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Knee Osteoarthritis Progression after Distal Femur Closing Wedge Osteotomy

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Abstract

Background: Despite the conservative treatment of tibio-femoral osteoarthritis through realignment osteotomies, the rate of total knee replacements following an osteotomy is increasing. The aim of this study was to identify the factors associated with the progression of knee osteoarthritis after a medial closing-wedge distal femoral osteotomy. **Methods**: Hospital-based observational study on 20 patients who underwent a medial closing-wedge distal femoral osteotomy evaluating the progression of osteoarthritis using the Kellgren and Laurence classification. The Wilcoxon test was used to compare the variation in the progressive stage of the Kellgren and Laurence classification of knee osteoarthritis preoperatively and at the final follow up. Univariate analysis made it possible to determine the factors associated with progression. The final significance threshold for statistical tests was set at 5% ($p < 0.05$). **Results:** Overall, the mean follow-up of 46 months ± 6.6 months, with a mean age of 43 years (range: 27 - 69 years) and a female predominance (M: F = 3/7). The progression of tibiofemoral osteoarthritis following a medial closing-wedge distal femoral osteotomy is associated with valgus or varum malalignment been a moderate valgus (OR 6.2 [1.5 - 42.7] at 95% CI; p-value = 0.02), a correction of the mechanical deviation angle with a valgus alignment (OR 2.7 [0.9 - 8.3] at 95% CI), and loss of correction (OR 3.8 [1.3 - 11.6] at 95% CI; p -value) for the lateral compartment while varus alignment (OR 1.7 [0.9 - 8.3] 95% CI, p-value = 0.05) and with rupture of the lateral cortex (OR 2.8 [1.7 - 11.5] 95% CI, p-value = 0.02) were those of the medial compartment. **Conclusion:** Distal femur closing wedge osteotomy does not definitively interrupt the progression of valgus knee osteoarthritis. The factors associated with the progression of this pathology are modifiable. Taking them into account when performing this surgical technique could improve the osteotomy survival curve.

Keywords

Knee, Osteoarthritis, Progression, Osteotomy, Distal Femur

1. Introduction

Osteoarthritis (OA) is a degenerative joint disease observed in the general population. With a prevalence of 365 million, the knee is the most affected bone, resulting in progressive functional loss, joint pain, and stiffness [1]. The surgical osteotomy technique for long bones on the lower limbs (the femur and the tibia) is a time-honoured procedure, which aims to correct the angular deformity of the affected limb, slowing down the evolutionary process of OA. As a result, it improves pain and limb function, and it can postpone knee replacement procedures, such as knee arthroplasty, for up to 10 years [2]. It can be a straightforward operation, but one of the principal complications is the secondary displacement of the bone fragments soon after the operation. A medial closing wedge distal femoral osteotomy (MCDFO) is a procedure that can be considered when a patient has a valgus alignment and arthritis in the lateral and patellofemoral compartments is present. This surgery aims to reduce lateral compartment overload and prevent knee osteoarthritis (OA) progression [3]. However, following this conservative treatment through osteotomy, several authors have noted a variable rate of conversion to total knee replacement ranging from 8% to 17% after 10 years [4]. This shows that despite the relatively long survival time of knee realignment osteotomies, cartilaginous degradation progresses. As a result, it becomes symptomatic and necessitates prosthetic replacement. Radiographs can show osteoarthritic changes in the bone; however, soft-tissue involvement may not be appreciated. Plain radiography remains a mainstay in the diagnosis of OA. The first formalized attempts at establishing a radiographic classification scheme for OA were described by Kellgren and Lawrence in 1957 and later accepted by the World Health Organisation (WHO) in 1961 as the radiological definition of OA for the purpose of epidemiological studies [5] [6]. Therefore, numerous variations of the Kellgren and Lawrence classification system have been used in research. This indicates a progression of knee osteoarthritis both radiographically and functionally.

This work therefore aims to identify the factors of progression of tibiofemoral knee OA after the completion of a medial closing-wedge distal femoral osteotomy.

