Coronal Alignment Correction and Maintenance of Tibial Slope in Opening-Wedge Valgus High Tibial Osteotomy Using a 4-Reference Kirschner Wire Technique

A Cadaveric Study

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Background: Opening-wedge valgus high tibial osteotomy (OWHTO) is a common surgical procedure used to treat symptomatic varus femorotibial malalignment in adults. Several intraoperative methods are available to determine the correct correction alignment, but achieving the desired alignment correction is difficult.

Purpose/Hypothesis: The aim of this study was to assess a 4-reference K-wire technique that is relatively easy to apply and can reliably assess actual alignment correction during surgery after determination of the desired corrective angle. We hypothesized that this technique would accurately determine the coronal correction and properly maintain the tibial slope intraoperatively during OWHTO.

Study Design: Descriptive laboratory study.

Methods: This study was conducted using 12 fresh-frozen cadavers; 12 randomly chosen knees were corrected 5° and 12 knees were corrected 10° by use of 2 coronal and 2 sagittal K-wires. The first and second coronal K-wires were drilled at 4 cm and 1 to 2 cm below the medial joint line toward the tibiofibular joint, respectively. The angles of these 2 coronal K-wires were measured before and after the gap was opened via a modified goniometer. The difference in the angle formed by these 2 coronal K-wires from before to after opening of the gap was the alignment correction angle. In addition, 2 sagittal K-wires were drilled parallel to each other before the gap opening above and below the osteotomy site. Ensuring that these 2 sagittal K-wires remained parallel after the gap opening confirmed that the tibial slope had been maintained. The paired *t* test was used to compare the desired alignment corrections and the different angles measured between the pre- and postoperative radiographic alignments.

Results: The mean ± SD differences in angles between the pre- and postoperative alignments of the 5° and 10° corrections were 5.04° ± 0.68° and 10.03° ± 0.68°, respectively, indicating no statistically significant differences between pre- and postoperative alignment in both groups. As well, no significant difference was noted between the pre- and postoperative medial tibial slope ($P = .54$).

Conclusion: The coronal alignment correction and maintenance of the tibial slope using the 4-reference K-wire technique was found to be highly accurate and reliable.

Clinical Relevance: Achieving the correct angle in OWHTO is difficult, and the 4-reference K-wire technique provides an easier and more reliable way to obtain the correct angle. This technique can be used in most hospital settings, with no need for expensive equipment.

Keywords: high tibial osteotomy; open-wedge; alignment correction

Osteoarthritis is a degenerative disease that is most commonly diagnosed in elderly patients, but it can also occur in younger adults. Many of those who develop this disease

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have precipitating factors such as fractures of the distal femur or proximal tibia, ligament (anterior or posterior cruciate) injury of the knee, or osteochondral injury of the knee. The most common problem of young adults with osteoarthritis is varus malalignment. When a patient is diagnosed with medial compartment osteoarthritis, 2 major treatment modalities are used. The treatment of choice is a nonoperative approach and consists of medication, corrective bracing,[8] neuromuscular exercise,[5] and strengthening[20] and range-of-motion exercises. If nonoperative treatment fails, the other option is surgery. The primary choices of operative treatment are opening-wedge valgus high tibial osteotomy (OWHTO) and unicompartmental knee arthroplasty.

Most young adult patients are treated with OWHTO, which is more suitable for active adults.[21] The key treatment goal of OWHTO is to alter the mechanical axis in the coronal plane to shift the load from the medial side to the lateral side but retain the sagittal plane axis in the tibial slope. The success rate of this procedure depends on selecting patients suitable for the procedure in terms of age, body mass index, and knee joint range of motion.[3,28] Many studies have reported poor outcomes of this procedure attributable to under- or overcorrection of the lower limb alignment.[11-13,16,17]

Several methods are available to assess the amount of alignment correction during surgery, such as the cable, gap measurement, navigator, and patient-specific cutting guide methods, all of which have different accuracies of correction. The cable method uses a fluoroscope to measure the alignment after correction in order to evaluate the position of an alignment guide at the level of the knee joint. If the alignment has been correctly achieved, the alignment guide will be able to pass the lateral compartment of the knee joint. With the gap-measurement method, the surgeon determines the corrected angle and gap distance using measurements calculated preoperatively. During surgery, the gap distance is used to determine the changing alignment, which may be affected by the shifting of the measurement landmarks due to rotation of the lower limb. Although both the cable and the gap measurement methods generally have low accuracy, they remain widely used because they are relatively easy to perform and do not require expensive equipment. In contrast, the navigator and patient-specific cutting guide methods measure the alignment correction directly from the bone and thus have high precision, but they are available only in large hospitals because the required equipment is expensive.

