Original article

Retrospective study of asymmetric vs symmetric tibial plates and ultracongruent vs posterior stabilized inserts in Indian population: An Indian experience of Natural Knee II

Ajay Deep Singh

IVY Hospital, Ram Colony Camp, Chandigarh Road, Hoshiarpur, Punjab, India

ARTICLE INFO

Article history:

Received 28 April 2016

Received in revised form 7 July 2016

Accepted 21 July 2016

Available online 26 July 2016

Keywords:

Asymmetric tibial base plate

Ultracongruent insert

Natural Knee II

Flexion deformity

ABSTRACT

Background: Results of asymmetric tibial base plates vs symmetric tibial base plates and ultracongruent insert vs posterior stabilized insert in Indian population.

Methods: A total of 47 knee replacements with mean age of 65.2 years in 38 patients (16 males and 22 females) between 2007–2011 were included. Natural Knee II (21 models) were compared with 26 models of other knees (12 PFC-Sigma, one PFC-RPF, 10 Nexgen and three Vanguard).

Results: The ultracongruent insert of NK II lead to creation of greater post-op mean flexion deformity of 18° (range 15–20°) as compared to 5.8° (range 5–8°) in other knees with PS insert ($P < 0.001$, confidence limit of 24.2–0.1). After 3 months NK II patients had a lower mean post-operative knee score of 87 as compared to mean post-operative knee score of 96 ($P < 0.001$, confidence limit of 17.9–0.1) in the non-NK II patients because of greater points deductions due to the creation of greater mean flexion deformity. When NO implant overhang is accepted on medial side, asymmetric tibial base plates leaves large portions of peripheral lateral tibial plateau uncovered by implant; decreasing the implant bone surface area ratio of Knee Society Radiographic Assessment Criteria. Similar problem is not encountered with symmetric tibial base plates.

Conclusion: Symmetric and not asymmetric tibial base plates provide greater bone coverage in Indian (ethnic Punjabi) population when no implant overhang is accepted. Further use of NK II was discontinued after just 21 cases in the interest of the patients.

© 2016

1. Introduction

Natural Knee (Zimmer, Warsaw, Indiana) was designed by Dr. Aaron A. Hofmann in 1985.¹ The Natural Knee II used in this study was introduced in 1995.¹ Morphologically, the medial tibial plateau is larger than the lateral tibial plateau.^{3–5} Anatomical studies have shown that the lateral side is 4–5 mm smaller than the medial side in the antero-posterior plane.^{6–8} Asymmetric tibial trays have a smaller lateral plateau which is supposed to increase the tibial coverage and reduce the tibial overhang at the lateral corner.^{9,10} Lateral overhang can lead to pain.¹¹ Similarly a medial component overhang can lead to pain due to pes bursitis.¹ Conversely, tibial underhang results in subsidence of the tibial tray and loosening.^{12,13} Traditionally, it has been proposed that maximizing tibial coverage to increase fixation by improving load transfer from the implant to the proximal tibia avoids subsidence

and loosening.¹⁴ Asymmetric tibial trays are claimed to be more anatomic in nature and therefore cover the tibial plateau more completely than symmetric tibial trays¹⁵; thus decreasing the incidence of tibial tray overhang and subsidence. However, tibial coverage rarely exceeds 78% and several authors have proposed a minimum of 75% coverage for adequate fixation. However, this is based on mechanical data and the degree to which this is clinically relevant is unknown.¹⁴

Different authors have reported contradictory results when comparing asymmetric tibial base plates with symmetric tibial base plates. A study by Incavo et al.¹⁵ has demonstrated that symmetric tibial base plates provide more coverage than asymmetric design. On the other hand, Wernecke et al.¹³ have shown that asymmetric tibial base plates achieve greater coverage of tibial plateau as compared to symmetric base plates but they have also admitted to the fact, that this greater tibial coverage using asymmetric tibial base plate is at the cost of increased posterolateral and increased posteromedial overhang. They accept that 48% of all tibial trays in their study had posterolateral

E-mail address: ajaydeepsingh107@gmail.com.

Table 1

Confounding factors which were ignored.

