Correction of Varus Deformity During TKA With Reduction Osteotomy

Arun B. Mullaji FRCS Ed, MCh Orth, MS Orth,
Gautam M. Shetty MS Orth

Published online: 25 May 2013
© The Association of Bone and Joint Surgeons® 2013

Abstract

Background Reduction osteotomy (removing the posteromedial tibial bony flare) is one step to aid in achieving deformity correction in varus arthritic knees during TKA. However, the amount of deformity correction achieved with reduction osteotomy during TKA is unclear.

Questions/purposes We therefore addressed the following questions: (1) What is the amount of deformity correction achieved with reduction osteotomy during TKA in varus knees? (2) What is the correlation of amount of deformity correction achieved to the amount of bone osteotomized and the degree of varus deformity?

Each author certifies that he or she, or a member of his or her immediate family, has no funding or commercial associations (eg, consultancies, stock ownership, equity interest, patent/licensing arrangements, etc) that might pose a conflict of interest in connection with the submitted article.

All ICMJE Conflict of Interest Forms for authors and *Clinical Orthopaedics and Related Research* editors and board members are on file with the publication and can be viewed on request. *Clinical Orthopaedics and Related Research* neither advocates nor endorses the use of any treatment, drug, or device. Readers are encouraged to always seek additional information, including FDA-approval status, of any drug or device prior to clinical use. Each author certifies that his or her institution approved the human protocol for this investigation, that all investigations were conducted in conformity with ethical principles of research, and that informed consent for participation in the study was obtained. This work was performed at Breach Candy Hospital, Mumbai, India.

A. B. Mullaji (✉)
The Arthritis Clinic, 101, Cornelian, Kemp's Corner,
Cumballa Hill, Mumbai 400036, India
e-mail: arunmullaji@gmail.com

A. B. Mullaji, G. M. Shetty
Department of Orthopaedic Surgery, Breach Candy Hospital,
Mumbai, India

Methods We prospectively collected and analyzed intra-operative data on the degree of varus deformity before and after reduction osteotomy (using computer navigation) and the amount of reduction osteotomy performed (using a measuring scale) in 71 primary, computer-assisted TKAs.

Results For a mean reduction osteotomy of 7.5 ± 2 mm, a mean correction of $3.5^\circ \pm 1^\circ$ was achieved; a mean osteotomy of 2 mm was required (confidence interval, 1.7–2.6 mm) for every 1° correction of varus deformity. Degree of varus correction achieved correlated positively with the amount of osteotomy performed, especially in knees with preoperative varus deformity of $< 15^\circ$ ($r = 0.77$, $p < 0.001$) and the pre-osteotomy residual varus deformity correlated positively with the amount of correction achieved ($r = 0.81$, $p < 0.001$).

Conclusions Reduction osteotomy can achieve deformity correction in a predictable 2 mm for 1° in most varus arthritic knees during TKA. Further studies are required to ascertain its effectiveness as a soft tissue-sparing step when performed early on during TKA to achieve deformity correction.

Level of Evidence Level IV, therapeutic study. See Guidelines for Authors for a complete description of levels of evidence.

Introduction

Varus deformities in arthritic knees are frequently associated with prominent medial tibial osteophytes and adaptive remodeling of the medial part of the proximal tibia [3, 10]. This results in tenting of the medial soft tissue sleeve including the medial collateral ligament. Although removal of medial osteophytes results in relaxation of the medial soft tissue structures and affords partial correction of varus deformity, complete correction of deformity and achieving

balance of the medial gap with the lateral gap may be facilitated by performing a reduction osteotomy [5, 13, 14, 19].

Reduction osteotomy [5, 14] is performed by removing the posteromedial tibial bony flare by using a well-positioned tibial trial component as a reference. The purpose of this technique is to remove the tenting effect of the medial flare of the proximal tibial bone on medial soft tissue structures. Although previously described as a method to achieve deformity correction and soft tissue balance of the medial gap with the lateral gap in varus arthritic knees [5, 14], the degree to which such an osteotomy effects this correction has not, to our knowledge, been quantified in TKAs performed for varus knees.

