Application of Elliptic Registration and Three-Dimensional Reconstruction in Postoperative Precise Measurement of Taylor Spatial Frame Parameters

Yanshi Liu
Xinjiang Medical University Affiliated First Hospital
Maimaiaili Yushan
Xinjiang Medical University Affiliated First Hospital
Zhenhui Liu
Xinjiang Medical University Affiliated First Hospital
Jialin Liu
Xinjiang Medical University Affiliated First Hospital
Chuang Ma
Xinjiang Medical University Affiliated First Hospital
Yusufu Ahemaitijiang (ahmatjang@163.com)
Xinjiang Medical University Affiliated First Hospital

Research article

Keywords: Computer-assisted, Deformity correction, Elliptic registration, Taylor spatial frame

Posted Date: April 27th, 2020

DOI: https://doi.org/10.21203/rs.3.rs-22510/v1

Version of Record: A version of this preprint was published at Injury on December 1st, 2020. See the published version at https://doi.org/10.1016/j.injury.2020.10.077.

Abstract

Background The Taylor spatial frame offered the ability of simultaneous correction of the multidirectional deformities without the need of change the frame, and it was widely used for limb lengthening, deformity correction and fracture reduction in recent years. There are still some inherent limitations which can affect the accuracy of correction, especially for the measurement of the mounting and rotational parameters. The purpose of our study was to perform precise postoperative measurement of Taylor spatial frame (TSF) parameters by application of elliptic registration and three-dimensional reconstruction.

Methods This retrospectively study included 28 trauma patients who suffered tibial fracture treated by the TSF at our institution from January 2016 to January 2018, including 25 males and 3 females with a mean age of 43 years (range 14–70 years). We conducted standard full-length anteroposterior and lateral X-rays of the injured extremity and the computed tomographic scans of the bilateral extremities after operation. Elliptic registration and 3D reconstruction were used to calculated the parameters by two types of software Mimics and CorelDRAW. Correction of the deformity was conducted by adjusting the struts of the TSF according to the electronic prescription. The standard anteroposterior and lateral X-rays after correction were taken to evaluate the effectiveness.

Results All patients acquired functional reduction which was evaluated by digital radiography. The mean coronal plane translation(1.9 ± 2.2 mm), coronal plane angulation(1.2 ± 1.0°), sagittal plane translation(2.7 ± 2.1 mm) and sagittal plane angulation(1.2 ± 1.0°) after correction were all less than those(5.5 ± 4.6 mm, 4.9 ± 3.9°, 4.7 ± 4.0 mm, 2.7 ± 2.3°) before correction.

Conclusions The TSF system can precise correct the 6-axis deformities simultaneously with the accurate parameters. Application of elliptic registration and three-dimensional reconstruction can precisely measure the TSF parameters, especially for the mounting and the rotational parameters.

Background

The Taylor spatial frame(TSF)(Smith&Nephew, Memphis, TN,USA) developed by Ilizarov technology which based on Stewart platform is a more modern multiplanar hexapod frame than traditional ring fixator that consists of 2 rings or partial rings connected by 6 telescopic struts at special universal joints[1,2].Considering the advantages of stability, reliability and the versatility of correcting translation, angulation and rotation deformities in the coronal, sagittal and axial planes simultaneously by adjusting the lengths of struts based on the electronic prescription, this system was played an important role over the years in the treatment of bone nonunion, bone fracture and correction of deformity[3–9].This kind of hexapod external fixator allow the surgeon correct complex multi-planar deformities without the need to alter the frame construct[8,10–12].

Deformity, mounting and frame parameters are needed to enter into a computer-based software when applying the TSF. The deformity and mounting parameters were measured on the basis of the digital radiography according to its instruction. The TSF is theoretically capable of accuracies to 1/1000000 inch and 1/10000 degree[13,14], but it does not realize such immeasurably accurate corrections in real world, only to approximately 1 mm and 1°[13,14].Wheras we can't get the accurate spatial information especially the axial rotational parameters obtained from the X-rays which is showed in the two-dimensional (2D) planes, and there will be error(s) of measurement in different doctors even in the same X-ray film. Therefore, the correction is less accurate than the theoretical value in clinical application.

The purpose of our study was to perform precise postoperative measurement of Taylor spatial frame parameters by application of elliptic registration and three-dimensional(3D) reconstruction, especially for the mounting and the rotational parameters.