In this study, we assessed an intraoperative 4-reference K-wire technique that is relatively easy to apply and can reliably measure actual alignment correction after determination of the desired corrective angle. We hypothesized that this technique would accurately determine the coronal correction and properly maintain the tibial slope intraoperatively during OWHTO.

METHODS

The study was conducted in 12 fresh-frozen cadavers, 5 female and 7 male, which were obtained from the anatomy department at our university. The study received ethics committee exemption. The mean ± SD age at death of the cadavers was 65 ± 12 years, and the mean length was 165 ± 8 cm. OWHTOs were performed in 12 right lower limbs and 12 left lower limbs. A total of 12 randomly chosen knees were corrected 5° and the other 12 were corrected 10°.

Surgical Procedure

All surgical procedures were performed by a single orthopaedist (W.P.) with more than 10 years of experience in OWHTOs. Each procedure was begun with a 10-cm anteromedial incision through the subcutaneous tissue at the proximal tibia. The incision was made midway between the tibial tubercle and the posterior part of the superficial medial collateral ligament. The sartorius fascia was incised proximal to the gracilis tendon in an oblique line. The gracilis and semitendinosus tendons were exposed and mobilized, and the gracilis was detached from the tibia using the periosteum. The posterior part of the superficial medial collateral ligament was released. The first coronal K-wire was drilled into the bone 4 cm below the medial joint line from the anteromedial aspect of the proximal tibia to the tibiofibular joint. The biplanar osteotomy was started above the first coronal K-wire. After the osteotomy, the second coronal K-wire was drilled 1 to 2 cm below the medial joint line, again from the anteromedial aspect of the proximal tibia to the tibiofibular joint. Before the bony gap was opened (Figure 1A), the angle of these 2 coronal K-wires was measured via a degree scale on a modified goniometer (Figure 1B). This device had 2 slots into which the K-wires could be inserted. A lamina spreader was inserted at the osteotomy site to open the bony gap until the desired alignment correction was achieved (Figure 1C). The difference in the angle formed by these 2 coronal K-wires from before to after opening of the gap was defined as the alignment correction angle.

To retain the posterior slope angle and to prevent rotation during alignment correction, 2 other parallel K-wires

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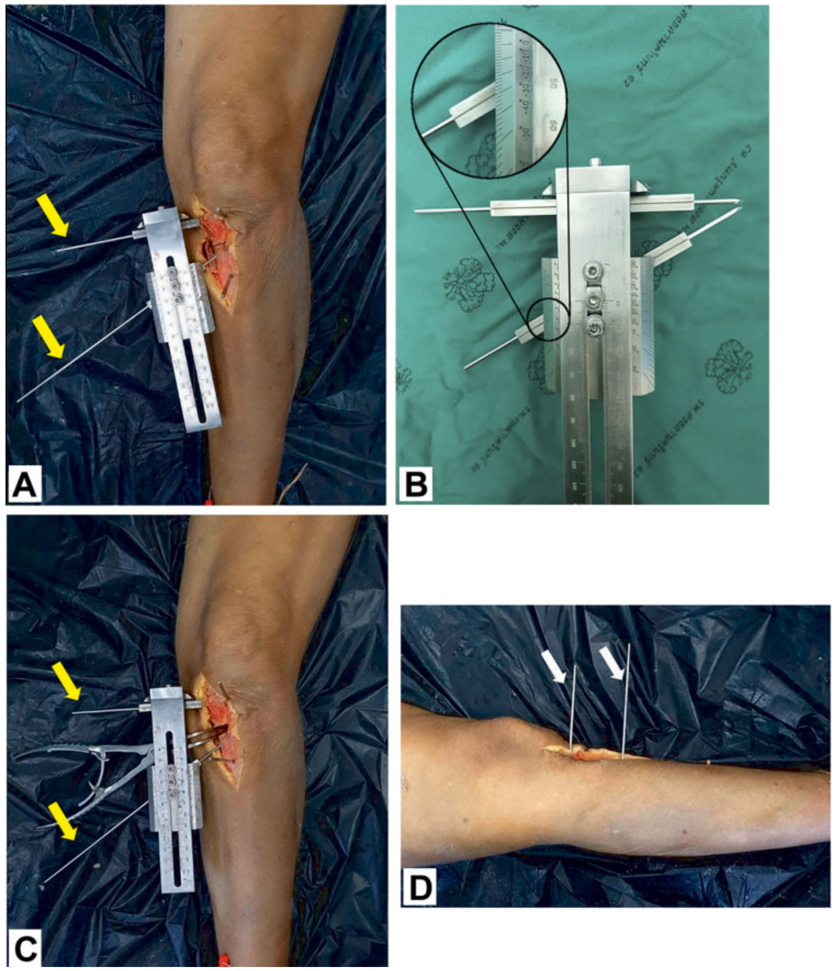

