Review Article

Knee Surg Relat Res 2018;30(1):3-16
https://doi.org/10.5792/ksrr.16.064
pISSN 2234-0726 · eISSN 2234-2451

KSRR
Knee Surgery & Related Research

Distal Femoral Varus Osteotomy for Valgus Arthritis of the Knees: Systematic Review of Open versus Closed Wedge Osteotomy

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Purpose: The purpose of this review is to compare the clinical and radiological outcomes between open and closed wedge distal femoral varus osteotomy (DFO).

Methods: A literature search of online databases (MEDLINE, EMBASE, and Cochrane Library database) was made in addition to manual search of major orthopedic journals. Data were searched from the time period of January 1990 to October 2016. A modified Coleman Methodology Score system was used to assess the methodologic quality of the included studies. A total of 20 studies were included in the review. All studies were level IV evidence.

Results: Comparative analysis of open and closed wedge DFO did not demonstrate clinical and radiological differences. The survival rates were also similar. Five studies (56%) on open wedge DFO mentioned the need for either bone grafting or substitute for osteotomy gap filling and reported higher incidences of reoperation for plate removal than the closed wedge DFO studies.

Conclusions: The present systematic review showed similar performance between open and closed wedge DFO. Outcomes including survival rates were not statistically significantly different. However, additional bone grafting or substitutes were often needed to prevent delayed union or nonunion for open wedge techniques. Additional operations for plate removal were commonly required due to plate irritation in both techniques.

Keywords: Knee, Femur, Valgus, Osteotomy

Introduction

Lateral compartment osteoarthritis in a young patient presents a challenge for the orthopedic surgeon. Realignment osteotomy, such as distal femoral varus osteotomy (DFO), is an established alternative to arthroplasty for the treatment of degenerative or traumatic valgus arthritis of the knee joint[1]. This procedure aims to reduce pain, slow the rate of progression of arthritis by correcting deformity, offloading the affected compartment, and potentially allowing a return to heavy functional loading[2-4].

Open wedge distal femoral varus osteotomy (OWDFO) and closed wedge distal femoral varus osteotomy (CWDFO) are two main surgical options. It is known that the OWDFO is a good choice for medium or large corrections and is particularly easy to perform and precise. Height restoration is one of the advantages of the procedure; however, the opening gap may necessitate bone grafting and increase the risk of opposite site hinge fracture,

Received October 25, 2016; Revised December 31, 2016;
Accepted January 12, 2017
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which may eventually result in collapse of the osteotomy site[5,6]. CWDFO heals the osteotomy site faster with a shorter rehabilitation time and there are lower risks of opposite hinge fracture[6]. However, CWDFO carries technical difficulties[7,8]. Various results of CWDFO[7,9-13] and OWDFO[6,12,14-20] have been described in the literature.

The survivorship of DFO may depend on 1) the open vs closed osteotomy, 2) fixation method (staple vs blade plate vs anatomical plate; locking vs non-locking), and 3) the use of bone graft materials etc.[16,19,21]. To the authors' knowledge, this is the first review written in English comparing the results of OWDFO and CWDFO. The purpose of this study was to compare the clinical and radiological outcomes including the survivorship and complications between OWDFO and CWDFO. The hypothesis was that CWDFO would have fewer complications with better clinical outcome than OWDFO.

Methods

1. Eligibility Criteria

Published studies meeting the selection criteria listed in Table 1 were included in the systematic review.

2. Search Strategy

A literature search of online databases (MEDLINE, EMBASE, and Cochrane Library database) was performed. The following keywords were used for search strategy (which was modified for each database): osteoarthritis, knee, femur, genu valgum, joint

Table 1. Inclusion and Exclusion Criteria

Inclusion criteria	Exclusion criteria
Studies involving patients who received opening wedge or closed wedge distal femoral osteotomy	Osteotomy other than medial opening or lateral closing (e.g. "V-shape", dome, chevron osteotomy, etc.)
Medial or lateral plate fixation for DFO	Other device (external fixator or staple) for DFO
Articles written in English	Articles written in language other than English
Human *in vivo* studies	Animal *in vivo* and human *in vitro* studies
Between level I and level IV studies	Technical notes, letters to the editor,biomechanical reports, or review articles

DFO: distal femoral varus osteotomy.

