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Posteromedially placed plates with anterior staple reinforcement are not successful in decreasing tibial slope in opening-wedge proximal tibial osteotomy

Chase S. Dean[2] · Jorge Chahla[2] · Lauren M. Matheny[2] · Tyler R. Cram[1,2] · Samuel G. Moulton[2] · Grant J. Dornan[2] · Justin J. Mitchell[2] · Robert F. LaPrade[1]

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Abstract
Purpose To document the effectiveness of a novel technique to decrease tibial slope in patients who underwent a proximal opening-wedge osteotomy with an anteriorly sloped plate placed in a posteromedial position. The hypothesis was that posteromedial placement of an anteriorly sloped osteotomy plate with an adjunctive anterior bone staple on the tibia would decrease, and maintain, the tibial slope correction at a minimum of 6 months following the osteotomy.
Methods All patients who underwent biplanar medial opening-wedge proximal tibial osteotomy with anterior staple augmentation to decrease sagittal plane tibial slope were included, and data were collected prospectively and reviewed retrospectively. Indications for decreasing tibial slope included medial compartment osteoarthritis with at least one of the following: ACL deficiency, posterior meniscus deficiency, or flexion contracture. Preoperative, immediate postoperative, and 6-month postoperative radiographs were reviewed.
Results Twenty-one patients (14 males and 7 females) were included in the study with a mean age of 36.5 years. Intrarater and interrater reliability of slope measurements were excellent at all time points ($ICC \geq 0.94$, $ICC \geq 0.85$). The osteotomy resulted in an average tibial slope decrease of 0.8 from preoperative (n.s.). At 6-month postoperative, average slope was not significantly different from time-zero postoperative slope (mean $= +0.2°$).
Conclusions The most important finding of this study was that posteromedial placement of an anteriorly angled osteotomy plate augmented with an anterior staple during a biplanar medial opening-wedge proximal tibial osteotomy did not decrease sagittal plane tibial slope. Whether a staple was effective in maintaining tibial slope from time zero to 6 months postoperatively was unable to be assessed due to no significant change in tibial slope from the preoperative postoperative states. The results of this study note that current osteotomy plate designs and surgical techniques are not effective in decreasing sagittal plane tibial slope.
Level of evidence IV.

Keywords Proximal tibial opening-wedge osteotomy · High tibial opening-wedge osteotomy · Posterior tibial slope · Sagittal plane tibial slope · Tibial staple

Introduction

Opening-wedge proximal tibial osteotomy has been reported to produce good to excellent outcomes when addressing the coronal plane alignment of the knee [5]. However, the importance of biplane alignment correction with osteotomies is also becoming increasingly recognized [3, 8]. While correction of coronal plane malalignment has been a reported goal of proximal tibial osteotomies, sagittal plane correction can be equally as important, especially in patients with cruciate ligament or posterior meniscus deficiency, or in patients who have an extension deficit [1, 3, 9]. Benefits to decreasing the tibial slope in these patients may include: decreased anterior tibial translation in ACL-deficient patients, decreased load on the posterior meniscus

✉ Robert F. LaPrade
drlaprade@sprivail.org

1 The Steadman Clinic, 181 West Meadow Drive, Suite 400, Vail, CO 81657, USA

2 Steadman Philippon Research Institute, 181 West Meadow Drive, Suite 400, Vail, CO 81657, USA

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is patients with posterior meniscal insufficiency, and the ability to achieve greater extension in patients with extension deficits [1, 3, 9].

In order to decrease the tibial slope, few methods have been proposed, including posteromedial placement of an anteriorly angled wedge plate without further adjunctive fixation to secure the osteotomy [18, 27]. However, it has been reported in a prospective study evaluating different plate positions that this technique alone may lead to increases in tibial slope, and is unable to maintain tibial slope correction between immediate postoperative and 6-month postoperative time periods [18]. To address the potential loss of correction over time, additional fixation with an anteriorly placed tibial staple may aid in maintaining the tibial slope in patients undergoing a biplanar medial opening-wedge proximal tibial osteotomy by fixing the anterior cortex immediately after the osteotomy has been performed.

