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Original Article

A New Classification for the Varus Knee

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ABSTRACT

Background: A new classification for osteoarthritis of the knee associated with varus deformity is presented. This classification is derived from the combination of conventional radiographs, stress radiographs (when needed), and clinical examination.
Methods: This study included the analysis of coronal alignment on full-leg standing radiographs of 526 patients awaiting knee arthroplasty for varus deformity in a single institution. Various mechanical and anatomic angles were measured, and these findings were combined with a basic clinical examination of patients. The radiographs were measured on 2 separate occasions to determine the intraobserver reliability. Cross-sectional studies such as computed tomography or magnetic resonance imaging were used to further refine observations about different wear patterns.
Results: Varus deformity can either be intra-articular or extra-articular. Intra-articular deformities can be correctable or fixed. In fixed deformities, the status of the lateral ligament is taken into account. Extra-articular deformity can be metaphyseal or diaphyseal, and the possibility for intra-articular correction will depend on the degree of deformity and its distance from the joint.
Conclusion: This new classification allows for better definition of varus deformity, which can help surgeons during preoperative planning, particularly with their choice of implant and potentially the degree of constraint. The classification can also be a tool for further prospective studies about varus deformity.

Coronal alignment is an important factor in orthopedic surgery, both preoperatively to describe the deformity and postoperatively to observe and report the radiological outcome [1]. Coronal alignment can be evaluated as an anatomic femorotibial angle, which is usually 6° of valgus relative to a vertical reference through the pubic symphysis. The anatomic axes for this measurement are determined as lines drawn through the center of the femoral and tibial intramedullary canals [2]. The anatomic axis can be found both during surgery and on radiographs. This allows the surgeon to align the limb according to the mechanical axis while using the anatomic axis available during surgery. The difference measured between the mechanical axis and the anatomic axis of the femur is referred to as the femoral mechanical-anatomic angle, which is perhaps the most critical aspect of alignment. The femoral mechanical-anatomic angle changes with height and pelvic width [3].

Coronal alignment can also be evaluated as mechanical alignment, which can be measured on a full-leg standing radiograph [4,5]. First, a line running from the center of the femoral head to the center of the talus, the load-bearing axis line or Maquet's line, can be used [6]. Neutral mechanical alignment runs from the center of the hip through the center of the knee and through the center of the talus. If there is varus deformity, the Maquet line will cross the tibia more medially or even medial to the knee joint in case of severe varus deformity.

Mechanical alignment can also be measured as a coronal plane angle. Therefore, the angle between a line from the center of the hip to the center of the knee and a line from the center of the knee to the center of the ankle will be drawn on full-leg radiographs. The angle where both lines cross each other at the knee joint is the hip-knee-ankle (HKA) angle. The HKA angle is expressed in the coronal plane in terms of 180° if both lines run parallel. In cases of varus deformity, by definition, the angle is <180°, and in case of valgus deformity, it is >180° [5]. Neutral alignment in the coronal plane is considered alignment within 3° of the 180° HKA angle [4,5,7,8], and

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Table 1
Kellgren-Lawrence Classification of Medial Femorotibial Arthritis.

Kellgren-Lawrence Grading	% of Study Group (N)	Ahlback Grading	% of Study Group (N)
1	0.5 (2)	1	0.5 (2)
2	7 (37)	2	2.5 (13)
3	22.5 (118)	3	27 (142)
4	70 (369)	4	70 (369)

therefore, knees considered to have varus alignment should measure ≤177° HKA [9].

Most osteoarthritic knees present with varus alignment [10,11]. This may be explained by the tendency of intrinsic varus alignment of the general population [7,8]. Obesity also plays a crucial role in the development of varus alignment. Consequently, about 90% of total knee arthroplasties (TKAs) are implanted because of varus deformity [10,11]. Despite the high frequency of varus pathology, to the best of our knowledge, no classification for varus deformity exists prior to knee arthroplasty.