Methods

This retrospectively study included 28 trauma patients who suffered tibial fracture treated by the TSF at our institution from January 2016 to January 2018.There were 25 males and 3 females with a mean age of 43 years (range 14–70 years). We excluded all patients with pathological fracture, old fracture, fracture associated with vascular and nerve injury, age > 70 years, poor compliance, fracture associated with infection and any other illness (such as diabetes, hypertension, osteoporosis, kidney disease, etc.) that can affect bone healing. Informed consent was obtained from all patients for their data to be recorded in our study (included hospital data, radiographs and photographs). This study was approved by the Ethical Committee of our institution.

Standard full-length anteroposterior (AP) and lateral X-rays of the injured extremity (include adjacent joints, complete reference ring and distal ring) after operation were conducted, and the radiographic data were imported into CorelDRAW X7(Corel, Canada) for subsequent analysis. Computed tomographic (CT) scans of the bilateral extremities after operation are also needed, data of Dicom format were imported into Mimics 17.0(Materialise, Belgium) for 3D reconstruction. The reconstructed 3D image of the proximal bony fragment as well as the reduction of 3D model of the injured limb was matched with the image of the mirrored 3D image of the contralateral limb. The deformity and mounting parameters needed by the computer-based software of the TSF were measured on the basis of X-rays and 3D images. Correction of the deformity in suffered extremity was conducted by adjusting the struts of the TSF according to the electronic prescription. The standard anteroposterior and lateral X-rays after correction were taken to evaluate the corrective effectiveness.

Required Parameters

Parameters needed to be measured include six deformity parameters and four mounting parameters. The deformity parameters include coronal plane translation (medial/lateral), coronal plane angulation (varus/valgus), sagittal plane translation (anterior/posterior), sagittal plane angulation (flexion/extension), axial plane translation (shortening /lengthening), and axial plane angulation (internal/external rotation).The mounting parameters which describe where the center of the reference ring is located relative to the origin point include anteroposterior view frame offset, lateral view frame offset, axial view frame offset and the rotary frame angle which defined as the rotation of the reference ring according to the reference bony fragment. We define the most prominent point on the fracture line of the proximal reference bony fragment as the center of rotation angulation (CORA), it is the origin point and its corresponding point is located on the distal bony fragment.

Parameters Measurement And Case Example

A 40-year-old female patient suffered tibial fracture in a traffic accident with a posttraumatic multidimensional deformity in tibia treated by the TSF. In this case, elliptic registration and three-dimensional reconstruction were applied to precisely measure the parameters needed by the computer-based software of the TSF (Fig. 1–7).

Anatomical axis of the reference bony fragment and distal bony fragment were drawn on the AP and lateral view. The origin point was defined as A, the corresponding point was defined as A'. The coronal plane translation was calculated using the distance of the line perpendicular to the anatomical axis of the reference bony fragment from point A to A'. The coronal plane angulation was calculated using the intersection angle of the two anatomical axes. The sagittal plane translation and angulation was also calculated using the aforementioned method. The axial plane translation was calculated using the distance of the line paralleled to the anatomical axis of the reference bony fragment from point A to A' (Fig. 1).

For the axial plane angulation, it was calculated using the 3D model. CT data were imported into Mimics to reconstruct the affected and contralateral limb by threshold division, bone separation and image process (Fig. 2). The mirrored 3D image of the contralateral limb was used as the reference for reduction. The reconstructed 3D image of the reference bony fragment was matched with the mirrored 3D image of the contralateral limb, and reduction of the distal bony fragment was done by moving and rotating (Fig. 2). The axial plane angulation was obtained which showed in the column of axial rotation from the Mimics (Fig. 3).

An ellipse was registered with the reference ring on the AP and lateral view. A rectangle which all four corners fall on the edge of the ellipse was drawn subsequently. The center of the reference ring which defined as O or O' is the intersection of the two diagonals belonged to the rectangle. We calculated the anteroposterior view frame offset using the distance of the line perpendicular to the anatomical axis of the reference bony fragment from point A to O. The lateral view frame offset was calculated using the distance of the line perpendicular to the anatomical axis of the reference bony fragment from point A to O'. The axial view frame offset was calculated using the distance of the line parallel to the anatomical axis of the reference bony fragment from point A to O or A to O'(Fig. 1).