The purpose of this study was to determine whether a posteromedial placed and anteriorly sloped angle osteotomy wedge plate would decrease the sagittal tibial slope in patients who underwent a proximal opening-wedge osteotomy, and whether an anterior cortical staple would maintain the tibial slope over time. To our knowledge, the use of a cortical staple to maintain a decrease in tibial slope has not been previously reported. The hypothesis was that posteromedial placement of an anteriorly sloped osteotomy plate with an anterior bone staple on the tibia would decrease and maintain the tibial slope correction at a minimum 6 months following the osteotomy.

Materials and methods

Patient data were prospectively collected, and a retrospective review was performed on skeletally mature patients 16 years and older who underwent a biplanar medial opening-wedge proximal tibial osteotomy with anterior staple augmentation in order to decrease the sagittal plane tibial slope. Indications for a decrease in tibial slope included at least one of the following: ACL deficiency, posterior medial meniscus deficiency with or without ipsilateral posterior articular cartilage joint wear or flexion contracture. All procedures were performed by a single surgeon (initials blinded for review) between 2010 and 2014. Patients were required to have radiographic examination at preoperative, immediate postoperative (time-zero), and minimum 6-month postoperative time points. Patients were excluded if they did not have complete radiographic films for all 3 time points or did not meet any of the inclusion criteria. Patients were also excluded if their radiographic films were low quality and the tibial slope was unable to be measured.

Radiographic examination and diagnosis

Preoperative radiographic evaluation consisted of single long-leg standing anteroposterior (AP) alignment radiographs, AP standing knee radiographs, and lateral radiographs with the knees flexed to 30º. Additionally, posterior kneeling stress radiographs [14] and varus [17] or valgus stress [16] radiographs at 20° of knee flexion were used in patients with suspected ligament injuries on a case-by-case basis.

Radiographic measurement

The mechanical axis of the knee was measured at initial clinical evaluation using long-leg standing radiographs. Long-standing alignment is reported as a percentage across the tibial plateau with the border of the medial tibial plateau noted as 0 %, and the lateral border reported as 100 %. Genu varus malalignment was defined as a mechanical axis passed medial to the apex of the medial tibial eminence (41 %) [19]. The correction of genu varus malalignment was preoperatively planned so that the corrected mechanical axis passed through the apex of the lateral tibial eminence as previously described [2].

Tibial slope was defined as the angle between the medial tibial plateau and a line perpendicular to the mid-diaphysis of the tibia. The tibial mid-diaphyseal line was centred through the tibial shaft using two digitally created circles (OrthoCase, Merge Healthcare Inc., Chicago, IL). These circles were sized and positioned so that the anterior and posterior borders of the tibia were tangential to their circumference and the diameters were equal to the width of the tibial shaft. A line was first drawn through the centres of these two circles, and a second line was drawn from where the first line intersected the tibial plateau and extended along the medial tibial plateau (Fig. 1) [18, 24]. The angle between the first and second lines was subtracted from 90° to obtain the sagittal plane tibial slope. The tibial slope was recorded at three time points: preoperative, immediate postoperative (time zero), and 6 months postoperative. All measurements were performed by two independent reviewers (T.R.C, J.C.) and entered into a password protected database.

Surgical technique

The technique consisted of an anteromedial skin incision that was equal distance from the tibial tubercle and the posteromedial border of the tibia, extending approximately 6–8 cm. Two guide pins were placed parallel to the joint line under fluoroscopic guidance in the coronal plane and adjusted as necessary in the sagittal plane to achieve the desired slope of the tibia depending on each case. This correction was based on returning the patient to a more normal tibial slope, while understanding that the plate only accommodates correction of four degrees. The osteotomy was performed to within 1 cm of the lateral cortex. A spreader device was used to slowly open the osteotomy to the desired amount of coronal and sagittal plane correction and left in place for several minutes to allow for stress relaxation of the lateral cortex. Slope correction was controlled under fluoroscopic guidance. After approximately 5 min, the spreader was removed and two calibrated osteotomy tines (previously marked to the planned opening height) were placed into the osteotomy site in order to confirm and sustain the desired amount of medial opening prior to plate positioning. An angle-stable wedge osteotomy plate (Puddu plate, Arthrex, Naples, FL) was then inserted on the posteromedial tibial cortex (Fig. 2), the tines were removed, and the plate secured with two fully threaded 6.5-mm cancellous screws proximal to the osteotomy and two fully threaded 4.5-mm bicortical screws distal to the osteotomy.