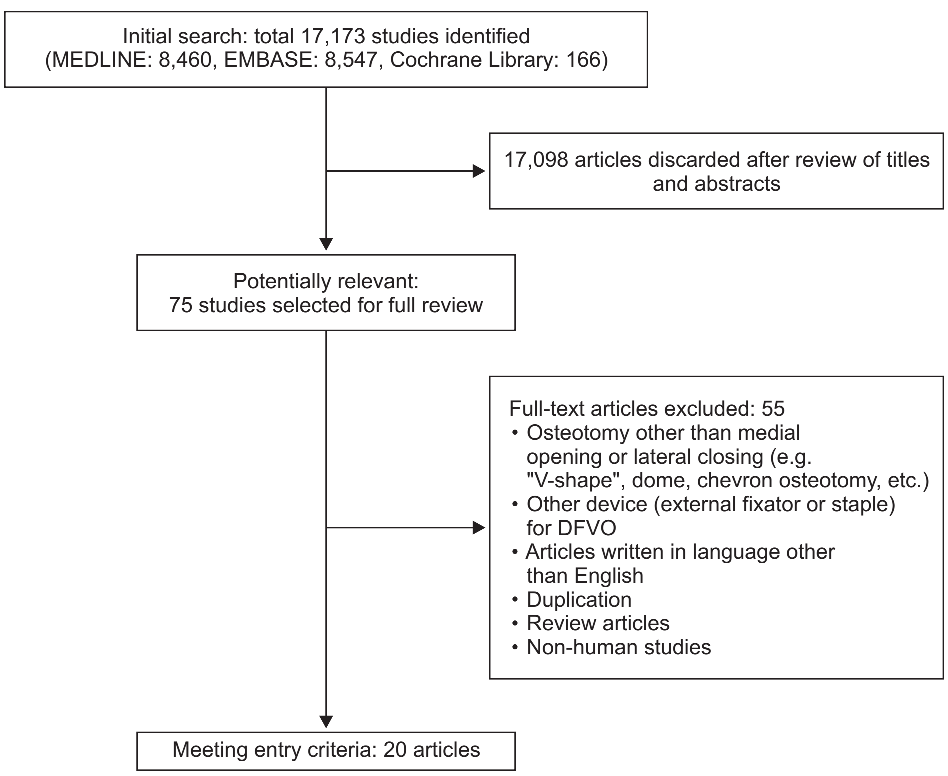

Fig. 1. PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-analyses) flow diagram. DFVO: distal femoral varus osteotomy.

deformities, and DFO. The search was performed from January 1990 to October 2016. Next, the references from the included studies were screened, and experts in the field were contacted for help in identifying additional studies. Two independent reviewers selected citations based on the titles and the abstracts. The eligibility of the full papers of those citations for study inclusion was then assessed. In cases where a consensus could not be reached, a third reviewer was consulted.

3. Data Abstraction

Each of the selected studies was evaluated by the two independent reviewers for methodological quality. The following data were extracted from each article: study type, level of evidence, demographic information, prostheses used, surgical details, outcome measures, clinical and radiographic findings, complications, and survival rates. The extracted data were then cross-checked for accuracy. Any disagreements were settled by the third reviewer.

4. Quality Assessment

The methodological quality of the included studies was assessed by the two reviewers using the 10 critical appraisal criteria of the Coleman Methodology Score (CMS). The final scores ranged from 0 to 100, a perfect score (100) indicating a study design that completely avoids the influences of chance, various biases, and confounding factors[22].

Results

1. Included Studies

Following the full-text review, 16 studies on DFO were ultimately included in the systematic review. There were 8 studies on OWDFO and 8 studies on CWDFO. A flowchart illustrating the study selection process is provided in Fig. 1. The characteristics of included studies are listed in Table 2. The number of knees included in each study ranged from 6 to 49. The preoperative diagnosis for DFO was lateral osteoarthritis with genu valgum deformity in all studies. All of the included studies except one study[23] that did not mention the follow-up period had a minimum follow-up of 2 years. All studies considered conversion to total knee arthroplasty (TKA) as an endpoint for cumulative survival analysis.

2. Quality Assessment

The mean CMS for all included studies was 71 (range, 50 to 79). Each score for each CMS criterion is shown in Table 3.

Table 2. Characteristics of Included Studies

Author	Year	DFO	Fixation	Osteotomy type	Osteotomy gap management (bone graft)	Age at DFO (yr), mean (range)	Country	No. of knees (M/F)	Mean duration of F/U (range)
Ekeland et al.[27]	2016	Opening	Puddu plate (non-locking)	Uniplane	Iliac crest autograft	43 (31–62)	Norway	24 (11/13)	7.9 (4.0–10.2 yr)
Cameron et al.[19]	2015	Opening	DynaFix (Biomet), 15 Puddu plate (Arthrex), 3 Puddu plate (Arthrex; non-locking)	Uniplane	Iliac crest autograft alone, 5; allograft alone, 3; both auto- and allograft, 11	41 (SD, 9)	Canada	19 (7/12)	4 (2–12 yr)
Saithna et al.[16]	2014	Opening	Locking femoral Puddu plate (Arthrex), locking TomoFix-DFO (Synthes)	Uniplane	Bone graft not used unless gap >12 mm	41 (28–58)	United Kingdom	21 (12/9)	4.5 (1.6–9.2 yr)
Madelaine et al.[17]	2014	Opening	Blade plate (Synthes, non-locking)	Uniplane	Tricortical iliac autograft	44.4 (33.1–55.7)	France	29 (12/17)	80.2±50.6 mo
Dewilde et al.[18]	2013	Opening	Puddu plate (Arthrex, non-locking)	Uniplane	calcium phosphate cement (Biobon)	47 (30–51)	Belgium	16 (N/A)	68 (31–127 mo)
Thein et al.[6]	2012	Opening	Puddu plate (Arthrex, non-locking)	Uniplane	Tricortical iliac crest allograft	46.7±10.7	Israel	6 (1/5)	6.5±1.5 yr