2. Methods

2.1. Ethics

This study was approved by the Institutional Ethics Board of Université Cheikh Anta Diop.

2.2. Study Design

This was a retrospective observational study, conducted at the Orthopedic Traumatology Department of the Order of Malta Hospital, located within the Fann Teaching Hospital in Dakar, Senegal. All patients who received a MCDFO osteotomy fixed by 90˚ blade-plate, with a minimum follow-up of 12 months postoperatively in our institution between 1/2011 and 1/2020 were included in this study osteotomy. Operations were performed by three consultants for orthopaedic surgery. The clinical and radiological data were collected as part of the postoperative follow-up and extracted from patient records for analysis. All patients freely gave their consent to the study. Patients had a mean body mass index (BMI) of 28.1 kg/m^2.

2.3. Patient Characteristics

Patients with valgus knee alignment OA were considered for valgus-correcting osteotomy.

The progression of knee osteoarthritis was measured radiographically using the Kellgren and Laurence classification. The patients were summoned by telephone call to be clinically evaluated and take a X-ray of the operated knee. The progressive stages of knee osteoarthritis were compared preoperatively and then at final follow-up. The design of this study was approved by our Institutional Ethics Review Board and informed consent was obtained from all patients. Out of 20 patients, we had 14 women and 6 men giving a sex ratio of 3:7. The sex ratio was 3/7. The average age was 44.4 years with extremes of 27 and 69 years at the time of the intervention. Patients had a mean body mass index (BMI) of 28.1 kg/m^2.

All patients consulted for knee pain on genu valgum with symptomatic involvement in 14 cases on the right, 5 cases on the left and 1 bilateral. The patient with bilateral involvement was operated on in two stages. Before the intervention, the degree of genu valgum was moderate in 17 cases and severe in 4 cases. 1 patient had undergone external meniscectomy. The knee osteoarthritis was primary in 21 cases. Associated patellofemoral osteoarthritis was found in 6 patients. The average preoperative mechanical deviation angle was 16.2˚. According to the Kellgren and Laurence classification, the pre-operative stages of knee osteoarthritis of the patients in the series were as follows: 1 knee was at stage 1, 11 at stage 2, 9 at stage 3 and 0 at stage 4.

Initial Evaluation

The main indication for the correction of the affected lower limb was valgus deformity > 12˚. For the preoperative planning, radiographs of the affected side were taken in antero-posterior and lateral views, in addition to a panoramic lower limbs radiograph for the calculation of the valgus angle and to determine if the deformity was in the distal femur. The criteria for correction were the following: Absence of diffuse or nonspecific knee pain or main pain complaint at the patellofemoral joint, previous meniscectomy in the weight-bearing compartment, weight-support compartment arthrosis, underlying diagnosis of inflammatory disease, and arc of movement ≥ 90˚ with contracture under flexion < 10˚.

2.4. Osteotomy Technique

All patients had been operated on by a surgeon under spinal anaesthesia. The technique of the distal femur osteotomy was that which was described by Mac Dermott [7] and taken up by Wang [8]. The patient was placed in the supine position on an ordinary radio-transparent table. A medial longitudinal incision of 5 to 8 cm was made over the distal femur. The fascia of the vastus medialis was excised and the vastus medialis was elevated superiorly and laterally. A distal femur closed wedge osteotomy with internal fixation using a 90˚ AO blade – plate was performed. After the osteotomy, reduction and fixation, the surgical site was washed, followed by closure under suction drainage. Postoperatively, the limb was immobilized for analgesic purposes, in a knee brace. Physiotherapy was started on the 2nd post-operative day. Mobilization to recover the joint range of motion of the knee was undertaken from the 2nd day, as well as verticalization without support on the operated limb. Partial loading of the limb began at the 8th week and was complete in the 12th week.

