Radiographic and clinical outcomes of slope and varus correction anterior closing wedge tibial osteotomy for primary anterior cruciate ligament injuries with steep posterior tibial slope, varus knee deformity, and medial meniscal posterior root tears

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Research Article

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Abstract

Background: previous biomechanical studies have investigated the influence of coronal and sagittal correction high tibial osteotomy in ACL-reconstructed knees. However, no studies have reported its clinical application. Our objective was to evaluate the radiological and clinical results after simultaneous slope and varus correction anterior closing wedge tibial osteotomy (ACWTO) and anterior cruciate ligament (ACL) reconstruction in patients with ACL deficiency combined with steep posterior tibial slope (PTS), varus deformity, and medial meniscal posterior root tear (MMPRT).

Methods: Between January 2018 and December 2021, 5 patients with ACL injuries who had steep PTS, varus deformity, and concomitant MMPRT underwent slope and varus correction ACWTO combined with primary ACLR. The mean follow-up duration was 26.2 months. Preoperative and postoperative radiological assessments included the degree of the femoral tibial angle (FTA), PTS, progression of medial osteoarthritis . For clinical outcomes, we evaluated KT-1000 side-to-side difference, pivot-shift test, International Knee Documentation Committee (IKDC) score, Lysholm score and Tegner activity score preoperatively and at the last follow-up.

Results: The mean PTS was 17.0° (range, 16°-19°) preoperatively and 7.8° (range, 6°-9°) postoperatively (P <0.01). The mean FTA was 5.6° (range, 5°-7°) preoperatively and -0.6°(range, -2°-0°) postoperatively (P < 0.01). According to the Kellgren-Lawrence classification, 4 patients was grade 1, and 1 patient was grade 2 at the last follow-up. All patients showed statistically significant improvements in knee stability (pre- vs postoperatively: mean side-to-side difference, 9.2 mm vs 0.6mm; and pivot-shift test, 2 grade I and 3 grade II vs 5 grade 0). All patients showed statistically significant improvements in function (pre- vs postoperatively: mean IKDC score, 48.8 vs 89.4; mean Lysholm score, 48.2 vs 93.0; and Tegner activity score, 4.0 vs 6.8). Moreover, no graft rerupture were found at the last follow-up.

Conclusion: Slope and varus correction ACWTO combined with primary ACLR is a safe and effective procedure to improve knee stability and function in patients with ACL tear, steep PTS, varus knee deformity, and MMPRT.

Background

Arthroscopic anterior cruciate ligament reconstruction (ACLR) is the most common surgical treatment to control anterior laxity associated with anterior cruciate ligament (ACL) deficiency [22]. For patients who have undergone anterior cruciate ligament reconstruction (ACLR), subsequent graft rupture is unacceptable. Unfortunately, despite graft failure continues occur and then may be the candidate for ACLR revision.

Previous studies reported that varus malalignment can lead to excessive abnormal loading of the medial compartment and ACL, resulting in increased ACL graft tension and pooer clinical outcomes[9,23,27]. Not only coronal deformity of lower extremity affects the biomechanical environment of ACL, but also sagittal deformity. In recent years, there is growing evidence demonstrated that posterior tibial slope (PTS) is a risk factor for ACL reconstruction failure [7,19,29,30]. Therefore, the role of reducing PTS has gradually gained more and more interest in the setting of ACLR revision. Biomechanically, tibial slope will generate a greater anterior shear force in the tibiofemoral joint[6], leading a greater force on graft, and this graft force is linearly associated with PTS[2]. For patients with ACL injury combined with bone deformity of the lower extremity, although isolated ACLR is helpful to improve the stability of the knee, the newly reconstructed ACL graft may fail due to excessive stress, resulting early osteoarthritis of the knee.

Correction of coronal and sagittal malalignment in the setting of ACL insufficiency provides a difficult challenge to the surgeon. Slope and varus correction anterior closing-wedge osteotomy (ACWTO) is a new procedure of correcting increased PTS in sagittal plane and varus deformity in coronal plane. Biomechanically, Imhoff et al[10] demonstrated that slope and varus correction ACWTO can significantly decrease the anterior tibial translation and ACL graft forces. However, there is no clinical studies reported such combined procedures.