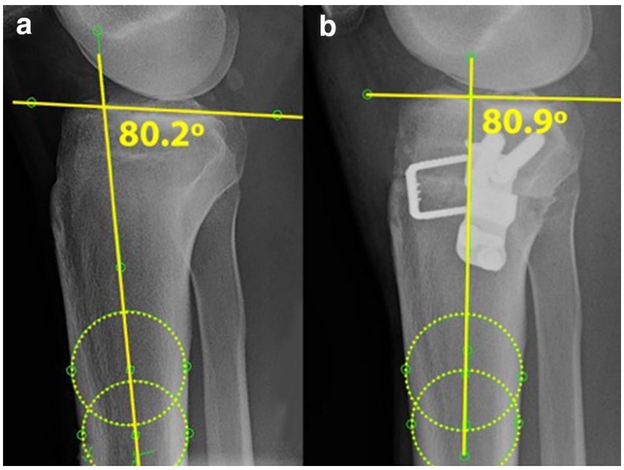

Fig. 1 **a** Preoperative and **b** immediate postoperative lateral radiographs of a right knee with the method used to measure the sagittal tibial slope superimposed on the radiographs. The tibial *mid-diaphyseal line* was centred through the tibial shaft using two digitally created *circles* that were positioned so that the anterior and posterior borders of the tibia were tangential to their circumference and the diameters were equal to the width of the tibial shaft. A *line* was drawn through the centres of these two *circles*, and another line was drawn from where the first line intersected the tibial plateau and extended along the medial tibial plateau. The angle between the first and second lines was subtracted from 90° to get the sagittal tibial slope. Despite the posteromedial placed plate and the anterior cortical staple seen in Fig. 1b, the tibial slope slightly decreased (9.8°–9.1°) according to the preoperative measurement

After securing the plate, a large staple was placed anteriorly on the tibia just posterior to the medial edge of the patellar tendon while hyperextending the knee and under fluoroscopic guidance, in an effort to maintain sagittal plane correction postoperatively (Fig. 3). The osteotomy was then bone grafted with demineralized allograft bone matrix, and confirmation of placement was confirmed with fluoroscopy (Fig. 4).

Rehabilitation protocol

Postoperatively, patients were non-weightbearing for 8 weeks and initiated passive range of motion at day one. Patients were instructed to perform isometric quadriceps exercises, and straight-leg raises a minimum of 4 times daily while wearing a knee immobilizer (locked at 0° of flexion when not working on knee motion for 8 weeks). A minimum range of motion of 90° was expected at 2 weeks postoperatively. Partial weightbearing on crutches was

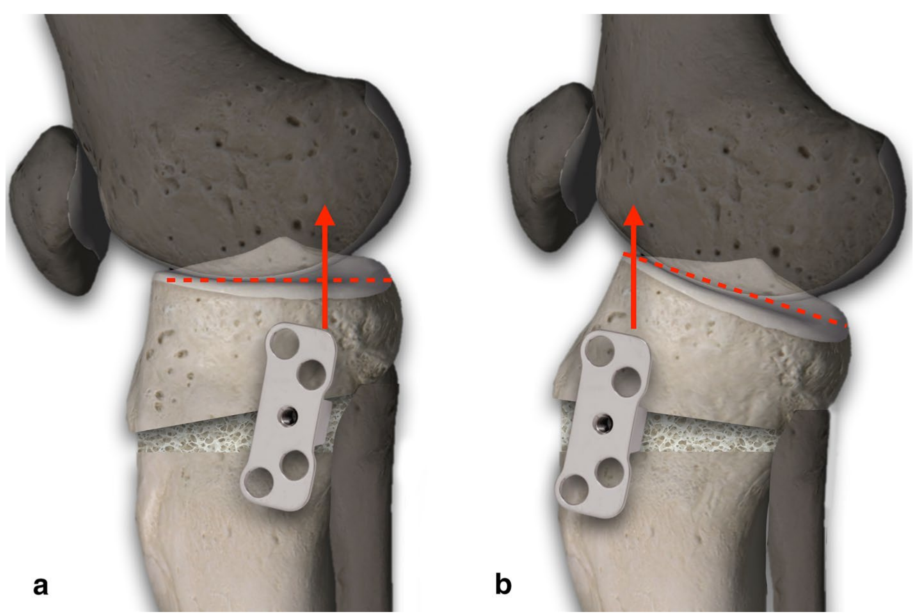

Fig. 2 Illustration of how a posteromedial placed plate (*left*) can theoretically decrease the tibial slope, while an anteromedial placed plate (*right*) can increase tibial slope on a right knee

initiated at week 8 postoperatively, starting with 25 % bodyweight and increasing by 25 % each week until fully weightbearing at 12 weeks. This study was approved by the institutional review board at the Steadman Philippon Research Institute (#2002–03) following individual patient consent.