Groups	Number of staged bilateral knee replacements	Number of patients lost to follow-up due to infection
Natural Knee II	2	0
Non-Natural Knee II	7	3

overhang of >1 mm that may result in popliteal tendon impingement. Therefore the advantage of improved tibial coverage by asymmetric tray maybe negated by increased rate of posterior overhang. What extent of tibial overhang will lead to clinical symptoms requiring revision surgery is still unclear.

Therefore this study was done to compare the tibial coverage of asymmetric and symmetric tibial trays when no overhang was permitted in the Indian (ethnic Punjabi) population.

The second focus of this study was the evaluation of the results of the ultracongruent polyethylene inserts.^{1,2} The ultracongruent insert was introduced for PCL deficient knees in 1991.² The ultracongruent polyethylene inserts were introduced as a substitute to standard posterior stabilized inserts in PCL deficient knees. The manufacturer claimed that the ultracongruent polyethylene inserts would solve all the problems of the standard posterior stabilized inserts and offer further advantage of bone preservation. The geometry of the ultracongruent insert¹ was such that it prevented excess anterior posterior femoral translation during flexion in PCL deficient knees. The ultracongruent insert has a raised anterior flange of up to 12 mm and increased radius.¹ This high anterior lip helps prevents tibial subluxation in case of an absent PCL, and avoids bone resection in the intercondylar notch. Therefore this study was done to evaluate whether shifting from a standard posterior stabilized insert to ultracongruent insert gives satisfactory immediate clinical results. This is a retrospective comparative study.

2. Materials and methods

The mean age of the patients was 65.2 (range 55–75) years with 16 male and 22 female patients. A total of 47 knee replacements done by single surgeon between 2007 and 2011 were included in this study. 3 patients were lost to follow-up, due to infection (although their infection was controlled with the use of iv vancomycin; they did not want to continue taking vancomycin for a long duration, because of its high cost, so they consulted other doctors and were lost to follow up). Therefore, although a total of 47 knees were done, only 44 knees were evaluated. 9 cases underwent knee replacement in their contra-lateral knees (staged bilateral knee replacement) (Table 1). So a total of 35 patients of ethnic Punjabi population were evaluated, although 38 patients were originally included in this study. 21 models of Natural Knee II were done and 26 models of other knees were done which included

Table 2

Demographic data for the 2 matched groups.

Groups	Mean age	Mean weight	Males	Females
NK II	65.1	75 kg	8	11
Non-NK II	65.3	76 kg	8	11

12 models of PFC-Sigma, 1 model of PFC-RPF, 10 models of Nexgen and 3 models of Vanguard knee. These knees were evaluated for knee function using the American Knee Society Score¹⁶ and the Knee Society Radiographic Assessment Criteria.¹⁷ All data were collected by the operating surgeon and there was no blinding or randomization. Patients with Osteoarthritis, varus deformity and good general health were included and those with Rheumatoid Arthritis, valgus deformity, co-morbidity and bad general health were excluded to get good functional knee score. In order to minimize sample bias mean pre-operative knee score in both groups was matched to be same (38) and both groups were matched for age, sex and weight (Table 2). Knee score was measured at 3 months post-op.

All surgeries were performed with medial parapatellar approach. The PCL was excised in all cases. No flexion deformity was accepted and full knee extension was achieved in all cases before wound closure. Patella was not resurfaced in any case.

3. Statistical method

Unpaired *t*-test was used for statistical testing of the difference in the mean values of the post-operative knee scores and the post operative flexion deformity of the Natural Knee II patients and the other group comprising of the non-Natural Knee II patients.

4. Results

The mean post-operative knee score at 3 months follow-up in the Natural Knee II patients was 87(range 85–90) and the mean post-operative knee score in the non-Natural Knee II was 96 (range 93–98); $P < 0.001$, confidence limit of 17.9–0.1 (Table 3). This is despite the fact that the mean preoperative knee score in both the groups was almost the same (38). The mean post operative knee score in the Natural Knee II patients was less because of greater points deductions due to the creation of greater flexion deformity after wound closure as compared to the non-Natural Knee II patients (Tables 4–6). The mean post-operative flexion deformity after wound closure in the Natural Knee II patients (ultracongruent insert) was 18° (range 15–20°) and in the non-Natural Knee II patients (posterior stabilized inserts) it was 5.8° (range 5–8°); $P < 0.001$, confidence limit of 24.2–0.1. *P* value of less than 0.001 indicates that there is very strong evidence of statistical correlation.