Figure 1. (A) The angle of the 2 K-wires (yellow arrows) in the coronal plane was measured before the gap was opened and (B) measured with the degree scale on a modified goniometer. (C) A lamina spreader was inserted at the osteotomy site to open the bony gap until the desired alignment correction angle was achieved. (D) Two sagittal K-wires (white arrows) were kept parallel to ensure maintenance of the original tibial slope before and after the gap was opened.

were drilled sagittally at 1 cm above the osteotomy site (proximal to the insertion of the patellar tendon) and 6 cm below the osteotomy site before the gap opening (Figure 1D). After the gap was opened, the 2 sagittal K-wires were kept parallel to ensure maintenance of the original tibial slope.[18] After the desired alignment correction was achieved, a TomoFix plate (DePuy Synthes) was applied and affixed.

Radiograph Procedure

Each lower limb of each cadaver underwent radiographic evaluation before and after alignment correction through use of digital radiography (GC85A; Samsung). All hip-knee-ankle radiographs were taken by a single experienced radiology technician. The distance between each lower limb and beam was approximately 100 to 110 cm. The kilovoltage was set between 35 and 45 kV. In addition, the radiographic quality was checked before the radiographic measurement by an experienced radiologist who was not on the study team.

Radiographic Measurements

In the coronal plane, the alignment correction angle was assessed by comparing preoperative (Figure 2A) and postoperative (Figure 2B) hip-knee-ankle radiographs with the mechanical axes of the femur and tibia marked via digital images with a computer angle measuring tool (Figure 2C). To decrease potential measurement bias, the angles of the coronal plane alignment and medial posterior slope were measured 3 times on both preoperative and postoperative radiographs by a single orthopaedist (C.C.) who did not know the angle of correction in each limb. For the mechanical axis of the femur, a circle was drawn around the femoral head to identify its center and then a second line was drawn from the center of the femoral head to the intercondylar notch of the distal femur. For the mechanical axis of