Using intraoperative measurements, we therefore addressed the following questions: (1) What is the amount of deformity correction achieved with reduction osteotomy during TKA in varus knees? (2) What is the correlation of amount of deformity correction to the amount of bone osteotomized and the degree of varus deformity?

Patients and Methods

The senior author (ABM) performed 91 primary computer-assisted TKAs during a 3-month period from April 2012 to June 2012. These included 85 TKAs in varus arthritic knees and six TKAs in valgus arthritic knees (as determined using preoperative full-length, hip-to-ankle radiographs; hip-knee-ankle angle $\leq 180^\circ$ was considered varus and $> 180^\circ$ was considered valgus). For the study, we prospectively collected intraoperative data in 85 knees undergoing computer-assisted primary TKAs in varus arthritic knees. We included all primary TKAs performed for varus arthritic knees secondary to primary osteoarthritis, rheumatoid arthritis, or posttraumatic arthritis. We excluded patients who were found to have fully correctable varus deformities intraoperatively or varus deformities correctable to within 2° of the ideal hip-knee-ankle axis (ie, 180°) after applying maximum valgus stress when assessed using computer navigation because performing a reduction osteotomy in these cases will result in excessive medial soft tissue laxity and overcorrection. Based on the exclusion criteria, 14 knees were excluded from analysis because they had fully correctable deformity and did not indicate a reduction osteotomy. Hence, 71 knees that required a reduction osteotomy during TKA were included in the analysis. These were performed in 50 patients (21 bilateral) with a mean age of 66 years (range, 39–89 years) and a mean body mass index of 28 kg/m^2 (range, $23\text{--}33 \text{ kg/m}^2$) at the time of surgery.

All knees were approached using an anterior longitudinal incision and a medial parapatellar arthrotomy under a

tourniquet. A cemented, posterior cruciate-substituting design was used for all cases, PFC Sigma (DePuy International, Warsaw, IN, USA) in 14 knees and Scorpio Single Axis (Stryker Orthopaedics, Mahwah, NJ, USA) in 57 knees. All patients had resurfacing of the patella. The image-free Ci Navigation System (Version 2.5; Brainlab, Munich, Germany) [6, 12, 15, 16] for PFC Sigma knees and the image-free Stryker Knee Trac Navigation System (Version 3.1; Stryker Orthopaedics) [8, 11] for Scorpio Single Axis knees were used to perform navigation during TKA.

The intraoperative technique protocol followed for this study is summarized (Fig. 1). Both cruciates, menisci, and medial femoral osteophytes were excised as part of the exposure before registration. Care was taken not to perform any soft tissue release initially during exposure and medial release was restricted to only the anteromedial capsule and deep medial collateral ligament (MCL) attached to the proximal tibial surface so as to facilitate anterior dislocation of the tibial plateau required for registration (Fig. 2A). During navigation, registration was performed in a standard fashion after insertion of two pins in the proximal tibia and distal femoral shaft to which arrays were affixed. The mechanical axis of the lower limb was obtained by navigation, registering the center of the femoral head, both malleoli, the center of the intercondylar notch, and the center of the tibial plateau. The surgical aim of navigated TKA was to achieve a final coronal plane limb alignment within 1° from neutral in full extension, a mediolateral soft tissue gap difference of less than 1 mm in full extension and less than 2 mm at 90° flexion, and a flexion-extension gap difference not exceeding 2 mm.