2.5. Radiographic Assessments

The progression of knee osteoarthritis was assessed radiographically. It was done on the X-ray images in incidence and from the front and in profile of the knee under load. The preoperative films constituted the starting point for the evaluation of progression and those of the last follow-up the end. The progression criteria analyzed were those described by Altman [9] namely the appearance or worsening of pinching, osteophyte, varus or valgus alignment, wear of a compartment or subchondral sclerosis. The Kellgren and Laurence classification (**Table 1**) is the one that was used to evaluate the progression of knee osteoarthritis. A change in the radiograph was pre-defined as a change in 2 mm or more in the tibiofemoral joint space and a change in the grade of the sclerosis or osteophytes, as described elsewhere [10].

Table 1. Kellgren-lawrence grading system for osteoarthritis.

Grade	Radiologic Findings
0	No radiological findings of osteoarthritis
I	Doubtful narrowing of joint space and possible osteophytic lipping
II	Definite osteophytes and possible narrowing of joint space
III	Moderate multiple osteophytes, definite narrowing of joint space, small pseudocystic areas with sclerotic walls and possible deformity of bone contour
IV	Large osteophytes, marked narrowing of joint space, severe sclerosis and definite deformity of bone contour

2.6. Data Collection

Medical files and imaging results from all of the patients were reviewed to collect data regarding gender, age at surgery, laterality, deformity, and intraoperative complications. Next, the patients were clinically analysed with their imaging results to characterize their current status: treatment failure required conversion to total knee arthroplasty, and other complications.

2.7. Statistical Analysis

The data were entered using Epi InfoTM® software version 7.1.5.2 and the analysis was done using the statistical software R Studio Version 1.0.143® (R Development Core Team, Vienna, Austria). Mean values and standard deviations were calculated for quantitative variables and numbers and percentages for qualitative variables. As the number was less than 30, the Chi-square test was carried out to test the homogeneity of the distribution of qualitative variables in the groups and analyse the differences between the proportions of events of interest between the groups. Fisher's exact test was performed when the theoretical numbers were less than or equal to 5. For quantitative variables, the Student's t-test was used. Univariate analysis made it possible to determine the factors associated with progression. The Wilcoxon test was used to compare the variation in the progressive stage of the Kellgren and Laurence classification of knee osteoarthritis preoperatively and at the final follow up. The final significance threshold for statistical tests was set at 5% ($p < 0.05$) with a 95% confidence interval (CI).

3. Results

3.1. Demographic Data

Twenty-one MCDFOs performed in 20 Patients (one bilateral; fourteen females, six males) were included in this study. The mean age was 44.4 (27 - 69) years and had a mean body mass index (BMI) of 28.1 kg/m^2.

3.2. Indication

The indication for the MCDFO was valgus osteoarthritis in all cases. In 100% cases, it was knee primary osteoarthritis affecting the right-side in 14 cases, left side in 5 cases and bilateral in 1 case. Out of the cases having a valgus osteoarthritis 30% had additionally a patellar maltracking/patellar instability and 5% had undergone external meniscectomy. Before surgery, in 80% case, the degree of valgum was moderate and in 20% of cases it was severe. The average preoperative mechanical deviation angle was 16.2˚. According to the Kellgren and Laurence classification, the pre-operative stages of knee osteoarthritis of the patients in the series were as follows: 1 knee was at stage 1, 11 at stage 2, 9 at stage 3 and 0 at stage 4 (Table 2).

3.3. Clinical Outcome

In total, we retained 20 files (21 operated knees). At the last follow-up, radiographic analyses of the knees showed that the average time for consolidation of the osteotomy was 4.3 months ± 1.3 month.

The valgus deformity mean angle of mechanical deviation was 0˚ ± 2.4˚ before the surgery. After the osteotomy, the mean angular correction was 16.2˚ ± 5.3˚ and the mean patellar height was 0.9 ± 0.2.

Postoperative anatomical alignment was done in valgus (n = 12, 57.14%) with an angle [−4˚ to 0˚] and in varus [(n = 9, 42.85%) with an angle of [0˚ to + 4˚].

