Comparison of Closing-Wedge and Opening-Wedge High Tibial Osteotomy for Medial Compartment Osteoarthritis of the Knee

A Randomized Controlled Trial with a Six-Year Follow-up

T. Duivenvoorden, MD, R.W. Brouwer, MD, PhD, A. Baan, MD, P.K. Bos, MD, PhD, M. Reijman, PhD, S.M.A. Bierma-Zeinstra, PhD, and J.A.N. Verhaar, MD, PhD

Investigation performed at the Department of Orthopedics, Erasmus University Medical Center, Rotterdam, The Netherlands

Background: Varus deformity increases the risk of progression of medial compartment knee osteoarthritis. The aim of this study was to investigate the clinical and radiographic mid-term results of closing-wedge and opening-wedge high tibial osteotomy when used to treat this condition.

Methods: From January 2001 to April 2004, ninety-two patients were randomized to receive either a closing-wedge or an opening-wedge high tibial osteotomy. The clinical outcome and radiographic results were examined preoperatively; at one year; and, for the present study, at six years postoperatively. The outcomes that we reviewed included maintenance of the achieved correction, progression of osteoarthritis (based on the Kellgren and Lawrence classification), severity of pain (as assessed on a visual analog scale [VAS]), knee function (as measured with the Hospital for Special Surgery [HSS] score and Knee injury and Osteoarthritis Outcome Score [KOOS]), walking distance, complications, and survival with conversion to a total knee arthroplasty as the end point. The results were analyzed on the basis of the intention-to-treat principle.

Results: Six years postoperatively, the mean hip-knee-ankle (HKA) angle (and standard deviation) was 3.2° ± 4.1° of valgus after a closing-wedge high tibial osteotomy and 1.3° ± 5.0° of valgus after an opening-wedge high tibial osteotomy (p = 0.343). In both groups, the six-year postoperative HKA angles did not differ from the respective one-year postoperative angles. No difference in the severity of pain or in knee function was found between the two groups. Four complications (9%) occurred in the closing-wedge group and seventeen (38%), in the opening-wedge group. Ten (22%) of the patients in the closing-wedge group and three (8%) in the opening-wedge group needed conversion to a total knee arthroplasty within the six-year period (p = 0.05). The difference in the percentage of cases with conversion to total knee arthroplasty was 14% (95% confidence interval [CI] = 21.7 to 0.2).

Conclusions: In the group of patients without conversion to a total knee arthroplasty, there was no difference between the high tibial closing-wedge and opening-wedge osteotomies in terms of clinical outcomes or radiographic alignment at six years postoperatively. Opening-wedge osteotomy was associated with more complications, but closing-wedge osteotomy was associated with more early conversions to total knee arthroplasty.

Level of Evidence: Therapeutic Level I. See Instructions for Authors for a complete description of levels of evidence.

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Knee osteoarthritis is one of the most common joint disorders, and it causes considerable pain and immobility. Malalignment increases the risk of progression of osteoarthritis of the knee. For patients with osteoarthritis of the medial compartment of the knee, a valgus high tibial osteotomy is a treatment option. Various techniques, such as closing-wedge, opening-wedge, and dome osteotomy, are available. Each technique has its advantages and disadvantages. It is clear from previous retrospective studies that a successful outcome requires an appropriate selection of patients as well as achievement and maintenance of sufficient correction of alignment. Loss of correction correlates with the type of fixation of the osteotomy site, grade of correction, and time to osseous union.

Little is known about the long-term results of opening-wedge osteotomy as compared to those of closing-wedge osteotomy. Retrospective studies of opening-wedge osteotomy have shown survival rates (rates of procedures not converted to total knee arthroplasty) ranging from 51% to 97.6% after ten years of follow-up. However, there is a lack of radiographic and clinical long-term results from well-designed prospective studies. Therefore, the aim of the present study was to determine the radiographic and clinical mid-term results as well as the survival rate (rate of procedures not converted to total knee arthroplasty) in participants of our randomized controlled trial comparing opening-wedge and closing-wedge osteotomy.