After registration, the severity of varus deformity was recorded using navigation. The degree of correctability of varus deformity was also recorded in all cases by the senior author (ABM) by using a standard method of applying maximum valgus stress at the knee with the knee in maximum extension and the limb in neutral rotation as denoted by the central position of the patella over the knee and the foot in neutral rotational alignment. A reduction osteotomy was planned if the varus deformity could not be brought to within 2° of the ideal hip-knee-ankle axis (ie, 180°) after applying maximum valgus stress. The amount of medial bone to be excised during osteotomy was based on the observations made by the senior author during previous navigated TKAs that a reduction osteotomy of 2 mm would approximately give a deformity correction of 1° . Therefore, if the residual varus deformity was found to be 4° , a reduction osteotomy of 8 mm was planned to be performed. Hence, the amount of osteotomy to be performed in each case was measured and marked (from the most medial edge of the medial flare and moving in the lateral direction) on the proximal tibial surface using a measuring scale. The line of

Fig. 1 A flow diagram showing the various steps followed for this study.

osteotomy along the medial aspect of the tibial surface was delineated using the medial margin of tibial tray as a reference with the lateral margin of the tray aligned with the lateral tibial plateau (Fig. 2B). The optimal tray size in each case was decided based on the corresponding femoral size and the amount of osteotomy required. Therefore, for a PFC Sigma implant, if the femoral size was 2.5 (which corresponds to either a size 2.5 or 2 tibial tray) and the amount of osteotomy required was 6 mm, then the tibial tray chosen would be usually a size 2 because a size 2.5 would be too large after excision of 6 mm of medial tibial bone. The osteotomy was then performed along the demarcated line using a broad osteotome.

The degree of correction after osteotomy was then measured using navigation. If residual varus deformity of $\leq 2^\circ$ persisted despite reduction osteotomy (40 knees), then release of proximal tibial attachment of semimembranosus was performed. However, if residual varus deformity

of $> 2^\circ$ persisted (12 knees), then further medial soft tissue release to include the posteromedial capsular attachment from the tibia with or without segmental excision of the posteromedial capsule was performed (Fig. 1). Proximal tibial and distal femoral cutting blocks were navigated into position and the tibial resection performed first. Tibial and distal femoral bone resection thickness was varied based on the degree of deformity and severity of lateral laxity (the greater the deformity and laxity, the lesser the bone was resected). Soft tissue balance in full extension was confirmed using spacer blocks in which a valgus and a varus stress was applied to determine the degree of laxity. In cases in which deformity was fully corrected but medial tightness persisted vis-à-vis the lateral side, further bone was osteotomized medially by downsizing the tibial component (in three knees) if that was feasible within the constraints of tray-femoral component compatibility. The flexion gap was equalized to the extension gap by the optimized gap-balancing feature of

Fig. 2A–D (A) An intraoperative photograph showing minimal release (anteromedial capsular attachment to the proximal tibial surface and deep medial collateral ligament) done to facilitate forward dislocation of the tibial plateau for registration. (B) The amount of osteotomy required being marked on the proximal tibial cut surface using a measuring scale and a marker using the most prominent point

of the medial tibial flare (arrow) as the starting point and measured in the medial to lateral direction. (C) The distal extent of the osteotomy (arrow), which is approximately 3 cm from the joint line, can be seen in this intraoperative photograph. (D) The distal extent of the osteotomy (arrow) and its relation to the medial soft tissue sleeve seen here after final implantation.

the computer software by simultaneously adjusting the femoral component size and position. Once the surgeon was satisfied with the femoral size and level of distal resection, the distal femoral resection was performed with navigation. The AP cutting blocking was navigated into position using the proximal tibial cut, Whiteside's line, and the transepicondylar axis for rotation while simultaneously referencing the anterior femoral surface with a stylus to avoid notching. Final alignment of the knee was confirmed by navigation after cementation.