The immediate and late postoperative complications found were rupture of the lateral cortex (n = 8, 38.09%), loss of correction (n = 7, 33.33%), disassembly of hardware (n = 2, 9.52%) and screw breakage (n = 1, 4.78%). The average loss of correction was 2.5˚ ± 0.8˚ (the difference between the mechanical deviation angle on post-operative day 1 and at the last follow-up).

3.4. Radiologic Results

There was the change in the tibiofemoral space in 7 cases (33.33%). We observed progression of OA in the tibiofemoral compartment in 7 cases among which 4 cases were internally while 3 cases were external. Among them, according to Kellgren and Laurence there was progression of OA from stage 2 to stage 3 in 4 cases (57.14%) and from stage 3 to stage 4 in 2 cases (28.57%). The analysis of factors associated with the progression of the external femoro-tibial compartment showed that patients who experienced progression of their gonarthrosis were on average 10 years younger compared to those in whom no progression was observed. This observation was reversed in the case of the internal femoro-tibial compartment. However, this difference was not significant. Furthermore, there was no influence of gender and BMI on the progression of gonarthrosis.

The presence of femoropatellar arthrosis had no influence on the progression of gonarthrosis. Neither did the patellar height. The loss of correction had an influence on the progression of cartilage degradation in the medial femoro-tibial compartment but not in the lateral compartment. **Figure 1** showed a case of progressive degradation of the external tibiofemoral compartment from stage 3 to stage 4 over a 1-year period.

Table 2. Change stage of knee osteoarthritis from entry to the last follow up.

	Kellgren and Lawrence stage	At the last follow up				
		I	II	III	IV	Total
At entry	I	1	0	0	0	1
	II	0	6	0	0	11
	III	0	0	12	0	9
	IV	0	0	0	2	0
	Total	1	6	12	2	21

$p < 0.05$ Wilcoxon signed rank test.

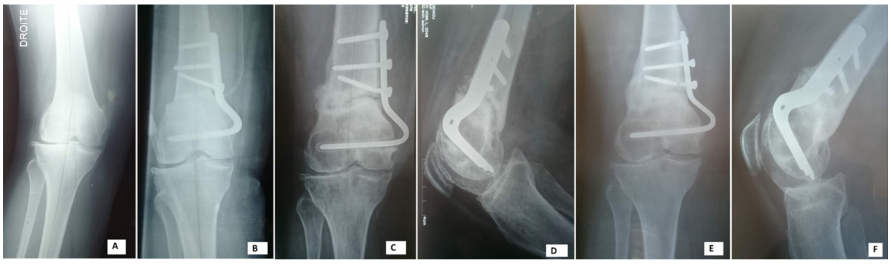

Figure 1. This figure illustrates the evolution of a stage 3 Kellgren and Laurence external tibiofemoral osteoarthritis (A). A rupture of the outer cortex with medial translation of the diaphyseal shaft is observed on the immediate postoperative control radiograph (B). In the 6^{th} postoperative month (C), (D) we observe a delay in consolidation (osteocondensation of the edges of the osteotomy, room for mobility of the blade), a deterioration of the internal tibiofemoral compartment linked to the increase in stresses in internal; twisting of the distal screw. At the 12^{th} postoperative month (E), (F) consolidation is obtained after breaking the distal screw.

At the last follow-up, the univariate analysis showed that a severe valgus (OR 6.2 [1.5 - 42.7] at 95% CI; p-value = 0.02), a valgus correction of the mechanical deviation angle (OR 2.7 [0.9 - 8.3] at 95% CI), and loss of correction (OR 3.8 [1.3 - 11.6] at 95% CI; p-value) were factors significantly associated with the progression of wear of the external tibiofemoral compartment (**Table 3**). Deterioration of the internal tibiofemoral compartment was significantly associated with varus correction (OR 1.7 [0.9 - 8.3] 95% CI, p-value = 0.05) and rupture of the lateral cortex (OR 2.8 [1.7 - 11.5] 95% CI, p-value = 0.02) (**Table 4**).

