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CASE REPORT

Three dimensional printing-assisted biplane stereotomy to treat severe varus knee with femoral deformity: a technical note

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Abstract
Double level osteotomy (DLO) is recommended for severe varus knees with deformities in both the femur and tibia or the deformity angle is greater than 20˚. with the assistance of preoperative computer planning and intraoperative 3D printing guides, DLO was successfully completed on the femoral and tibial sides. Meanwhile, the lateral osteotomy angle was intentionally increased by 2˚ to reduce the potential risk of instability in the posterior lateral knee joint. The last follow-up showed the VAS and KOOS decreased from 5 to 193 to 0 and 84. The ROM and KSS increased from 115 ° and 128 to 120° and 199.

Keywords Double level osteotomy, Three dimensional printing, Varus knee, Surgical technique

Introduction

Knee varus deformity can cause knee joint pain, dysfunction, and even disability. Surgical methods include periarticular knee osteotomy and knee joint replacement [1]. Peripheral knee osteotomy, such as distal femoral osteotomy (DFO) and high tibial osteotomy (HTO), rebuilds the mechanical axis (MA) of the lower limbs, which can transfer the weight-bearing area of the knee from the diseased side to the healthy side and relieve symptoms. For severe varus knees with deformities in both the femur and tibia or the deformity angle is greater than 20˚, double level osteotomy (DLO) is recommended, that is, DFO combined with HTO [2, 3].

However, when the first osteotomy of the femur or tibia is completed, the marking point of the MA will change. In the absence of reliable intraoperative landmarks, the second osteotomy will be challenging [4]. In addition, most severe varus knees are often accompanied by varying degrees of lateral collateral ligament (LCL) laxity. How to maintain the postoperative knee joint stability through DLO is also a problem.

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This paper reports a surgical technique for 3D printing combined with DLO to treat severe varus knee with laxity of LCL and femoral shaft anterior arch deformity. This is a case of maximum varus deformity corrected by DLO.

Method

Preoperative examination

A 64-year-old male patient has a varus deformity of his right lower limb for more than 40 years with a BMI of 23.2 kg/m² and knee pain. The cause of the deformity was unclear. The physical examination showed a 40˚ deformity of the right lower limb, visual analogue scale (VAS) score of 5, range of joint motion (ROM) of 0˚-115˚, knee society score (KSS) of 128, knee injury and osteoarthritis outcome score (KOOS) of 193, drawer test (-), apley's distraction testinternal (-) and external rotation squeeze test (-).

Imaging examination

Taking anteroposterior and lateral X-rays of both lower limbs (weight-bearing), lateral stress X-ray of the knee joint and full-length computed tomography (CT) films of both lower limbs. Measure MA, lateral proximal femoral angle (LPFA), mechanical lateral distal femoral angle (mLDFA), mechanical medial proximal tibia angle (mMPTA), mechanical lateral distal tibial angle (mLDTA), femoral and tibial sagittal axis on X-rays and CT to determine the direction and angle of osteotomy on the femur and tibia (Fig. 1).

Three dimensional (3D) modeling and surgical simulation

The 3D modeling of the full-length CT of the lower limbs was completed by Arigin 3D STS Design software. With reference to the MA of the left lower limb (varus 0.3 ˚), we adjusted the MA by increasing 1˚-2˚ or reducing 1˚-2˚ of valgus osteotomy angle on 3D software, and finally determined the most suitable MA which was more valgus than the healthy side (valgus 2˚). In the preoperative software planning, we set the proximal apex of the lateral femoral condyle as the landmark point and perform DFO on the lateral femur (the deformity vertex was 71 mm away from the landmark point, with a thickness of 22.5 mm and a correction angle of 30 ˚). Set the medial tibial plateau as a landmark point and perform HTO on the medial tibia (with a thickness of 12.6 mm for the osteotomy block, 13.6 mm for the tibial tuberosity retention, and a correction angle of 12˚) (Fig. 2). In addition, the preoperative simulated surgery was performed, using 3D printed models and osteotomy guide plates. (Fig. 3)