Table 2. Continued

Author	Year	DFO	Fixation	Osteotomy type	Osteotomy gap management (bone graft)	Age at DFO (yr), mean (range)	Country	No. of knees (M/F)	Mean duration of F/U (range)
Zarrouk et al.[14]	2010	Opening	Sterelitzia-type 95° blade plate (n=21), blade plate (Synthes; n=1, non-locking)	Uniplane	No bone graft	53 (27–66)	Tunisia	22 (7/13)	54 (36–132 mo)
Jacobi et al.[20]	2010	Opening	TomoFix-DFO (Synthes, locking)	Uniplane	N/A	46 (28–63)	Switzerland	14 (8/6)	45 mo
Marin Morales et al.[12]	2000	Opening	Blade plate (Synthes, n=13), straight plate (n=4, non-locking)	Uniplane	N/A	55 (50–72)	Spain	19 (5/12)	6.5 (2–15 yr)
Forkel et al.[21]	2014	Closing	TomoFix-DFO (Synthes)	Uniplane	None	47 (25–55)	Germany	23 (6/17)	13.6 yr
Kosashivili et al.[11]	2010	Closing	90° offset blade plate (Synthes, non-locking)	Uniplane	Bone graft from resected bone wedge	45.5 (24–63)	Canada	33 (23/8)	15.1 (10–25 yr)
Omidi-Kashani et al.[26]	2009	Closing	90° offset blade plate (Synthes, non-locking)	Uniplane	None	23.3 (17–41)	Iran	23 (4/12)	16.3 (8–25 mo)
Backstein et al.[9]	2007	Closing	90° offset blade plate (Synthes, non-locking)	Uniplane	None	44.1 (10–67)	Israel	38 (10/28)	123 (39–245 mo)
Wang and Hsu[13]	2005	Closing	90° offset blade plate (Synthes, non-locking)	Uniplane	None	53 (31–64)	Taiwan	30 (2/28)	99 (61–169 mo)
Navarro and Carneiro[23]	2004	Closing	90° offset blade plate (Synthes), fixation from lateral side (non-locking)	Uniplane	None	49.5 (17–77)	Brazil	26 (4/18)	N/A
Stahelin et al.[25]	2000	Closing	Malleable semitubular plate (AO, non-locking)	Uniplane	None	57 (39–71)	Switzerland	21 (9/10, 2 bilateral)	5 (2–12 yr)
Healy et al.[4]	1998	Closing	90° offset blade plate (AO, non-locking)	Uniplane	None	56 (19–70)	USA	23 (5/18)	4 (2–9 yr)
Cameron et al.[29]	1997	Closing	90° offset blade plate (Synthes, non-locking)	Uniplane	None	60 (23–84)	Canada	49 (15/34)	3.5 (1–7 yr)
Finkelstein et al.[10]	1996	Closing	90° offset blade plate (Synthes, non-locking)	Uniplane	None	56 (27–77)	Canada	21 (6/15)	133 (97–240 mo)
McDermott et al.[24]	1988	Closing	Blade plate (non-locking)	Uniplane	Bone graft from resected bone wedge	53 (22–74)	Canada	24 (4/20)	4 (2–11.5 yr)

DFO: distal femoral osteotomy, F/U: follow-up, SD: standard deviation, N/A: not applicable, AO: arbeitsgemeinschaft für osteosynthesefragen.

Table 3. Coleman Scores for Each Selected Article

Author	Year	Part A							Part B			Total score
		Study size	Mean follow-up	No. of different surgical procedures included in each reported outcome	Type of study	Diagnostic certainty	Description of surgical procedure	Postoperative rehabilitation	Outcome criteria	Procedure	Description of subject selection process	
Ekeland et al.[27]	2016	4	5	10	10	5	5	0	7	8	15	69
Cameron et al.[19]	2015	4	2	10	0	5	5	10	7	12	15	70
Saithna et al.[16]	2014	4	5	10	10	5	5	10	7	8	15	79
Madelaine et al.[17]	2014	4	5	10	10	5	5	10	7	8	15	79
Dewilde et al.[18]	2013	0	5	10	0	5	5	10	7	8	15	65
Thein et al.[6]	2012	4	5	10	10	5	5	10	7	8	15	79
Zarrouk et al.[14]	2010	4	5	10	0	5	5	0	10	12	15	66
Jacobi et al.[20]	2010	0	5	10	0	5	5	0	7	3	15	50
Marin Morales et al.[12]	2000	0	5	7	10	5	5	0	10	8	15	65
Forkel et al.[21]	2014	4	5	10	10	5	5	10	7	8	15	79
Kosashivili et al.[11]	2010	4	5	10	0	5	5	10	7	3	15	64
Omidi-Kashani et al.[26]	2009	4	2	10	10	5	5	10	7	8	15	76
Backstein et al.[9]	2007	4	5	10	0	5	5	10	7	12	15	73
Wang and Hsu[13]	2005	4	5	10	0	5	5	10	7	8	15	74
Navarro and Carneiro[23]	2004	4	0	10	10	5	5	0	7	12	15	68
Stahelin et al.[25]	2000	0	0	10	10	5	5	10	7	8	15	70
Healy et al.[4]	1998	4	0	10	0	5	5	10	7	8	15	64
Cameron et al.[29]	1997	7	5	10	10	5	5	0	7	8	15	72
Finkelstein et al.[10]	1996	4	5	10	10	5	5	10	7	8	15	79
McDermott et al.[24]	1988	4	0	10	0	5	5	10	7	8	15	64

3. Surgical Intervention and Rehabilitation

Most of the cases in the included studies used either a locking plate or a blade plate to provide strong stability after osteotomy (Table 2). The plate was fixed on the medial side in cases of CWDFO and lateral side in cases of OWDFO. In Navarro and Carneiro[23] series, medial CWDFO was performed using the anterior approach and plate fixation on the lateral side. For the gap filling material after OWDFO, a majority of the studies used autologous bone graft while allografts[6,19] or calcium phosphates were used in the rest[18]. Saithna et al.[16] mentioned that the gap was filled only if the gap size was over 12 mm in their OWDFO series. Bone grafting was not done in one study[14]. In CWDFO series, most studies did not use additional bone graft material. Two studies mentioned the use of morcellized bone grafting which was obtained from the resected bone wedge[11,24]. The post-operative weight bearing permit time is demonstrated in Table 4. Generally, weight bearing was delayed for OWDFO by 2–4 weeks compared to CWDFO.

4. Clinical Outcomes

The clinical outcomes are provided in Table 5. All but one study[23] reported clinical outcome. Various knee scoring systems were used for clinical assessment including Knee Society score (KSS, the French version), modified KSS, Hospital of Special Surgery score, Oxford knee score, Knee Injury and Osteoarthritis Outcome score (pain, symptoms, and function in daily living, knee-related quality of life, and function in sport and recreation), International Knee Documentation Committee score, Lysholm, Tegner, and Short Form 36. All series showed improvement in clinical scores after DFO.