According to the Knee Society Radiographic Assessment Criteria,¹⁷ the Implant bone surface area ratio (percentage of

Table 3

Comparison of patient outcome based on knee score between Natural Knee II and non-Natural Knee II.

Group	Sample size	Mean pre-op knee score	Mean post-op knee score	Standard deviation	<i>P</i> -value
Natural Knee II group	21	38	87	2.48	$P < 0.001$
Non-Natural Knee II group	23	38	96	2.44	$P < 0.001$

Table 4

Comparison of post-op flexion deformity between ultra-congruent and posterior-stabilized inserts.

Group	Sample size	Mean post-op flexion deformity	Standard deviation	<i>P</i> -value
Ultra-congruent insert	21	18 (17.86)	2.43	$P < 0.001$
Posterior-stabilized insert	23	5.8	1.32	$P < 0.001$

Table 5
Knee Society Knee Score – point deductions due to post-op flexion contracture.

Flexion contracture in degrees	Point deduction in knee score
5–10	–2
10–15	–5
16–20	–10
>20	–15

tibial surface covered with implant) was not calculated as the Metal Artifact Reduction Sequence MRI is not available here and the author did not have access to the software needed to calculate the exact percentage of implant/bone surface area ratio, from the Metal Artifact Reduction Sequence MRI films. Therefore, the exact figure in numerical terms of implant/bone surface area ratio, is not

quoted in this study, but post-operative CT scan show large parts of the peripheral lateral tibial plateau uncovered, in cases in which Natural Knee II (asymmetric tibial base plate) has been used (Fig. 1); while post-operative CT scan in other cases in which, other models of TKR (symmetric tibial base plate) were used show adequate coverage of the peripheral lateral tibial plateau (Fig. 2).

5. Discussion

Findings of this study are in direct contradiction to the claims of the manufacturer, that the use of asymmetric tibial base plates leads to greater coverage of tibial plateau as compared to use of symmetric tibial base plates. One of the justifications for the use of asymmetric tibial base plates is to prevent tibial base plate overhang. Therefore when no tibial base plate overhang was permitted, the size of the tibial base plate which completely

Table 6
Effect of post-op flexion contracture on knee score of the 2 groups.

Group	Mean post-op flexion contracture	Mean point deduction in knee score due to flexion contracture	Mean knee score	Difference between point deduction due to flexion contracture	Difference between knee score of the 2 groups
Ultracongruent insert	18 (17.86)	10	87	10 – 2 = 8	96 – 87 = 9
Posterior stabilized insert	5.8	2	96	10 – 2 = 8	96 – 87 = 9

The mean 9 points difference in knee score between the 2 groups is solely due to mean 8 points difference in point deduction due to greater post-op flexion deformity.

Fig. 1. 2D CT scan of knee showing large part of peripheral tibial plateau uncovered by asymmetrical tibial plate of NKII.

Fig. 2. 2D CT scan of knee showing very small part of peripheral tibial plateau uncovered by symmetrical tibial plate of PFC-sigma.

covered the lateral tibial plateau, almost always led to a large implant overhang in the medial side. Therefore one size smaller tibial base plate size, which did not create a soft-tissue over hang in the medial side was selected, and every time that left a large peripheral portion of the lateral tibial plateau uncovered (Fig. 1). This anomaly decreased the Implant bone surface area ratio or the percentage of tibial surface covered by the implant in the American Knee Society Total Knee Arthroplasty Roentgenographic Evaluation and Scoring System.¹⁷ On the other hand when the conventional tibial base plates with equal medial and lateral sides were used, this problem was not encountered (Fig. 2). In other words use of symmetric tibial base plates leads to greater coverage of tibial plateau as compared to the use of asymmetric tibial base plates when no implant overhang is permitted in the Indian population.