The aim of the present study was to assess clinical outcomes of slope and varus correction ACWTO for ACL injuries with varus knee and increased PTS. It was hypothesized that such combined procedures can effectively restore knee stability, reduce PTS, and yield satisfactory clinical outcomes. To our best knowledge, this is the first study reported the clinical results of this combined procedure.

Materials And Methods

From January 2018 to December 2021, patients who underwent ACL reconstruction combined slope and varus correction ACWTO at the orthopedic department of our hospital were prospectively enrolled. Our surgical indication of ACL reconstruction combined slope and varus correction ACWTO were as follows: (1) ACL injury is associated with severe anterior tibial instability and is required ACL reconstruction; (2) PTS□13°□According to julliard et al. 's measurement□ (3) varus deformity (more than 5°); (4) medial meniscal posterior root tears (MMPRT) confirmed by preoperative MRI and arthroscopic exploration.

The inclusion criteria were as follows: (1) aged over 16 years; (2) complete ACL rupture confirmed by arthroscopic exploration; (3) a minimum 2-year follow-up;(4) unilateral ACL injury. The exclusion criteria were as follows: (1) first or second ACL revision; (2) combined other ligamentous laxities; (3) high-grade positive pivot shift test result (□grade 3, gross), and need for lateral extra-articular tenodesis (5) generalized joint laxity (Beighton score□5); (6) presence of radiological signs of arthritis on plain radiographs of the lateral compartment according to the Kellgren-Lawrence classification[13]. This study was approved by the Institutional review board.

Radiological Assessment For PTS

All included patients underwent anteroposterior and lateral weightbearing whole leg radiographs (Figure 1). PTS is calculated from lateral radiographic image according to a previously established measurement technique[12]. The PTS was defined as the angle between a line drawn along the anatomic axis of the medial tibial plateau and the perpendicular line of the mechanical axis of the lower leg. In addition, the measurement of the femoral tibial angle (FTA) on coronal plane and presence of radiological signs of arthritis according to the Kellgren-Lawrence classification also can be obtained from whole-leg radiographs. All measurements were made by two independent senior radiologists.

Surgical Procedures

All surgical procedures were performed by 2 senior surgeons (JC.L. and Z.L.). Surgery was performed with the patient under general anesthesia with a femoral nerve block. The patient was positioned supine on a radiolucent table with a narrow cuff tourniquet at the root of the thigh and a lateral post at the level of the tourniquet.

Knee arthroscopic evaluation was firstly performed through standard anteromedial and anterolateral portals and all intra-articular structures of the knee were examined. Hamstring (gracilis and semitendinosus) tendons were harvested through a 3 cm incision on anteromedial surface of the proximal tibia at the level of tibial tubercle. The diameter of the graft must be at least 8mm. Two-tunnel transtibial pull-out MMPRT repair was performed using the PDS suture (Deputy) (Figure 2). Two sutures were placed in a vertical, simple suture configuration. Thereafter, two tibial tunnels were created using an anterior cruciate ligament reconstruction tibial tunnel guide (Smith & Nephew), with its tip in contact with the attachment site of the posterior root. Stitched sutures were passed through the Epidural needle through the tibial tunnel and then pulled out through the tibial tunnel entry.