Surgical procedure

The surgery was performed in the supine position. A 10 centimeters (cm) lateral incision was made on the distal femur. Exposure of the distal femur along the lateral femoral muscle space. The bony landmark of the lateral femoral condyle was exposed and the osteotomy guide plate was placed in the correct position. According to the osteotomy guide plate, the lateral closed osteotomy was completed (30˚), and the medial hinge was cut off. The femoral reduction plate was used to fit the osteotomy ends of femur, and Kirschner wires were used to fix them temporarily. After removing the femoral reduction guide plate, a distal femoral locking plate was placed on the lateral side of the femur. The lateral femoral cortex was freshened and wedge-shaped osteotomy was implanted between the femur and the plate.

A 7 cm incision was made on the inner side of the proximal tibia to expose the goose foot stop, medial tibial plateau and tibial tubercle. The tibial osteotomy guide plate was placed at the medial tibial landmarks. Biplane osteotomy of tibial tubercle and tibial shaft was performed along the osteotomy guide plate, and the outside hinge (1.5 cm) was retained. The tightness of LCL was assessed and comfirmed. The proximal tibial osteotomy surface was raised (12˚) with the support guide plate as reference. X-ray was used to confirm the MA (valgus 2˚) again. A locking plate was placed on the medial side of the proximal tibia. The osteotomy space was filled with allogeneic bone. Layer by layer suture incision and apply coverage (Fig. 4).

Postoperative management

On the first day after operation, the patient was allowed to perform flexion and extension of the knee flexion and partial bearing under the protection of braces. Five days after operation, the patient was allowed to lean on crutches and fall to the ground in an incomplete weight-bearing state. Twelve weeks after operation, the patient can carry weight completely. Due to the patient returning to his hometown over 2600 km away from our hospital 3 months after surgery, he have been unable to cooperate with the follow-up work. Until 47 months after surgery, the patient completed follow-up work with the help of local doctors. The last follow-up in 47th months showed good knee joint function and stability, with a VAS score of 0, ROM of 0-120 ˚, KSS of 199 and KOOS of 84, apley's distraction testinternal (-). (Fig. 5)

Discussion

In order to relieve knee joint pain, Benjamin et al. [5] reported DLO for the first time in the treatment of rheumatoid arthritis and osteoarthritis. A retrospective study by Schröter et al. [6] showed that DLO can improve knee joint function while restoring the mechanical axis of severe varus osteoarthritis. Ihle C et al. [7] believe that in the short term, DLO can improve quality of life and restore work activities. However, the dynamic changes of