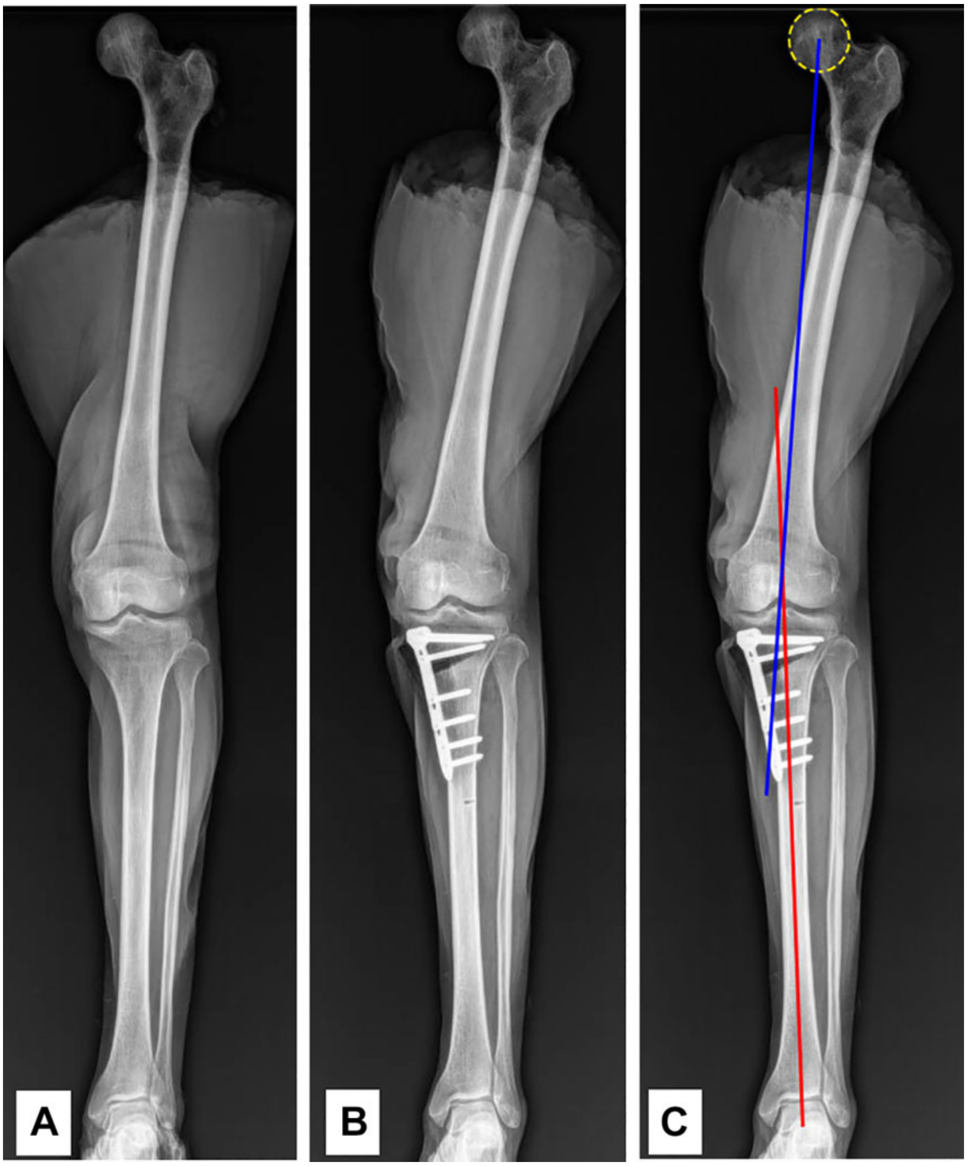

Figure 2. (A) Preoperative and (B) postoperative radiographs of hip, knee, and ankle. (C) The mechanical axis of coronal plane alignment was defined as the angle between the mechanical femoral axis (blue line) and the mechanical tibial axis (red line). The dotted yellow circle indicates the femoral head.

the tibia, the line was drawn from the center of the proximal tibia to the center of the ankle.[22]

An investigator (C.C.) measured the medial posterior tibial slopes using the Brazier method (Figure 3).[6] The angle of the medial posterior tibial slope was measured between the medial tibial plateau (blue line in Figure 3) and the posterior tibial cortex (yellow line in Figure 3).

Statistical Analysis

Statistical analysis was performed with the R program and Epicalc package (version 3.4.3; R Foundation for Statistical Computing). The paired *t* test was used to compare desired alignment corrections and the different angles between preoperative and postoperative alignments. A *P* value of less than .05 was deemed to have statistical significance.

RESULTS

The mean ± SD differences in angles between preoperative and postoperative alignments of the 5° correction and 10° correction groups were 5.04° ± 0.68° and 10.03° ± 0.68°, respectively. No statistically significant differences were found between the desired amount of alignment correction and the corrections achieved through use of the intraoperative 4-reference K-wire technique in the 5° (*P* = .78) and 10° (*P* = .718) correction groups. The medial posterior tibial slope was 5.74° ± 1.05° preoperatively and 5.8° ± 1.05°

Figure 3. The medial posterior tibial slope was determined by measuring the angle between the medial tibial plateau (blue line), perpendicular to the posterior tibial cortex (yellow line).

postoperatively. No significant differences were seen between the preoperative and postoperative medial tibial slope ($P = .54$). Excellent intraobserver correlations in each measurement were found, with correlation coefficients between 0.97 and 0.99.

DISCUSSION

This study demonstrates that a surgeon can accurately measure the alignment of correction intraoperatively using the 4-reference K-wire technique. This technique is simple, involving nothing more than the insertion of the 2 coronal K-wires at each of the distal and proximal parts before the gap opening. This method is accurate because the K-wires can clearly show small changes in the bone alignment. The changing angle between the 2 coronal K-wires is representative of the actual alignment correction, whereas the accuracies of other surgical techniques used for this purpose, such as the cable method[9,19] or gap measurement method,[7,23,26] are unpredictable. The cable and gap measurement methods are based on indirect measurements, which are themselves intrusive and can thus disturb the accuracy of alignment correction. For example, the alignment of correction in the cable method is evaluated via fluoroscopic visualization at the knee joint, and the tension of the cable, the rotation of the lower limb, and the multiple fluoroscopic images can disturb the accuracy of evaluation.