Only intraoperative data were used for analysis in this study. No postoperative followup was required. Degree of varus deformity before and after reduction osteotomy, amount of osteotomy performed, and final alignment after implantation of prosthesis were recorded intraoperatively (Table 1). Reduction osteotomy was performed in 71 knees for deformity correction in this study. The mean varus deformity before reduction osteotomy was $14^\circ \pm 4.5^\circ$

(range, 6° – 32°). There were 44 knees (62%) with a preosteotomy varus deformity of $< 15^\circ$ and 27 knees (38%) with a preosteotomy varus deformity of $\geq 15^\circ$. The mean knee alignment after implantation of the prosthesis was $0.5^\circ \pm 0.5^\circ$.

For statistical analysis, the correlation between the amount of osteotomy and the degree of correction achieved, between preoperative varus deformity and the degree of correction achieved, and between the degree of preosteotomy residual varus deformity and the degree of correction achieved was determined using Pearson's correlation coefficient. A multiple regression analysis was performed using the SPSS (Version 15; SPSS, Chicago, IL, USA) statistical analysis software to determine which factor among preoperative varus deformity, preosteotomy residual varus deformity, and the amount of osteotomy determined the amount of correction achieved.

Results

For every 2 mm taken from the medial tibia, an average of approximately 1° of correction of varus deformity was achieved. In the 71 knees, we performed osteotomies measuring a mean 7.5 ± 2 mm and observed a mean correction of varus of $3.5^\circ \pm 1^\circ$.

The degree of varus correction achieved correlated positively with the amount of osteotomy performed ($r = 0.71$, $p < 0.001$). This correlation was stronger among knees with preoperative varus deformity of $< 15^\circ$ ($r = 0.77$, $p < 0.001$) compared with knees with a preoperative varus deformity of $\geq 15^\circ$ ($r = 0.55$, $p < 0.001$) (Fig. 3). The preosteotomy residual varus deformity correlated positively with the amount of correction achieved ($r = 0.81$, $p < 0.01$). Multiple regression analysis revealed that the amount of correction achieved depended on the amount of osteotomy performed and the amount of preosteotomy residual varus deformity.

Discussion

Reduction osteotomy is just one step to aid in achieving deformity correction in varus arthritic knees during TKA [11]. However, how much reduction osteotomy contributes in correction of varus deformity is unclear. Hence, we

Table 1. Intraoperative data in knees with $< 15^\circ$ and $\geq 15^\circ$ varus deformity

Parameter	All knees	$< 15^\circ$ varus deformity	$\geq 15^\circ$ varus deformity
Number of knees	71	44	27
Preoperative varus deformity ($^\circ$)	14 ± 4.5 (6–32)	12 ± 2 (6–14.5)	18.5 ± 4 (15–32)
Amount of osteotomy (mm)	7.5 ± 2 (2–12)	7 ± 2 (2–12)	8 ± 2 (4–12)
Postosteotomy varus deformity ($^\circ$)	1.5 ± 1 (0–5.5)	1 ± 1 (0–4.5)	2 ± 1 (0–5.5)
Correction achieved ($^\circ$)*	3.5 ± 1 (1–8)	3 ± 1 (1–7)	4 ± 1.5 (1.5–8)
Amount of osteotomy per degree of varus correction (mm)†	2 ± 2 (1–4)	2 ± 2 (1–4)	2 ± 2 (1–3)
Final alignment ($^\circ$)	0.5 ± 0.5 (1.5 varus to 1 valgus)	0.5 ± 0.5 (1.5 varus to 1 valgus)	0.5 ± 0.5 (1.5 varus to 1 valgus)

All values are expressed as mean $\pm$ SD with range in parentheses; * values represent mean of individual differences between preosteotomy residual varus deformity and postosteotomy varus deformity;

† values represent mean of amount of osteotomy per degree of varus correction in each knee calculated as amount of osteotomy (mm)/correction achieved ($^\circ$).

sought to answer the following questions: (1) What is the amount of deformity correction achieved with reduction osteotomy during TKA in varus knees? (2) What is the correlation of amount of deformity correction to the amount of bone osteotomized and the degree of varus deformity?