The 3D model was used to calculated the rotary frame angle by Mimics. We rotated the 3D model to a proper position to ensure that the reference ring was parallel to the horizontal plane in AP view, and obtained the axial view of the reference ring and reference bony fragment. The standard orientation of the master lab is the direct anterior position, and we defined the standard master lab as the corrected master lab in our study. The center of the reference bony fragment defined as point C was found by the aforementioned method of elliptic registration. The rotary frame angle defined as α in our study is the intersection angle of the two lines which connecting point C and original master lab, point C and corrected master lab respectively (Fig. 4).

Statistical analysis

Statistical analysis was performed with the SPSS 22.0(IBM Corp, USA). Continuous variables were analyzed by Paired-samples T tests and expressed as the mean and standard deviation (SD). Statistically significant difference was set at $P < 0.05$.

Results

The differences before and after correction are shown in Table 1. All patients acquired functional reduction which was evaluated by digital radiography (Fig. 5). The mean follow-up after removal of the TSF was 15 months (range 12–20 months) and no patient was lost to follow up. All the patients had bone union and no recurrence of fracture was observed (Fig. 6).The mean coronal plane translation(1.9 ± 2.2 mm), coronal plane angulation(1.2 ± 1.0°), sagittal plane translation(2.7 ± 2.1 mm) and sagittal plane angulation(1.2 ± 1.0°) after correction were all less than the mean coronal plane translation(5.5 ± 4.6 mm), coronal plane angulation(4.9 ± 3.9°), sagittal plane translation(4.7 ± 4.0 mm) and sagittal plane angulation(2.7 ± 2.3°) before correction. All the difference between the parameters before and after correction were statistically significant ($p < 0.05$).

Table 1
Comparison of residual deformities before and after correction

Parameters	Before	After	t	P-value
Coronal plane translation	5.5 ± 4.6	1.9 ± 2.2	4.873	P < 0.001
Coronal plane angulation	4.9 ± 3.9	1.2 ± 1.0	5.129	P < 0.001
Sagittal plane translation	4.7 ± 4.0	2.7 ± 2.1	3.287	0.003
Sagittal plane angulation	2.7 ± 2.3	1.2 ± 1.2	3.174	0.004
Values are presented as mean ± SD. Translation in mm and angulation in degree (°).				

Discussion

External fixation characterized by rapid, simple, effective, minimally invasive and fixated reliably, which can preserve the biomechanical microenvironment needed for fracture healing has a clear role in the management of unstable fractures, especially for high-energy injuries with extensive soft tissue damage[15,16]. The Ilizarov method of deformity correction was the most important contribution in the field of deformity correction, whereas years of training and frame changing were needed when used the Ilizarov frame for multiplanar deformities. The hexapod system such as TSF, based on the same principle as the Ilizarov system, comprised of two rings and six struts, uses a six-axis deformity analysis incorporated within a computer-based software to establish a virtual hinge in 3D space, around which multiple deformities including translation, angulation, rotation and shortening are corrected simultaneously by adjusting the strut lengths[17,18].

Precise parameters measurement are required when applying the TSF,the accuracy of the frame is depend upon the input of precise parameters. For the six deformity parameters, the translation and angulation of the coronal plane and sagittal plane respectively and the axial plane translation can be obtained from the AP and lateral X-rays. However, we can't acquire the axial plane angulation (rotation) which was theoretically calculated by the spatial information through the 2D X-rays. The axial plane angulation is determined by clinical examination in traditional measurement which is not accurate[19,20]. We used the CT scans data obtained from the affected tibia to reconstruct a 3D model, and calculated the actual axial plane angulation by virtual reduction assisted by Mimics.

The TSF system required orthogonal AP and later X-rays when define the deformity parameters[21–24], which was conducted subjectively by radiologists and it is impossible to determine the orthogonality of the X-rays in clinical practice. Additionally, X-rays may need to be taken repeatedly because of the manual measurement errors. Considering above mentioned possible error, foot ring was used

and determined that the two vertical edges are parallel to the reference platform when conducted the AP and lateral X-rays (Fig. 7). This method contributed to reduce the possible error caused by different postures of the affected tibia during radiological examination.

The mounting parameters define the location of the origin relative to the reference ring, which is essential to describe the relationship between the frame and bone. One third of the patients suffered residual deformity after the initial correction[10,17,25–27]. The majority of residual deformities consist of insufficient correction or unexpected translation-angulation with the correction of TSF have been reported due to inaccurate mounting parameters[19].Many methods have been proposed to define the mounting parameters, including intraoperative fluoroscopy, postoperative radiography and CT scans[19,21,28,29].

