Introduction

Lateral compartment osteoarthritis in a young patient repre-

sent  a challenge for the orthopedic surgeon. Realignment osteoarthritis, 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. 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.

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.
which may eventually result in collapse of the osteotomy site\textsuperscript{(5,6)}. CWDOF heals the osteotomy site faster with a shorter rehabilitation time and there are lower risks of opposite hinge fracture\textsuperscript{(6)}. However, CWDOF carries technical difficulties\textsuperscript{(7,8)}. Various results of CWDOF\textsuperscript{(7,9-13)} and OWDOF\textsuperscript{(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.\textsuperscript{(14,19,21)}. To the authors’ knowledge, this is the first review written in English comparing the results of OWDOF and CWDOF. The purpose of this study was to compare the clinical and radiological outcomes including the survivorship and complications between OWDOF and CWDOF. The hypothesis was that CWDOF would have fewer complications with better clinical outcome than OWDOF.

**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

| 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    |

Table 1. Inclusion and Exclusion Criteria

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.

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 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.
| 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.          | 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.           | 2010 | Opening | TomoFix-DFO (Synthes, locking)                                           | Uniplane       | N/A                                  | 46 (28–63)                   | Switzerland   | 14 (8/6)          | 45 mo                  |
| Marin Morales et al.    | 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.           | 2014 | Closing | TomoFix-DFO (Synthes)                                                   | Uniplane       | None                                 | 47 (25–55)                   | Germany       | 23 (6/17)         | 13.6 yr                |
| Kosashivili et al.      | 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.    | 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.        | 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            | 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    | 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.         | 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.            | 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.          | 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.      | 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.        | 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 | 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 | Total score |
|---------------------|------|------------|----------------|-----------------------------------------------------------------------|---------------|----------------------|-----------------------------------|------------------------|----------------|-----------|----------------------------------------|-------------|
| Ekeland et al.      | 2016 | 4          | 5              | 10                                                                     | 10            | 5                    | 5                                 | 0                      | 7              | 8         | 15                                    | 69          |
| Cameron et al.      | 2015 | 4          | 2              | 10                                                                     | 10            | 5                    | 5                                 | 10                     | 7              | 12        | 15                                    | 70          |
| Saithna et al.      | 2014 | 4          | 5              | 10                                                                     | 10            | 5                    | 5                                 | 10                     | 7              | 8         | 15                                    | 79          |
| Madelaine et al.    | 2014 | 4          | 5              | 10                                                                     | 10            | 5                    | 5                                 | 10                     | 7              | 8         | 15                                    | 79          |
| Dewilde et al.      | 2013 | 0          | 5              | 10                                                                     | 0             | 5                    | 5                                 | 10                     | 7              | 8         | 15                                    | 65          |
| Thein et al.        | 2012 | 4          | 5              | 10                                                                     | 10            | 5                    | 5                                 | 0                      | 10             | 12        | 15                                    | 66          |
| Zarrouk et al.      | 2010 | 0          | 5              | 10                                                                     | 0             | 5                    | 5                                 | 0                      | 10             | 12        | 15                                    | 50          |
| Jacobi et al.       | 2010 | 0          | 5              | 10                                                                     | 0             | 5                    | 5                                 | 0                      | 7              | 3         | 15                                    | 65          |
| Marin Morales et al.| 2000 | 0          | 5              | 7                                                                      | 10            | 5                    | 5                                 | 0                      | 10             | 8         | 15                                    | 65          |
| Forkel et al.       | 2014 | 4          | 5              | 10                                                                     | 10            | 5                    | 5                                 | 10                     | 7              | 8         | 15                                    | 79          |
| Kosashivili et al.  | 2010 | 4          | 5              | 10                                                                     | 0             | 5                    | 5                                 | 10                     | 7              | 3         | 15                                    | 64          |
| Omidi-Kashani et al.| 2009 | 4          | 2              | 10                                                                     | 10            | 5                    | 5                                 | 10                     | 7              | 8         | 15                                    | 76          |
| Backstein et al.    | 2007 | 4          | 5              | 10                                                                     | 10            | 5                    | 5                                 | 10                     | 7              | 12        | 15                                    | 73          |
| Wang and Hsu        | 2005 | 4          | 5              | 10                                                                     | 0             | 5                    | 5                                 | 10                     | 7              | 8         | 15                                    | 74          |
| Navarro and Carneiro| 2004 | 4          | 0              | 10                                                                     | 10            | 5                    | 5                                 | 0                      | 7              | 12        | 15                                    | 68          |
| Stahelin et al.     | 2000 | 0          | 0              | 10                                                                     | 10            | 5                    | 5                                 | 10                     | 7              | 8         | 15                                    | 70          |
| Healy et al.        | 1998 | 4          | 0              | 10                                                                     | 0             | 5                    | 5                                 | 10                     | 7              | 8         | 15                                    | 64          |
| Cameron et al.      | 1997 | 7          | 5              | 10                                                                     | 10            | 5                    | 5                                 | 0                      | 7              | 8         | 15                                    | 72          |
| Finkelstein et al.  | 1996 | 4          | 5              | 10                                                                     | 10            | 5                    | 5                                 | 10                     | 7              | 8         | 15                                    | 79          |
| McDermott et al.    | 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\(^{20}\) 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.\(^{30}\) | 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.\(^{30}\) | 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.\(^{24}\) | 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                                         |                                          |
| Omid-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\(^{33}\)   | 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 weeks                                                                        |                                          |
| McDermott et al.\(^{14}\) | 1988 | Closing | After 6 weeks                                                                         |                                          |