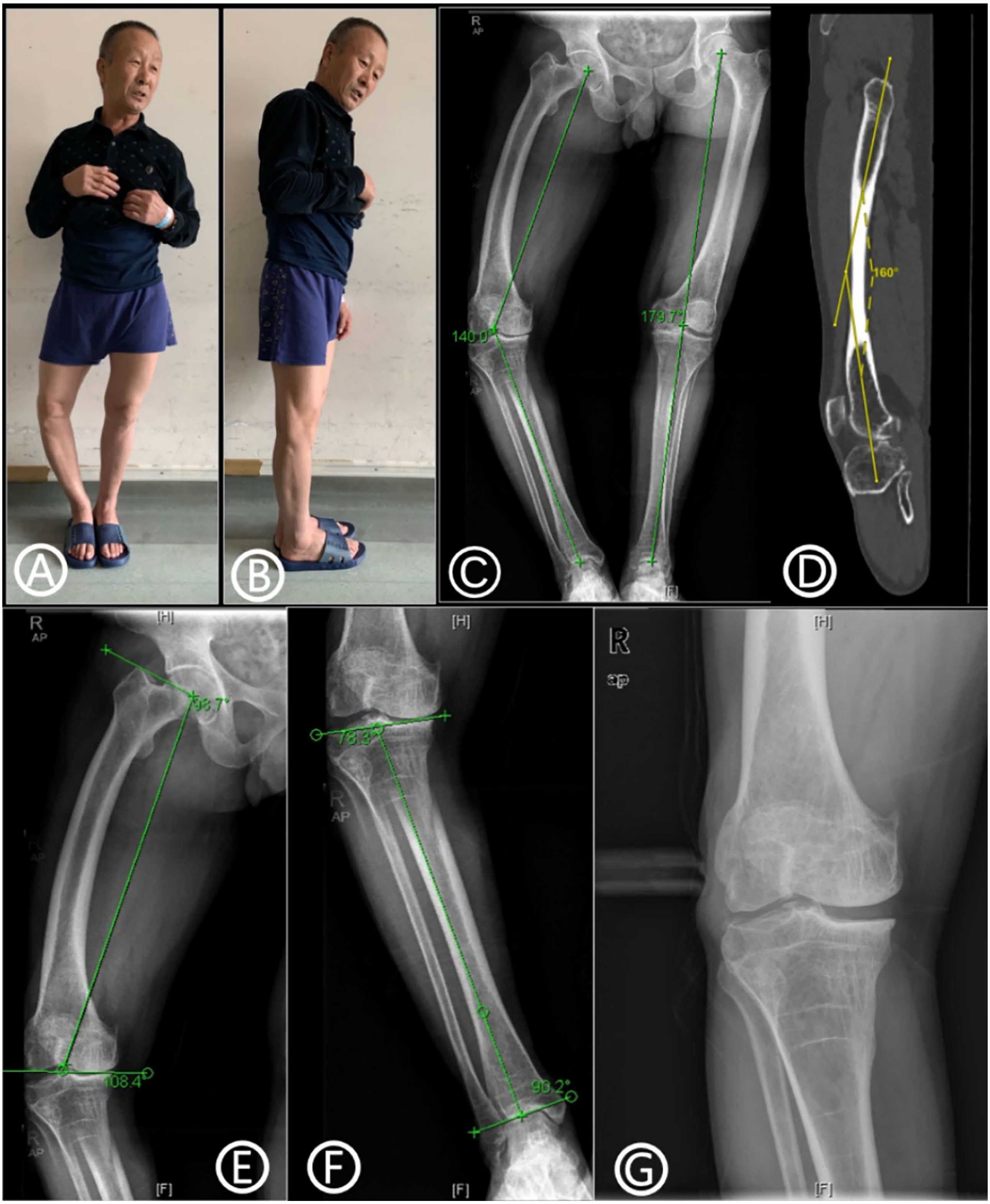

Fig. 1 Preoperative data. **A**-**B**. Appearance of the right lower limb; **C**. Mechanical axis of the right lower limb is 140˚; **D**. The sagittal plane angle is 20˚ forward; **E**. The lateral proximal femoral angle is 98.7˚ and mechanical lateral distal femoral angle is 108.4˚; **F**. The mechanical medial proximal tibia angle is 78.3˚ and mechanical lateral distal tibial angle is 90.2˚; **G**. Knee valgus stress position X-ray shows medial knee joint gap can be opened