This leads to the question as to why the results of this study are in direct contradiction to the claims of the manufacturer. Firstly, all patients in this study belonged to Indian ethnic Punjabi population. Natural Knee II was designed using anthropometric data of Western population. The aspect ratio (defined as medio-lateral length divided by antero-posterior length of tibial plateau) of Indian proximal tibia is smaller than that of western Caucasian population. The aspect ratio of proximal tibia of Caucasian population according to Mensch et al.¹⁸ is 1.65, while that of Korean population according to Kwak et al.¹⁸ is 1.57, while that of Chinese population according to Cheng et al.¹⁸ is 1.49, and that of Indian population according to Shah et al.¹⁸ is only 1.45. The aspect ratio of asymmetric tibial base plate of Natural Knee II is greater than the aspect ratio of symmetrical tibial base plates of all the other knee models used in this study. It must be noted that the aspect ratio of different sizes of tibial base plates of any one knee model, whether symmetrical or asymmetrical, is not constant and is different for different sizes of the same model. The aspect ratio of tibial base plate of standard sizes of Natural Knee II varies from 1.6 to 1.5, whereas the aspect ratio of tibial base plate of standard sizes of Nex Gen varies from 1.6 to 1.4, whereas the aspect ratio of tibial base plate of standard sizes of PFC Sigma varies from 1.5 to 1.4. As the aspect ratio of Natural Knee II is greater than the aspect ratio of all the other knee models used in this study and as the aspect ratio of Indian proximal tibia is smaller than the aspect ratio of western Caucasian population this problem was encountered with asymmetric tibial base plates of Natural Knee II and not with the symmetric tibial base plates of all the other knee models used in this study. Therefore implants with smaller tibial aspect ratio like PFC and Nexgen are more suitable for implantation in Indian

population than implants like NKII which have higher tibial aspect ratio.

Secondly, and most importantly, the tibial base plate has to be implanted in appropriate rotation, which should not only match the external rotation of the femoral component but it should not increase the Q-angle. Internal rotation of the tibial plate increases the Q-angle by moving the tibial tubercle laterally. Increased Q-angle leads to lateral subluxation of patella, anterior knee pain and patellofemoral wear.^{19,20} It has been observed that the best mediolateral or anteroposterior cortical fit of the tibial component in most cases does not result in optimal rotational alignment with the femoral component,¹³ i.e. it leads to malrotation of tibial tray with respect to femoral component. Also complete medial and lateral cortical coverage may lead to posterolateral or posteromedial overhang.¹³ This posterolateral or posteromedial overhang can be reduced by internally rotating the tibial tray. But internal rotation of tibia increases the Q-angle and causes a mismatch between the femoral and tibial rotations. Therefore the rotation of the tibial tray affects the extent of bone coverage and the surgeon has to do a trade off between bone coverage and tibial rotation during placement of the tibial tray.

Intra-operatively it was observed that if no tibial overhang is accepted, then the asymmetric tibial tray which maximally covers both lateral and medial tibial plateau, has to be placed in internal rotation (malrotation). As placing the tibial tray in internal rotation in order to increase the bone coverage was not acceptable to the author, a trade off was made between bone coverage and tibial rotation by selecting one size smaller asymmetric tibial tray which left large portions of peripheral lateral tibial plateau uncovered by implant. This problem was not encountered with the symmetric tibial base plates.

Most studies^{13,14} which demonstrate the superiority of asymmetric tibial base plates over symmetric tibial base plates have not been done on cases of post knee replacement patients, but they have been done on hypothetical computer generated models of anthropometric western tibia; ignoring the fact that the tibial base plate has to be implanted matching the external rotation of the femoral component. External rotation of the femoral component differs from patient to patient and population to population. Even the MRI study with controlled rotation of Wernecke et al.¹³ has ignored this fact and still their increased coverage of tibial plateau by asymmetric tibial plates over symmetric tibial plates is at the cost of increased posterolateral and increased posteromedial overhang. On the other hand the study of Incavo et al.,¹⁵ clearly supports my study that it is the symmetric tibial plates and not the

Fig. 3. 2D CT scan of knee showing subsidence of asymmetrical tibial plate of NKII laterally after 7 years of follow up.

asymmetric tibial plates which provide greater tibial coverage when no component overhang is permitted.