In the cable method, the surgeon applies an alignment rod or a cautery cord extending from the center of the femoral head to the midtalar dome bypassing the knee joint using fluoroscopic visualization. The position of the alignment rod at the knee joint intraoperatively represents the mechanical axis of lower limb. Two studies have reported accuracies of this method of 23% and 66.2%, demonstrating its unpredictability.[9,19] Many factors can interfere with the accuracy of correction, such as the degree of rotation of the lower limb, cable tension, and radiographic technique, and calculation errors can result from any combination of these steps. For example, while determining the center of the hip joint and midtalar dome using a fluoroscope, the surgeon needs to evaluate each location separately before evaluating the knee joint, a step that may be complicated by limb rotation and cable tension while moving the fluoroscope.

In the gap measurement method, the surgeon determines the corrected angle using measurements calculated preoperatively. Precise measurements are required to use this surgical technique, and these measurements depend on the devices used, the location of the measurement bases, and the alignment after correction. The surgeon must use a precise scale device such as a precut paper ruler, a gap-measuring device, or corpectomy calipers to measure the gap distance intraoperatively. It is difficult to ensure that the actual gap during the operation correlates with the preoperative radiograph plan. To maintain the posterior tibial slope, the surgeon must open the anterior gap to a size approximately 67% of the posterior gap. In cases where this ratio is not correctly achieved, the alignment will be overcorrected by measurement of the distance of the anterior gap and undercorrected in the posterior gap reference. The accuracy of the gap measurement method has been examined in several studies, again with inaccurate corrections ranging from 15% to 44%, mainly involving undercorrection.[7,23,26]

Currently, the navigator and patient-specific cutting guide methods are used in many operations, including OWHTO. The benefit of the navigator system is the real-time visualization in all planes of the alignment correction. Many studies have compared postoperative coronal alignment corrections between computer-navigated and conventional high tibial osteotomy and have found the accuracy of the navigator system to be 80% to 86%, more precise than the conventional high tibial osteotomy by 0.93° to 1.4°.[4,14,19,25] Several disadvantages of the navigator system have been reported, notably the longer operation time required due to the need to fasten position transmitters to the limb, the technical difficulties associated with calibrating the system, and a relatively high learning curve and high cost of equipment.[2,19,26] The patient-specific cutting guide method provides specific instrumentation for each patient based on a preoperative CT scan; one study reported that both overall operative time and fluoroscopic time were shorter with this technique than with conventional high tibial osteotomy.[20] The correction accuracy is also quite high; Chaouche et al[10] and Jacquet et al[20] reported differences between the desired correction defined preoperatively and the correction obtained postoperatively measured on CT scan of less than 2°. Thus, the accuracy of both of these methods is high, but these techniques are available only in large hospitals that can afford the expensive equipment.

The accuracy of coronal plane alignment correction is important in OWHTO. Many studies have reported poor outcomes if the lower limb alignment was under- or overcorrected. Excessive overcorrection leads to poor functional symptoms and degenerative changes in the lateral compartment, whereas undercorrection does not improve the pain that led to the operation in the first place, because the mechanical axis passed the medial compartment.[11-13,17,23]

Correct alignment of the posterior slope is also important because the actions of knee flexion and extension can be affected by changes in the posterior tibial slope.[1,15] Nha et al[24] reported that the posterior tibial slope increased an average of 2.02° in OWHTO. In cases of varus malalignment without ligament laxity, the posterior tibial slope should not change postoperatively. In the current study, we maintained the posterior tibial slope by opening an anterior gap to approximately 67% of the posterior gap[27] and maintained the 2 parallel reference K-wires before and after the OWHTO in the sagittal and axial planes, ensuring the posterior tibial slope remained the same.[18]

This study had some limitations. First, this was a cadaveric study and therefore used nonweightbearing films, so we could not interpret hip-knee-ankle alignment on a weightbearing film. Second, the study was performed in the lower limbs of cadavers by hip disarticulation, which may have entailed loss of muscle tension (adductor longus and the hamstrings). Third, there was a possibility of measurement bias in the radiographic process (some degree of lower limb rotation during radiography) and performance of the radiographic measurements. To decrease this possibility, all radiographic images were performed by a single experienced radiologist who controlled the distances between the x-ray beam and the lower limb and also controlled the position of the lower limb. Fourth, the orthopaedist who performed the radiographic measurements could not be blinded to the angle of correction because the difference between 5° and 10° correction was clearly evident. To decrease the bias, each radiographic measurement was performed according to a standard protocol.

CONCLUSION

The coronal alignment corrections and maintenance of the tibial slope through use of the intraoperative 4-reference K-wire technique were found to be highly accurate and reliable, and this technique may provide a useful option in hospitals where expensive equipment is not available.

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