Gantsoudes et al.[28] declared it is easily reproducible in the operating room and allows for accurate measurement of the mounting parameters when conducted intraoperative measurement, whereas Sami et al.[30] thought that there is no difference between perioperative and postoperative measurements. These methods may not be very accurate when the images of the reference ring are incomplete or the reference marks are overlapped and obscured. Kucukkaya et al.[19] calculated the mounting parameters using the tomographic images in CT, they demonstrated its advantages, especially in deformities with a rotational deformity. But we thought the biggest drawback of this method for the rotary frame angle was that they only calculate the projection of the true angle onto the horizontal plane, not the true angle in spatial position if the reference ring is not parallel to the horizontal plane. The projection is less than the true spatial angle as the generally accepted theory.

The methods of elliptic registration and the intersection of the two diagonals belonged to the rectangle were used in our study to helped us accurately find the center of the reference ring, especially in conditions that the images of the reference ring is incomplete or overlapped and obscured, it greatly prevents the measurement errors caused by incorrect center of the reference ring. The rotary frame angle is also determined by clinical examination in traditional measurement which is not accurate[20]. We rotated the 3D model to ensure that the reference ring was parallel to the horizontal plane in AP view by Mimics, the measurement of the spatial angle is transformed into the measurement of the planar angle in this way. In addition, the rotary frame angle can be measured easily with the use of the visualized master lab.

The present study had several limitations. Firstly, we used two types of software Mimics and CorelDRAW which required the surgeon to have a basic knowledge of these software, the procedures are tedious and time-consuming, especially under the influence of metal artifacts for 3D reconstruction. Secondly, we conducted elliptical registration and fracture reduction by visual observation, there will be inevitable subjective error.

Conclusions

The TSF system can precise correct the six-axis deformities simultaneously with the accurate parameters. Elliptic registration and three-dimensional reconstruction are alternative methods to accurately measure the parameters needed by the computer-based software, especially for the mounting and the rotational parameters.

Abbreviations

TSF
Taylor spatial frame
2D
two-dimensional
3D
three-dimensional
AP
anteroposterior
CT
Computed tomographic
CORA

center of rotation angulation

Declarations

Ethics approval and consent to participate

This retrospective study was approved by the Ethics Committee of The First Affiliated Hospital of Xinjiang Medical University. Written informed consent was obtained from all patients for their data to be recorded in our study.

Consent for publication

Not applicable.

Availability of data and materials

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

Competing interests

The authors declare that they have no conflict of interest.

Funding

This study was funded by the grants from National Natural Science Foundation of China (No. 81560357 and 81760397). The funding body was involved in the collection, analysis, and interpretation of data by supporting with salary for the time needed. They were not involved in the design or writing the manuscript.

Authors' contributions

YSL: Conducted the study. Collected, analyzed and interpreted the data. Edited the images. Wrote the manuscript.

MY: Designed the study. Edited the manuscript.

ZHL: Edited the images and interpreted the data.

JLL: Created and statistical analyzed the data.

CM: Planned the project. Reviewed the manuscript.

AY: Planned the project. Reviewed the manuscript.

Final approval of the version to be submitted: YSL, MY, ZHL, JLL, CM, AY

Acknowledgements

The authors would like to thank Tao Zhang and Zhenhui Sun for their theoretical guidance in this study