4. Discussion

This study reports knee osteoarthritis progression after distal femur closing wedge osteotomy in our institution over a 9-year period. This procedure for valgus knees in active population achieved good outcomes in a review by Saithna *et al*, demonstrating long survivorship (mean range: 64% - 87% at 10-year follow-up) and good function (mean range of post-operative HSS score: 72-88) [11]. Also, it has the great advantage of been a successful treatment for lateral osteoarthritis especially in young patient because it slows down the process of cartilage destruction leading to disease progression delay and improvement of the overall knee function preventing need for early Unilateral or total Knee arthroplasty (UKA/TKA) however there is a long rehabilitation time, a considerable risk for complications, and a high need for hardware removal [12]. Nonetheless, a conversion rate 10 to 20% to TKA was observed for up to 10 years due to the progression of cartilage degradation [13]. In regards to OA progression, several pathways have been reported and can be induce by various mechanical factors among which there is reduction in the loading of a joint that will stimulate the growth of the subchondral bone by reducing the pressure of local fluids; while trauma will induce microlesions of the cartilage and which will activate the growth of the subchondral bone through the appearance of local shear stresses then mechanical anomalies will increase the wear of the joint surfaces; and other factors of mechanical origin [14]. In addition, repeated trauma leads to alteration of the cartilaginous matrix which affects the function of the chondrocyte [15].

Table 3. Factors associated with the progression of external tibiofemoral osteoarthritis.

	Effective	Deterioration of the external tibiofemoral compartment (%)	Univariate analysis	
			OR [CI 95%]	p-value
Mean age (standard deviation*)				
OA with progression	7	35.6 (7)		0.104
OA without progression	14	45.8 (11.2)	1.12 [0.95 - 1.33]	
Sex				
Female	14	2 (14.3)		1
Male	6	1 (14.3)	1 [0.07 - 13.36]	
BMI				
18 - 24.5	6	0 (0)	-	
24.5 - 30	9	2 (22.2)	$8.9e^{+8}$[0 - 13.36]	0.319
30.1 - 34.5	6	1 (16.6)	1.43 [0.1 - 20.4]	0.793
Patellofemoral Osteoarthritis				
Yes	6	0 (0)	0.8 [0.15 - 2.67]	0.526
No	15	3 (20)		
Patella height				
Normal	20	3 (54.1)	0 [0 - 233.15]	1
Low	1	0 (0)		
Valgum degree				
0˚ - 10˚	0	0 (0)		**0.02**
10˚ - 20˚	17	0 (0)	1	
≥20˚	4	3 (75)	6.2 [1.5 - 42.7]	
Correction angle				
Varus correction	12	0 (0)	1	**0.05**
Valgus correction	9	3 (33.3)	2.7 [0.9 - 8.3]	
Loss of correction				
Yes	7	0 (0)	1	**0.04**
No	14	3 (21.4)	3.8 [1.3 - 11.6]	
Lateral cortical rupture				
Yes	8	2 (25)	1	0.452
No	13	1 (7.7)	1.8 [1.7 - 14.9]	

In parentheses, it is the standard deviation only for the mean age, then it is the proportion for the rest of the variables.

Table 4. Factors associated with wear of the internal tibiofemoral compartment.

	Effective	Deterioration of the internal tibiofemoral compartment (%)	Univariate analysis	
			OR [IC 95%]	p-value
Mean age (standard deviation)				
OA with progression	4	53.2 (11.1)		0.14
OA without progression	17	42.3 (10.4)	1 [−5.4 - 27.3]	
Sex				
Female	14	4 (28.6)		0.25
Male	7	0 (0)	1 [−27.35 - 5.44]	
BMI				
18 - 24.5	6	1 (16.7)		
24.6 - 30	9	2 (22.2)	1.43 [0.16 - 12.7]	0.74
30.1 - 34.5	6	1 (16.7)		
Patellofemoral Osteoarthritis				
Yes	6	2 (33.3)	0.32 [0.02 - 5.89]	0.54
No	15	2 (13.3)		
Patella height				
Normal	20	4 (54.1)	1 [0 - 165]	1
Low	1	0 (0)		
Valgum degree				
0˚ - 10˚	0	0 (0)		1
10˚ - 20˚	17	3 (17.6)	0.65 [0.03 - 44.8]	
≥20˚	4	1 (25)		
Correction angle				
Varus correction	12	3 (25)	1.7 [0.9 - 8.3]	**0.05**
Valgus correction	9	1 (11.1)	1	
Loss of correction				
Yes	7	3 (34.6)	0.15 [0.002 - 2.4]	0.25
No	14	1 (66.7)		
Lateral cortical rupture				
Yes	8	4 (50)	2.8 [1.7 - 11.5]	**0.02**
No	13	0 (0)	1	

