly painful patello-femoral crepitus during ROM and one patient (patient two, female, 67 years) described a moderate anterior knee pain rising from a chair or during stair climbing. Both patients had CT measurements falling in the normal range. Radiological evaluation (Merchant's view) of the first painful knee showed a medial tilt of the replaced patella with a medial

bony impingement (Fig. 6); this complication was related to an insufficient patellar bone removal, leaving the patella with an excessive cross-section. Radiological evaluation of the second painful knee showed an asymmetric patellar bone cut (Fig. 7), whereby the proximal pole of the patella had a diameter of 13.2 mm with respect to 9.8 mm in the distal pole, favouring patellar tilting and proximal soft tissue entrapment.

Discussion

Three decades of total knee arthroplasties have been highly successful. Implant survivorship was reported between 90.6% and 99% during the first decade and between 85% and 96.5% during the second decade of follow up [21]. Patello-femoral pain, crepitus, and locking are infrequent symptoms after total knee arthroplasty, still representing a premiere cause of revision [22]. Surgical technique and implant design are keys to a successful TKA. Controversies existing over resurfacing the patella in TKA remain in the literature. In a recent systematic metanalysis of patellar resurfacing in TKA, the overall incidence of postoperative anterior knee pain of the 1,421 knees included was 12.9% in the patellar resurfacing group and 24.1% in the no resurfacing group [23]. Re-operation rates to convert unresurfaced patellae to resurfaced patellae exceed those for complications after patellar resurfacing [24]. On the other hand, the success rate of secondary patellar resurfacing is poor and patients should be counselled carefully [25].

The centering of the patella in TKA depends on distal femoral osseous factors which determine PCA and anterior trochlear angle on either side of the transepicondylar axis. Since the correct reproduction of the obliquity of the transepicondylar axis with respect to the PCA depends on the surgeon skills, the anterior trochlear angle is peculiar to the chosen prosthetic implant. Optimum prosthetic design features for patella resurfacing include an anatomic,

Fig. 6 Bilateral Merchant's view of a 69-year-old female. On the left side a medial tilt of the replaced patella with a medial bony impingement is present

Fig. 7 Lateral view of the left knee showing an asymmetric patellar bone cut of a 67-year-old female

asymmetric trochlear groove that is broad, extended and deeper compared to first-generation designs [26].

The author's institution was in the first line in the development of patellar implants for TKA [27] and since then, patellar resurfacing has been routinely performed in the majority of our TKA. In 2001, the authors reviewed their experience with extensor mechanism complications after TKA utilizing three different prosthetic implants: the complication rate was 20% in the IB I TKA (Zimmer Inc., Warsaw, USA), 5% in the modified IB I and 2% in the IB II [28]. More recently, Aglietti et al. [29] reported as very rare the incidence of clunks or major patello-femoral complications with the use of newer TKA designs. This phenomenon was linked to severe modifications in the original IB I femoral component design: the box edge was rounded (IB I Modified) and the trochlear groove was deeper and prolonged proximally (IB II) in order to better accommodate the patellar tracking.

A similar pathway was followed by the Press-Fit Condylar (PFC) TKA, an improvement of the total condylar knee implant [30]. The PFC implant was designed with a deeper patellar groove and a single peg patella adapted to maximize contact area and decrease the amount of exerted pressure.

The clinical results of this implant were satisfactory overall with a 93% survival rate at 15 years; the revision rate for patello-femoral related problems was 5.2% [31]. The PFC-Sigma implant was first used in 1996, showing an updated femoral coronal geometry and a deeper trochlear groove to improve patellar tracking. Painless or painful patellar crepitations and patellar clunk syndromes have been reported with an incidence between 1 and 5% by many authors, including the implant's designers [32]. Revisions for patello-femoral problems have been shown to still be a minor issue with this implant [33], not differing between patients sex [34]. The use of the mobile-bearing option did not reduce the patello-femoral complication rate, nor improve the patella tracking [35]. Previous studies hypothesized that a high rate of patello-femoral complications might be linked to the medialization of the prosthetic femoral groove typical of this implant; in fact, Meijerink et al. [36] demonstrated 3 mm of average medialization of the femoral groove when using the PFC knee implant. In a different study, Barink et al. [37] noted a trend toward lateral tracking of the patella in early flexion when using the PFC-Sigma prosthesis.