5. Radiological Outcomes

The radiological outcomes are provided in Table 6. Seventeen of the 20 studies reported radiological outcome. Kosashivili et al.[11] did not report the radiological results. Navarro and Carneiro[23] only reported the joint line obliquity value, and Stahelin et al.[25] reported the mean angular correction after CWDFO. The

Table 4. Rehabilitation (Weight Bearing Period)

Author	Year	DFO	Partial weight bearing	Full weight bearing
Ekeland et al.[27]	2016	Opening	Toe touch immediately postoperatively and increasing weight bearing after 6 weeks	Few weeks later depending on healing of the osteotomy
Cameron et al.[19]	2015	Opening	Toe touch for 6 weeks then partial weight bearing	Start between 8–16 weeks
Saithna et al.[16]	2014	Opening	Toe touch for 4 weeks followed by partial weight bearing for another 4 weeks	
Madelaine et al.[17]	2014	Opening	After 8 weeks	
Dewilde et al.[18]	2013	Opening	Non-weight bearing for 4 weeks then partial weight bearing	Start after 8 weeks
Thein et al.[6]	2012	Opening	Non-weight bearing for 6 weeks	Start after 12 weeks
Zarrouk et al.[14]	2010	Opening	Weight bearing after 3 months	
Jacobi et al.[20]	2010	Opening	N/A	
Marin Morales et al.[12]	2000	Opening	N/A	
Forkel et al.[21]	2014	Closing	For 6 weeks	
Kosashivili et al.[11]	2010	Closing	From 6–8 weeks, until then non-weight bearing	
Omidi-Kashani et al.[26]	2009	Closing	From 6–8 weeks	From 3 months
Backstein et al.[9]	2007	Closing	From 6–8 weeks	From 3 months
Wang and Hsu[13]	2005	Closing	From 6–8 weeks	From 3 months
Navarro and Carneiro[23]	2004	Closing	N/A	
Stahelin et al.[25]	2000	Closing	For 8 weeks	N/A
Healy et al.[4]	1988	Closing	For 6 weeks	From 3 months
Cameron et al.[29]	1997	Closing	N/A	
Finkelstein et al.[10]	1996	Closing	From 6–8 week	
McDermott et al.[24]	1988	Closing	After 6 weeks	

DFO: distal femoral osteotomy, N/A: not applicable.

Table 5. Clinical Outcome

Author	Year	DFO	Knee Society score		HSS sore	Oxford knee sore	KOOS					IKDC	IKS	Lysholm	Tegner	Short Form 36
			French version	Modified			Pain	Sex	ADL	QOL	Sport					
Ekeland et al.[27]	2016	Opening	N/A	N/A	N/A	N/A	53/72	51/62	67/79	29/58	19/42	N/A	N/A	N/A	N/A	N/A
Cameron et al.[19]	2015	Opening	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	47 (SD, 15)/ 67 (SD, 10)	N/A	N/A	N/A	N/A
Saithna et al.[16]	2014	Opening	N/A	N/A	N/A	N/A	49.1 (14–97) /70.3 (39–94)	45.3 (11–100) /57.5 (32–86)	62.7 (21–99) /73.9 (43–100)	33.5 (13–100) /42 (6–75)	23.7 (0–90) /32.7 (0–95)	36.4 (10.3–51.7) /52.6 (20.7–94.3)	N/A	48.5 (18–100) /54 (31–92)	2.8 (1–6) /3.2 (1–9)	79.8 (61.1–107.2) /88.7 (65–105.9)
Madelaine et al.[17]	2014	Opening	80.5±19 /65.8±21.3 Functional score 50.4±14.6 /68.5±27.6	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Dewilde et al.[18]	2013	Opening	N/A	43±8/78±23	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Thein et al.[6]	2012	Opening	N/A	N/A	N/A	13.1±8.6 /26±12.5	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Zarrouk et al.[14]	2010	Opening	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	49.28 (14–70) /74.23 (41–92) Functional score 50.68 (30–80)/ 72.85 (40–90)	N/A	N/A	N/A
Jacobi et al.[20]	2010	Opening	N/A	N/A	N/A	N/A	36±20 /76±24	46±28 /79±18	51±26 /84±17	12±9 /51±28	12±10 /55±30	N/A	N/A	N/A	N/A	N/A
Marin Morales et al.[12]	2000	Opening	N/A	N/A	47.5 (36–67) /83.3 (57–97)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Forkel et al.[21]	2014	Closing	N/A	N/A	N/A	N/A	55±34 /90±10	54±10 /88±9	54±29 /90±9	39±39 /83±10	49±39 /80±19	N/A	N/A	N/A	3.5±1.1 /4.2±1.1	N/A
Kosashvili et al.[11]	2010	Closing	N/A	36.8/77.5	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A

Table 5. Continued

Author	Year	DFO	Knee Society score		HSS sore	Oxford knee sore	KOOS					IKDC	IKS	Lysholm	Tegner	Short Form 36
			French version	Modified			Pain	Sex	ADL	QOL	Sport					
Omidi-Kashani et al.[26]	2009	Closing	N/A	N/A	90.7 (77–96) /98.13 (93–100)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Backstein et al.[9]	2007	Closing	N/A	18 (0–74) /87.2 (50–100) Functional score 54 (0–100)/ 85.6 (40–100)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Wang and Hsu[13]	2005	Closing	N/A	N/A	46 (20–63) /88 (65–99)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Navarro and Carneiro[23]	2004	Closing	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Stahelin et al.[25]	2000	Closing	N/A	N/A	65 (56–70) /84 (61–100)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Healy et al.[4]	1998	Closing	N/A	N/A	65 (42–100) /86 (36–100)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Cameron et al.[29]	1997	Closing	N/A	Preop score, not recorded; postop score, 84.8±18.5 (functional 64.5±21.5)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Finkelstein et al.[10]	1996	Closing	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
McDermott et al.[24]	1988	Closing	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A

Values are presented as mean±standard deviation and preoperative/postoperative score (range).
DFO: distal femoral osteotomy, HSS: Hospital for Special Surgery, KOOS: Knee Injury and Osteoarthritis Outcome score (pain, symptoms, function in daily living, knee-related quality of life, function in sport and recreation), IKDC: International Knee Documentation Committee, IKS: International Knee Score, ADL: activites of daily living, QOL: knee-related quality of life, N/A: not applicable, SD: standard deviation, Preop: preoperative, Postop: postoperative.