With arthroscopic assistance, femoral tunnel was prepared through the anteromedial portal at the midpoint between anteromedial and posterolateral bundle by using the standard inside-out technique. The tibial guide was placed at 55°and taken from the external cortex into the center of the ACL tibial footprint, and a guide K-wire was inserted. And then, slope and varus correction ACWTO was performed though 2cm medial to the tibial tuberosity with a 10-15 cm anterior longitudinal incision. With the fluoroscopic guidance, two parallel 2.0-mm K-wires are obliquely inserted from both side of the distal patellar tendon toward the posterior tibial cortex, aiming for the insertion site of the posterior cruciate ligament. These two parallel Kirschner wires formed the first plane of the osteotomy. Based on preoperative measurements, the second distal osteotomy line on tibial was marked to ensure achieve proper correction. Next, two 2.0-mm K-wires were placed distal to the previously mentioned placed pins with aim of converging the pins just anterior to the posterior cortex. These two additional Kirschner wires formed the second plane of the osteotomy. These 4 pins consisting of two osteotomy planes ensures that the osteotomy bone is wedge-shaped on both the sagittal and coronal planes, and will serve as the guide for the bone cuts for the closing wedge osteotomy (Figure 2). After the anterior bony segment was resected, the anterior fracture was closed and temporarily fixed with two 2.0-mm K-wires. And then, the fluoroscopy was performed to measure corrected PTS and mechanical axis. When the desired correction was achieved, fixation was performed using the TomoFix instrumentation system, and ensure that the

TomoFix plate did not interfere with tibial tunnel (Figure 2). The tibial tunnel was sequentially reamed the same size as the 4-strand hamstring tendon autografts. The Rigidfix cross pin system (DePuty) was used foremoral-side fixation. The ACL graft was tensioned while the knee was moved through full range of motion for 20 cycles. Then tibial fixation was performed with Intrafix interference screw system (DePuty) at 30° knee flexion. Finally, the previously stitched sutures were manually tensioned and tied using a surgeon's knot at 30° knee flexion

Postoperative Protocol

The rehabilitation protocol was identical for all patients. All patients were to remain non-weightbearing for 6 weeks and in a dynamic knee hinged knee brace. Isometric quadriceps exercise, ankle pump, straight leg exercise was started as soon as possible. Early rehabilitation is focused on pain and swelling control, knee range of motion (ROM) training, quadriceps control. ROM exercises aimed at obtaining full extension in early stage, and obtaining at least 90° flexion at fourth weeks. After the sixth week, the goals were to regain full ROM and muscle function. Partial weight-bearing allowed after the 4 postoperative weeks, and full weight bearing is allowed after 8 weeks, depending on results of radiological confirmed bony consolidation. Another goal was for patients to start non-pivoting sports at 4 months, and to return preinjury level of sports activities at 9 months to 12 months.

Evaluation Criteria

For radiologic evaluation, preoperative and at the final follow-up PTS and mechanical axis were assessed with weightbearing lateral radiographs of the whole lower extremity using the method as previously mentioned.

Knee stability evaluation consisted of side-to-side difference in anterior tibial translation (ATT), the grade of Lachman test and pivot-shift test at preoperative and final follow-up. ATT was measured using the KT-1000 arthrometer with the knee in 20° of flexion. The Lachman test was graded as 0 (0–2 mm), 1 (3–5 mm), 2 (6–10 mm), or 3 (>10 mm). The pivot shift test was graded as 0 (absent), 1 (glide), 2 (clunk), 3 (gross). The grade of Lachman test and pivot-shift test were independently determined with two experienced knee surgeons (JC.L. and Z.L.).

Kee functional measures included patient reported outcomes (Lysholm knee score[16], IKDC subjective knee score[8], Tegner Activity Level Scale[26]).

Statistical Analysis

Statistical analysis was performed using SPSS 20.0 software (IBM). Preoperative and final follow-up outcome measures were compared. The paired Student *t* test or Wilcoxon signed-rank test was used to compare continuous variables according to the assumption of normality and homoscedasticity. A *P* value < 0.05 was considered statistically significant.

Results

Patient Demographic Data

Between January 2018 to October 2020, 6 patients met the selection criteria. One patient was excluded for failed to attend follow-up visits despite efforts to contact them, with the remaining 5 patients completing preoperative and subsequent minimum 2-year postoperative surveys. 1 patient had hyperextension (□5°) at the time of the final follow-up visit. No complications were occurred in other patients, and all osteotomies were radiologically united at 1 year.