The authors of the present study reviewed their experience with the fixedbearing PFC PS Sigma focusing on the hypothetical reproducibility of a patello-femoral congruency as close as that of non-osteoarthritic knees. Three CT measurements (PTA, CA, LPD) highlighted the patella positioning with respect to the femoral component, while the PCA showed the rotational alignment of the femoral component. Our CT results fell in the normal range, according to numerous previous studies in non-osteoarthritic knees [7, 13, 16, 18], suggesting a satisfactory positioning of the patella with respect to the prosthetic trochlea. In regard to the PTA, previous radiographic studies suggested a value inferior to 5° as normal for a non-osteoarthritic knee [19]. Aglietti et al. [13], studying the patellar congruence angle (CA) in a series of TKA, reported a value of more than 5° as an index of potential patellar subluxation. Brossman et al. [20] suggested less than 5 mm of patellar lateralization (LPD) as a normal value in a non-osteoarthritic knee. According to our results, the mean PCA at follow-up was 2.8°. Previous reports suggested that commonly reported 3° of external rotation might be insufficient to make a rectangular flexion gap at 90° [38], increasing the risk of patello-femoral complications.

In this consecutive series, we registered two (6.6%) patients reporting patello-femoral complications related to imperfections in the surgical technique (patient one: excessive patellar thickness; patient two: asymmetric patellar osteotomy). This study showed that, when resurfacing the patella utilizing the PFC PS Sigma knee-system, strict surgical principles are paramount to avoid complications; these include duplication of the original patella thickness, performance of a symmetric patellar osteotomy, accurate removal of peripatellar synovial tissues, achievement of central

patellar tracking and proper positioning of the femoral, tibial, and patellar components. Other recognized technical errors include proximal placement of the joint line, excessive loosening of the flexion gap and excessive flexion of the femoral component.

There are several limitations to this study. First, the patella is constrained partly by the design of the prosthetic trochlear groove and CT is a sensitive and accurate method of assessing components positioning [39], but patellar tracking is governed by a combination of static and dynamic factors. Maltracking may result from excessive or unbalanced tension in the surrounding soft tissues during knee flexion, so our radiographic measurements do not reflect patello-femoral congruence during ROM. A CT scan or MRI in vivo assessment might be necessary [18, 40, 41]. Anyway, Varadarajan et al. [42] demonstrated that, even with a correct external rotation, the trochlear groove in current TKA designs only partially restores normal anatomy.

Second, the authors did not include tibial measurements; internal rotation of the tibial prosthetic component results in a net external rotation of the tibia. This might cause the tibial tubercle to be in a more lateral position, increasing the Q angle and the lateral subluxation force of the patella. The authors believe that their “curve on curve” technique allows the tibial component to be centered in between the medial border and the center of the tibial tubercle. Third, this study was based on small numbers; the IRB approval was obtained only for a small study group, because of the invasivity of the protocol.

This study suggests that newer femoral designs with softer edges and a prolonged femoral groove allow for a correct reproducibility of the patello-femoral conformity. The incidence of extensor mechanism complications appear to be more related to a poor surgical technique than implant design.

Acknowledgments The authors wish to acknowledge Luca Manfredini PT for his help in the realization of this study.