DFO: distal femoral osteotomy, N/A: not applicable.
| Author                | Year | DFO   | Knee Society score | HSS score | Oxford knee score | KOOS                      | IKDC | IKS | Lysholm | Tegner | Short Form 36 |
|----------------------|------|-------|--------------------|-----------|-------------------|---------------------------|------|-----|---------|--------|---------------|
| Ekeland et al.       | 2016 | Opening | N/A                | N/A       | N/A               | 53/72, 51/62, 67/79, 29/58 | 19/42 | N/A | N/A     | N/A    | N/A           |
| Cameron et al.       | 2015 | Opening | N/A                | N/A       | N/A               | 47 (SD, 15)/67 (SD, 10)   | N/A  | N/A | N/A     | N/A    | N/A           |
| Saithna et al.       | 2014 | Opening | N/A                | N/A       | N/A               | 49.1 (14–97)/703 (59–96) | 53.5 (13–100)/73.9 (43–100) | 23.7 (0–90)/527 (0–99) | N/A  | N/A | N/A     | N/A    | N/A           |
| Madelaine et al.     | 2014 | Opening | 80.5±19/65.8±21.3  | N/A       | N/A               | N/A                       | N/A  | N/A | N/A     | N/A    | N/A           |
| Dewilde et al.       | 2013 | Opening | N/A                | N/A       | N/A               | 43±8/78±23                | N/A  | N/A | N/A     | N/A    | N/A           |
| Thein et al.         | 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           |
| Zarrouk et al.       | 2010 | Opening | N/A                | N/A       | N/A               | N/A                       | N/A  | N/A | N/A     | N/A    | N/A           |
| Isorbi et al.        | 2010 | Opening | N/A                | N/A       | N/A               | 36±20, 46±28, 51±26, 12±9 | 12±10 | N/A | N/A     | N/A    | N/A           |
| Marin et al.         | 2000 | Opening | N/A                | N/A       | N/A               | 47.5 (36–67)/83.3 (57–97) | N/A  | N/A | N/A     | N/A    | N/A           |
| Forkel et al.        | 2014 | Closing | N/A                | N/A       | N/A               | 55±34, 54±10, 54±29, 39±39 | 49±39 | N/A | N/A     | N/A    | 3.5±1.1       |
| Kosashvili et al.    | 2010 | Closing | N/A                | N/A       | N/A               | 36.8±77.5                | N/A  | N/A | N/A     | N/A    | N/A           |
| Author                  | Year | DFO  | French version | Modified | Knee Society score | HSS sore | Oxford knee sore | KOOS Pain | KOOS Sex | KOOS ADL | KOOS QOL | KOOS Sport | IKDC | IKS | Lysholm | Tegner | Short Form 36 |
|------------------------|------|------|----------------|----------|--------------------|---------|------------------|-----------|---------|---------|---------|-------------|------|-----|--------|--------|---------------|
| Omidi-Kashani et al.   | 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.       | 2007 | Closing | N/A            | 18 (0–74) | 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           |
| Wang and Hsu           | 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   | 2004 | 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           |
| Stahelin et al.        | 2000 | Closing | N/A            | N/A      | 65 (42–100)        | 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.           | 1998 | Closing | N/A            | N/A      | 65 (42–100)        | 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           |
| Cameron et al.         | 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 | N/A | N/A | N/A |
| Finkelstein et al.     | 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    | N/A           |