However, 2 popular radiological classifications exist to classify severity of arthritic knees, which are the Ahlback and Kellgren-Lawrence ratings of radiographs. Most patients eligible for TKA will be in the Ahlback III-IV or Kellgren-Lawrence III-IV group, but this does not really help surgeons foresee potential technical difficulties of the scheduled surgery [12,13].

Recently, a new classification for the severity of arthritic disease was proposed using simple semantic terms that will allow surgeons to compare deformities in the near future. Mechanical alignment within 3° was considered normal and a deformity within 4°-10° a common deformity. With increments of 10°, the classification considers 11°-20° a substantial deformity, 21°-30° an important deformity, and >30° an extreme deformity [14].

The purpose of this retrospective study on a wide variety of surgical cases is to propose a new classification for the different types of varus knees suffering from medial compartment arthritis. This classification tries to help surgeons better understand and structure varus pathology of the knee.

Materials and Methods

Preoperative full-leg radiographs of 526 patients who underwent TKA for varus deformity between 2012 and 2015 in a university hospital with a single surgeon were retrospectively analyzed. Only patients who underwent a full-leg standing radiograph preoperatively were included. Both primary osteoarthritis and posttraumatic arthritis patients were eligible for the study. Patients with rheumatoid arthritis were excluded as the inflammatory nature of the disease was believed to affect the periarticular tissues including the collateral ligaments without any association with the deformity. All patients were Caucasian with 212 (40%) males and 314 (60%) females. The mean ± standard deviation age of the patients in the entire cohort was 67 ± 10 years without a significant difference between men and women. The mean body mass index was 30.5 ± 5.5 kg/m^2. The mean preoperative HKA alignment was 173° ± 5° (range, 149°-177°). Thirty-six percent of the study group patients underwent unicompartmental arthroplasty (UKA) and 64% received TKA. The degree of arthritis in the knees was classified using the Kellgren-Lawrence and Ahlback knee arthritis classification (Table 1). Hundred ninety-five patients had received magnetic resonance imaging (MRI), and 331 patients had computed tomography (CT) arthrography of their knee preoperatively. The results of these cross-sectional studies were incorporated into the study whenever possible.

One observer who measured the full-leg radiographs twice for each patient performed all measurements. The intraobserver accuracy was 1° as measured by 10 consecutive measurements at the start of the study. The intraobserver reliability of the classification was measured by comparing the second evaluation with

Fig. 1. Shows type IA—anteromedial osteoarthritis varus knee.

Fig. 2. Shows type IA—posteromedial osteoarthritis varus knee with typical posterior wear on the lateral radiograph.

Fig. 3. Shows type IA—fixed deformity knee with laxity on the convex side of deformity.

the first observation. The Cronbach method was used to determine the score that is a measure of intraobserver reliability. A Cronbach score of 0.90 was obtained.

Proposed Classification

Intra-articular Deformity (Type IA)

1. Reducible anteromedial osteoarthritis (AMOA) with an intact anterior cruciate ligament (ACL): typically Kellgren-Lawrence grade IV femorotibial disease with bone-on-bone contact. Anteromedial location can be observed on advanced imaging such as MRI or CT arthrography (Fig. 1).
2. Reducible posteromedial osteoarthritis with a deficient ACL: Kellgren-Lawrence grade IV femorotibial disease with bone-on-bone contact. Posteromedial wear can be observed on radiographs and confirmed by MRI or CT arthrography (Fig. 2).
3. Fixed varus deformity without lateral laxity.
4. Fixed varus with lateral laxity.

Metaphyseal Deformity (Type M; Within 5 cm of Joint Line) either at the Femoral (F) or Tibial (T) Level

1. Metaphyseal involvement because of wear (bone defects).
2. Metaphyseal involvement because of changed joint line obliquity.

Diaphyseal Deformity (Type D; At Least 5 cm Away From Joint Line)

1. Deformity at the tibial level.
2. Deformity at the femoral level.
3. Deformity at the tibial and femoral level combined.

Fig. 4. Shows type M—metaphyseal wear.