References

- Scuderi GR, Insall JN, Scott NW (1994) Patellofemoral pain after total knee arthroplasty. *J Am Acad Orthop Surg* 2(5):239–246
- Parratte S, Pagnano MW (2008) Instability after total knee arthroplasty. *Instr Course Lect* 57:295–304, Review
- Patel J, Ries MD, Bozic KJ (2008) Extensor mechanism complications after total knee arthroplasty. *Instr Course Lect* 57:283–294, Review
- Laurin CA, Dussault R, Levesque HP (1979) The tangential x-ray investigation of the patellofemoral joint: X-ray technique, diagnostic criteria and their interpretation. *Clin Orthop Relat Res* 144:16–26
- Laurin CA, Lévesque HP, Dussault R, Labelle H, Peides JP (1978) The abnormal lateral patellofemoral angle: a diagnostic roentgenographic sign of recurrent patellar subluxation. *J Bone Joint Surg Am* 60(1):55–60
- Sasaki T, Yagi T (1986) Subluxation of the patella. Investigation by computerized tomography. *Int Orthop* 10(2):115–120
- Fulkerson JP, Schutzer SF, Ramsby GR, Bernstein RA (1987) Computerized tomography of the patellofemoral joint before and after lateral release or realignment. *Arthrosc* 3(1):19–24
- Inoue M, Shino K, Hirose H, Horibe S, Ono K (1988) Subluxation of the patella. Computed tomography analysis of patellofemoral congruence. *J Bone Joint Surg Am* 70(9):1331–1337
- Kujala UM, Osterman K, Kormanen M, Komu M, Schlenzka D (1989) Patellar motion analyzed by magnetic resonance imaging. *Acta Orthop Scand* 60(1):13–16
- Grelsamer RP, Weinstein CH, Gould J, Dubey A (2008) Patellar tilt: the physical examination correlates with MR imaging. *Knee* 15(1):3–8, Review
- Merchant AC, Mercer RL, Jacobsen RH, Cool CR (1974) Roentgenographic analysis of patellofemoral congruence. *J Bone Joint Surg Am* 56(7):1391–1396
- Hughston JC (1989) Patellar subluxation. A recent history. *Clin Sports Med* 8(2):153–162
- Aglietti P, Insall JN, Cerulli G (1983) Patellar pain and incongruence: I. Measurements of incongruence. *Clin Orthop Relat Res* 176:217–224
- Nagamine R, Miura H, Inoue Y, Urabe K, Matsuda S, Okamoto Y, Nishizawa M, Iwamoto Y (1998) Reliability of the anteroposterior axis and the posterior condylar axis for determining rotational alignment of the femoral component in total knee arthroplasty. *J Orthop Sci* 3(4):194–198
- Aglietti P, Sensi L, Cuomo P, Ciardullo A (2008) Rotational position of femoral and tibial components in TKA using the femoral trans-epicondylar axis. *Clin Orthop Relat Res* 466:2751–2755
- Boisgard S, Moreau PE, Descamps S, Courtalhac C, Silbert H, Moreel P, Michel JL, Levai JP (2003) Computed tomographic study of the posterior condylar angle in arthritic knees: its use in the rotational positioning of the femoral implant of total knee prostheses. *Surg Radiol Anat* 25(3–4):330–334
- Griffin FM, Insall JN, Scuderi GR (1998) The posterior condylar angle in osteoarthritic knees. *J Arthroplasty* 13(7):812–815
- Brossmann J, Muhle C, Schröder C, Melchert UH et al (1993) Patellar tracking patterns during active and passive knee extension: evolution with motion-triggered Cine MR imaging. *Radiology* 187(1):205–212
- Grelsamer RP, Bazos AN, Proctor CS (1993) Radiographic analysis of patellar tilt. *J Bone Joint Surg Br* 75(5):822–824
- Brossmann J, Muhle C, Büll CC, Zieplies J, Melchert UH, Brinkmann G, Schröder C, Heller M (1995) Cine MR imaging before and after realignment surgery for patellar maltracking—comparison with axial radiographs. *Skeletal Radiol* 24(3):191–196
- Keeney JA, Eunice S, Pashos G, Wright RW, Clohisy JC (2011) What is the evidence for total knee arthroplasty in young patients?: A systematic review of the literature. *Clin Orthop Relat Res* 469(2):574–583
- Rand JA (2005) Extensor mechanism complications after total knee arthroplasty. *Instr Course Lect* 54:241–250
- Li S, Chen Y, Su W, Zhao J, He S, Luo X (2010) Systematic review of patellar resurfacing in total knee arthroplasty. *Int Orthop* 35(3):305–316
- Parvizi J, Rapuri VR, Saleh KJ, Kuskowski MA, Sharkey PF, Mont MA (2005) Failure to resurface the patella during total knee arthroplasty may result in more knee pain and secondary surgery. *Clin Orthop Relat Res* 438:191–196
- Mockford BJ, Beverland DE (2005) Secondary resurfacing of the patella in mobile-bearing total knee arthroplasty. *J Arthroplasty* 20(7):898–902