Table 6. Radiological Results

Author	Year	DFO	mFA (°)	mTA (°)	mFTA (°)	LDFA (°)	Tibiofemoral angle (°)	MA (°)	WBL (%)	Angular correction (°)	Intraop correction (mm)	Insall-Salvati index	Patella congruency angle (°)	LLD	Joint line obliquity	Radiological bone union
Ekeland et al.[27]	2016	Opening	N/A	N/A	N/A	N/A	11.5 (7–20) /2.0 (3–7)	N/A	N/A	9.6 (4–20)	N/A	N/A	N/A	N/A	N/A	75% healed in 3 mo and 100% healed in 6 mo
Cameron et al.[19]	2015	Opening	N/A	N/A	N/A	N/A	N/A	Valgus 7±4/ varus 2±4	N/A	N/A	10±2	N/A	N/A	N/A	N/A	6 mo
Saithna et al.[16]	2014	Opening	N/A	N/A	N/A	N/A	N/A	N/A	75 (60–90) /37 (10–58)	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Madelaine et al.[17]	2014	Opening	97.4±3.7 /90±2.2	90.4±2 /90±2.2	187.8±3.5 /180.4±2.6	N/A	N/A	N/A	N/A	8.3±2.3	N/A	N/A	N/A	–0.7±1.1 /–0.6±1.1	N/A	N/A
Dewilde et al.[18]	2013	Opening	N/A	N/A	N/A	N/A	N/A	Valgus 5.3±2.5 /varus 1.3±4	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Thein et al.[6]	2012	Opening	N/A	N/A	N/A	N/A	13.5±4.1 /1.6±2.1	N/A	N/A	N/A	N/A	1.1±0.1/ 1.1±0.1	N/A	N/A	N/A	N/A
Zarrouk et al.[14]	2010	Opening	N/A	N/A	194.5 (188–198)/181.5 (177–186)	69.63/81 (75–87)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	14 (12–20 wk)
Jacobi et al.[20]	2010	Opening	N/A	N/A	N/A	N/A	N/A	N/A	N/A	5.8±0.6 (3–9)	N/A	N/A	N/A	N/A	N/A	N/A
Marin Morales et al.[12]	2000	Opening	N/A	N/A	N/A	N/A	16 (10–27) /1 (–10–8)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Forkel et al.[21]	2014	Closing	N/A	N/A	N/A	N/A	N/A	N/A	77.3±11.6 /42.6±4.4	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Kosashvili et al.[11]	2010	Closing	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Omidi-Kashani et al.[26]	2009	Closing	N/A	N/A	N/A	N/A	20.3±4.2 /0.13±2.9	N/A	N/A	N/A	N/A	N/A	14.8±7.2 /1.48±3.8	N/A	N/A	4.1 (2–6 mo)
Backstein et al.[9]	2007	Closing	N/A	N/A	N/A	N/A	11.6 (4–15) /1.2 (0–5)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A

Table 6. Continued

Author	Year	DFO	mFA (°)	mTA (°)	mFTA (°)	LDFA (°)	Tibiofemoral angle (°)	MA (°)	WBL (%)	Angular correction (°)	Intraop correction (mm)	Insall-Salvati index	Patella congruency angle (°)	LLD	Joint line obliquity	Radiological bone union
Wang and Hsu[13]	2005	Closing	N/A	N/A	N/A	N/A	18.2 (12–27) /1.2 (−6–10)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	4.7 (3–9 mo)
Navarro and Carneiro[23]	2004	Closing	N/A	N/A	N/A	N/A	N/A	N/A	N/A	5	N/A	N/A	N/A	N/A	+3.1/ −2	N/A
Stahelin et al.[25]	2000	Closing	N/A	N/A	N/A	N/A	N/A	N/A	N/A	1.7 (0–4)	N/A	N/A	N/A	N/A	N/A	N/A
Cameron et al.[29]	1997	Closing	N/A	N/A	N/A	N/A	13 (7–23) /1.0 (8–10)	N/A	N/A	11.8±4	N/A	N/A	N/A	N/A	N/A	N/A
Finkelstein et al.[10]	1996	Closing	N/A	N/A	N/A	N/A	1.7 (0–3)/10	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
McDermott et al.[24]	1988	Closing	N/A	N/A	N/A	N/A	0 degree, 18; 2–8 varus degree, 4; 6 valgus degree, 2	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A

Values are presented as mean±standard deviation and preoperative/postoperative (range).
DFO: distal femoral osteotomy, mFA: mechanical femoral axis, mTA: mechanical tibial axis, mFTA: mechanical femoro-tibial axis, LDFA: lateral distal femoral angle, MA: mechanical axis, WBL: weight bearing line, Intraop: intraoperative, LLD: leg length discrepancy, +: medial inclincation, −: lateral inclincation, N/A: not applicable.

reported parameters were mechanical femoral axis, mechanical tibia axis, mechanical femoro-tibial axis, lateral distal femoral angle, tibiofemoral angle, mechanical axis, weight bearing line, leg length discrepancy (LLD), and patella-related parameters. All studies demonstrated improvement toward neutral-to-varus alignment after DFO. According to few studies[6,26], there were minimal impact on the patella. The LLD was not a significant factor after OWDFO[17]. The mean radiological bone union time was between 3–6 months for OWDFO[14,19] and around 4 months for CWDFO[13,26].