| McDermott et al.       | 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    | 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: activities 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 (°) | Angular correction (°) | Intraop correction (mm) | Insall-Salvati index | Patella congruency angle (°) | LLD Joint line obliquity | Radiological bone union |
|-------------------------|--------|------|---------|---------|----------|----------|------------------------|--------|------------------------|------------------------|-----------------------|--------------------------|--------------------------|--------------------------|
| Ekeland et al.          | 2016   | Opening | N/A     | N/A     | N/A      | N/A      | 11.5 (7–20) /20 (3–7) | N/A    | N/A                    | 9.6 (4–20)             | N/A                   | N/A                      | N/A                      | 75% healed in 3 mo and 100% healed in 6 mo |
| Cameron et al.          | 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                      | 6 mo                    |
| Saithna et al.          | 2014   | Opening | N/A     | N/A     | N/A      | N/A      | N/A        | 75 (60–90) /37 (10–58)| N/A    | N/A                    | 8.3±2.3                | N/A                   | N/A                      | N/A                      | 6 mo                    |
| Madelaine et al.        | 2014   | Opening | 97.4±3.7/90±2.2 | 90±4.2   | 187.8±3.5/180±4±2.6 | N/A | N/A | Valgus 5.3±2.5/varus 1.3±4 | N/A | N/A | N/A | N/A | 1.1±0.1/1.1±0.1 | N/A | N/A | N/A | N/A |
| Dewilde et al.          | 2013   | Opening | N/A     | N/A     | N/A      | N/A      | N/A        | 13.5±4.1/1.6±2.1      | N/A    | N/A                    | N/A                    | N/A                   | N/A                      | N/A                      | N/A | N/A | N/A | N/A |
| Thein et al.            | 2012   | Opening | N/A     | N/A     | N/A      | N/A      | 194.5 (188–186)/191.5 (177–186) | N/A | N/A | N/A | N/A | 58±6.6 (3–9) | N/A | N/A | N/A | N/A |
| Zarrour et al.          | 2010   | 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 | N/A |
| Jacoby et al.           | 2010   | Opening | N/A     | N/A     | N/A      | N/A      | N/A        | 20.3±4.2 /2.9 ±6      | N/A    | N/A                    | 20.3±4.2 /2.9 ±6      | N/A                   | N/A                      | N/A                      | N/A | N/A | N/A | N/A |
| Marin Morales et al.    | 2000   | Opening | 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 | N/A | N/A | N/A |
| Forkel et al.           | 2014   | Closing | N/A     | N/A     | N/A      | N/A      | N/A        | 14.8±7.2 /1.48±3.8    | N/A    | N/A                    | N/A                    | N/A                   | N/A                      | N/A                      | N/A | N/A | N/A | N/A |
| Kosashvili et al.       | 2010   | Closing | N/A     | N/A     | N/A      | N/A      | N/A        | N/A | N/A | N/A | N/A | 11.6 (4–15) /1.2 (0–5) | N/A | N/A | N/A | N/A |
| Omidi-Kashani et al.    | 2009   | Closing | N/A     | 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 | N/A |
| Backstein et al.        | 2007   | Closing | N/A     | N/A     | N/A      | N/A      | N/A        | N/A | N/A | N/A | N/A | 11.6 (4–15) /1.2 (0–5) | N/A | N/A | N/A | N/A |
reported parameters were mechanical femoral axis, mechanical tibial axis, weight bearing line, leg length discrepancy (LLD), joint line obliquity, and radiological bone union.