In parentheses, it is the standard deviation only for the mean age, then it is the proportion for the rest of the variables.

For 4 cases following MCDFO, a progressive degradation of the internal tibiofemoral compartment was observed, this was significantly associated with a varus correction and a rupture of the lateral cortex. These two factors tend to create varus alignment. In 2015, in their metanalysis Bastix *et al* found varus alignment as a prognostic factor for radiographic progression of tibiofemoral knee OA [16]. The deterioration of the external tibiofemoral joint space observed in 3 cases was significantly associated with severe valgus, correction of the angle of mechanical deviation in valgus, and a loss of correction. All risk factors associated with the degradation of the different compartments common point is that they move the mechanical axis of the member away from the zero angle of deviation (0˚). The wear appearance of the medial tibiofemoral joint space was associated with rupture of the lateral cortex leading to varus increases either by an exuberant callus, or by the medial translation of the metaphysis during screwing. This would increase internal constraints and therefore promote this degradation of the medial compartment. In the case of the lateral compartment, its degradation could be explained by the reversed mechanisms. All these risk factors associated with the degradation of the different compartments have a common point which is that they move the mechanical axis of the member away from the zero angle of deviation (0°). The medial tibiofemoral joint space wear was associated with rupture of the lateral cortex, it increases the varus either by an exuberant callus, or by the medial translation of the metaphysis during screwing. This would increase internal constraints and therefore promote this degradation of the medial compartment. For lateral compartment, its degradation could be explained by the reversed mechanisms. In valgus knees that are resistant to correction due to the often-associated medial laxity, the valgus correction and loss of correction generate, maintain or aggravate the pre-operative valgus which promotes continued wear of the cartilage of the external compartment. Sharma *et al.* [17] in their prospective study observed that varus and valgus alignment were respective factors in the progression of knee osteoarthritis in the internal and external compartments. Varus or valgus misalignments of the degenerative knee cause joint mechanical stress. Felson *et al* [18], in their study on OA using magnetic resonance imaging showed that if there is a presence of subchondral oedema due to this mechanical stress can be a factor of knee OA progression. Knee osteotomy surgery causes a functional limitation of the extensor system during the rehabilitation period. According to Dell'isola *et al*, limitation of the extensor system is often accompanied by amyotrophy of the quadriceps which is a factor associated with the progression of knee OA. Although body mass index was not found as a factor associated with the progression of knee osteoarthritis in our study, previous study like Dieppe *et al.* [19] series of more than 500 patients demonstrated that a BMI greater than 27 kg/m^2 is an independent factor in the progression of knee osteoarthritis. The Dutch Rotterdam study, conducted with over 3500 patients with an average age of 55 and followed over a period of 6 years, showed that, compared to a BMI lower than 25, a BMI higher than 27 is associated with a 3.3-fold increased risk of progression of knee osteoarthritis [20].

Our study limitations were the retrospective data collection system used and the small sample size which could make the search for factors associated with the progression of knee osteoarthritis non-exhaustive.

5. Conclusion

Correction of valgus femoral deformity is a viable treatment option for a well-defined patient group suffering from valgus malalignment. The factors associated with degradation or wear of the cartilage of the tibiofemoral joint were varus or valgus alignment of more than 4˚, fracture of the lateral cortex and loss of correction. All factors associated with factors associated with the progression of knee osteoarthritis following conservative osteotomy of the distal femur are modifiable, therefore MCDFO could be considered a good procedure in order to delay or even avoid knee replacement.