Materials and Methods

All patients who attended the outpatient clinic of the Department of Orthopedics of our institution because of medial joint pain of the knee from January 2001 to April 2004 were potentially eligible for inclusion. The criteria for inclusion in the study were radiographic evidence of medial compartment knee osteoarthritis with an Ahlbäck score of less than grade III, medial joint pain, and varus malalignment of 1° to 14°. The criteria for exclusion were symptomatic osteoarthritis of the lateral compartment, rheumatoid arthritis, knee motion of <100°, grade 3 or 4 collateral ligament laxity, a previous fracture or open operation in the lower limb, and a flexion contracture of >10°. Patients with a contralateral high tibial osteotomy were excluded if the first knee had been included in this trial; thus, if both knees were symptomatic, only the first knee was included. No limits were placed on the degree of patellofemoral osteoarthritis, age, or body mass index (BMI).

The protocol was approved by the local Ethics Committee (MEC 196.813/2000/232), and all patients gave written informed consent. Ninety-two patients were enrolled and were randomized, by a computer-generated procedure in blocks of sixteen, to receive one of the two procedures. Patients were randomized to one of four orthopaedic surgeons who performed the operations. All surgeons were experienced with both techniques. Details of the study design and the one-year results were published earlier and the trial was registered in ClinicalTrials.gov (NCT01977261).

After a mean follow-up time of seven years (range, 6.1 to 10.5 years) postoperatively, we invited all participating patients for outpatient evaluation. Some patients were not able to visit in person because of a long travel distance, problems with travel logistics, or other reasons, but they completed questionnaires. All non-responders were sent a reminder by mail and were contacted by telephone. Additionally, municipal records were searched to find the correct addresses and telephone numbers of the non-responders. Eleven patients were lost to follow-up (Fig. 1).

The grade of osteoarthritis was scored according to the classification of Kellgren and Lawrence, on the basis of measurements on a standing short posteroanterior radiograph. The mechanical alignment was assessed with use of the hip-knee-ankle (HKA) angle, which was obtained from a standardized standing whole-lower-extremity radiograph. We used lateral fluoroscopic control by superimposing the dorsal aspect of the femoral condyles to ensure a perfect anteroposterior full-length exposure. The HKA angle was determined by measuring the angle between the mechanical axis of the femur (from the center of the femoral head, determined with use of Mose circles, to the central point between the tibial spines) and the mechanical axis of theibia (from the center of the tibial spines to the center of the ankle).

Treatment Groups

Patients were randomized to receive either (1) closing-wedge high tibial osteotomy fixed with two stepped Vitallium staples (Stryker, Schöningen, Germany), or (2) opening-wedge high tibial osteotomy fixed with a Puddu plate (Arthrex, Naples, Florida).

For the closing-wedge technique, the Alloprocalibrated osteotomy guide (Zimmer, Winterthur, Switzerland) was used to obtain accurate resection of bone. The common peroneal nerve was exposed and retracted. Subsequently, the anterior aspect of the proximal part of the fibular head, representing the anterior part of the proximal tibiofibular syndesmosis, was resected. The osteotomy site was fixed with two staples (see Appendix). At the end of the procedure, a fasciotomy of the anterior compartment was performed to prevent compartment syndrome.

For the opening-wedge technique, the extent of the wedge depended on the length of the osteotomy and the diameter of the proximal part of the tibia and was calculated preoperatively (see Appendix). The Arthrex instruction manual provides a goniometric formula table, which gives the extent of the opening wedge for a specific correction. Additionally, the degree of correction performed during the procedure was controlled with fluoroscopy perioperatively. If the opening wedge was >7.5 mm, the open gap was filled with bone harvested from the ipsilateral iliac crest.

The goal of both techniques was to achieve a correction of 4° of valgus (see Appendix).

Both groups received the same rehabilitation program. Patients were mobilized on the first postoperative day, partial weight-bearing was allowed for six weeks, and full weight-bearing was begun thereafter.

Preoperative Evaluation

Age, sex, BMI, severity of medial and lateral osteoarthritis (Ahlbäck score on a scale ranging from 0 to 6, and Kellgren and Lawrence score on a scale ranging from 0 to 4), varus malalignment (HKA angle); severity of pain measured on a visual analag scale (VAS); knee function according to the Hospital for Special Surgery (HSS) score, and walking distance were scored preoperatively.

Outcome Assessment at Six Years

All follow-up measurements were performed by one non-blinded physician. The difference between the maintained valgus correction and the objective of 4° of overcorrection was determined. In addition, the HKA angle was dichotomized into (1) correctly aligned (between 2° and 6° of valgus alignment) or (2) not correctly aligned (alignment outside this range).