There are a few limitations to this study. First, although reduction osteotomy does facilitate correction of deformity, the effect may not be always as predictable, especially in the presence of recalcitrant medial soft tissue contracture because there is clearly a limit to the extent of bone that can be excised. Further correction demands additional soft tissue release; in fact, a sliding medial condylar osteotomy has been described recently for more resistant contractures [15]. However, most of the knees (69%) in our study showed a narrow range of 1.5 to 2.5 mm for the amount of osteotomy required for every 1° of correction with a 95% confidence interval of 1.7 to 2.6 mm for the amount of osteotomy required per degree of correction. Second, deformity and imbalance in an arthritic knee undergoing TKA are the result of a combination of bony and soft tissue changes locally. Therefore, studying the effect of either

Fig. 3A–B (A) A scatterplot showing the correlation between the amount of osteotomy performed and the amount of correction achieved in knees with $< 15^\circ$ varus deformity. (B) A scatterplot showing the correlation between the amount of osteotomy performed and the amount of correction achieved in knees with $\geq 15^\circ$ varus deformity.

bone resection (by reduction osteotomy) or soft tissue release alone on deformity correction during TKA may be challenging. We have tried to work around this problem by performing reduction osteotomy early on during the TKA before any significant soft tissue release was performed and recording the relevant data then to ensure that only the effect of reduction osteotomy is observed (Fig. 1). Third, reduction osteotomy that involves excision of the uncovered medial flare from the proximal tibia may seem to act by achieving release of the superficial MCL attachment from the proximal tibia. However, the tibial attachment of the superficial MCL is approximately 6- to 7-cm distal to the joint line [9] and is far away from the distal extent of the reduction osteotomy (Fig. 2D). Fourth, our study specifically aimed to quantify the effect of reduction osteotomy on the degree of varus deformity correction using intraoperative data; determining its effect on clinical or radiographic outcome was not an aim of this study. However, Dixon et al. [5] in their small series of 12 TKAs in which reduction osteotomy was performed to correct severe varus deformity during TKA reported excellent clinical and radiographic outcome at a mean followup of 42 months. Finally, studies have reported stress shielding and change in bone density around the tibial component, especially on the medial aspect, in TKA [17, 20]. Factors such as tibial base plate size [1] and position [7], limb alignment [21], and even cementing technique [2, 4] have been attributed to this change in bone density. Whether reduction osteotomy (which involves removal of the excessive bone medially) alters bone density around the tibial implant and leads to any adverse effect on long-term survival of the implant is not known. Dixon et al. [5] in their short series of 12 TKAs performed with reduction osteotomy have reported no evidence of osteolysis, loosening, or component subsidence in any patient at a mean followup of 42 months. Hence, in the short term, reduction osteotomy does not seem to have any adverse effect on the outcome and survival. We are currently reviewing the long-term results of reduction osteotomy.

The results of our study showed that reduction osteotomy when performed in varus arthritic knees during TKA can achieve deformity correction in a predictable manner (approximately 1° of correction per 2 mm of osteotomy). For this study we performed a reduction osteotomy as the first step before any release to assess its standalone effect on the degree of deformity correction, whereas reduction osteotomy usually is performed after preliminary or sometimes extensive medial soft tissue release [5, 14]. In the authors' opinion, reduction osteotomy can therefore be performed early before any major soft tissue release and can act as a soft tissue-sparing step during TKA. This has the advantage of minimizing the amount of release required to balance the knee and preventing any overrelease medially