Statistical analysis

Given the repeated measures design and assuming an overall alpha level of 0.05 with a Bonferroni correction for three pairwise comparisons, 21 subjects were sufficient to detect an effect size of $d = 0.76$ with 80 % statistical power. Pairwise t tests were used to compare mean slope among the three time points. Equal group variances of the differences (sphericity) were not assumed, and the multiple comparisons problem was addressed with the Holm's sequential Bonferroni procedure.

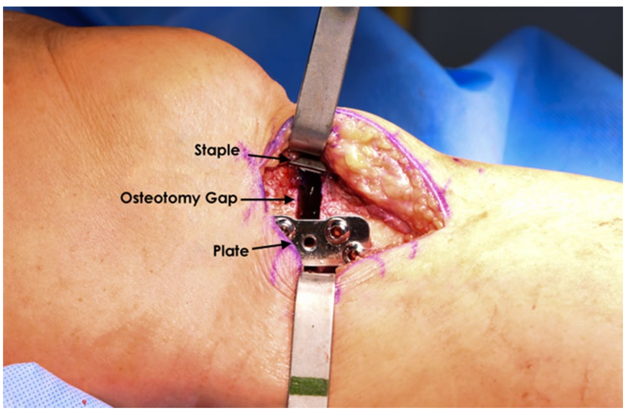

Fig. 3 Intraoperative photograph of a posteromedial placed plate and an anterior cortical staple placed after a medial opening-wedge proximal tibial osteotomy has been performed, but before the bone graft has been inserted into the osteotomy site. (Left knee)

Tibial slope measurements were made by two researchers independently, and one investigator made a second round of measurements 2 weeks after the initial round. Interrater and intrarater reliability were assessed using the two-way random-effects, single measures absolute agreement definition of the intraclass correlation coefficient (ICC). ICCs are reported with nonparametric 95 % bootstrap confidence intervals. Additionally, to aid in clinical relevance, Bland–Altman analysis (average bias ± 2*SD of the difference) was conducted to judge the measurement agreement in the units of the slope angle (degrees). All further data analysis utilized the first round of measurements from the primary rater. The statistical software R, with packages *psy* and *boot*, was used for all analysis [6].

Measurement reliability

Interrater and intrarater reliability results are presented in Table 3. Intrarater reliability was excellent at all time points (ICC > 0.94), with average bias between two rounds of measurements no greater than 0.3° and 95 % limits of agreement (LOAs) within ± 3°. Interrater reliability exhibited higher bias of approximately 1.5° difference between the two raters. The intraclass correlation coefficients (ICCs)