Demographics and characteristics of 5 patients are presented in Table 1. A total of 5 patients (4 male, 1 female) were included at a median follow-up of 26.2 (24-30) months and with a median age of 29.6 (21-35) years at the time of surgery.

Table1

Patient Demographics and Characteristics[a]

	Patient 1	Patient 2	Patient 3	Patient 4	Patient 5
Sex	male	Female	male	male	male
Age,y	21	29	35	30	33
BMI	19.2	21.2	26.6	25.7	24.2
Side	right	Right	left	Right	Left
Follow-up, mo	24	24	27	30	26
Repair technique for MMPRT	Pull-out	Pull-out	Pull-out	Pull-out	Pull-out
Pre PTS,°	16	19	17	17	16
Pre FTA□°	5	5	6	5	7
Kellgren-Lawrence grade					
Preoperative	1	1	2	1	1

[a] BMI, body mass index; MMPRT, medial meniscal posterior root tears; PTS, posterior tibial slope; FTA, femoral tibial angle

Radiologic Evaluation

The mean PTS was 17.0° (range, 16°-19°) preoperatively and 7.8° (range, 6°-9°) postoperatively (P □ 0.01).

The mean FTA was 5.6° (range, 5°-7°) preoperatively and-0.6° (range,-2°-0°) postoperatively (P □ 0.01).

According to the Kellgren-Lawrence classification, there were 4 patients preoperatively classified as grade 1, 1 patients classified as grade 2. At the last follow-up visit, 3 patients was grade 1, 1 patients classified as grade 2 and 1 patient was grade 2 (P □ .05).

Knee Stability Evaluation

The mean side-to-side difference assessed with KT-1000 arthrometer was 9.2 mm (range, 7-12 mm) preoperatively and significantly decreased to 0.8 mm (range, -1-3 mm) at the final follow-up visit (*P* □ 0.01).

Preoperatively, 2 patients had a grade I, and 3 patients had a grade II for the pivot-shift test result. At the final follow-up visit, all patients showed negative results for the pivot-shift test (*P* □0.01) (Table 2).

Kee Functional Evaluation

The preoperative and postoperative clinical scores are summarized in Table 3. At the final follow-up, all clinical scores (Lysholm knee score, IKDC subjective knee score, Tegner Activity Level Scale) showed significant improvements (*P* □ .01).

Table 2

Pre- and Postoperative Comparisons of Functional Scores[a]

	Preoperative	Postoperative	P value
Mean PTS, °	17.0	7.8	<0.05
Mean FTA, °	5.4	-0.6	<0.05
Kellgren-Lawrence grade, no. of patients			*n.s*
1	4	3	
2	1	2	
3	0	0	
Mean side-to-side difference, mm	9.2	0.6	
pivot-shift test, no. of patients			<0.05
0	0	5	
I	2	0	
II	3	0	
Mean Lysholm knee score	48.2	93.0	<0.05
Mean IKDC subjective knee score	48.8	89.4	<0.05
Mean Tegner activity score	4	6.8	<0.05

[a] PTS, posterior tibial slope; FTA, femoral tibial angle; IKDC, International Knee Documentation Committee

Discussion

The main finding of this study is that patients who underwent combined ACLR and biplanar anterior closing-wedge osteotomy showed significant improvements in the Lysholm score, IKDC subjective score, and Tegner activity level without residual instability, major complications and deterioration of knee arthritis for at least 2 years. These findings support our hypothesis that such combined procedures can effectively restore knee stability, reduce PTS, and yield satisfactory clinical outcomes in patient with varus malalignment with primary ACL injury associate increased PTS.

Although the understanding of the importance of the lower extremity deformity for ACLR has deepened, correcting lower extremity deformity in treating ACL injuries is not well understood. Slope-reducing osteotomy is an invasive and technically demanding procedure. Previous case series preferred to perform it in patients who experienced primary or multiple failed ACLR. However, patients with steep lower extremity deformity still remain at high risk for graft failure after primary isolated ACLR. Moreover, revision ACLR is associated with worse clinical outcomes as compared with primary ACL reconstruction[24]. Therefore, correction of lower extremity deformities that are risk factors for ACLR failure is acceptable during primary ACLR. In our current study, the indication for biplanar anterior closing-wedge osteotomy in primary ACLR is combination of varus, steep posterior tibial slope (≥12°) and MMPRT.