Abbreviations

OA: Osteoarthritis; BMI: Body Mass Index.

Authors Contributions

All authors analyzed and interpreted the patient data. NMF performed the operations and made a major contribution to writing the manuscript. All authors read and approval the final manuscript.

Availability of Data and Materials

The datasets obtained and or analyzed during the current study are available from the corresponding authors on reasonable request.

Ethics Approval and Consent to Participate

The design of this study was approved by the ethics committee of the Dakar Faculty of Medicine (n˚0212). Informed consent has been obtained from all patients included in this study

Consent for Publication

Informed consent has been obtained from all patients included in this study.

Conflicts of Interest

The authors declare that they have no competing interests.

References

[1] Long, H., Liu, Q., Yin, H., Wang, K., Diao, N., Zhang, Y., *et al.* (2022) Prevalence Trends of Site-Specific Osteoarthritis from 1990 to 2019: Findings from the Global Burden of Disease Study 2019. *Arthritis & Rheumatology*, **74**, 1172-1183.

https://doi.org/10.1002/art.42089

[2] Brouwer, R.W., Huizinga, M.R., Duivenvoorden, T., Raaij, T.M, Van Verhagen, A.P., Bierma-Zeinstra, S.M.A. and Verhaar, J.A.N. (2023) Osteotomy for Treating Knee Osteoarthritis. *Cochrane Database of Systematic Reviews*, No. 12, Article No. CD004019.
https://www.cochranelibrary.com/cdsr/doi/10.1002/14651858.CD004019.pub4/full
https://doi.org/10.1002/14651858.CD004019.pub4

[3] Sternheim, A., Garbedian, S. and Backstein, D. (2011) Distal Femoral Varus Osteotomy: Unloading the Lateral Compartment: Long-Term Follow-Up of 45 Medial Closing Wedge Osteotomies. *Orthopedics*, **34**, e488-e490.
https://doi.org/10.3928/01477447-20110714-37

[4] Chahla, J., Mitchell, J.J., Liechti, D.J., Moatshe, G., Menge, T.J., Dean, C.S., *et al.* (2016) Opening- and Closing-Wedge Distal Femoral Osteotomy: A Systematic Review of Outcomes for Isolated Lateral Compartment Osteoarthritis. *Orthopaedic Journal of Sports Medicine*, **4**, Article 2325967116649901.
https://doi.org/10.1177/2325967116649901

[5] Kellgren, J.H. and Lawrence, J.S. (1957) Radiological Assessment of Osteo-Arthrosis. *Annals of the Rheumatic Diseases*, **16**, 494-502.
https://doi.org/10.1136/ard.16.4.494

[6] Thomas, K.A., Kidzinski, Ł., Halilaj, E., Fleming, S.L., Venkataraman, G.R., Oei, E.H.G., *et al.* (2020) Automated Classification of Radiographic Knee Osteoarthritis Severity Using Deep Neural Networks. *Radiology*: *Artificial Intelligence*, **2**, e190065.
https://doi.org/10.1148/ryai.2020190065

[7] McDermott, A.G., Finklestein, J.A., Farine, I., Boynton, E.L., MacIntosh, D.L. and Gross, A. (1988) Distal Femoral Varus Osteotomy for Valgus Deformity of the Knee. *The Journal of Bone & Joint Surgery*, **70**, 110-116.
https://doi.org/10.2106/00004623-198870010-00017

[8] Wang, J.-W. and Hsu, C.-C. (2005) Distal Femoral Varus Osteotomy for Osteoarthritis of the Knee. *The Journal of Bone & Joint Surgery*, **87**, 127-133.
https://doi.org/10.2106/JBJS.C.01559

[9] Altman, R.D., Hochberg, M., Murphy Jr, W.A., Wolfe, F. and Lequesne, M. (1995) Atlas of Individual Radiographic Features in Osteoarthritis. *Osteoarthritis and Cartilage*, **3**, 3-70.