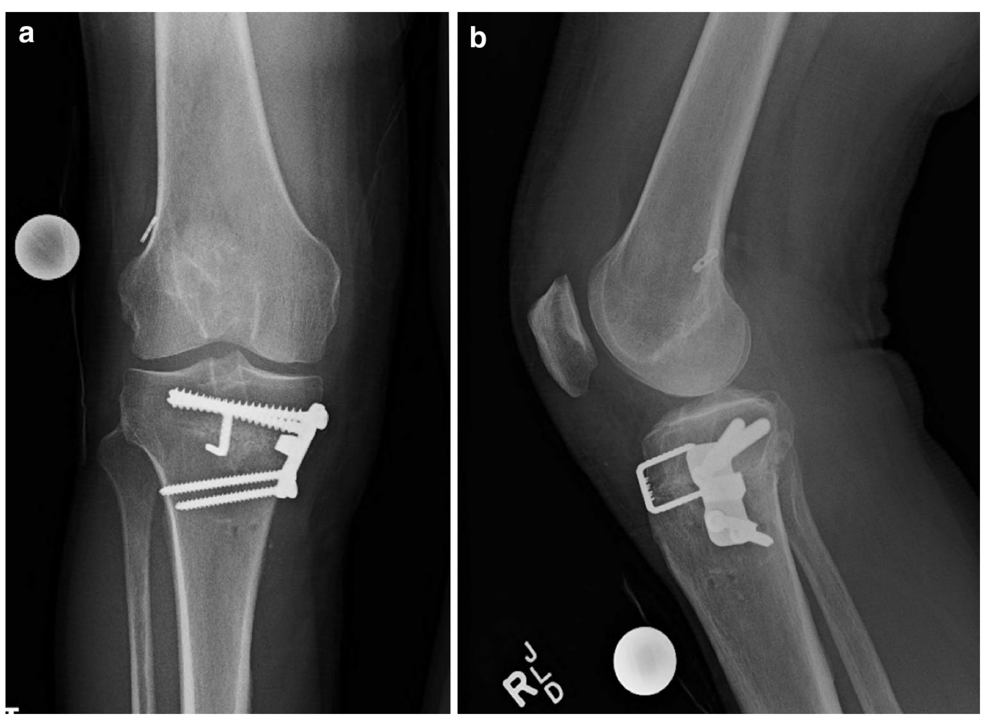

Fig. 4 Anteroposterior (**a**) and lateral (**b**) postoperative radiographs following a biplanar proximal tibial osteotomy with a posteromedially positioned plate and an adjunctive anterior staple

for interrater agreement were at least 0.85 for all time points. Mechanical axis (described in percentage) and slope (degrees) were measured using a PACS system (Centricity PACS, GE Medical System Information Technologies, Milwaukee, Wisconsin). Both measurements were reported to one decimal, which was the native accuracy of the imaging software.

Table 1 Concomitant procedures performed at the time of biplanar osteotomy in this patient cohort

Concomitant procedures	*n* (%)
OAT	5 (23.8)
Meniscus repair	2 (9.5)
Microfracture	1 (4.8)

OAT osteochondral allograft transplantation

Results

There were 33 patients who had a proximal tibial opening-wedge osteotomy between 2010 and 2014. Twelve patients were excluded from this study. Eleven patients were removed due to the lack of staple fixation and anteromedial plate placement, and 1 patient was removed due to substandard radiographic films. Twenty-one patients (14 males and 7 females) with a mean age of 36.5 years (range 16.4–56.0 years) were

Table 2 Age at time of surgery, sex, and indications for decreasing the tibial slope for each patient

Patient	Age at surgery	Sex	Indication to decrease slope
1	30	M	Posterior meniscus deficiency
2	45	M	Extension deficit
3	16	M	ACL deficiency
4	45	M	Posterior meniscus deficiency
5	46	F	Posterior meniscus deficiency
6	18	F	ACL deficiency + posterior meniscus deficiency
7	39	F	ACL deficiency
8	40	M	Extension deficit
9	43	F	ACL deficiency + posterior meniscus deficiency
10	23	M	Extension deficit
11	56	M	Posterior meniscus deficiency
12	49	F	Extension deficit + posterior meniscus deficiency
13	49	F	Posterior meniscus deficiency
14	30	M	Extension deficit
15	17	M	ACL deficiency + posterior meniscus deficiency + extension deficit
16	34	M	Posterior meniscus deficiency
17	22	M	Extension deficit
18	46	M	Posterior meniscus deficiency
19	20	M	Extension deficit + posterior meniscus deficiency
20	55	M	Extension deficit
21	34	F	Extension deficit

Table 3 Tibial slope measurement agreement

	Time	*n*	ICC	95 % CI LB	95 % CI UB	Bias	Lower LOA	Upper LOA
Interrater agreement	Preop	21	0.868	0.769	0.94	−1.3	−4.6	2.1
	Time 0	21	0.856	0.731	0.951	−1.6	−4.8	1.6
	6 months	21	0.85	0.561	0.943	−1.5	−5.2	2.2
Intrarater agreement	Preop	21	0.943	0.875	0.975	0.1	−2.6	2.8
	Time 0	21	0.969	0.929	0.989	−0.1	−2.2	2.0
	6 months	21	0.957	0.887	0.984	0.3	−2.0	2.5

ICC is the intraclass correlation coefficient, reported with nonparametric 95 % bootstrap confidence intervals. Bland–Altman analysis reports the average bias ±2 *SD of the difference (lower LOA and upper LOA, respectively)

CI confidence interval, *preop* preoperative, *LB* lower bound, *UB* upper bound

Table 4 Radiographic measurements for each patient, including all 3 tibial slope time point measurements and preoperative and postoperative mechanical axis