For Coronal plane deformity. It is well-known that valgus high tibial osteotomy (HTO) is a successful treatment option for early medial osteoarthritis with varus alignment. Some clinical studies and systematic reviews reported good results of combined HTO and ACLR in the treatment for patients with varus and ACL deficiency[3,15,21]. However, regrading slope correction, open-wedge HTO is not very effective. Indeed, open-wedge HTO has a natural tendency to unintentionally increase the tibial slope. A meta-analysis assessed the change in PTS after HTO as a mean increase of 2°[18]. Therefore, if the main goal is to decrease the PTS rather than to correct the varus, open-wedge HTO is not appropriate. By comparison, anterior closing wedge tibial osteotomy can directly and effectively decrease the PTS and is technically easier. Biomechanically, Imhoff et al[11] reported that a 10° anterior closing-wedge osteotomy can significantly reduce the anterior tibial translation in the ACL-deficient knee and decrease the ACL-graft forces at axial load condition. Similarly, Yamaguchi et al[28] also found anterior closing-wedge osteotomy led a significant reduction on the anterior tibial translation and graft force. The positive biomechanical results of slope-reducing osteotomy as also supported by good clinical outcomes [1,5,24,25]. With these in mind, in the setting of ACL insufficiency increased PTS and varus alignment, we performed combined ACLR and biplanar anterior closing-wedge osteotomy for coronal and sagittal correction. Recently, Imhoff et al[10] demonstrated that combined varus and slope correction anterior closing-wedge osteotomy can significantly decrease the anterior tibial translation and ACL graft forces. The author also found that an isolated varus correction in the ACL-deficient knee can lead to higher anterior translation and internal tibial rotation, resulting in a more unstable knee[10].

The exact angle that needs to be corrected on both coronal and sagittal planes is controversial. In this study, the weight bearing line of lower extremity was set to 50% position of the tibial plateau on coronal plane. We did not overcorrect weight-bearing line into valgus condition, which may also increase the forces of ACL grafts[17]. In addition, since the patients were young and did not have severe knee degeneration, we believed that a 50% weight-bearing line was the most appropriate for these patients. Regarding slope correction, Sonnery-Cottet et al[25] performed a combined ACL revision with slope-correction osteotomy in 5 patients, to correct the mean PTS from 13.6° preoperatively to 9.2° postoperatively. Dejour et al[5] reported 9 patients who second revision ACL reconstruction combined with anterior closing-wedge osteotomy. The PTS decreased from 13.2° ± 2.6° preoperatively to 4.4° ± 2.3° postoperatively. Akoto et al[1] reported outcomes of 22 patients undergoing revision ACLR and slope-correction osteotomy combined with lateral extra-articular tenodesis. The mean preoperative PTS was 15.3°, and the mean postoperative PTS was 8.9°. Most of these studies performed anterior closing-wedge osteotomy in the setting of primary or second revision ACLR. Of note, they were different from Song et al[24], which reported 9 patients after anterior closing-wedge osteotomy in setting of primary ACLR, and the mean PTS was reduced to 8.1° postoperatively. In our study, we aim to correct the PTS to 7° to 10°. At the final follow-up time, the mean PTS was 7.8°,which was similar with Sonnery-Cottet[20] et al, Akoto et al[1] and Song et al[24].