26. Dennis DA (2006) The role of patellar resurfacing in TKA. *Point. Orthopedics* 29(9):832–835
27. Aglietti P, Insall J, Walker Pand Trent P (1975) A new patella prosthesis: design and application. *Clin Orthop Relat Res* 107:175–187
28. Aglietti P, Baldini A, Buzzi R, Indelli PF (2001) Patella resurfacing in TKA: functional evaluation and complications. *Knee Surg Sport Traumatol Arthrosc* 11:27–33
29. Aglietti P, Baldini A, Buzzi R, Lup D, De Luca L (2005) Comparison of mobile-bearing and fixed-bearing total knee arthroplasty: a prospective randomized study. *J Arthroplasty* 20(2):145–153
30. Ranawat CS, Rose HA, Rich DS (1984) Total condylar knee arthroplasty for valgus and combined valgus-flexion deformity of the knee. *Instr Course Lect* 33:412–416
31. Rodricks DJ, Patil S, Pulido P, Colwell CW Jr (2007) Press-fit condylar design total knee arthroplasty fourteen to seventeen-year follow-up. *J Bone Joint Surg Am* 89(1):89–95
32. Ranawat AS, Ranawat CS, Slamin JE, Dennis DA (2006) Patellar crepitation in the P.F.C. sigma total knee system. *Orthopedics* 29(9 Suppl):S68–S70
33. Dalury DF, Barrett WP, Mason JB, Goldstein WM et al (2008) Midterm survival of a contemporary modular knee replacement. A multicentre study of 1970 knees. *JBJS (Br)* 90:1594–1596
34. Dalury DF, Mason JB, Murphy JA, Adams MJ (2009) Analysis of the outcome in male and female patients using an unisex total knee replacement system. *JBJS (Br)* 91-B:357–360
35. Pagnano MV, Trousdale RT (2004) Rotating platform knees did not improve patellar tracking: a prospective, randomized study of 240 primary TKA. *Clin Orthop Relat Res* 428:221–227
36. Meijerink HJ, Barink M, Van Loon CJ et al (2007) The trochlea is medialized by total knee arthroplasty: an intraoperative assessment in 61 patients. *Acta Orthop* 78(1):123–127
37. Barink M, Van de Groes S, Verdonschot N et al (2006) The difference in trochlear orientation between the natural knee and current prosthetic knee designs: towards a truly physiological prosthetic groove orientation. *J Biomech* 39:1708
38. Winemaker MJ (2002) Perfect balance in total knee arthroplasty: the elusive compromise. *J Arthroplasty* 17(1):2–10
39. Jazrawi LM, Birdzell L, Kummer FJ, Di Cesare PE (2000) The accuracy of computed tomography for determining femoral and tibial TKA component rotation. *J Arthroplasty* 15:761–766
40. Abadiea P, Galauda B, Michaut M, Falletc M, Boisrenoulta P et al (2009) Distal femur rotational alignment and patellar subluxation: A CT scan in vivo assessment. *Orthop Traumatol Surg Res* 95(4):267–271
41. Lee KY, Slavinsky JP, Ries MD, Blumenkrantz G, Majumdar S (2005) Magnetic resonance imaging of in vivo kinematics after total knee arthroplasty. *J Magn Reson Imaging* 21(2):172–178
42. Varadarajan KM, Rubash HE, Guoan L (2011) Are current total knee arthroplasty implants designed to restore normal trochlear groove anatomy ? *J Arthroplast* 26(2):274–281