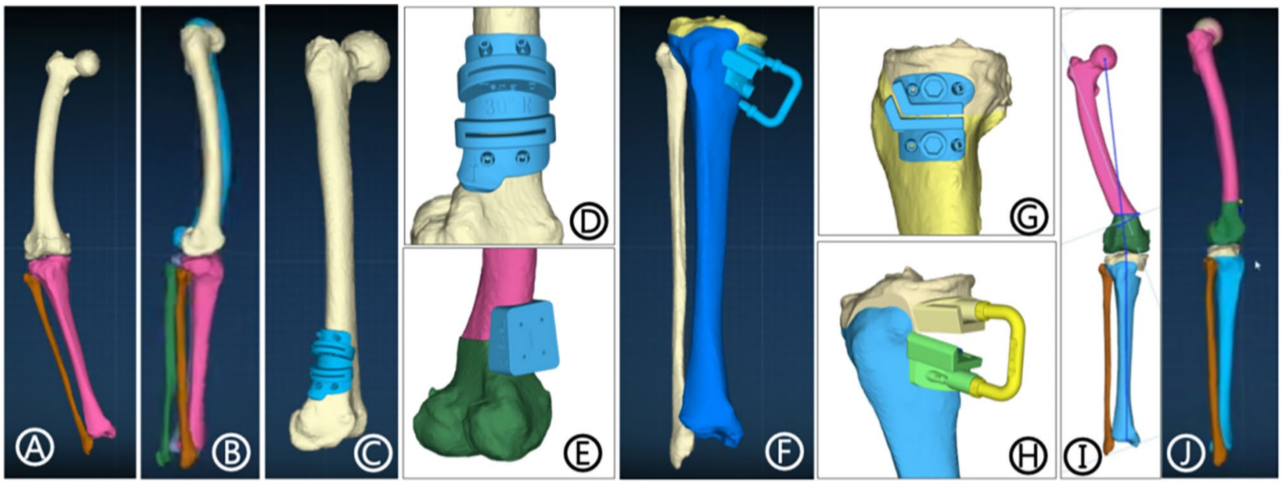

Fig. 2 Preoperative planning. **A**-**B**. Original three-dimensional model of right lower limb; **C**-**D**. Distal femoral osteotomy guide plate; **E**. Distal femoral fit limit block; **F**-**G**. Proximal tibia osteotomy guide plate; **H**. Tibia extension limit block; **I**-**J**. Three dimensional model of right lower limb after osteotomy

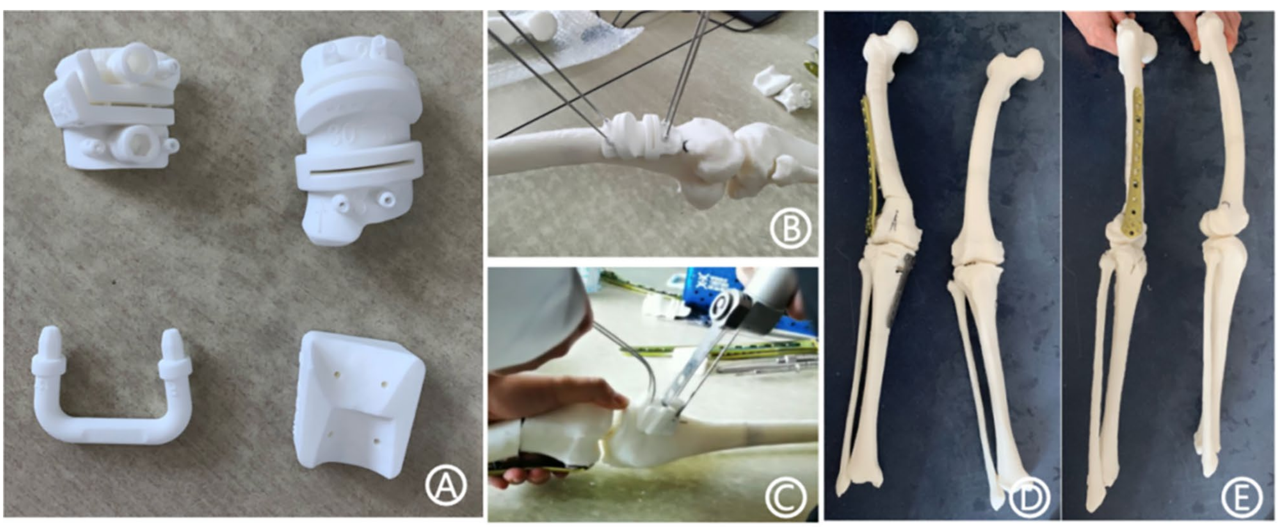

Fig. 3 Preoperative surgical rehearsal. **A**. 3D printing osteotomy guide plate; **B**-**C**. Osteotomy simulated under the guidance of osteotomy guide plate; **D**-**E**. The appearance of the right lower limb after osteotomy and plate fixation

the mechanical axis of the lower limbs during the operation make the second osteotomy difficult.