Another important reason for performing biplanar anterior closing-wedge osteotomy in our study was the concomitant MMPRT. MMPR is a critical stabilizer of the knee, acting as a mechanical block or wedge against anterior tibial translation and transmitting shear force with compressive force. Previous studies have shown that the PTS is affected by both the coronal and sagittal planes: on the coronal plane, Samuelsen et al demonstrated that MMPRT can magnify the effect of the increased PTS on ACLR graft forces.[20]; On the sagittal plane, the varus deformity is an important prognostic factor in meniscal healing and long-term outcomes following MMPRT repair[14]. Therefore, in this study, we choose MMPRT as one of surgical indications of performing slope-reducing osteotomy. We believe that, for patients with MMPRT repair, biplanar anterior closing-wedge osteotomy can provide a good mechanical environmental condition for MMPR repair; and for patients required partial MMPR meniscectomy, osteotomy slope-reducing osteotomy can reduce anterior tibial translation following ACL reconstruction [4] and protect ACLR graft.

There were several limitations to our study. Firstly, this study was a retrospective study with a relatively small number of patients. Secondly, the relatively short follow-up time was insufficient to evaluate the long-term efficacy of such combined procedure. Thirdly, the slope and varus correction ACWTO is mainly aimed at correcting the sagittal deformity. However, for patients with lower extremity bone deformity mainly from varus rather than PTS, for patients with lower extremity bone deformity mainly derived from varus rather than PTS, the increased correction of the sagittal face may lead to torsion and fracture of the posterior tibial cortex, which may affect fracture healing and knee function. Lastly, due to the lack of control group, the clinical efficacy of this study was not compared with that of isolated ACLR, combined ACLR and HTO, or combined ACLR and anterior closing-wedge osteotomy, which needs to be further studied.

Conclusion

Slope and varus correction ACWTO combined with primary ACLR is a safe and effective procedure to improve knee stability and function in patients with steep PTS, varus knee deformity, and MMPRT.

Abbreviations

ACWTO: anterior closing wedge tibial osteotomy; ACL: anterior cruciate ligament; PTS: steep posterior tibial slope; MMPRT: medial meniscal posterior root tear; FTA: femoral tibial angle; IKDC: International Knee Documentation Committee; ACLR: anterior cruciate ligament reconstruction; ROM: knee range of motion

Declarations

Acknowledgements

None.

Authors’ contributions

JC L analyzed the data and drafted the manuscript. PZ collected the data and drafted the manuscript. PZ analyzed the data and revised the manuscript. JC L and HJ assessed and collected the data. JL preformed statistical analysis of the data. JL followed up the patients and collected the data. ZL and JC L participated in the design of the study, performed the surgery, and revised the manuscript. All authors read and approved the final manuscript.

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Availability of data and materials

All data generated or analyzed during this study are included in this published article.

Declarations Ethics approval and consent to participate

This retrospective review study involving human participants was in accordance with the ethical standards of the institutional and national research committee and with the 1964 Helsinki Declaration and its later amendments or comparable ethical standards. The study was approved by the medical ethics committee of our hospital. Informed consent was obtained from all individual participants included in the study.

Consent for publication

Not applicable.

Competing interests

The authors declare that they have no competing interests.