The severity of pain (as assessed with the VAS), walking distance, and knee function score were evaluated.

Knee function was measured with the HSS score and the Knee injury and Osteoarthritis Outcome Score (KOOS); BMI, early and late complications, and additional surgery such as removal of implants or conversion to a total knee prosthesis were noted.

Sample Size

The sample size of the initial trial was calculated on the basis of the primary outcome—namely, the alignment measured on the standing whole-lower-extremity radiograph one year postoperatively. The hypothesis of the initial trial was that the success rate of the opening-wedge procedure would be higher than that of the closing-wedge procedure. We hypothesized that the success rate would be 85% for the opening-wedge procedure and 60% for the closing-wedge.
A successful operative result was defined as achievement of approximately 4° of valgus alignment. To detect such a difference with one-sided testing ($\alpha = 0.05$ and a power of 80%), forty-six patients were required in each group.

**Statistical Analysis**

The radiographs were evaluated by two observers, independently of each other, to measure the severity of the osteoarthritis and the HKA angle. One observer repeated the measurements after two weeks. To determine the intraobserver and interobserver reproducibility, we calculated the intraclass correlation coefficient (ICC) for the HKA angle and the kappa statistic for the severity of the osteoarthritis as measured with the Kellgren and Lawrence score.

To evaluate the possibility of selective dropout during follow-up, we used the Kruskal-Wallis or chi-square test to compare the baseline characteristics of the patients seen at six years postoperatively with those of the patients lost to follow-up.

To test the difference between the two intervention groups during midterm follow-up, a linear regression model with repeated measures was used with the baseline value and the different measurements in the model. If there was doubt about violation of assumptions regarding residuals' distributions, then we carried out a Mann-Whitney test comparing the two groups with respect to the average of the measurements. The HKA angle, VAS knee pain score, HSS knee score, and walking distance were used as the dependent variables in the model. The type of high tibial osteotomy was used as the independent variable. Sex, age, BMI, and follow-up time were considered as possible confounders and were included in the regression models if they changed the relationship between the dependent variable and the type of high tibial osteotomy by at least 10%.

A Kaplan-Meier survival analysis, with conversion to a total knee arthroplasty as the end point, was carried out. We repeated the analysis with assumption of a worst-case scenario—i.e., that cases lost to follow-up were converted to a total knee arthroplasty, with the date of the last available knee radiograph considered the date of failure of the high tibial osteotomy. A $p$ value of 0.05 was considered to be significant.

**Source of Funding**

No external funds were received in support of this study.

**Results**

From January 2001 to April 2004, 122 patients underwent a high tibial osteotomy, and ninety-two of them were recruited for this trial. Of the excluded patients, thirteen had a previous...
fracture or open operation in the lower limb, three had a previous contralateral high tibial osteotomy, two had collateral ligament laxity, three were scheduled to have a combined procedure, one had osteoarthritis of the lateral compartment, and one had rheumatoid arthritis. Seven patients refused to participate for various reasons.

Of the ninety-two included patients, forty-seven were randomized to receive a closing-wedge osteotomy and forty-five, an opening-wedge osteotomy. The mean follow-up time was 7.3 years (range, 6.1 to 10.5 years) for both groups combined, and the two groups did not differ significantly with regard to follow-up time.

**TABLE I Baseline Characteristics of the Total Study Population, Opening-Wedge Group, Closing-Wedge Group, and Patients Lost to Follow-up**