Computer navigation [4, 8, 9] has been used in DLO, with some disadvantages, such as repeated positioning, prolonged operation time and expensive price. In recent years, with the application of digital planning software [10, 11] and 3D printing systems [12, 13], combined tools such as computer software, osteotomy guides, and simulated bone models have greatly improved the accuracy of osteotomy, reduced surgical trauma and shortened operation time. We used computer system to plan the angle and direction of intraoperative osteotomy, standardized intraoperative osteotomy and reduction through 3D printing osteotomy guide plate, so as to improve the accuracy of osteotomy, correct coronal (genu varus) and sagittal deformity (anterior femoral arch), and improve the MA of lower limb.

The treatment of LCL relaxation of severe varus knee by DLO is a technical problem. The preoperative valgus stress test of the knee joint indicated that the medial collateral ligament was functioning well, and it has the potential to restore joint stability by osteotomy alone. On the basis of conventional osteotomy, an additional lateral osteotomy angle (2°) was added to reduce the potential risk of instability of the posterior lateral knee joint and avoid the reconstruction of LCL [10, 14]. By increasing the postoperative valgus angle, the short-term stabilization needs of LCL can be reduced. When the lateral soft tissue repaired, the long-term stability of the knee joint can be achieved. During HTO, X-ray is recommended to