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Figures

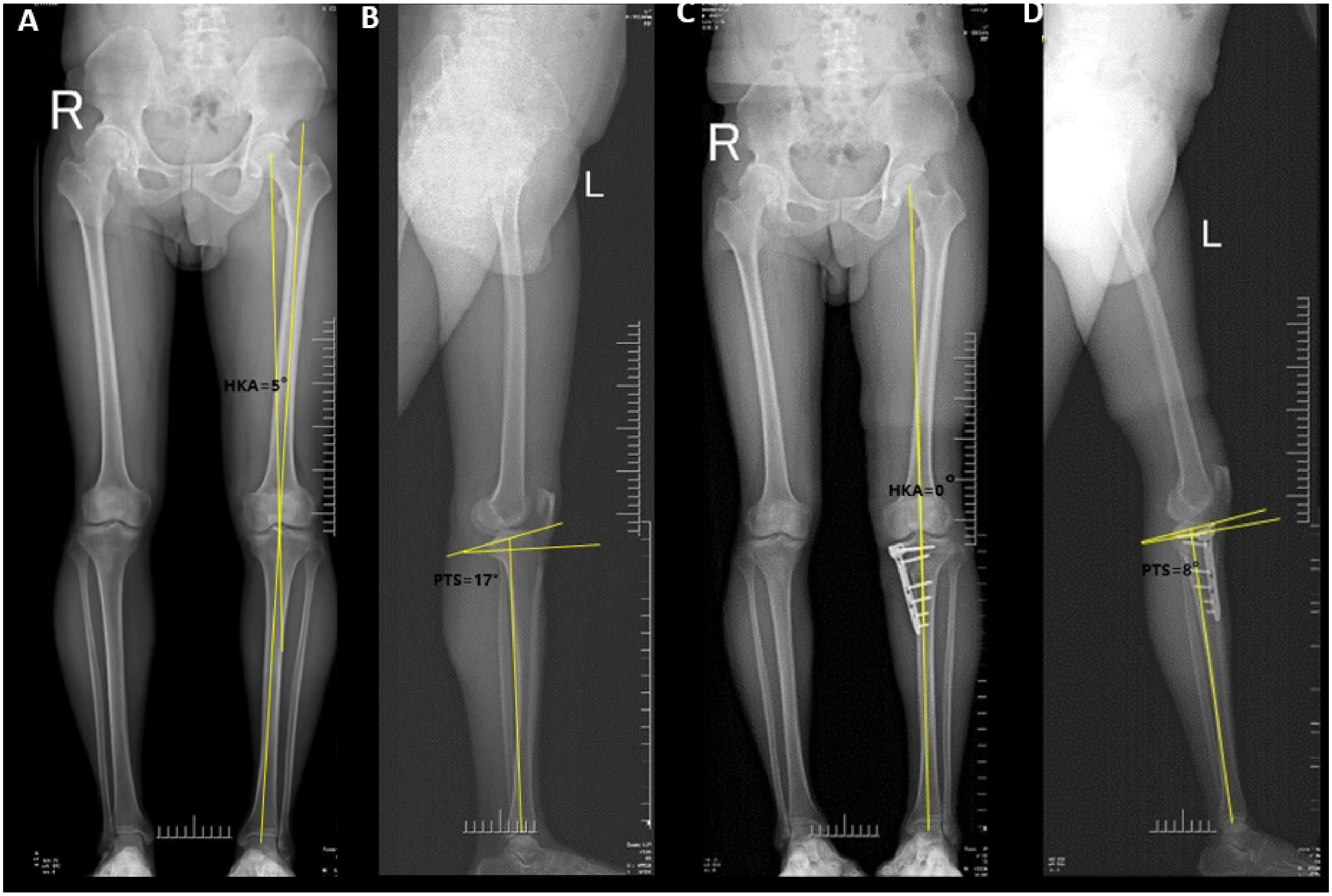

Figure 1

A typical case of slope and varus correction ACWTO combined with ACLR in patient 4. (A) The anteroposterior whole leg radiograph illustrates the FTA, measured as the angle created by the intersection of the line between the mechanical axis of femur, and the mechanical axis of the tibia. For this case, the FTA was 5°. (B) The lateral whole leg radiograph illustrates the PTS, measured as the angle created by the tangent line to the medial tibial plateau and the line perpendicular to the mechanical axis of the tibia. For this case, the PTS was 17°. (C) (D) After the slope and varus correction ACWTO combined with ACLR, the anteroposterior and lateral whole leg radiograph illustrates the FTA was corrected to 0° （C），and PTS was decreased to 8° (D).

Figure 2

A typical case of slope and varus correction ACWTO combined with ACLR in patient 4. (A) MMPRT was repaired by double trans-osseous pullout suture technique. (B) Fluoroscopic control of K-wires determines the osteotomy plane (C) Intraoperative view after the anterior bony segment resection. (D) Final view of slope and varus correction ACWTO after the fixation with TomoFix instrumentation system (Synthes).

Supplementary Files

This is a list of supplementary files associated with this preprint. Click to download.

- Table1.docx
- Table2.docx