Fig. 5. Shows type M—joint line obliquity inversed after closed-wedge high tibial osteotomy with late-stage development of medial osteoarthritis.

Type IA stands for intra-articular wear. Type IA can be grossly classified according to the reducibility of the varus. The reducible varus can be either anteromedial or posteromedial. AMOA is clearly seen on anteroposterior and lateral radiographs, which show that the ACL is intact. If posteromedial osteoarthritis is present, this is suggestive for a tear of the ACL. Fixed varus can exist with or without lateral laxity. The former is often present in cases with varus thrust and usually seen after a previous ACL tear and extra-articular reconstruction of the knee (Fig. 3).

The second type of varus osteoarthritis, type M, is a metaphyseal deformity extending from the epiphyseal region but within 5 cm of the joint line. This type of varus knee has so much medial wear because of collapse or avascular necrosis of the plateau that the disease extends beyond the epiphyseal area of the proximal tibia (Fig. 4). Usually, the disease remains within the metaphyseal area. Within the metaphyseal area, changes to the joint line obliquity can also be observed either by congenital disease such as Blount's disease or by idiopathic changes with rarely a reversed joint line obliquity. However, metaphyseal changes are most frequently the result of surgical interventions such as high tibial osteotomy, corrective distal femoral osteotomy, or treatment of periarticular fractures (Fig. 5).

The third type of varus deformity is a diaphyseal deformity or type D that should be at a distance >5 cm from the joint line (Fig. 6). This extra-articular deformity can be at the distal tibia level, distal femoral level, or combined at the distal tibial and femoral level.

Fig. 6. Shows type D—DF level deformity with an extra-articular deformity of the femur. DF, diaphyseal femoral.

Results

Table 2 presents the results of the study group according to the newly proposed varus classification. Table 3 shows the frequency of diaphyseal deformity according to the anatomic location.

Discussion

After analyzing full-leg radiographs of a consecutive series of patients awaiting TKA, a new classification for knee osteoarthritis with varus deformity is proposed. The classification intends to help surgeons better prepare for TKA by selection of the appropriate implant and eventually the correct degree of constraint. The classification makes a distinction between intra-articular and extra-articular deformities as well as the flexibility of the deformity.

Type IA wear patterns were stratified according to basic clinical and radiological features. AMOA with intact ACL is usually limited to the anteromedial part of the tibia and femur and can be considered an indication for UKA [15,16]. If the ACL is no longer intact, clinical laxity can be observed and in general posteromedial arthritis is observed [17-19]. This can be seen on standard lateral radiographs and should be considered an indication for TKA. Previous articles about the absence of the ACL in knee arthritis observed this in 14.5%-17% of cases, comparable with our findings in this study (12%) [20]. Fixed varus deformities that are in need of medial releases are usually an indication for TKA because one of the principles of successful UKA is the avoidance of ligament release [15]. Patients who have

Table 2
Frequency of Different Types of Varus Arthritis in Study Group (N = 526).

Type I (Intra-articular)	N	%
AMOA with intact ACL	422	80
PMOA with deficient ACL	63	12
Type M (metaphyseal)	15	3
Type D (diaphyseal)	26	5

AMOA, anteromedial osteoarthritis; ACL, anterior cruciate ligament; PMOA, posteromedial osteoarthritis.

Table 3
Classification of Anatomic Location in Diaphyseal Deformity Group.

Type	N	%
DT	15	3
DF	9	2
DTF	2	0.5

DT, diaphyseal tibia; DF, diaphyseal femur; DTF, diaphyseal tibia and femur combined.

a gait pattern with an important varus thrust [21] can develop lateral laxity and should be well aligned postoperatively, if not in a little valgus on the femur, to reduce this lateral collateral ligament laxity. The use of more constrained implants could also be a solution in cases of remaining collateral laxity [22].