### Table 6. Continued

| Author                  | Year | DFO   | mFA (°) | mTA (°) | mFTA (°) | LDFA (°) | Tibiofemoral angle (°) | MA (°) | WBL (°) | Angular correction (°) | Intraop correction (mm) | Insl-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(20) | 2004 | Closing | N/A     | 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                 | +3.1/2                |
| Stahelin et al.(18)     | 2000 | Closing | N/A     | N/A     | N/A      | N/A      | 13 (7–23)              | N/A    | N/A    | N/A                    | 11.8±4                | N/A             | N/A                         | N/A | N/A                 | 1.0 (8–10)            |
| Cameron et al(21)       | 1997 | Closing | N/A     | N/A     | N/A      | N/A      | 1.7 (0–3)/10           | 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                    |
| McDermott et al.(22)    | 1996 | 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                    |
| Finkelstein et al.(21)  | 1998 | 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 femorotibial axis, LDFA: lateral distal femoral angle, MA: mechanical axis, WBL: weight bearing line, Intraop: intraoperative, LLD: leg length discrepancy, +: medial inclination, -: lateral inclination, N/A: not applicable.

### 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 for precise control of the correction amount. By contrary, 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, OWDFO series showed more improvement of postoperative radiological alignment between OWDFO and CWDFO contrary to our initial hypothesis.

### Complications and Survivorship

Complications of both procedures are shown in Table 7. Among various complications, plate irritation requiring a removal procedure was reported in up to 12/14 cases (86%) in an OWDFO study. The incidence of other complications, such as loss of coronal correction, nonunion, infection, and fractures, did not differ between OWDFO and CWDFO. The incidence of plate removal was low in CWDFO series beside one study reporting 16/23 cases (70%) (21). One study reported 31.3% (13%) of delayed union in their OWDFO series. The incidence of other complications, such as infection, nonunion, and fractures, did not differ between OWDFO and CWDFO. The incidence of plate removal was low in CWDFO series beside one study reporting 16/23 cases (70%) (21).

