The Coronal Plane High Tibial Osteotomy. Part 1: A Clinical and Radiographic Analysis of Intermediate Term Outcomes

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Abstract The coronal plane high tibial osteotomy is a novel technique that is used to treat tibiofemoral malalignment. The authors hypothesize that the coronal plane high tibial osteotomy is (1) efficacious in treating both varus and valgus tibiofemoral malalignment; (2) does not alter the slope of the proximal tibia; and (3) does not alter the relationship between the patella and tibial tubercle. A retrospective review of 25 patients with tibiofemoral malalignment (19 varus/6 valgus) treated with a coronal plane osteotomy with a minimum of 2-year follow-up was performed. A Kaplan–Meyer survival curve was performed using knee arthroplasty and a Hospital for Special Surgery (HSS) knee score < 70 as failure criteria. The Insall–Salvati ratio and the proximal tibial slope were measured. A *p* value of 0.05 was considered significant. At 60-month follow-up, knees with initial varus malalignment had an 84% survival rate using both knee arthroplasty and the HSS score as endpoints. Knees with initial valgus malalignment had an 84 and 60% survival rate using knee arthroplasty and the HSS score as endpoints, respectively. There was no statistically significant change in the Insall–Salvati ratio and proximal tibial slope after coronal plane osteotomy. The coronal plane osteotomy is efficacious in treating varus and valgus tibiofemoral malalignment and does not alter the patellar–tibial tubercle relationship or the posterior tibial slope [case series (level of evidence: IV)].

Key words knee · osteotomy · malalignment · arthritis · coronal

Introduction

Originally, knee osteotomies were used to treat tricompartmental osteoarthritis. With the development of total knee arthroplasty, knee osteotomies fell out of favor as a treatment for tricompartmental osteoarthritis. Nonetheless, knee osteotomies continue to be an efficacious treatment for unicompartmental arthritis and tibiofemoral malalignment.

With the increasing popularity of cartilage resurfacing procedures, such as autologous chondrocyte implantation, autologous and allogenic osteochondral grafting, and meniscal transplantation, there has been a resurgence of knee osteotomies within the field of sports medicine to correct concomitant lower extremity malalignment [1–10]. In addition, osteotomies about the knee are commonly used by the sports medicine physician in treating anterior cruciate ligament (ACL) deficient knees with tibiofemoral malalignment [11–16].

Osteotomy of the knee was first reported by J. P. Jackson [17] in 1958 at the Joint Meeting of the Orthopaedic Associations. In 1964, Garipey [18] described a closing wedge technique that was further modified and popularized by Coventry [19] in 1965. Modifications of the Coventry closing wedge osteotomy continue to be widely used today.

The opening wedge osteotomy was developed as an alternative to Coventry's closing wedge osteotomy [20]. Opening wedge osteotomies are appealing because multiplanar correction can be readily obtained, and they can be used to correct varus malalignment and lesser degrees of valgus malalignment. In addition, opening wedge osteotomies may be technically easier to perform than closing wedge osteotomies, as they require only one bone cut. Unlike closing wedge osteotomies, opening wedge osteotomies add bone to the diseased, collapsed side instead of removing bone from the more normal side [21]. In addition, it is not necessary to disrupt the proximal tibiofibular joint or osteotomize the fibula as it is with the closing wedge osteotomy [22, 23].

Disadvantages of the opening wedge osteotomy include the potential need for either autogenous bone graft with

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harvest site morbidity or allogenic bone with the potential for disease transmission, the potential increased risk for delayed or nonunion, an increased length of restricted weight bearing, and pin site infections when external fixation is used [24].

The primary goal of the high tibial osteotomy is to correct frontal plane malalignment. However, the traditional osteotomy techniques also create alignment changes in the sagittal plane, which can adversely affect knee biomechanics and kinematics. Closing wedge osteotomies have been shown to decrease posterior tibial slope [25–27], whereas opening wedge osteotomies cause an increase in posterior tibial slope [25, 28]. These changes can adversely affect postsurgical outcomes in patients with concomitant ligamentous laxity or patients that eventually require arthroplasty.