Another purpose of this study was to compare the results of the ultracongruent tibial inserts,^{1,2} with the traditional posterior stabilized design. But the biggest problem encountered with the use of the ultra-congruent insert is the creation of a greater flexion deformity after wound closure, even in knees which did not have any flexion deformity preoperatively. The flexion deformity is created after wound closure as the muscle tone returns after the effect of spinal anesthesia weans off. This flexion deformity can be reduced by choosing, one size thinner tibial insert. But a thinner tibial insert creates joint instability in full knee extension (varus/valgus play due to collateral ligament laxity) and instability in knee flexion at 90° (>5 mm anterior tibial subluxation). The thickness of the tibial insert which gave maximum joint stability in full knee extension (0° varus/valgus play, no collateral ligament laxity) and knee flexion at 90° (<5 mm anterior tibia subluxation) were implanted in both groups and as a consequence to that, post-operatively patients had a greater flexion deformity (mean 18°, range 15–20°) after wound closure in the ultra-congruent (NKII) group; than the other group in which standard posterior stabilized inserts were used (mean flexion deformity of 5.8°, range 5–8°). A review of the surgical technique of Natural Knee II provided to operating surgeons by Zimmer and authored by the designer of the implant, accepts that the use of the ultracongruent insert creates a flexion deformity after wound closure and advises surgeons that this flexion deformity created due to the use of the ultra-congruent insert of Natural Knee II is supposed to resolve over a period of about 6 months as the POSTERIOR CAPSULE STRETCHES. To quote page 30, para 1, line 4 of Natural Knee II Primary System Surgical Technique as published by Zimmer *"If the PCL is resected, the knee is balanced so that the collateral ligaments have no laxity and the knee rests with 5° to 10° of spring short of full extension. One size/thickness larger tibial insert than the measured amount of bone resection should be implanted. For example, if 9 mm of tibia is resected, use an 11 mm insert. The posterior capsule will stretch out over the first six months"*.

On the other hand, the surgical technique of all the other PS models used in this study do not advise the surgeon to implant one size thicker tibial insert than the measured amount of bone resection.

Therefore these patients were put on physiotherapy (quadriceps static exercises) to resolve the flexion deformity by stretching of the posterior capsule. A very interesting finding seen after physiotherapy was started in these patients was that, knee flexion increased more with physiotherapy and flexion deformity decreased less with physiotherapy in the same time span; i.e.

improvement in knee flexion, responds better to physiotherapy than resolution of flexion deformity in the same time frame. From an average knee flexion of 90° at the fifth post-operative day, knee flexion increased to 125–135° at 30 post-operative days (35–45° increase in knee flexion in 25 days); but in the same time frame, flexion deformity did NOT even decrease by an average of 4–5°, with physiotherapy. This created a second problem that, most of the patients lost faith in the author's advice that, flexion deformity would resolve with physiotherapy over a period of 6 months. As flexion deformity resolves very, very slowly with quadriceps static exercises it is very difficult, to keep these patients motivated, to keep on doing quadriceps static exercises. Moreover, as no or only marginal improvement is seen in flexion deformity over a period of first 7–10 days, most patients may lose faith in the advice of their doctor, that flexion deformity would resolve with time if quadriceps static exercises are done aggressively.

The resolution of flexion deformity^{21–24} with time is a matter of debate. McPherson et al.²¹ evaluated 29 patients with flexion contracture less than 30° and found that all resolved. Tanzer and Miller²² evaluated patients with a mean flexion contracture of less than 15° postoperatively and found that these resolved as well. However in 41% of these cases they did a posterior capsular stripping at the time of primary surgery. In contrast Firestone et al.²³ found that any patient left with a significant residual flexion contracture at the end of the procedure (average 8.6°) deteriorated with time, increasing to an average flexion contracture of 13.4°. Tew and Forster²⁴ in separate reports found no improvement in flexion contractures beyond what could be corrected at the time of surgery.