All studies demonstrated improvement toward neutral-to-varus alignment after OWDFO. The mean radiological bone union time was between 3–5 months for OWDFO (14,19) and around 4 months for CWDFO (13,26).
| 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.          | 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.          | 2015 | 19           | 4 (2–12 yr)        | 3 (16)                      | 0                 | 1 (5)     | 0             | 0         | 0        | Four additional arthroscopic surgeries for persistent symptoms        | 5 (26)           | 74% at 5 yr                    |
| Saithna et al.          | 2014 | 21           | 4.5 (1.6–9.2 yr)   | 10 (48)                     | 2 (10)            | 1 (5)     | 1             | 5 (1)     | 0        | Two additional arthroscopic surgeries for persistent symptoms         | 4 (19)           | 79% at 5 yr                    |
| Madelaine et al.        | 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.          | 2013 | 16           | 68 (31–127 mo)     | 4 (25)                      | 0                 | 0         | 0             | 0         | 0        | Four additional arthroscopic surgeries for persistent symptoms        | 2 (13)           | 82% at 7 yr                     |
| Thein et al.            | 2012 | 6            | 6.5±1.5 yr         | 0                            | 0                 | 0         | 0             | 0         | 0        | Four additional arthroscopic surgeries for persistent symptoms        | 0                | N/A                             |
| Zarrouk et al.          | 2010 | 22           | 54 (36–132 mo)     | 12 (86)                     | 1 (7)             |           |               |           |          | Four additional arthroscopic surgeries for persistent symptoms        | N/A              | N/A                             |
| Jacobi et al.           | 2010 | 14           | 45 mo              | 12 (86)                     | 1 (7)             |           |               |           |          | Four additional arthroscopic surgeries for persistent symptoms        | N/A              | N/A                             |
| Marin Morales et al.    | 2000 | 19           | 6.5 (2–15 yr)      | 2 (11)                      | 0                 | 1 (5)     |               |           |          | Four additional arthroscopic surgeries for persistent symptoms        | N/A              | N/A                             |
| Forkel et al.           | 2014 | 23           | 13.6 yr            | 16 (70)                     | 1 (4)             | 0         |               |           |          | Four additional arthroscopic surgeries for persistent symptoms        | 0                | N/A                             |
| Kosashvili et al.       | 2010 | 33           | 15.1 (10–25 yr)    | 1 (3)                       | 1 (3)             |           |               |           |          | Four additional arthroscopic surgeries for persistent symptoms        | 15 (45)          | N/A                             |
| Omidi-Kashani et al.    | 2009 | 23           | 16.3 yr (8–25 mo)  | 1 (4)                       |                  |           |               |           |          | Four additional arthroscopic surgeries for persistent symptoms        | N/A              | N/A                             |
| Backstein et al.        | 2007 | 38           | 123 (39–245 mo)    | 1 (3)                       | 1 (3)             |           |               | 1 (3)     |          | Four additional arthroscopic surgeries for persistent symptoms        | 12 (32)          | 82% at 10 yr and 45% at 15 yr   |
| Wang and Hsu            | 2005 | 30           | 99 (61–169 mo)     | 1 (3)                       |                  | 1 (3)     | 1             | 1 (3)     |          | Four additional arthroscopic surgeries for persistent symptoms        | 3 (10)           | 87% at 10 yr                    |
| Navarro and Carneiro    | 2004 | 26           | N/A                |                             |                  |           |               |           |          | Four additional arthroscopic surgeries for persistent symptoms        | N/A              | N/A                             |
| Stahelin et al.         | 2000 | 19           | 5 (2–12 yr)        | 1                            |                  | 1         | 1             | 2         |          | Four additional arthroscopic surgeries for persistent symptoms        | 2                | N/A                             |
| Healy et al.            | 1998 | 23           | 4 (2–9 yr)         | 3                            |                  | 2         | 2             | 1         |          | Four additional arthroscopic surgeries for persistent symptoms        | 1                | N/A                             |
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\(^{20}\). 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 OWDO 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 OWDO 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 OWDO and CWDFO series with similar performance.

On the surgical aspect of the procedures, the OWDO 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

| Author                        | Year   | No.of cases | F/U period (range) | Plate irritation (removal) | Loss of correction | Non-union | Delayed union | Fracture | Others | Conversion to TKA | Survivorship (TKA as endpoint) |
|-------------------------------|--------|-------------|--------------------|---------------------------|--------------------|-----------|---------------|---------|--------|-----------------|--------------------------------|
| Cameron et al.\(^{29}\)       | 1997   | 49          | 3.5 (1–7 yr)       | 1 (2)                     | 6 (12)             |           |               |         |        | 5 (10)          | 87% at 10 yr                   |
| Finkelstein et al.\(^{10}\)   | 1996   | 21          | 1.3 (97–240 mo)    | 1 (5)                     | 1 (5)              |           |               |         |        | 7 (33)          | 64% at 110 yr                  |
| McDermott et al.\(^{24}\)    | 1988   | 24          | 4 (2–11.5 yr)      | N/A                       | N/A                |           |               |         |        | 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.
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. They suggested that plate prominence caused friction on the iliotibial band.

Although Forkel et al. 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. Saithna et al. 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. 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.

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