The traditional osteotomies also have been shown to alter the anatomical relationship between the patella and the tibial tubercle. Patella infera can occur after either type of osteotomy [25, 27, 29] and contributes to less favorable results of the total knee arthroplasty after high tibial osteotomy [27, 29–31].

A third type of osteotomy, the coronal plane osteotomy, was developed at this institution to treat varus gonarthrosis. Whereas the closing and opening wedge techniques employ an osteotomy in the axial plane, the coronal plane osteotomy technique uses an osteotomy in the sagittal plane. The distal tibia is then rotated around an axis in the coronal plane to correct the varus malalignment. The purpose of this study is to describe the surgical technique for the coronal plane osteotomy and to present its intermediate term clinical outcomes. We hypothesize that the coronal plane osteotomy (1) is effective in treating both symptomatic varus and valgus tibiofemoral malalignment, (2) does not alter the proximal tibial slope, and (3) does not change the anatomic relationship between the patella and the tibial tubercle.

Materials and methods

A retrospective review of patients treated with a coronal plane high tibial osteotomy for tibiofemoral malalignment was undertaken. Inclusion criteria were patients with either varus or valgus tibiofemoral malalignment and a minimum clinical follow-up of 2 years. Patients that had closing or opening wedge high tibial osteotomy or a femoral osteotomy were excluded. After the Institutional Review Board approval was obtained, patients were identified by retrospective chart review and were invited back to the clinic for physical examination, outcome analysis, and radiographic analysis. Clinical outcomes analyses included the Hospital for Special Surgery (HSS) knee score [32], the Tegner Activity Scale [33], and the International Knee Documentation Committee (IKDC) scoring system [34, 35]. Radiographic analysis included the anatomic axis, the weight bearing axis, the Insall–Salvati ratio [36], and the proximal tibial anatomic axis to determine tibial slope [37]. The weight-bearing axis was determined by drawing a line from the center of the femoral head to the center of the

ankle mortise. The measurement from the medial edge of the proximal tibia to this line divided by the entire width of the tibia determined the weight-bearing axis (Fig. 1).

Surgical technique

Preoperative antibiotics were administered to the patient, and regional anesthesia was induced by the anesthesiologists. The patient was placed supine on a radiolucent operating table. A nonsterile tourniquet was placed over the proximal thigh, and an electrocardiogram (EKG) lead was placed over the center of the femoral head with the use of fluoroscopic guidance. The patient's affected lower extremity was prepped in draped in sterile fashion. The lower extremity was exsanguinated by gravity, and the tourniquet was raised to 300 mmHg. Arthroscopy was indicated if there are loose bodies present, or the patient is having locking sensations.

A 2-cm incision was made over the proximal aspect of the fibula diaphysis. Dissection was performed down to the fibula and the periosteum was split. Two retractors were placed subperiosteally around the fibula. An oblique fibular osteotomy was made with a sagittal saw in a supero-lateral to infero-medial direction.

Fig. 1. The weight-bearing axis is determined by extending a line from the center of the femoral head down to the center of the ankle mortise. The measurement from the medial edge of the proximal tibia to this line (a) divided by the entire width of the tibia (b) determined the weight-bearing axis

Next, a 6- to 8-cm incision was made from the inferior pole of the patella to just distal to the tibial tubercle. Electrocautery was used to incise the fascia over the tibia. An elevator was used to dissect subperiosteally. A deep retractor was placed lateral and posterior to the tibia retracting the anterior compartment. The oblique coronal plane osteotomy was started anteriorly, proximal to the tibial tubercle, and was extended distal and posterior (Fig. 2). Two preliminary drill holes were drilled in the distal aspect of the osteotomy with the 4.5-mm drill bit before creation of the osteotomy. A sagittal saw was used to start the osteotomy, and osteotomes were used to complete it. Just before completion of the osteotomy, a smooth Steinman pin was temporarily placed across the osteotomy site to act as a pivot and provide rotational control. After completion of the osteotomy, a varus or valgus force was placed on the distal piece, and the angular correction was performed (Figs. 3 and 4). A bone-holding forceps was used to hold the proximal and distal fragments stable once the appropriate correction was made. The electrocautery cord was placed over the EKG lead, across the tibiofemoral joint, and down to the center of the tibiotalar joint to recreate the weight-bearing axis. Fluoroscopy was used to confirm appropriate correction of the weight-bearing axis. For a valgus-producing osteotomy, the goal was to have the weight-bearing axis pass through the 62 percentile of the joint line [38]. For a varus-producing osteotomy, the goal was to have the weight-bearing axis pass through the medial tibial spine. Two 4.5-mm cortical screws were used to compress and stabilize the osteotomy site in an anterior to posterior direction. An L-plate was used as a neutralization plate and placed laterally on the tibia (Figs. 5 and 6). Initially, the authors used a small fragment plate but have now modified the technique to a large fragment plate for increased stability at the osteotomy site. The wounds were irrigated, and the fascia and skin were closed in standard fashion, and a soft, sterile dressing was applied. Patients were placed in a hinged knee brace, which was initially locked in extension.