leading to instability [5, 13]. In a previous cadaveric study, Mullaji et al. [13] have shown that with every step of release of soft tissues, there is an effect on the flexion and/or extension gaps and that may differ medially and laterally. Obviating or minimizing releases mitigates the adverse effect of releases on gaps. To the best of our knowledge, this is the only study that has attempted to quantify the effect of reduction osteotomy on correction of varus deformity during TKA. Dixon et al. [5] have reported the short-term clinical and radiographic results of correction of severe varus deformity in 12 TKAs by tibial component downsizing and resection of the uncapped proximal medial bone from the tibia. However, they had not quantified the amount of osteotomy performed in their case series. Similarly, Mullaji et al. [14] in their series of 173 TKAs performed in knees with profound varus deformity ($> 20^\circ$) had also described the use of reduction osteotomy as a method to achieve deformity correction and mediolateral soft tissue balance after extensive soft tissue release. However, there is no mention of the effect of reduction osteotomy on the degree of deformity correction in that study [14].

Furthermore, our study clearly showed a strong positive correlation between the degree of varus correction achieved and the amount of osteotomy performed, especially in knees with varus deformity of $< 15^\circ$, although this correlation was not strong in knees with varus deformity of $\geq 15^\circ$. This was probably attributable to the fact that in knees with $\geq 15^\circ$ varus deformity, there could be associated severe medial soft tissue contracture, excessive lateral soft tissue laxity, or rarely an associated extraarticular deformity (like tibia vara or femoral bowing) [15, 16, 18], which makes it difficult to achieve deformity correction with minimal medial soft tissue release and reduction osteotomy alone [15, 16, 18]. Our study also showed a strong positive correlation between the preosteotomy residual varus deformity and the degree of varus correction achieved, ie, the greater the preosteotomy residual varus deformity, the greater the correction achieved. Hence, these findings suggest that in knees with greater varus deformity ($\geq 15^\circ$), although the absolute correction achieved with reduction osteotomy was greater compared with knees with lesser varus deformity ($< 15^\circ$), it may not always fit the 2 mm for 1° pattern.

Based on the findings of our study, reduction osteotomy can be used to achieve deformity correction in varus arthritic knees in a predictable manner, especially in knees with $< 15^\circ$ varus deformity, and will help the surgeon in avoiding or minimizing medial soft tissue release. However, the surgeon needs to be careful in knees in which the varus deformity is correctible to $< 5^\circ$ or highly correctable deformities in which performing a reduction osteotomy may lead to excessive slackening of soft tissue medially and overcorrection. Reduction osteotomy can achieve deformity correction in a predictable manner in a 2 mm for

1° pattern in most varus arthritic knees during TKA. It is an effective soft tissue-sparing step when performed early on during TKA to achieve deformity correction.

Acknowledgments We thank Prof Harshad Thakur MD, School of Health System Studies, TATA Institute of Social Sciences, Mumbai, India, for his help with statistical analysis.