	Preoperative tibial slope	Postoperative tibial slope (time 0)	Postoperative tibial slope (6 months)	Preoperative mechanical axis	Postoperative mechanical axis
Mean ± SD	10.1 ± 3.9	9.3 ± 4.3	9.5 ± 3.9	23.7 ± 9.5	49.0 ± 9.9
Median [min, max]	9.2 [4.3, 18.2]	9.7 [2.3, 19.0]	9.4 [1.9, 18.5]	25.3 [6.0, 36.4]	48.6 [31.5, 73.1]

Not all patients returned for postoperative standing long-leg radiographs; therefore, postoperative mechanical axis is not reported in all patients

Table 5 Group comparisons of tibial slope

	Mean difference	CI LB	CI UB	Holm *p* value
Preoperative versus Time 0	−0.8	−2.4	+0.7	(n.s.)
Preoperative versus 6 Months	−0.6	−2.1	+0.9	(n.s.)
Time 0 versus 6 Months	+0.2	−0.3	+0.8	(n.s.)

p value is adjusted for multiplicity using the Holm–Bonferroni procedure

CI 95 % confidence interval, *LB* lower bound, *UB* upper bound

included. The median body mass index was 26.7 (range 20.7–44.6). Concomitant treatments are listed in Table 1. The age at time of surgery, gender, and indications for decreasing the tibial slope are listed in Table 2.

Mechanical axis

The mechanical axis was measured preoperatively for all patients (21/21), using long-leg standing radiographs. The average preoperative mechanical axis was 23.7 ± 9.5 % across the tibial plateau. Postoperative long-leg standing radiographs demonstrated an average mechanical axis of 49.0 ± 9.9 % (Table 3).

Radiographic analysis of sagittal plane tibial slope

The osteotomy procedure resulted in a non-significant average decrease in tibial slope of 0.8º relative to the preoperative slope (n.s.), (Table 4. At 6 months postoperative, the average slope was not significantly different from the time-zero slope (mean = + 0.2°, n.s.) (Table 5).

Complications

Of the 21 patients included in this study, 7 (33 %) reported complications. The most common complication ($n = 4$, 19 %) was hardware irritation justifying removal of hardware. The mean time from surgery to hardware removal was 17.5 months (range 9–33 months). The most serious complication was a small pulmonary embolism in 1 patient (5 %) that was successfully treated with anticoagulation. Two patients (10 %) developed superficial infections postoperatively that were successfully treated with oral antibiotics. One patient (5 %) required an incision and drainage of a haematoma, but removal of hardware was not required.

Discussion

The most important finding of this study was that posteromedial placement of an anteriorly angled osteotomy plate during biplanar medial opening-wedge proximal tibial osteotomy did not decrease sagittal plane tibial slope. As a result, the secondary hypothesis of this study regarding maintaining tibial slope correction with an anterior cortical staple was unable to be assessed. Several studies have reported that osteotomy plate placement has an effect on tibial slope; however, the ideal method to achieve a decrease in tibial slope remains unclear.

A prospective study by LaPrade et al. [18] demonstrated a larger increase in tibial slope with an anteromedial placed plate, compared to the posteromedial placed plate. Additionally, the authors reported that a decrease in tibial slope was not attained from posteromedial plate placement, which may have been due to a lack of fixation along the anteromedial portion of the osteotomy or that current plates designs do not allow for proper posteromedial positioning. A biomechanical study reported similar findings by demonstrating increased slope regardless of plate location. However, the authors reported that an anteromedial placed plate resulted in a 6.6° greater increase in tibial slope compared to a posteromedial placed plate [27]. Madry et. el [22] further emphasized the importance of instrument placement, stating that the osteotomy spreading device should be placed posteriorly to achieve parallel opening of the osteotomy, thereby avoiding an increase in the slope. While there was not a significant decrease in tibial slope in the current study, the slope did not increase either, which may be due to the posteromedial plate placement.

In this study, a medial opening-wedge osteotomy was utilized to correct both varus malalignment of the knee and the sagittal tibial slope. Although biplanar correction can be achieved with both closing-wedge and opening-wedge osteotomies, the previous literature contends that an opening-wedge osteotomy may be advantageous compared to a closing-wedge osteotomy due to various factors. Closing-wedge osteotomies can be technically demanding because of anatomical proximity to the common peroneal nerve, and may be less accurate due to the requirement of two cuts in the proximal tibia [12]. In addition, bone stock is reduced in a closing-wedge osteotomy and the medullary canal may acquire an eccentric position, making a future total knee arthroplasty more challenging [7, 13, 26]. Despite the mentioned limitations to closing-wedge osteotomies, use of a closing-wedge osteotomy may be beneficial in the patient population described in the present study because of its ability to decrease tibial slope.