Fig. 2. The coronal plane osteotomy requires a single tibial cut (black arrow). This oblique osteotomy is started anteriorly, proximal to the tibial tubercle, and is extended distal and posterior

Fig. 3. (a) The weight-bearing axis passes through the medial compartment in this knee with varus malalignment. (b) After the valgus-producing coronal plane osteotomy, the weight-bearing axis has been shifted toward the lateral compartment

Postoperatively, all patients remained nonweight bearing until there was both clinical and radiographic evidence of healing ranging from 6 to 8 weeks. Range of motion was started on the operative day using a continuous passive motion (CPM) machine. CPM was used for the first 2 weeks and was combined with a physical therapy regimen to focus on regaining range of motion. Patients were gradually progressed to closed-chain strengthening exercises. More strenuous exercise was allowed after 5 months.

Statistical analysis

Descriptive statistics were calculated for continuous (mean, standard deviation) and discrete (frequencies, percentages) variables. Inferential analysis consisted of hypothesis testing using a Mann–Whitney test for independent samples and Wilcoxon rank sums test for paired samples. These tests were chosen for the continuous measures because of the small sample size and likelihood of violating the assumption of a normal distribution. A Kaplan–Meier survival analysis

Fig. 4. (a) The weight-bearing axis passes through the lateral compartment in this knee with valgus malalignment. (b) After the varus-producing coronal plane osteotomy, the weight-bearing axis has been shifted toward the medial compartment

Fig. 5. Intraoperative photo showing the two 4.5-mm cortical screws used to compress and stabilize the osteotomy site in an anterior to posterior direction. A L-plate, placed laterally on the tibia, is used as a neutralization plate

was performed to determine the success of the coronal plane high tibial osteotomy. The failure criteria were identified as (1) persistent pain and dysfunction requiring a total knee arthroplasty, (2) a fair or poor HSS knee score (<70). All p values were considered statistically significant at 0.05. All analyses were conducted using Statistical Package for the Social Sciences (SPSS) for Windows 11.0 (Chicago, IL, USA).

Results

Thirty-five consecutive patients were identified, who were treated with a coronal plane high tibial osteotomy, by the senior author between January 1, 1998 and March 1, 2003. All patients had greater than 2-year clinical and radiographic

follow-up. Five patients declined to participate in the study, and five patients could not be contacted after an exhaustive search. Therefore, 25 patients were enrolled in this study. Nineteen patients had varus malalignment treated with a valgus-producing coronal plane high tibial osteotomy. Six patients had valgus malalignment treated with a varus-producing coronal plane high tibial osteotomy.

Demographics

Varus malalignment

There were 8 men and 11 women with a mean age of 39 years (range, 15–55). The mean length of follow-up was 50 months. Ten patients had prior medial meniscectomies, three patients had a medial compartment microfracture procedure, two patients had a medial femoral condyle osteochondral autologous transplantation (OATs procedure), three patients had a prior ACL rupture with one patient having persistent ACL deficiency, two patients had a diagnosis of adolescent blount's disease, one patient had medial femoral condyle osteonecrosis, and one patient had a medial tibial plateau allograft for osteonecrosis. Five patients had an idiopathic etiology to their tibiofemoral malalignment. Preoperative IKDC radiographic scores were determined, and two patients were classified as A, three patients were classified as B, and eight patients were classified as D. Because of the retrospective nature of this study, six patients did not have sufficient radiographic studies to determine the preoperative IKDC radiographic scores.