[10] Cooper, C., Cushnaghan, J., Kirwan, J.R., Dieppe, P.A., Rogers, J., McAlindon, T., *et al.* (1992) Radiographic Assessment of the Knee Joint in Osteoarthritis. *Annals of the Rheumatic Diseases*, **51**, 80-82. https://doi.org/10.1136/ard.51.1.80

[11] Saithna, A., Kundra, R., Modi, C.S., Getgood, A. and Spalding, T. (2012) Distal Femoral Varus Osteotomy for Lateral Compartment Osteoarthritis in the Valgus Knee. A Systematic Review of the Literature. *The Open Orthopaedics Journal*, **6**, 313-319. https://doi.org/10.2174/1874325001206010313

[12] Ismailidis, P., Schmid, C., Werner, J., Nüesch, C., Mündermann, A., Pagenstert, G., *et al.* (2023) Distal Femoral Osteotomy for the Valgus Knee: Indications, Complications, Clinical and Radiological Outcome. *Archives of Orthopaedic and Trauma Surgery*, **143**, 6147-6157. https://doi.org/10.1007/s00402-023-04923-w

[13] Wieland, H.A., Michaelis, M., Kirschbaum, B.J. and Rudolphi, K.A. (2005) Osteoarthritis—An Untreatable Disease? *Nature Reviews Drug Discovery*, **4**, 331-344.
https://doi.org/10.1038/nrd1693

[14] Hu, Y., Chen, X., Wang, S., Jing, Y. and Su, J. (2021) Subchondral Bone Micro-environment in Osteoarthritis and Pain. *Bone Research*, **9**, Article No. 20.

https://doi.org/10.1038/s41413-021-00147-z

[15] Bastick, A.N., Belo, J.N., Runhaar, J. and Bierma-Zeinstra, S.M.A. (2015) What Are the Prognostic Factors for Radiographic Progression of Knee Osteoarthritis? A Meta-Analysis. *Clinical Orthopaedics and Related Research*, **473**, 2969-2989. https://doi.org/10.1007/s11999-015-4349-z

[16] Sharma, L., Song, J., Felson, D.T., Cahue, S., Shamiyeh, E. and Dunlop, D.D. (2001) The Role of Knee Alignment in Disease Progression and Functional Decline in Knee Osteoarthritis. *JAMA*, **286**, 188-195. https://doi.org/10.1001/jama.286.2.188

[17] Felson, D.T., McLaughlin, S., Goggins, J., LaValley, M.P., Gale, M.E., Totterman, S., *et al*. (2003) Bone Marrow Edema and Its Relation to Progression of Knee Osteoarthritis. *Annals of Internal Medicine*, **139**, 330-336.

[18] van Tunen, J.A.C., Dell'Isola, A., Juhl, C., Dekker, J., Steultjens, M., Thorlund, J.B., *et al*. (2018) Association of Malalignment, Muscular Dysfunction, Proprioception, Laxity and Abnormal Joint Loading with Tibiofemoral Knee Osteoarthritis—A Systematic Review and Meta-Analysis. *BMC Musculoskeletal Disorders*, **19**, Article NO. 273. https://doi.org/10.1186/s12891-018-2202-8

[19] Dieppe, P.A., Cushnaghan, J. and Shepstone, L. (1997) The Bristol 'OA500' Study: Progression of Osteoarthritis (OA) over 3 Years and the Relationship between Clinical and Radiographic Changes at the Knee Joint. *Osteoarthritis and Cartilage*, **5**, 87-97. https://doi.org/10.1016/S1063-4584(97)80002-7

[20] Reijman, M., Pols, H.A.P., Bergink, A.P., Hazes, J.M.W., Belo, J.N., Lievense, A.M., *et al*. (2007) Body Mass Index Associated with Onset and Progression of Osteoarthritis of the Knee but Not of the Hip: The Rotterdam Study. *Annals of the Rheumatic Diseases*, **66**, 158-162. https://doi.org/10.1136/ard.2006.053538