6. Complications and Survivorship

Complications of both procedures are shown in Table 7. Among various complications, plate irritation needing a removal procedure was reported in up to 12/14 cases (86%) in an OWDFO study[20]. On the contrary, the incidence of plate removal was low in CWDFO series beside one study reporting 16/23 cases (70%)[21]. One study[27] reported 3/13 cases (13%) of delayed union in their OWDFO series. The incidence of other complications, such as loss of correction, nonunion, infection, and fractures, did not differ between OWDFO and CWDFO. The survivorship (TKA as endpoint) was reported in some studies (Table 7). There was no notable difference in survivorship between OWDFO and CWDFO.

Discussion

The important finding of this systematic review is that the clinical and radiological outcome including the survival rate did not significantly differ between OWDFO and CWDFO contrary to our initial hypothesis.

It has been known that OWDFO is effective for medium or large corrections and particularly easy to perform and allows for precise control of the correction amount[5,6]. By contrary, CWDFO is known to be technically more difficult than OWDFO because the surgeon is very reliant on the accuracy of preoperative planning and bony resection[16]. However, differences in the improvement of postoperative radiological alignment between OWDFO and CWDFO series were not demonstrated in this study. The reason may be multifactorial and include improvement of surgical techniques for CWDFO. Compared to CWDFO techniques, however, the main concern for OWDFO techniques is the inferior mechanical stability[28] at the osteotomy site as well as the longer healing time of the defect. In a previous biomechanical study on axial and torsional stability after supracondylar osteotomies, the least amount of motion and highest stiffness were measured

Table 7. Complications and Survivorship

Author	Year	No.of cases	F/U period (range)	Plate irritation (removal)	Loss of correction	Non-union	Delayed union	Infection	Fracture	Others	Conversion to TKA	Survivorship (TKA as endpoint)
Ekeland et al.[27]	2016	24	7.9 (4.0–10.2 yr)				3 (13)	0	2	One patient with antecurvation after fall injury and 1 patient of arthroscopic adhesiolysis for reduced flexion	6 (25)	88% at 5 yr and 74% at 10 yr
Cameron et al.[19]	2015	19	4 (2–12 yr)	3 (16)	0	1 (5)		0	0	Four additional arthroscopic surgeries for persistent symptoms	5 (26)	74% at 5 yr
Saithna et al.[16]	2014	21	4.5 (1.6–9.2 yr)	10 (48)	2 (10)	1 (5)		1 (5)		Two additional arthroscopic surgeries for persistent symptoms	4 (19)	79% at 5 yr
Madelaine et al.[17]	2014	29	80.2±50.6 mo	23 (79)	2 (7)	1 (3)				One case of Judet's arthromyolysis for stiffness	5 (17)	91.4% at 5 yr
Dewilde et al.[18]	2013	16	68 (31–127 mo)	4 (25)					1 (6)		2 (13)	82% at 7 yr
Thein et al.[6]	2012	6	6.5±1.5 yr	0	0	0		0	0		0	N/A
Zarrouk et al.[14]	2010	22	54 (36–132 mo)									N/A
Jacobi et al.[20]	2010	14	45 mo	12 (86)		1 (7)						N/A
Marin Morales et al.[12]	2000	19	6.5 (2–15 yr)	2 (11)		0		1 (5)				N/A
Forkel et al.[21]	2014	23	13.6 yr	16 (70)	1 (4)	0					0	N/A
Kosashvili et al.[11]	2010	33	15.1 (10–25 yr)	1 (3)							15 (45)	N/A
Omidi-Kashani et al.[26]	2009	23	16.3 yr (8–25 mo)			1 (4)				One patient with plate revision after fall injury		N/A
Backstein et al.[9]	2007	38	123 (39–245 mo)								12 (32)	82% at 10 yr and 45% at 15 yr
Wang and Hsu[13]	2005	30	99 (61–169 mo)	1 (3)		1 (3)		1 (3)			3 (10)	87% at 10 yr
Navarro and Carneiro[23]	2004	26	N/A									N/A
Stahelin et al.[25]	2000	19	5 (2–12 yr)		1			1		Two hematoma and one popliteal vein thrombosis (conservative treatment)		
Healy et al.[4]	1998	23	4 (2–9 yr)	3		2			1	One patient with manipulation, two additional arthroscopic surgeries for persistent symptoms at lateral joint	2	N/A

Table 7. Continued

Author	Year	No.of cases	F/U period (range)	Plate irritation (removal)	Loss of correction	Non-union	Delayed union	Infection	Fracture	Others	Conversion to TKA	Survivorship (TKA as endpoint)
Cameron et al.[29]	1997	49	3.5 (1–7 yr)		1 (2)	6 (12)			0	One patient with derotational osteotomy (15 degrees of external rotational deformity developed after DFO) and 14 additional arthroscopic surgeries for persistent symptoms	5 (10)	87% at 7 yr
Finkelstein et al.[10]	1996	21	133 (97–240 mo)		1 (5)				1 (5)	One patient with stiffness underwent manipulation under anesthesia	7 (33)	64% at 10 yr
McDermott et al.[24]	1988	24	4 (2–11.5 yr)					1		One patient with plate revision after fixation failure	N/A	N/A

Values are presented as mean±standard deviation or number (%).
F/U: follow-up, TKA: total knee arthroplasty, N/A: not applicable, DFO: distal femoral osteotomy.

in medial oblique CW osteotomy fixated with an angled blade plate. The lateral OW techniques resulted in less stability and lower stiffness than the medial CW osteotomy[28]. Both of these factors are considered to work in favor when direct bone-to-bone apposition is obtained as in a CW technique. To overcome the concern, addition of bone substitute in the osteotomy gap or iliac cortico-cancellous bone graft has been performed in a majority of OWDFO series[6,18,19,29].