Furthermore it is to be emphasized that despite these problems, patients who were fitted with Natural Knee II; at 3 months post-operative follow-up were able to walk unlimited distance (full 50 points) and climb and descend stairs without railing support (full 50 points), despite presence of residual flexion deformity. A review of literature shows that weight bearing, walking and stair climbing with flexion deformity requires a greater effort from the quadriceps. Therefore by putting more effort on their quadriceps, patients can mask the effects of flexion deformity; hence the Functional Knee Score of the Knee Society (which covers unlimited walking and unassisted stair climbing and descending) remains unaffected in cases in which Natural Knee II is used; although the knee score decreases, because of greater point deductions, due to creation of greater flexion deformity after wound closure, with the use of the ultracongruent insert of Natural Knee II. What effect, these problems would have on the long term survival of the implant, was not evaluated in this study.

Fig. 4. 2D CT scan of knee showing subsidence of asymmetrical tibial plate of NKII posteriorly after 7 years of follow up.

Fig. 5. 3D CT scan of knee showing subsidence of asymmetrical tibial plate of NKII laterally after 7 years of follow up.

Fig. 6. 3D CT scan of knee showing no subsidence of symmetrical tibial plate of PFC-Sigma after 6 years of follow up.

The biggest drawback of this study is that the sample size is small. As the asymmetric tibial base plate and ultracongruent insert of Natural Knee II were giving rise to problems, only 21 cases of Natural Knee II were done. Further use of Natural Knee II was discontinued in the interest of the patients. This decision to restrict sample size of NKII to only 21 cases is justified by the long term follow up of these patients. Figs. 3 and 4 are 2D CT scans and Fig. 5 is 3D CT scan of a patient after 7 years of follow up after being implanted with asymmetric base plate of NKII. These figures clearly show tibial plate subsidence laterally and posteriorly. This plate subsidence is the direct result of the uncovered tibial plateau seen in Fig. 1. On the other hand Fig. 6 is the 3D CT scan of a patient implanted with PFC symmetrical tibial plate, and after 6 years of follow up, it is showing no tibial plate subsidence, as there is adequate tibial plate coverage as seen in Fig. 2. Secondly, the Implant bone surface area ratio (percentage of tibial surface covered with implant) was not calculated as the Metal Artifact Reduction Sequence MRI was not available to the author, and the author also did not have access to the software needed to calculate the exact percentage of implant/bone surface area ratio, from the Metal Artifact Reduction Sequence MRI films. Therefore, the exact figure in numerical terms of implant/bone surface area ratio, is not quoted in this study. Thirdly a study needs to be done to determine whether the asymmetry of the proximal tibia differs among different ethnic subgroups of the Indian population. All patients included in this study belonged to ethnic Punjabi population. Also,

sub-group analysis, of results based on age, sex, weight and most importantly the extent of femoral component rotation was not done. A separate study needs to be done to determine that. Fourthly, patients fitted with symmetrical tibial base plates were not evaluated post operatively either clinically or radiologically to find out whether the increased tibial coverage of symmetrical tibial plates led to increased incidence of popliteal tendon impingement or pes bursitis as compared to the asymmetrical tibial base plate patients (NKII group). Lastly all data were collected by the operating surgeon and there was no blinding or randomization.

Conflicts of interest

The author has none to declare.

References

- Hofmann AA. The design principles of the natural knee system. *Am J Orthop.* 2010;39:2–4.
- Hofmann AA, Tkach TK, Evanich CJ, Camargo MP. Posterior stabilization in total knee arthroplasty with use of an ultracongruent polyethylene insert. *J Arthroplasty.* 2000;15:576–583.
- Mensch JS, Amstutz HC. Knee morphology as a guide to knee replacement. *Clin Orthop Relat Res.* 1975;112:231–241.
- Westrich GH, Haas SB, Insall JN, Frachie A. Resection specimen analysis of proximal tibial anatomy based on 100 total knee replacement specimens. *J Arthroplasty.* 1995;10:47–51.