Valgus malalignment

There were five women and one man in this group with a mean age of 39 years (range, 21–50). The mean length of follow-up was 46 months. Five patients had a prior lateral

Fig. 6. (a) Anterior–posterior radiograph after coronal plane high tibial osteotomy. (b) Lateral radiograph after coronal plane high tibial osteotomy

meniscectomy, and one had a lateral tibial plateau fracture. Two patients had a prior ACL rupture with reconstruction, and one patient had a lateral meniscal transplant. Using the IKDC radiographic scoring system, three patients were classified as B, one was classified as C, one was classified as D, and one patient had insufficient preoperative radiographs for classification.

Clinical examination

Varus malalignment

Mean preoperative extension was $0.7 \pm 1.9^\circ$, and mean preoperative flexion was $128 \pm 13.6^\circ$. Twelve patients had a lateral thrust with ambulation. Six patients had an effusion on examination. Mean postoperative extension was $0.5 \pm 1.4^\circ$, and mean postoperative flexion was $128 \pm 19.3^\circ$. No patients had a thrust on ambulation postoperatively (Table 1).

Valgus malalignment

Mean preoperative extension was 0° , and mean preoperative flexion was $130 \pm 13.5^\circ$. No patients had a thrust with ambulation. One patient had an effusion on examination. Mean postoperative extension was 0° , and mean postoperative flexion was $135 \pm 10.6^\circ$. No patient had a thrust on ambulation postoperatively (Table 1).

Days to union and complications

Varus malalignment

The mean days to radiographic union were 106 ± 73 days. Six patients required cast immobilization postoperatively. There were six complications including two nonunions requiring revision surgery, one delayed union of the tibia, two patients lost the initial correction and underwent an early manipulation under anesthesia and cast immobilization, and one patient had a regional complex pain syndrome. Three patients required removal of hardware after radiographic healing.

Valgus malalignment

The mean days to radiographic union were 76 ± 27 days. No patient required cast immobilization postoperatively. There were two complications including a delayed union of the

Table 2. Preoperative and postosteotomy radiographic measurements for patients with varus and valgus tibiofemoral malalignment

	Pre-Surgery	Post-Surgery	p Value
Valgus malalignment			
Anatomic axis	$169.6 \pm 4.2^\circ$	$177.4 \pm 4.4^\circ$	0.04
Weight-bearing axis	0.70 ± 0.20	0.34 ± 0.19	0.04
Insall–Salvati ratio	0.91 ± 0.16	0.98 ± 0.13	0.66
Tibial slope	$7.7 \pm 3.5^\circ$	$7.3 \pm 2.8^\circ$	0.32
Varus malalignment			
Anatomic axis	$181.3 \pm 4.0^\circ$	$176.1 \pm 5.3^\circ$	0.01
Weight-bearing axis	0.12 ± 0.16	0.39 ± 0.23	0.03
Insall–Salvati ratio	0.98 ± 0.09	1.03 ± 0.17	0.58
Tibial slope	$8.9 \pm 3.4^\circ$	$7.7 \pm 3.2^\circ$	0.12

fibula and a nonunion of the fibula requiring revision surgery.

Radiographic measurements

Varus malalignment

The mean initial anatomic axis measured $181.3 \pm 4.0^\circ$, and the mean final anatomic axis at final follow-up after osteotomy was $176.1 \pm 5.3^\circ$ ($p=0.01$). The mean weight-bearing axis was corrected from 0.12 ± 0.16 to 0.39 ± 0.23 ($p=0.03$). There was no statistically significant change in the Insall–Salvati ratio or the proximal tibial slope comparing initial measurements to the measurements at final follow-up after the osteotomy was performed. The initial Insall–Salvati ratio was 0.98 ± 0.09 , and the final Insall–Salvati ratio was 1.03 ± 0.17 ($p=0.58$). The initial posterior slope measured $8.9 \pm 3.4^\circ$ compared to a final slope of $7.7 \pm 3.2^\circ$ ($p=0.12$) (Table 2).