Type M deformities are varus deformities that are either femoral (type MF) or tibial (type MT). Important tibial or femoral wear with bone loss can be observed after progression of the disease, usually in important or extreme deformities [14]. Depending on the level of the wear, a choice between bone grafting and metal substitution should be made [23-25]. Metaphyseal deformity without bone loss is usually either posttraumatic, due to metabolic bone disease (Paget, rickets, and so forth), or congenital conditions (tibia vara, Blount, and so forth). It can also be iatrogenic after previous osteotomies about the knee [26]. Depending on the amount of deformity, a choice should be made between corrective osteotomy and intra-articular correction combined with a more constrained implant.

Finally, diaphyseal deformities up to the metaphysis of the hip or ankle (type D) can be classified depending on the anatomic localization: DT (Diaphyseal Tibia), DF (Diaphyseal Femur) or DTF (Diaphyseal Tibia and Femur). Depending on the level of the deformity, the correction can be performed with an intra-articular osteotomy for the implant or should be corrected extra-articularly with a corrective osteotomy [27-29]. The impact of the deformity on the mechanical alignment and the option to correct it with an intra-articular osteotomy should be studied preoperatively. The varus effect of the extra-articular deformity can be calculated at its apex and then multiplied by the distance to the joint line. A deformity at the midlevel of the femur (50%) has a 0.5 impact on the varus alignment of the leg. If that angle is smaller than the osteotomy needed through the lateral distal condyle without breaching the insertion of the collateral ligament, an intra-articular correction can be performed. However, the impact on soft tissue laxity in extension should be evaluated first.

Knee osteoarthritis with varus deformity is the most common form of bone-on-bone arthritis. This proposed varus classification according to "Thienpont and Parvizi" (Table 4) is a simple way of organizing varus pathology, similar to the Krackow valgus classification [30,31], to make prospective studies and treatment options available to surgeons performing TKA.

Table 4
Varus Deformity Classification According to "Thienpont and Parvizi."

Type IA: Intra-articular diaphyseal
Reducible:
AMOA with ACL intact
PMOA with deficient ACL
Fixed:
Without lateral laxity
With lateral laxity
Type M: Metaphyseal (within 5 cm of joint line) at femoral (F) or tibial (T) level
Wear extending to the metaphyseal region
Changes to joint line obliquity and metaphyseal anatomy
Type D: Diaphyseal (>5 cm away from joint line)
DT: Diaphyseal tibial level
DF: Diaphyseal femoral level
DTF: Diaphyseal tibial and femoral level

AMOA, anteromedial osteoarthritis; ACL, anterior cruciate ligament; PMOA, posteromedial osteoarthritis.