The cumulative survival of DFO series should be noted. Saithna et al.[16] reported 79% at 5 years and Madelaine et al.[17] reported an even higher rate of 91.4% at 5 years in their OWDFO series. Likewise, Backstein et al.[9] reported 82% at 10 years and 45% at 15 years in their recent CWDFO series. Finkelstein et al.[10] previously reported 83% at 4 years and 64% cumulative survival at 10 years. Although heterogeneity between studies may prevent further statistical analyses, the survivorship figures were favorable for both OWDFO and CWDFO series with similar performance.

On the surgical aspect of the procedures, the OWDFO technique allows fine-tuning of deformity correction with application of an opening device such as a laminar spreader until the desired angle is achieved. By contrast, in a CW osteotomy, the surgeon is very reliant on the preoperative plan for accuracy of bony resection; however, precise resection of a wedge is technically difficult although not demonstrated in this study.

The choice of implant is an important consideration. Edgerton et al.[7] reported 17/24 patients (70%) complications including 7 cases of delayed union or non-union by using staples for fixation. Stahelin et al.[25] used a malleable semitubular plate. They modified the conventional tubular plate into a fixed angle blade plate to improve the mechanics of fixation. They suggested that the strong fixation device is one of critical factors for successful outcome. Although the studies using the Puddu plate (Arthrex, Naples, FL, USA)[6,18] did not demonstrate inferior results compared to the studies using the blade plate (Synthes, Oberdorf, Switzerland) or the locking TomoFix plate (Synthes), it has been recommended to use these devices with greater axial and torsional stability[30]. In contrast to the tibial bone, the femur has a longer lever arm with more rotational force applied requiring more stable plate configuration than the previously used or currently used implants for high tibial osteotomy. Improving plate stability will also facilitate rapid rehabilitation shortening the non-weight bearing or partial weight bearing period.

Evaluation of the type of graft (i.e., autograft vs. allograft or synthetic materials) among the OW osteotomy studies was limited due to the heterogeneity of graft choice. Given the wide variability, no conclusions can be drawn on the optimal graft choice for

OW osteotomies.

The rehabilitation protocols differed among studies. Generally, weight bearing is delayed for OWDFO by 2–4 weeks than CWDFO. Complication rates following DFO may also be influenced by the rehabilitation regimen used because early loading may increase the risk of loss of fixation. The most frequent complication reported was secondary operation due to plate prominence both for OWDFO and CWDFO series. Jacobi et al. reported an 12/14 cases (86%) reoperation rate for removal of the TomoFix plate in their OWDFO series[20]. They suggested that plate prominence caused friction on the iliotibial band[20]. Although Forkel et al.[21] also demonstrated a high rate of additional operations for plate removal in their CWDFO series, the incidence of plate irritation was low due to bulky muscle tissue on the medial thigh. Before the development of a low profile plate with strong stability, patients should be aware preoperatively that an additional operation may be necessary after OWDFO.

Recently, a few systematic review articles have been published[31,32]. Saithna et al.[32] included 6 case series and demonstrated poor reporting and heterogeneity among studies that precluded any statistical analysis. They commented that DFO is a technically demanding procedure and requires a significant period of rehabilitation. Overall, they concluded that DFO is a potential option for valgus osteoarthritis considering the long-term survivorship and good function. Chahla et al.[31] performed a systematic review that included 14 studies. All were retrospective studies with good to excellent patient-reported outcomes. They also noted that the included literature demonstrated heterogeneity, but DFO is a viable treatment option to delay or reduce the need for joint arthroplasty.

Limitations of this systematic review should be noted. First, due to the rarity of DFO, the articles included a small number of patients. Further correlation among clinical scores, radiological parameters, demographics, and other variables, such as the choice of implant, could not be assessed. Second, due to the heterogeneity nature of the included studies, meta-analysis could not be performed. Third, only retrospective case series without control group were included and thus there is possibility that the pooled analyses are biased. However, a prospective study comparing OWDFO versus CWDFO is difficult to justify from an ethical point of view. Longer follow-up studies are required for definitive conclusions.

The present systematic review suggests that OWDFO and CWDFO show similar performance. Clinical and radiological outcome including survival rates did not statistically differ in the included studies. However, additional bone grafting or substitutes are often needed to prevent delayed union or nonunion for OW techniques. An additional operation for plate removal is commonly required in both techniques.

Conflict of Interest

No potential conflict of interest relevant to this article was reported.

References

1. Coventry MB. Proximal tibial varus osteotomy for osteoarthritis of the lateral compartment of the knee. J Bone Joint Surg Am. 1987;69:32-8.
2. Puddu G, Cipolla M, Cerullo G, Franco V, Gianni E. Osteotomies: the surgical treatment of the valgus knee. Sports Med Arthrosc. 2007;15:15-22.
3. van Heerwaarden R, Wymenga A, Freiling D, Lobenhoffer P. Distal medial closed wedge varus femur osteotomy stabilized with the Tomofix plate fixator. Operat techn Orthop. 2007;17:12-21.
4. Healy WL, Anglen JO, Wasilewski SA, Krackow KA. Distal femoral varus osteotomy. J Bone Joint Surg Am. 1988;70:102-9.
5. Terry GC, Cimino PM. Distal femoral osteotomy for valgus deformity of the knee. Orthopedics. 1992;15:1283-9.
6. Thein R, Bronak S, Thein R, Haviv B. Distal femoral osteotomy for valgus arthritic knees. J Orthop Sci. 2012;17:745-9.
7. Edgerton BC, Mariani EM, Morrey BF. Distal femoral varus osteotomy for painful genu valgum: a five-to-11-year follow-up study. Clin Orthop Relat Res. 1993;(288):263-9.
8. Hofmann S, Lobenhoffer P, Staubli A, Van Heerwaarden R. Osteotomies of the knee joint in patients with monocompartmental arthritis. Orthopade. 2009;38:755-69.
9. Backstein D, Morag G, Hanna S, Safir O, Gross A. Long-term follow-up of distal femoral varus osteotomy of the knee. J Arthroplasty. 2007;22(4 Suppl 1):2-6.
10. Finkelstein JA, Gross AE, Davis A. Varus osteotomy of the distal part of the femur: a survivorship analysis. J Bone Joint Surg Am. 1996;78:1348-52.
11. Kosashvili Y, Safir O, Gross A, Morag G, Lakstein D, Backstein D. Distal femoral varus osteotomy for lateral osteoarthritis of the knee: a minimum ten-year follow-up. Int Orthop. 2010;34:249-54.
12. Marin Morales LA, Gomez Navalon LA, Zorrilla Ribot P, Salido Valle JA. Treatment of osteoarthritis of the knee with