Valgus malalignment

The mean initial anatomic axis measured $169 \pm 4.2^\circ$, and the mean final anatomic axis at final follow-up after osteotomy was $177 \pm 4.4^\circ$ ($p=0.04$). The mean weight-bearing axis was corrected from 0.70 ± 0.20 to 0.34 ± 0.19 ($p=0.04$). There was no statistically significant change in the Insall–Salvati ratio or the proximal tibial slope comparing initial measurements to the measurements at final follow-up after the osteotomy was performed. The initial Insall–Salvati ratio was 0.91 ± 0.16 , and the final Insall–Salvati ratio was 0.98 ± 0.13 ($p=0.66$). The initial posterior slope measured $7.7 \pm 3.5^\circ$ compared to a final slope of $7.3 \pm 2.8^\circ$ ($p=0.32$).

Table 1. Preoperative and postosteotomy range of motion measurements for patients with varus and valgus tibiofemoral malalignment

	Valgus Malalignment	Varus Malalignment
Extension		
Preoperative	0	$0.7 \pm 1.9^\circ$
Postoperative	0	$0.5 \pm 1.4^\circ$
Flexion		
Preoperative	$130 \pm 13.5^\circ$	$128 \pm 13.6^\circ$
Postoperative	$135 \pm 10.6^\circ$	$128 \pm 19.3^\circ$

Table 3. Outcomes scores after coronal plane high tibial osteotomy

	Valgus Malalignment	Varus Malalignment	p Value
Outcomes measures			
Tegner	4.8 ± 1.9	4.8 ± 2.0	0.76
HSS score	90.0 ± 14.5	87.7 ± 9.5	0.49

Postoperative scores

There was no statistically significant difference between the varus and valgus malalignment groups with regard to the Tegner score ($p=0.76$) and the HSS score ($p=0.49$; Table 3).

Varus malalignment

The mean Tegner activity score was 4.8 ± 2.0 . The mean HSS score was 87.7 ± 9.5 with 11 excellent results, six good results, and no fair or poor results. However, two patients underwent a total knee arthroplasty before final follow-up and did not have prearthroplasty HSS scores recorded. Using the final grades of the IKDC scoring system, two patients had an A, three patients had a B, three patients had a C, nine patients had a D, and the remaining two had a total knee arthroplasty before IKDC scoring.

Valgus malalignment

The mean Tegner activity score was 4.8 ± 1.9 . The mean HSS score was 90 ± 14.5 with four excellent results, one fair result, and no poor results. However, one patient underwent a total knee arthroplasty before final follow-up and did not have prearthroplasty HSS scores recorded. Using the final grades of the IKDC scoring system, three patients had a B, two patients had a D, and the remaining patient had a total knee arthroplasty before IKDC scoring.

Survival analysis

A Kaplan–Meier survival analysis was performed to determine the survival rate at 60 months of patients with either initial varus or valgus malalignment treated with the coronal plane high tibial osteotomy (Table 4). Using total knee arthroplasty as the benchmark for success, 84% of patients with initial varus malalignment and 80% of patients with initial valgus malalignment survived to 60 months ($p=0.62$), an insignificant difference. Using a good to excellent HSS score (>70) as a successful indicator, 84% of patients with initial varus malalignment had success compared to 60% of patients with initial valgus malalignment ($p=0.20$), again an insignificant difference.

Discussion

The clinical results of the coronal plane osteotomy are similar to the results of the closing and opening wedge osteotomy that are described in the literature. Using total

knee arthroplasty and the HSS knee score as the criteria for survival, the coronal plane osteotomy has an 84% success rate when treating varus malalignment, and a 60 to 80% success rate when treating valgus malalignment at 5-year follow-up. The survivorship of the closing wedge high tibial osteotomy has ranged from 50 to 87% at 5-year follow-up [26, 39–42]. The survival rate of the opening wedge high tibial osteotomy was 84% at 5 years in a recent study [23].