<table>
<thead>
<tr>
<th></th>
<th>Total Group (N = 81)</th>
<th>Closing-Wedge Osteotomy (N = 45)</th>
<th>Opening-Wedge Osteotomy (N = 36)</th>
<th>Lost to Follow-up (N = 11)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Women (no. [%])</td>
<td>30 (37)</td>
<td>18 (40)</td>
<td>12 (33)</td>
<td>1 (9)</td>
</tr>
<tr>
<td>Age* (yr)</td>
<td>49.8 ± 8.5</td>
<td>49.5 ± 9.2</td>
<td>49.9 ± 7.9</td>
<td>53.8 ± 7.9</td>
</tr>
<tr>
<td>BMI* (kg/m²)</td>
<td>28.2 ± 4.9</td>
<td>28.2 ± 4.9</td>
<td>27.3 ± 5.4</td>
<td>27.2 ± 5.0</td>
</tr>
<tr>
<td>VAS score (0-10)*</td>
<td>6.1 ± 1.8</td>
<td>6.3 ± 1.6</td>
<td>6.0 ± 2.0</td>
<td>6.6 ± 1.4</td>
</tr>
<tr>
<td>HSS score (0-10)*</td>
<td>71.6 ± 9.6</td>
<td>71.5 ± 9.9</td>
<td>72.3 ± 9.5</td>
<td>68.0 ± 10.8</td>
</tr>
<tr>
<td>Walking distance* (km)</td>
<td>3.0 ± 2.8</td>
<td>3.1 ± 2.9</td>
<td>3.4 ± 2.9</td>
<td>2.8 ± 3.0</td>
</tr>
<tr>
<td>HKA angle† (deg)</td>
<td>6 (4-8)</td>
<td>6 (4.5-9)‡</td>
<td>5 (4-8)‡</td>
<td>6 (6-9)‡</td>
</tr>
<tr>
<td>Kelzgren and Lawrence grade-3 medial compartment osteoarthritis (no. [%])</td>
<td>12 (15)</td>
<td>5 (11)</td>
<td>7 (19)</td>
<td>0 (0)</td>
</tr>
</tbody>
</table>

*The values are presented as the mean and standard deviation. †The values are presented as the mean and interquartile range. A positive angle represents varus alignment, and a negative angle represents valgus alignment. ‡P < 0.05 for the difference between the two groups.

Of the ninety-two included patients, forty-seven were randomized to receive a closing-wedge osteotomy and forty-five, an opening-wedge osteotomy. The mean follow-up time was 7.3 years (range, 6.1 to 10.5 years) for both groups combined, and the two groups did not differ significantly with regard to follow-up time.

**TABLE II Comparison of Outcomes Between Closing-Wedge and Opening-Wedge Osteotomy Groups at Six Years***

<table>
<thead>
<tr>
<th></th>
<th>Closing-Wedge Osteotomy* (N = 45)</th>
<th>Opening-Wedge Osteotomy* (N = 36)</th>
<th>P Value†</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total knee arthroplasty during follow-up (no. [%])</td>
<td>10 (22)</td>
<td>3 (8)</td>
<td>0.05</td>
</tr>
<tr>
<td>HKA angle†‡ (deg)</td>
<td>−3.2 ± 4.1</td>
<td>−1.3 ± 5.0</td>
<td>NS#</td>
</tr>
<tr>
<td>Alignment outside range of 2°-6° of valgus† (no. [%])</td>
<td>16 (43)</td>
<td>16 (50)</td>
<td>NS</td>
</tr>
<tr>
<td>Progression of osteoarthritis** (no. [%])</td>
<td>28/36 (78)</td>
<td>21/33 (64)</td>
<td>NS</td>
</tr>
<tr>
<td>Medial compartment</td>
<td>33/36 (92)</td>
<td>32/33 (97)</td>
<td>NS</td>
</tr>
<tr>
<td>Lateral compartment</td>
<td>4.0 ± 3.2</td>
<td>3.4 ± 3.2</td>
<td>NS#</td>
</tr>
<tr>
<td>VAS score (0-10)‡</td>
<td>81.8 ± 13.0</td>
<td>80.8 ± 13.8</td>
<td>NS#</td>
</tr>
<tr>
<td>HSS score (0-100)‡</td>
<td>67.3 ± 26.2</td>
<td>67.7 ± 24.7</td>
<td>NS#</td>
</tr>
<tr>
<td>KOOS (0-100)‡</td>
<td>68.7 ± 21.0</td>
<td>70.0 ± 22.8</td>
<td>NS#</td>
</tr>
<tr>
<td>Pain</td>
<td>68.2 ± 27.2</td>
<td>67.7 ± 26.8</td>
<td>NS#</td>
</tr>
<tr>
<td>Symptoms</td>
<td>40.4 ± 30.7</td>
<td>36.2 ± 32.1</td>
<td>NS#</td>
</tr>
<tr>
<td>Activities of daily living</td>
<td>47.2 ± 27.9</td>
<td>44.6 ± 25.8</td>
<td>NS#</td>
</tr>
<tr>
<td>Sports</td>
<td>6.7 ± 4.2</td>
<td>8.2 ± 4.7</td>
<td>NS#</td>
</tr>
</tbody>
</table>