Although the opening-wedge osteotomy with a posterior plate placement succeeded in correcting varus knee alignment, there was no significant difference in tibial slope in the present study. However, based on previous studies demonstrating a postoperative increase in sagittal slope despite posterior placement of a plate in a similar group of patients [18], the placement of an adjunctive staple may have a role in prevention increased tibial slope. Further, placement of the cortical hinge may be varied for specific correcting of the sagittal slope [9, 10, 15, 20, 21, 23, 28]. While this cannot be fully elucidated based on present results, the findings from the present study suggest that the addition of an anterior staple to the construct may have a benefit preventing undesired increases in slope, and further suggests that additional clinical and radiological studies are necessary to determine the most effective way to alter tibial slope with the use of high tibial osteotomy.

Decreasing tibial slope can be beneficial to certain patient populations [1, 3, 4, 11, 25]. A recent study by Arun et al. [3]. examined patients with ACL deficiency with medial compartment osteoarthritis and varus malalignment who underwent a medial opening-wedge osteotomy and a posteriorly placed tricortical bone graft with the aim of decreasing the tibial slope. Patients whose tibial slope decreased by more than 5° compared to the preoperative value had significantly ($p < 0.05$) better functional outcomes scores (IKDC and Lysholm score) at 2 years postoperatively. Giffin et al. [11] demonstrated that increasing the tibial slope resulted in increased anterior tibial translation relative to the femur that was accentuated during axial loading. They hypothesized that decreasing the tibial slope may therefore be protective in an ACL-deficient knee by increasing stability. Furthermore, this change in anteroposterior translation of the tibia may have effects on the meniscus. Particularly, decreasing the tibial slope with a subsequent decrease in anterior translation of the tibia may be beneficial for patients with a posterior meniscus deficiency, decreasing load on the meniscus [11]. Additionally, it has been reported that an increased tibial slope requires increased quadriceps strength to achieve full knee extension [1]. As a result, decreasing the slope may help with extension deficits.

The authors recognize some limitations of this study. First, there was no control or comparison group in this study. The lack of a comparison group in this study may limit the findings, as we were unable to compare a posterior plate placement to a more anterior or central one. We were also unable to compare a group that underwent correction without the adjunctive staple fixation as there were insufficient patients from which to perform an accurate match based on body mass index (BMI), age, comorbidities, etc. Further, establishing an appropriate comparison group would be difficult for this population, as a control group would necessarily include patients treated using a differing technique and during a different time period before the current technique was utilized. The use of malleable allograft bone material could also induce the potential for motion at the osteotomy side while healing is taking place; however, potential affects of the bone graft are likely mitigated by the plate and staple construct. The medical centre in which patients were treated is a tertiary referral clinic, and therefore, the sample may not be representative of the general population. The use of a single technique performed by the same experienced surgeon diminishes variability within the study considerably; however, generalizability for other practices with multiple surgeons may be diminished. The sample size in this study was small and future studies could benefit from a larger sample size.

The results of this study note that current osteotomy plate designs and surgical techniques are not effective in decreasing sagittal plane tibial slope. In those cases where a flattening of the tibial slope is desired, such as in revision ACL surgery, one must take extra caution to ensure that the tibial slope is decreased and not solely rely on an angled osteotomy plate to accomplish this.

Conclusions

This study found that a posteromedial placed anteriorly angled wedge plate augmented with an anterior staple was not able to decrease sagittal tibial slope during a medial opening-wedge proximal tibial osteotomy. In order to decrease the tibial slope, a differently designed osteotomy plate than what is currently available may be required. Once new plate designs become available, outcomes studies will be necessary to determine whether plate placement may aid in the ability to decrease the tibial slope. After the tibial slope can be reliably decreased, an anterior cortical staple can be investigated to determine whether the additional fixation may aid in stabilization of the sagittal correction over time.

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Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

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Ethical approval This study was approved and performed in accordance with the standards set forth by our institutional review board.

Informed consent Informed consent was obtained for each patient in the study prior to the surgical procedure.

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