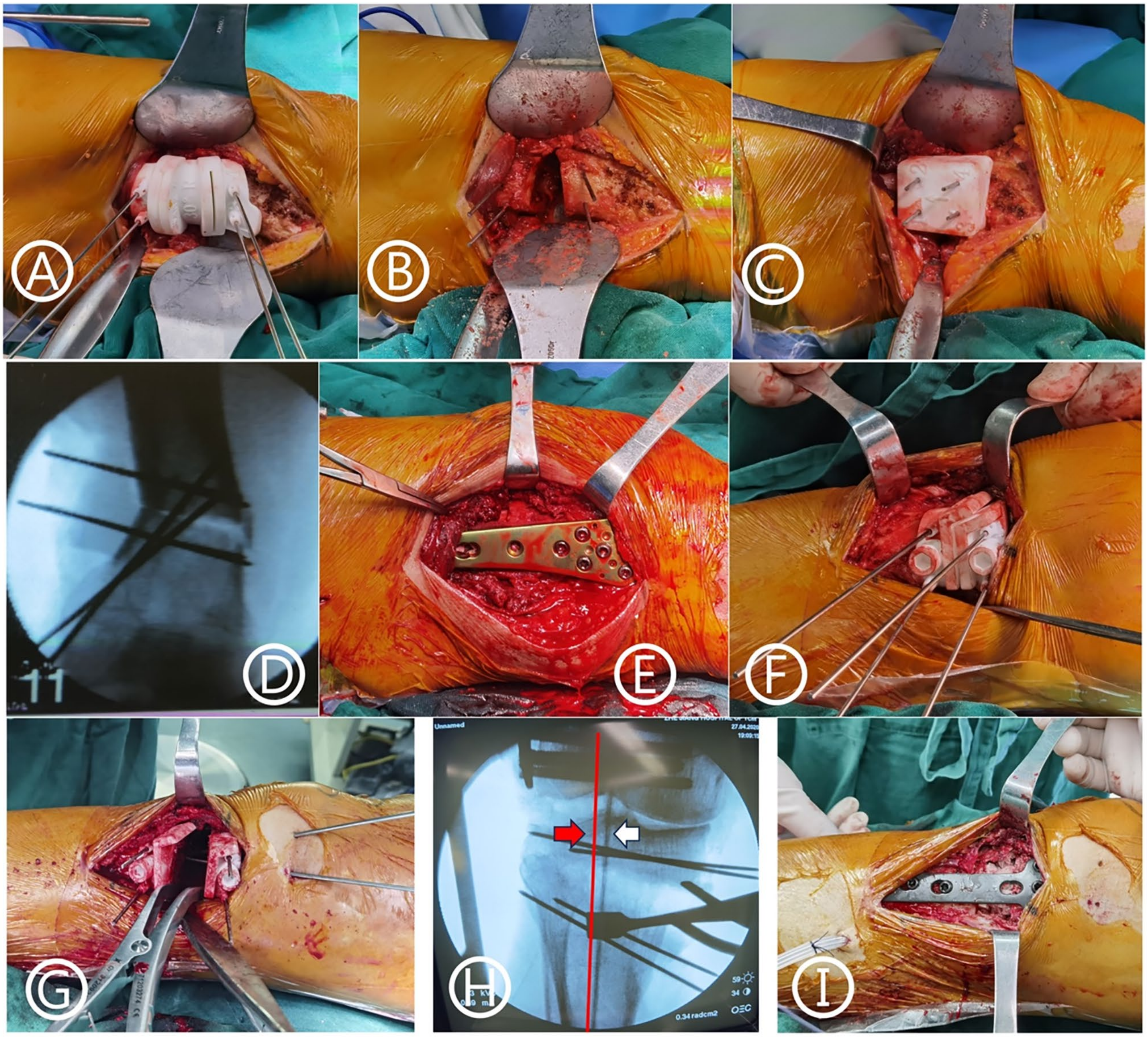

Fig. 4 Intraoperative data. (**A**) placement of distal femoral osteotomy guide; (**B**) closed distal femoral osteotomy (30˚); (**C**) placement of distal femoral reduction guide; (**D**) Kirschner wire fixation of osteotomy end; **E**. placement of lateral femoral plate; **F**. placement of proximal tibial osteotomy guide; **G**. distraction of proximal tibial osteotomy surface (12˚); **H** The final mechanical axis (red arrow), the mechanical axis of conventional HTO (white arrow); **I**. placement of proximal tibial medial plate

verify the correction results of MA before plate fixation (Fig. 4). According to the temporary MA, the operator can adjust the final MA to the ideal position to improve the accuracy of osteotomy.

Compared to traditional surgical methods, our technology has the following advantages: (1) Accurate osteotomy, which can better correct the three-dimensional MA [15]. (2) Simplify the operation process and reduce the number of intraoperative fluoroscopy. (3) Shorten the operation time and reduce the surgical trauma. (4) It is suitable for some severe varus knees with loose LCL, effectively avoiding the reconstruction of LCL. (5) This is knee-sparing surgery, which can delay or avoid knee joint replacement.

Conclusion

3D printing combined with DLO to treat severe varus knee can improve the accuracy of intraoperative osteotomy and reduction. For patients with LCL relaxation and posterolateral instability, the long-term knee joint stability can be improved by increasing the valgus osteotomy angle (2˚-3˚).