References

1. Kamath AF, Israelite C, Horneff J, et al. Editorial. What is varus or valgus knee alignment? A call for a uniform radiographic classification. Clin Orthop Relat Res 2010;468:1702.
2. Tew M, Waugh W. Tibiofemoral alignment and the results of knee replacement. J Bone Joint Surg Br 1985;67:551.
3. Nam D, Maher PA, Robles A, et al. Variability in the relationship between the distal femoral mechanical and anatomical axes in patients undergoing primary total knee arthroplasty. J Arthroplasty 2013;28:798.
4. Hsu RW, Himeno S, Coventry MB, et al. Normal axial alignment of the lower extremity and load-bearing distribution at the knee. Clin Orthop Relat Res 1990;255:215.
5. Moreland JR, Bassett LW, Hanker GJ. Radiographic analysis of the axial alignment of the lower extremity. J Bone Joint Surg Am 1987;69:745.
6. Maquet P. Biomechanics of gonarthrosis. Acta Orthop Belg 1972;38(Suppl 1):33.
7. Bellemans J, Colyn W, Vandenneucker H, et al. The Chitranjan Ranawat award: is neutral mechanical alignment normal for all patients? The concept of constitutional varus. Clin Orthop Relat Res 2012;470:45.
8. Shetty GM, Mullaji A, Bhayde S, et al. Factors contributing to inherent varus alignment of lower limb in normal Asian adults: role of tibial plateau inclination. Knee 2014;21(2):544.
9. Nam D, Shah RR, Nunley RM, et al. Evaluation of the 3-dimensional, weight-bearing orientation of the normal adult knee. J Arthroplasty 2014;29(5):906.
10. Chou PH, Chen WM, Chen CF, et al. Clinical comparison of valgus and varus deformities in primary total knee arthroplasty following midvastus approach. J Arthroplasty 2012;4:604.
11. Rossi R, Rosso F, Cottino U, et al. Total knee arthroplasty in the valgus knee. Int Orthop 2014;38:273.
12. Galli M, De Santis V, Tafuro L. Reliability of the Ahlbäck classification of knee osteoarthritis. Osteoarthr Cartil 2003;11:580.
13. Menkes CJ. Radiographic criteria for classification of osteoarthritis. J Rheumatol Suppl 1991;27:13.
14. De Muylder J, Victor J, Cornu O, et al. Total knee arthroplasty in patients with substantial deformities using primary knee components. Knee Surg Sports Traumatol Arthrosc 2015;23:3653.
15. Price A, Beard D, Thienpont E. Uncertainties surrounding the choice of surgical treatment for 'bone on bone' medial compartment osteoarthritis of the knee. Knee 2013;20(Suppl 1):16.
16. Rout R, McDonnell S, Hulley P, et al. The pattern of cartilage damage in anteromedial osteoarthritis of the knee and its relationship to the anterior cruciate ligament. J Orthop Res 2013;31:908.
17. White SH, Ludkowski PF, Goodfellow JW. Anteromedial osteoarthritis of the knee. J Bone Joint Surg Br 1991;73:582.
18. Keyes GW, Carr AJ, Miller RK, et al. The radiographic classification of medial gonarthrosis. Correlation with operation methods in 200 knees. Acta Orthop Scand 1992;63:497.
19. Johnson AJ, Howell SM, Costa CR, et al. The ACL in the arthritic knee: how often is it present and can preoperative tests predict its presence? Clin Orthop Relat Res 2013;471:181.
20. Stein V, Li L, Lo G, et al. Pattern of joint damage in persons with knee osteoarthritis and concomitant ACL tears. Rheumatol Int 2012;32:1197.
21. Noyes FR, Barber-Westin SD, Hewett TE. High tibial osteotomy and ligament reconstruction for varus angulated anterior cruciate ligament-deficient knees. Am J Sports Med 2000;28:282.
22. Okamoto S, Okazaki K, Mitsuyasu H, et al. Lateral soft tissue laxity increases but medial laxity does not contract with varus deformity in total knee arthroplasty. Clin Orthop Relat Res 2013;471:1334.
23. Lee JK, Choi CH. Management of tibial bone defects with metal augmentation in primary total knee replacement: a minimum five-year review. J Bone Joint Surg Br 2011;93:1493.
24. Franceschina MJ, Swienckowski JJ. Correction of varus deformity with tibial flip autograft technique in total knee arthroplasty. J Arthroplasty 1999;14:172.
25. 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.
26. Carothers JT, Kim RH, Dennis DA. Bent but not broken: managing severe deformity in total knee arthroplasty. Semin Arthroplasty 2008;19:103.
27. Thienpont E, Paternostre F, Pietsch M, et al. Total knee arthroplasty with patient-specific instrument improves function and restores limb alignment in patients with extra-articular deformity. Knee 2013;20:407.
28. Wang JW, Wang CJ. Total knee arthroplasty for arthritis of the knee with extra-articular deformity. J Bone Joint Surg Am 2002;84:1769.
29. Wang JW, Chen WS, Lin PC, et al. Total knee replacement with intra-articular resection of bone after malunion of a femoral fracture: can sagittal angulation be corrected? J Bone Joint Surg Br 2010;92:1392.
30. Krackow KA, Jones MM, Teeny SM, et al. Primary total knee arthroplasty in patients with fixed valgus deformity. Clin Orthop Relat Res 1991;273:9.
31. Ranawat AS, Ranawat CS, Elkus M, et al. Total knee arthroplasty for severe valgus deformity. J Bone Joint Surg Am 2005;87(Suppl 1):271.