References

- Berend ME, Small SR, Ritter MA, Buckley CA. The effects of bone resection depth and malalignment on strain in the proximal tibia after total knee arthroplasty. *J Arthroplasty*. 2010;25:314–318.
- Cawley DT, Kelly N, Simpkin A, Shannon FJ, McGarry JP. Full and surface tibial cementation in total knee arthroplasty: a biomechanical investigation of stress distribution and remodeling in the tibia. *Clin Biomech (Bristol, Avon)*. 2012;27:390–397.
- Chang CB, Koh JJ, Seo ES, Kang YG, Seong SC, Kim TK. The radiographic predictors of symptom severity in advanced knee osteoarthritis with varus deformity. *Knee*. 2011;18:456–460.
- Chong DY, Hansen UN, van der Venne R, Verdonchot N, Amis AA. The influence of tibial component fixation techniques on resorption of supporting bone stock after total knee replacement. *J Biomech*. 2011;44:948–954.
- Dixon MC, Parsch D, Brown RR, Scott RD. The correction of severe varus deformity in total knee arthroplasty by tibial component downsizing and resection of uncapped proximal medial bone. *J Arthroplasty*. 2004;19:19–22.
- Fickert S, Jawhar A, Sunil P, Scharf HP. Precision of Ci-navigated extension and flexion gap balancing in total knee arthroplasty and analysis of potential predictive variables. *Arch Orthop Trauma Surg*. 2012;132:565–574.
- Innocenti B, Truyens E, Labey L, Wong P, Victor J, Bellemans J. Can medio-lateral baseplate position and load sharing induce asymptomatic local bone resorption of the proximal tibia? A finite element study. *J Orthop Surg Res*. 2009;4:26.
- Krackow KA. Total knee arthroplasty using the Stryker Knee Trac system. In: Stiehl JB, Konermann WH, Haaker RG, DiGioia AM, eds. *Navigation and MIS in Orthopaedic Surgery*. Heidelberg, Germany: Springer Medizin Verlag; 2007:100–105.
- Liu F, Yue B, Gadikota HR, Kozanek M, Liu W, Gill TJ, Rubash HE, Li G. Morphology of the medial collateral ligament of the knee. *J Orthop Surg Res*. 2010;5:69–77.
- Lo GH, Tassinari AM, Driban JB, Price LL, Schneider E, Majumdar S, McAlindon TE. Cross-sectional DXA and MR measures of tibial periarticular bone associate with radiographic knee osteoarthritis severity. *Osteoarthritis Cartilage*. 2012;20:686–693.
- Molli RG, Anderson KC, Buehler KC, Markel DC. Computer-assisted navigation software advancements improve the accuracy of total knee arthroplasty. *J Arthroplasty*. 2011;26:432–438.
- Mullaji A, Kanna R, Marawar S, Kohli A, Sharma A. Comparison of limb and component alignment using computer-assisted navigation versus image intensifier-guided conventional total knee arthroplasty: a prospective, randomized, single-surgeon study of 467 knees. *J Arthroplasty*. 2007;22:953–959.
- Mullaji A, Sharma A, Marawar S, Kanna R. Quantification of effect of sequential posteromedial release on flexion and extension gaps: a computer-assisted study in cadaveric knees. *J Arthroplasty*. 2009;24:795–805.
- Mullaji AB, Padmanabhan V, Jindal G. Total knee arthroplasty for profound varus deformity: technique and radiological results in 173 knees with varus of more than 20 degrees. *J Arthroplasty*. 2005;20:550–561.
- Mullaji AB, Shetty GM. Surgical technique: computer-assisted sliding medial condylar osteotomy to achieve gap balance in varus knees during TKA. *Clin Orthop Relat Res*. 2013;471:1484–1491.
- Mullaji AB, Shetty GM, Lingaraju AP, Bhayde S. Which factors increase risk of malalignment of the hip-knee-ankle axis in TKA? *Clin Orthop Relat Res*. 2013;471:134–141.
- Munro JT, Pandit S, Walker CG, Clatworthy M, Pitto RP. Loss of tibial bone density in patients with rotating- or fixed-platform TKA. *Clin Orthop Relat Res*. 2010;468:775–781.
- Nagamine R, Miura H, Bravo CV, Urabe K, Matsuda S, Miyamishi K, Hirata G, Iwamoto Y. Anatomic variations should be considered in total knee arthroplasty. *J Orthop Sci*. 2000;5:232–237.
- Ritter MA, Faris GW, Faris PM, Davis KE. Total knee arthroplasty in patients with angular varus or valgus deformities of > or = 20 degrees. *J Arthroplasty*. 2004;19:862–866.
- Soininvaara TA, Miettinen HJ, Jurvelin JS, Suomalainen OT, Alhava EM, Kröger HP. Periprosthetic tibial bone mineral density changes after total knee arthroplasty: one-year follow-up study of 69 patients. *Acta Orthop Scand*. 2004;75:600–605.
- Wong J, Steklov N, Patil S, Flores-Hernandez C, Kester M, Colwell CW Jr, D'Lima DD. Predicting the effect of tray malalignment on risk for bone damage and implant subsidence after total knee arthroplasty. *J Orthop Res*. 2011;29:347–353.