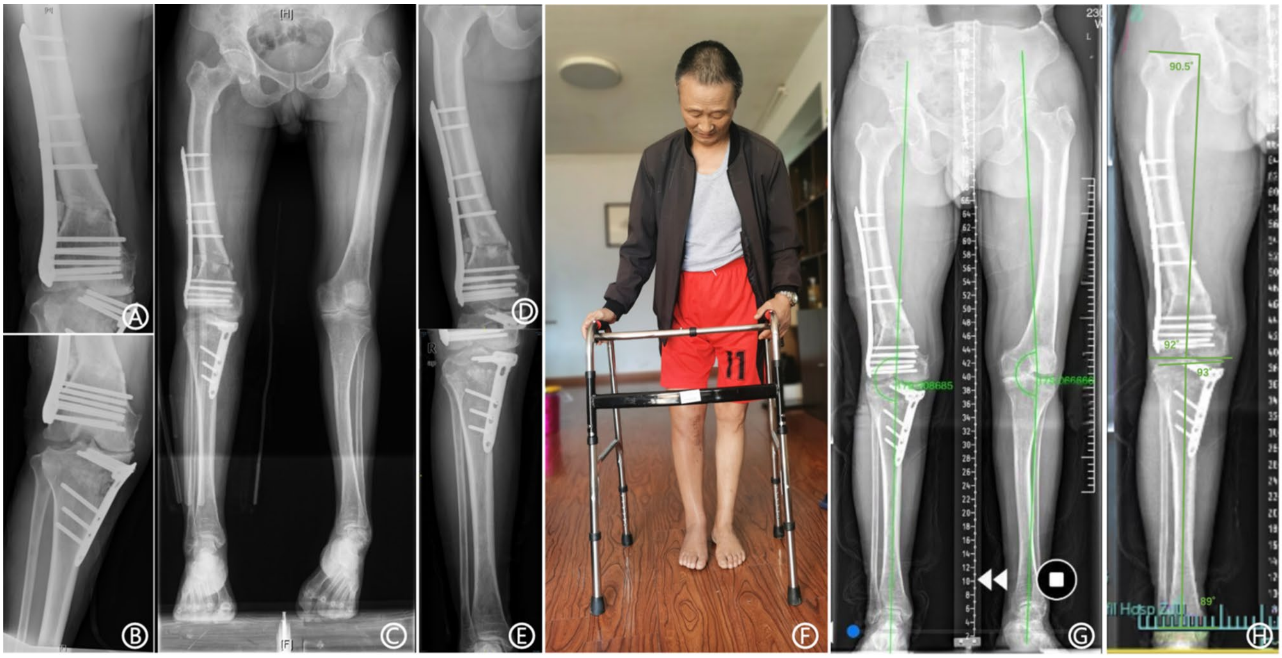

Fig. 5 Postoperative data. **A**-**B**. Intraoperative X-ray; **C**. Postoperative X-ray at 2 weeks; **D**-**F**. Postoperative X-ray and appearance of the right lower limb at 3 months; **F**-**G**. Mechanical axis of the right lower limb is 179˚ at 47 months. The lateral proximal femoral angle is 90.5˚, mechanical lateral distal femoral angle is 92˚, mechanical medial proximal tibia angle is 93˚ and mechanical lateral distal tibial angle is 89˚

Supplementary Information

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Supplementary Material 1

Author contributions

LSJ, LXS, JZK, ZYH and HJF were responsible for the overall writing and conceptualization of the article. LSJ, LXS, JZK, LX, YJ and TY, collected and analysed the data. YJ, TPJ, ZYH and HJF were responsible for data visualization. LSJ, ZYH and HJF were responsible for guiding and revising the article. All the authors proofread and approved the final manuscript. All authors wrote, reviewed and edited the original draft and approved the final submitted version. Each author agreed to the statement here for their own contributions.

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Data availability

The datasets used during the current study are available from the corresponding author on reasonable request.

Declarations

Ethics approval and consent to participate

This patient was given a clear and comprehensive explanation of the study based on the Declaration of Helsinki and written informed consent for participation in the study were obtained from all patients. Research governance permission for the use of anonymous patient data for this study was provided by the The First Affiliated Hospital of Zhejiang Chinese Medical University ethics committee (NO. 2020-X-049-02).

Consent for publication

We have anonymized the information of the participating patients. In addition, written informed consent and published consent were obtained from all patients.

Competing interests

The authors declare no competing interests.

Clinical trial number

Not applicable.

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