*All outcomes were assessed for patients without a total knee prosthesis. If the patient underwent a total knee arthroplasty during the follow-up period, the last radiograph made before the arthroplasty was analyzed. Radiographs were missing for nine of the forty-five patients in the closing-wedge group and three of the thirty-six patients in the opening-wedge group. †NS = not significant. ‡The values are presented as the mean and standard deviation. §A positive angle represents varus alignment, and a negative angle represents valgus alignment. #Corrected for baseline HKA angle, sex, age, BMI, and follow-up time. **Measured according to the Kelzgren and Lawrence system.
Two patients in the closing-wedge group and nine patients in the opening-wedge group were lost to follow-up. Of these eleven patients, one patient in the closing-wedge group and three in the opening-wedge group died as a result of non-osteotomy-related factors. The characteristics of the eleven patients lost to follow-up were similar to those of the patients who completed the study (Table I).

We analyzed eighty-one patients in the current study, and a whole-lower-extremity radiograph was available for fifty-six of them. Twelve patients were not able to visit the outpatient clinic in person because of long travel distance, problems with travel logistics, or other reasons, but they completed questionnaires. Ten (22%) of the patients in the closing-wedge group and three (8%) in the opening-wedge group underwent a total knee arthroplasty (Fig. 1).

The results of the intraobserver and interobserver reproducibility tests of the Kellgren and Lawrence scores were \( \kappa = 0.82 \) (95% confidence interval [CI] = 0.67 to 0.97) and \( \kappa = 0.77 \) (95% CI = 0.56 to 0.98), respectively. The results of the intraobserver and interobserver reproducibility tests of the HKA angle were ICC = 0.97 (95% CI = 0.96 to 0.98) and ICC = 0.94 (95% CI = 0.92 to 0.96), respectively.

**Outcomes Six Years Postoperatively (Table II)**

At six years postoperatively, the mean HKA angle (and standard deviation) was 3.2° ± 4.1° of valgus in the closing-wedge group and 1.3° ± 5.0° of valgus in the opening-wedge group.

Valgus alignment within the range of 2° and 6° was not found in sixteen (44%) of the patients in the closing-wedge group with available radiographs and sixteen (48%) of the patients in the opening-wedge group with available radiographs. Five patients (15%) in the opening-wedge group had a recurrent varus alignment six years postoperatively; none of these patients had a valgus alignment seen on the one-year whole-lower-extremity radiograph.

The only significant difference that we found was in the rate of conversion to total knee arthroplasty during the follow-up period: ten (22%) of the patients in the closing-wedge group and three (8%) in the opening-wedge group underwent a total knee arthroplasty (p = 0.05). The difference in the rates of

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**TABLE III Outcomes for Closing-Wedge and Opening-Wedge Osteotomy Groups at Baseline, One Year, and Six Years Postoperatively**

<table>
<thead>
<tr>
<th></th>
<th>Closing-Wedge Osteotomy*</th>
<th>Opening-Wedge Osteotomy*</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Baseline</td>
<td>One Year</td>
</tr>
<tr>
<td>HKA angle† (deg)</td>
<td>5.7 ± 2.7</td>
<td>−3.4 ± 3.6</td>
</tr>
<tr>
<td>VAS score (0-10)</td>
<td>6.3 ± 1.6</td>
<td>3.6 ± 2.2</td>
</tr>
<tr>
<td>HSS score (0-100)</td>
<td>71.5 ± 9.9</td>
<td>79.4 ± 12.0</td>
</tr>
<tr>
<td>Walking distance (km)</td>
<td>3.1 ± 2.9</td>
<td>4.6 ± 3.6</td>
</tr>
</tbody>
</table>

*The values are presented as the mean and standard deviation. †The differences between the closing-wedge and opening-wedge groups were analyzed during follow-up with repeated-measures linear regression analysis. Sex, age, BMI, and follow-up time were considered as possible confounders. NS = not significant. ‡A positive angle represents varus alignment, and a negative angle represents valgus alignment.