The amount of angular correction provided by the osteotomy has been correlated with clinical outcome. Knees with initial varus malalignment that were overcorrected into valgus alignment had the best clinical and radiographic results [40, 43–49]. Coventry showed that survivorship was dependent on the amount of correction. Knees with less than 5° of valgus angulation had a 63% survival at 10 years, whereas knees with 6 to 7° of valgus angulation had an 87% survival rate, and knees with 8° or more or valgus angulation had a 94% survival rate at 10 years [39]. Sprenger and Doerzbacher [42] showed that a valgus alignment of 8 to 16° at 1 year postoperatively significantly improved knee scores, patient subjective satisfaction, and increased survivorship at 5 years (95 vs 80%), 10 years (90 vs 55%), and 15 years (72 vs 34%) compared to corrections less than 8° of valgus or greater than 17° of valgus.

Coventry recommended an anatomic axis of 167 to 170° (10 to 13° of valgus) for valgus-producing osteotomies [19, 50]. Others have recommended correction ranging from 164 to 177° [46, 51–54]. The weight-bearing axis passes through the center of the knee when the anatomic axis is 171.7° (8.3° of anatomic valgus) [55]. In this study, the valgus-producing coronal plane osteotomy had a mean postoperative anatomic axis of $176.1 \pm 5.3^\circ$, which is less than that recommended in most studies in the literature. Although the valgus-producing coronal plane osteotomy did not provide as much angular correction as suggested in the literature, the clinical survival rates were similar to those of studies examining intermediate term follow-up of both closing and opening wedge osteotomies. Longer-term follow-up will be necessary to see if the results of this series deteriorate as a result of undercorrection.

For patients with varus malalignment, it was our intention to achieve a postoperative weight-bearing axis at the 62nd percentile, but correction was achieved at only 39th percentile. Thus, our method of determining correction intraoperatively using a plumb line from the femoral head to the ankle mortise was inaccurate. A more reliable angular correction (e.g., a jig or goniometer or computer navigation) might limit the amount of undercorrection that occurs in the future.

Coventry [56] recommended that patients with valgus malalignment be corrected to between 5° of valgus (anatomic axis of 175°) and 4° of varus (anatomic axis of 184°) but believed the optimal alignment was 0° (anatomic axis of 180°). The mean postoperative anatomic axis of the varus-producing coronal plane osteotomy in our study was $177.4 \pm 4.4^\circ$.

A common complication in closing wedge osteotomies is the loss of correction that range from 1.5 to 3.3° [26, 39, 47, 54, 57]. Progression of osteoarthritis and the return of pain is more prevalent in knees that had loss of initial correction

Table 4. Kaplan Meier survival curve for the coronal plane high tibial osteotomy

	Valgus Malalignment (%)	Varus Malalignment (%)	<i>p</i> Value
Failure criteria			
TKR	80	84	0.62
HSS<70	60	84	0.20

compared to knees that maintained the correction [43, 47, 58]. The mean loss of correction for both varus- and valgus-producing coronal plane osteotomies was only 0.6°.

No significant difference in the preoperative and postoperative Insall–Salvati ratio was found but that may be confounded by the small number of patients in this study. In addition, no significant difference was found in the preoperative and postoperative proximal tibial slope. These data suggests that the coronal plane osteotomy is a better option for preserving proximal tibia anatomy than both the closing wedge osteotomy and the opening wedge osteotomies. This anatomic preservation may improve postoperative knee kinematics, may decrease difficulty with surgical exposure when converting to knee arthroplasties, and may improve postarthroplasty function. Further studies are needed to determine if preservation of the anatomic tibial slope and relationship between the tibial tubercle and patella actually affects the aforementioned outcomes. The authors do acknowledge that there are situations that the alteration of the tibial slope with the classic osteotomies may be advantageous. Outcomes of osteotomies in the setting of ligamentous injuries may be improved with intentional increasing or decreasing the tibial slope [59]. In these situations, the closing wedge or opening wedge osteotomies should be considered over the coronal plane osteotomy.

Conclusion

The coronal plane high tibial osteotomy is a novel technique that is equally effective in treating both varus and valgus tibiofemoral malalignment. Although, the osteotomies did not achieve the intended amount of angular correction, the intermediate term results found in this study were similar to those of both the closing wedge and opening wedge osteotomies at a similar follow-up period. Unlike the closing and the opening wedge osteotomy, the coronal plane high tibial osteotomy does not alter the proximal tibial slope and the patellar–tibial tubercle relationship.

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