5. Hitt K, Shurman II JR, Greene K, et al. Anthropometric measurements of the human knee: correlation to the sizing of current knee arthroplasty systems. *J Bone Joint Surg Am.* 2003;85:115–122.
6. Vaidya SV, Ranawat CS, Aroojis A, Laud NS. Anthropometric measurements to design total knee prostheses for the Indian population. *J Arthroplasty.* 2000;15:79–85.
7. Hofmann AA, Bachus KN, Wyat RW. Effect of the tibial cut on subsidence following total knee arthroplasty. *Clin Orthop Relat Res.* 1991;269:63–69.
8. Hofmann AA, Murdock LE, Wyatt RW, Alpert JP. Total knee arthroplasty. Two- to four-year experience using an asymmetric tibial tray and a deep trochlear-grooved femoral component. *Clin Orthop Relat Res.* 1991;269:78–88.
9. Stulberg BN, Dombrowski RM, Froimson M, Easley K. Computed tomography analysis of tibial coverage. *Clin Orthop Relat Res.* 1995;311:148–156.
10. Westrich GH, Laskin RS, Haas SB, Sculco TP. Resection specimen analysis of tibial coverage in total knee arthroplasty. *Clin Orthop Relat Res.* 1994;309:163–175.
11. Chau R, Gulati A, Pandit H, et al. Tibial component overhang following unicompartmental knee replacement – does it matter? *Knee.* 2009;16:310–313.
12. Goldstein SA, Wilson DL, Sonstegard DA, Matthews LS. The mechanical properties of human tibial trabecular bone as a function of metaphyseal location. *J Biomech.* 1983;16:965–969.
13. Wernecke GC, Haris IA, Houang MT, Seeto BG, Chen DB, MacDessi SJ. Comparison of tibial coverage of 6 knee prosthesis: a magnetic resonance imaging study with controlled rotation. *J Orthop Surg.* 2012;20:143–147.
14. Martin S, Saurez A, Ismaili S, Ashfaq K, Noble P, Incavo SJ. Maximizing tibial coverage is detrimental to proper rotational alignment. *Clin Orthop Relat Res.* 2013. [Epub ahead of print].
15. Incavo SJ, Ronchetti PJ, Howe JG, Tranowski JP. Tibial plateau coverage in total knee arthroplasty. *Clin Orthop Relat Res.* 1994;299:81–85.
16. Insall JN, Dorr LD, Scott RD, Scott WN. Rationale of knee society clinical rating system. *Clin Orthop Relat Res.* 1989;248:13.
17. Ewald FC. The Knee Society Total Knee Arthroplasty Roentgenographic Evaluation and Scoring System. *Clin Orthop Relat Res.* 1989;248:9–12.
18. Shah DS, Ghyar R, Ravi B, Hegde C, Shetty V. Morphological measurements of knee joints in Indian population: comparison to current knee prosthesis. *Open J Rheumatol Autoimmune Dis.* 2014;4:75–85.
19. Malo M, Vince KG. The unstable patella after total knee arthroplasty: etiology, prevention, and management. *J Am Acad Orthop Surg.* 2003;11:364–371.
20. Parker DA, Dunbar MJ, Rorabeck CH. Extensor mechanism failure associated with total knee arthroplasty: prevention and management. *J Am Acad Orthop Surg.* 2003;11:238–247.
21. McPherson EJ, Cushner FD, Schiff CF, Friedman RJ. Natural history of uncorrected flexion contractures following total knee arthroplasty. *J Arthroplasty.* 1994;9:499–502.
22. Tanzer M, Miller J. The natural history of flexion contracture in total knee arthroplasty. A prospective study. *Clin Orthop Relat Res.* 1989;248:129–134.
23. Firestone TP, Krackow KA, Davis JD, Teeny SM, Hungerford DS. The management of fixed flexion contractures during total knee arthroplasty. *Clin Orthop Relat Res.* 1992;284:221–227.
24. Tew M, Forster IW. Effect of knee replacement on flexion deformity. *J Bone Joint Surg Br.* 1987;69:395–399.