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**TABLE IV Early and Late Complications After Closing-Wedge and Opening-Wedge Osteotomy**

<table>
<thead>
<tr>
<th></th>
<th>Closing-Wedge Osteotomy (N = 47)</th>
<th>Opening-Wedge Osteotomy (N = 45)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Early complications (at &lt;1 yr)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Wound infection</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>Nonunion</td>
<td>0</td>
<td>2</td>
</tr>
<tr>
<td>Palsy of common peroneal nerve</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>Pain in proximal tibiofibular joint</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>Iliac crest morbidity</td>
<td>0</td>
<td>9</td>
</tr>
<tr>
<td>Fracture of tibial plateau</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>Reoperation (further valgus correction)</td>
<td>0</td>
<td>3</td>
</tr>
<tr>
<td>Reoperation (reduction of valgus correction)</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>Late complications (at &gt;1 yr)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Revision to joint arthroplasty</td>
<td>10</td>
<td>3</td>
</tr>
<tr>
<td>Removal of osteosynthesis material</td>
<td>19</td>
<td>27</td>
</tr>
</tbody>
</table>
conversion to total knee arthroplasty was 14% (95% CI = 21.7 to 0.2).

**Differences Between One-Year and Six-Year Postoperative Results in Closing-Wedge and Opening-Wedge Groups**

No significant difference was found between the one-year and six-year follow-up clinical results in either group (Table III). The severity of osteoarthritis measured on radiographs was increased in both compartments of the knee in both the closing-wedge and the opening-wedge group.

**Early and Late Complications During Follow-up Period (Table IV)**

**Early Complications (within First Postoperative Year)**

In the opening-wedge group, thirty-three of the forty-five patients required bone-grafting. Nonunion developed in two patients in the opening-wedge group, one with a wedge of 12.5 mm with bone graft and the other with a wedge of 7.5 mm without bone graft. Persistent pain at the iliac crest was reported by nine patients. One of them had additional surgery because of a symptomatic exostosis at the donor site. Another sustained an injury to the lateral femoral cutaneous nerve.

One patient in the closing-wedge group required a corrective varus osteotomy because of overcorrection by the initial osteotomy. Three patients in the opening-wedge group had another valgus osteotomy because of recurrent varus alignment.

**Late Complications (More Than One Year Postoperatively)**

Because of pain, the staples or the plate were removed from nineteen patients (40%) in the closing-wedge group and from twenty-seven patients (60%) in the opening-wedge group.

**Failure**

Failure was defined as conversion to a total knee arthroplasty; 16% of the patients underwent a total knee arthroplasty within six years after the high tibial osteotomy. Ten patients (22%) in the closing-wedge group and three patients (8%) in the opening-wedge group underwent total knee arthroplasty because of progression of symptoms during the follow-up period (Fig. 2); this difference between groups was significant (p = 0.05).

When we assumed a worst-case scenario, in which cases lost to follow-up were considered to have been converted to a total knee arthroplasty, we found no significant difference between the closing-wedge and opening-wedge osteotomy groups at six years postoperatively (Fig. 3).

**Discussion**

The aim of this randomized controlled trial was to compare the radiographic and clinical mid-term results and survival rates between closing-wedge and opening-wedge osteotomies used to treat varus knee deformity. Ten patients (22%) in the closing-wedge group and three (8%) in the opening-wedge group required conversion to a total knee arthroplasty within six years. We found no relationship between conversion to total knee arthroplasty and preoperative varus deformity, preoperative radiographic grade of the osteoarthritis, or achieved correction.

In the group of patients without conversion to a total knee arthroplasty, there was no difference between the high tibial closing-wedge and opening-wedge osteotomies in terms of clinical outcomes or radiographic alignment at six years postoperatively. The staples were removed from nineteen (40%) of the patients in the closing-wedge group, and the fixation plate was removed from twenty-seven (60%) in the opening-wedge group. Complications developed in seventeen patients (38%) in the...
opening-wedge group and four (9%) in the closing-wedge group. The primary complication in the opening-wedge group was morbidity at the iliac crest bone graft donor site (nine of the seventeen complications in that group).

Our finding that 84% of the patients did not require a total knee arthroplasty after high tibial osteotomy within a mean follow-up period of six years compares well with the results of other studies. Conversion rates ranging from 51% to 98% at a follow-up period of six years compares well with the results of total knee arthroplasty after high tibial osteotomy within a mean follow-up period of six years. When we extrapolate the survival rates in our study, we expect that the percentages will fall within these ranges. Thus, both closing-wedge and opening-wedge osteotomies have good survival rates.