valgus deformity by means of varus osteotomy. Acta Orthop Belg. 2000;66:272-8.
13. Wang JW, Hsu CC. Distal femoral varus osteotomy for osteoarthritis of the knee. J Bone Joint Surg Am. 2005;87:127-33.
14. Zarrouk A, Bouzidi R, Karray B, Kammoun S, Mourali S, Kooli M. Distal femoral varus osteotomy outcome: is associated femoropatellar osteoarthritis consequential? Orthop Traumatol Surg Res. 2010;96:632-6.
15. Saragaglia D, Chedal-Bornu B. Computer-assisted osteotomy for valgus knees: medium-term results of 29 cases. Orthop Traumatol Surg Res. 2014;100:527-30.
16. Saithna A, Kundra R, Getgood A, Spalding T. Opening wedge distal femoral varus osteotomy for lateral compartment osteoarthritis in the valgus knee. Knee. 2014;21:172-5.
17. Madelaine A, Lording T, Villa V, Lustig S, Servien E, Neyret P. The effect of lateral opening wedge distal femoral osteotomy on leg length. Knee Surg Sports Traumatol Arthrosc. 2016;24:847-54.
18. Dewilde TR, Dauw J, Vandenneucker H, Bellemans J. Opening wedge distal femoral varus osteotomy using the Puddu plate and calcium phosphate bone cement. Knee Surg Sports Traumatol Arthrosc. 2013;21:249-54.
19. Cameron JI, McCauley JC, Kermanshahi AY, Bugbee WD. Lateral opening-wedge distal femoral osteotomy: pain relief, functional improvement, and survivorship at 5 years. Clin Orthop Relat Res. 2015;473:2009-15.
20. Jacobi M, Wahl P, Bouaicha S, Jakob RP, Gautier E. Distal femoral varus osteotomy: problems associated with the lateral open-wedge technique. Arch Orthop Trauma Surg. 2011;131:725-8.
21. Forkel P, Achtnich A, Metzlaff S, Zantop T, Petersen W. Midterm results following medial closed wedge distal femoral osteotomy stabilized with a locking internal fixation device. Knee Surg Sports Traumatol Arthrosc. 2015;23:2061-7.
22. Coleman BD, Khan KM, Maffulli N, Cook JL, Wark JD. Studies of surgical outcome after patellar tendinopathy: clinical significance of methodological deficiencies and guidelines for future studies: Victorian Institute of Sport Tendon Study Group. Scand J Med Sci Sports. 2000;10:2-11.
23. Navarro R, Carneiro M. Inclination of the joint line in supracondylar osteotomy of the femur for valgus deformity. Knee. 2004;11:319-21.
24. McDermott AG, Finklestein JA, Farine I, Boynton EL, MacIntosh DL, Gross A. Distal femoral varus osteotomy for valgus deformity of the knee. J Bone Joint Surg Am. 1988;70:110-6.
25. Stahelin T, Hardegger F, Ward JC. Supracondylar osteotomy of the femur with use of compression: osteosynthesis with a malleable implant. J Bone Joint Surg Am. 2000;82:712-22.
26. Omidi-Kashani F, Hasankhani IG, Mazlumi M, Ebrahimzadeh MH. Varus distal femoral osteotomy in young adults with valgus knee. J Orthop Surg Res. 2009;4:15.
27. Ekeland A, Nerhus TK, Dimmen S, Heir S. Good functional results of distal femoral opening-wedge osteotomy of knees with lateral osteoarthritis. Knee Surg Sports Traumatol Arthrosc. 2016;24:1702-9.
28. Brinkman JM, Hurschler C, Agneskirchner JD, Freiling D, van Heerwaarden RJ. Axial and torsional stability of supracondylar femur osteotomies: biomechanical comparison of the stability of five different plate and osteotomy configurations. Knee Surg Sports Traumatol Arthrosc. 2011;19:579-87.
29. Cameron HU, Botsford DJ, Park YS. Prognostic factors in the outcome of supracondylar femoral osteotomy for lateral compartment osteoarthritis of the knee. Can J Surg. 1997;40:114-8.
30. Stoffel K, Stachowiak G, Kuster M. Open wedge high tibial osteotomy: biomechanical investigation of the modified Arthrex Osteotomy Plate (Puddu Plate) and the TomoFix Plate. Clin Biomech (Bristol, Avon). 2004;19:944-50.
31. Chahla J, Mitchell JJ, Liechti DJ, Moatshe G, Menge TJ, Dean CS, LaPrade RF. Opening- and closing-wedge distal femoral osteotomy: a systematic review of outcomes for isolated lateral compartment osteoarthritis. Orthop J Sports Med. 2016;4:2325967116649901.
32. Saithna A, Kundra R, Modi CS, Getgood A, Spalding T. Distal femoral varus osteotomy for lateral compartment osteoarthritis in the valgus knee: a systematic review of the literature. Open Orthop J. 2012;6:313-9.