Opening-wedge osteotomy was associated with a higher complication rate. Morbidity caused by harvesting cancellous bone at the iliac crest to perform the bone-grafting accounted for nearly half of the early complications. In a recent randomized controlled trial, Zorzi and colleagues concluded that autologous bone graft is unnecessary for wedges of <12.5 mm². It is clear that avoidance of cancellous bone graft will decrease the complication rate of the opening-wedge procedure. Therefore, we recommend autologous iliac bone graft for patients in whom the opening wedge is <12.5 mm².

Five patients in the opening-wedge group had recurrent varus alignment six years postoperatively. None of these patients had had 4° of valgus alignment on the whole-lower-extremity radiograph at one year postoperatively. This malalignment was probably caused by early loss of correction due to suboptimal stabilization of the Puddu plate⁷, with increasing malalignment of the mechanical axis in subsequent years. Other authors have reported that the Puddu plate is not strong enough to sustain perioperative correction⁸. The authors of another study concluded that the use of a rigid locking plate for both opening-wedge and closing-wedge osteotomies provides better stability⁹. We recommend fixation with a rigid locking plate instead of a Puddu plate.

Because of pain, the staple or plate was removed from nineteen patients (40%) in the closing-wedge group and from twenty-seven patients (60%) in the opening-wedge group. These high removal rates are comparable with those in the literature. Hoell et al. reported an implant removal rate of 50% in patients treated with an opening-wedge osteotomy and reported significantly more implant removals in those patients than in patients treated with closing-wedge osteotomy (p < 0.05)⁴. High tibial osteotomy implants are fixed laterally when a closing-wedge procedure is used and medially when an opening-wedge is used. Most people have less soft tissue at the medial side of the lower limb; therefore, the explanation for the difference in implant removal rates between opening and closing-wedge osteotomies could be anatomic.

There are some limitations of our study. First, despite intensive efforts to reach all of our patients, eleven patients were lost to follow-up. Because there were no significant differences in baseline characteristics between these patients and those who were followed, we assume that there was no selective dropout. The dropout of patients did not reduce the power of the study, but the power of the survival analysis was reasonable (79%). Moreover, the survival analysis was repeated with the lost patients considered to have had a failure. We assume that the lost patients did not significantly influence our six-year results.

Second, four orthopaedic surgeons performed these procedures. Although all had experience with both techniques, a single surgeon would have been preferable to reduce possible operator-dependent variability. However, a higher number of surgeons improves the generalizability of the results.

Finally, the outcome assessor at six years postoperatively was not blinded to the group allocation, and the radiographs could not be blinded with regard to group allocation. The measured HKA angle could have been influenced by a preference for one of the two procedures. However, the HKA angle was measured by two independent observers, who showed a high reproducibility of 0.94.

Physical examination was also not blinded. However, because the study hypothesis was that the closing-wedge osteotomy would produce better one-year postoperative results, bias due to a non-blinded assessor would be in favor of the closing-wedge osteotomy and result in a better HSS score in the closing-wedge group. No difference was seen between the results of the closing-wedge and opening-wedge groups. We assume that observer bias did not influence our results because the patients’ self-assessed outcomes, such as pain and walking distance, did not show any differences between groups.

Achievement and maintenance of an adequate operative correction are required for a successful outcome⁵,⁶,⁷,⁸. Opening-wedge osteotomy is thought to allow a more accurate correction than closing-wedge osteotomy. In our study, the achieved and maintained correction following opening-wedge osteotomy was influenced by loss of correction due to suboptimal plate design. We are aware of only one randomized controlled trial comparing the accuracy of closing-wedge osteotomy with that of opening-wedge osteotomy performed with use of a rigid locking plate, but that study lacked power (n = 50)⁹. In conclusion, at six years postoperatively, no clinical or radiographic difference between closing-wedge and opening-wedge osteotomy was found. The disadvantage of the closing-wedge osteotomy was the lower survival rate (more conversions to total knee arthroplasty) and the disadvantage of opening-wedge osteotomy was the higher number of complications. On the basis of the results of our study and the recent literature, we advise using an opening-wedge high tibial osteotomy with rigid plate fixation and without autologous bone graft for patients with medial osteoarthritis of the knee and varus malalignment of <12° to minimize the risk of complications and to maximize the survival.

Appendix

Radiographs made after a closing-wedge high tibial osteotomy stabilized by two staples and an opening-wedge high tibial osteotomy stabilized by a Puddu plate are available with the online version of this article as a data supplement at jbjs.org.
References