References

1. Sokucu S, Demir B, Lapcin O, et al. Perioperative versus postoperative measurement of Taylor Spatial Frame mounting parameters. Acta Orthop Traumatol Turc. 2014;48:491–4.
2. Sala F, Elbatrawy Y, Thabet AM, et al. Taylor spatial frame fixation in patients with multiple traumatic injuries: study of 57 long-bone fractures. J Orthop Trauma. 2013;27:442–50.
3. Henderson DJ, Barron E, Hadland Y, et al. Functional outcomes after tibial shaft fractures treated using the Taylor spatial frame. J Orthop Trauma. 2015;29:e54–9.
4. Iobst CA. Hexapod External Fixation of Tibia Fractures in Children. J Pediatr Orthop. 2016;36(Suppl 1):24–8.
5. Krappinger D, Zegg M, Smekal V, et al. [Correction of posttraumatic lower leg deformities using the Taylor Spatial Frame]. Oper Orthop Traumatol. 2014;26:520–31.
6. Kucukkaya M, Karakoyun O, Armagan R, et al. [Correction of complex lower extremity deformities with the use of the Ilizarov-Taylor spatial frame]. Acta Orthop Traumatol Turc. 2009;43:1–6.
7. Seide K, Wolter D, Kortmann HR. Fracture reduction and deformity correction with the hexapod Ilizarov fixator. Clin Orthop Relat Res 1999:186–195.
8. Feldman DS, Shin SS, Madan S, et al. Correction of Tibial Malunion and Nonunion With Six-Axis Analysis Deformity Correction Using the Taylor Spatial Frame. J Orthop Trauma. 2003;17:549–54.
9. Sontich JK. Posttraumatic Taylor Spatial Frame Deformity Correction in Adults. Operative Techniques in Orthopaedics. 2011;21:129–43.
10. Feldman DS, Madan SS, Koval KJ, et al. Correction of Tibia Vara With Six-Axis Deformity Analysis and the Taylor Spatial Frame. Journal of Pediatric Orthopaedics. 2003;23:387–91.
11. Binski JC. Taylor Spatial Frame in Acute Fracture Care. Techniques in Orthopaedics. 2002;17:173–84.
12. Docquier PL, Rodriguez D, Mousny M. Three-dimensional correction of complex leg deformities using a software assisted external fixator. Acta Orthop Belg. 2009;74:816–22.
13. Gantsoudes GD, Fragomen AT, Rozbruch SR. Intraoperative measurement of mounting parameters for the Taylor Spatial Frame. J Orthop Trauma. 2010;24:258–62.
14. Rogers MJ, McFadyen I, Livingstone JA, et al. Computer hexapod assisted orthopaedic surgery (CHAOS) in the correction of long bone fracture and deformity. J Orthop Trauma. 2007;21:337–42.
15. Scalea TM, Boswell SA, Scott JD, et al. External fixation as a bridge to intramedullary nailing for patients with multiple injuries and with femur fractures: damage control orthopedics. J Trauma. 2000;48:613–21, 621–623.

16. Lahoti O, Findlay I, Shetty S, et al. Intentional deformation and closure of soft tissue defect in open tibial fractures with a taylor spatial frame–a simple technique. J Orthop Trauma. 2013;27:451–6.
17. Kucukkaya M, Karakoyun O, Armagan R, et al. [Correction of complex lower extremity deformities with the use of the Ilizarov-Taylor spatial frame]. Acta Orthop Traumatol Turc. 2009;43:1–6.
18. Rozbruch SR, Fragomen AT, Ilizarov S. Correction of tibial deformity with use of the Ilizarov-Taylor spatial frame. J Bone Joint Surg Am. 2006;88(Suppl 4):156–74.
19. Kucukkaya M, Karakoyun O, Armagan R, et al. Calculating the mounting parameters for Taylor Spatial Frame correction using computed tomography. J Orthop Trauma. 2011;25:449–52.
20. Keshet D, Eidelman M. Clinical utility of the Taylor spatial frame for limb deformities. Orthop Res Rev. 2017;9:51–61.
21. Kanellopoulos AD, Mavrogenis AF, Kanellopoulos ND, et al. A guide frame for the Taylor Spatial Frame. J Orthop Trauma. 2009;23:537–40.
22. Rogers MJ, McFadyen I, Livingstone JA, et al. Computer Hexapod Assisted Orthopaedic Surgery (CHAOS) in the Correction of Long Bone Fracture and Deformity. J Orthop Trauma. 2007;21:337–42.
23. Whitehouse MR, Livingstone JA. Taylor Spatial Frame Application With the Aid of a Fine Wire Half Frame. J Orthop Trauma. 2008;22:276–81.
24. Paley FD. Six-Axis Deformity Analysis and Correction.: Springer Berlin Heidelberg; 2002.
25. Al-Sayyad MJ. Taylor Spatial Frame in the treatment of pediatric and adolescent tibial shaft fractures. J Pediatr Orthop. 2006;26:164–70.
26. Naqui SZ, Thiryayi W, Foster A, et al. Correction of simple and complex pediatric deformities using the Taylor-Spatial Frame. J Pediatr Orthop. 2008;28:640–7.
27. Al-Sayyad MJ. Taylor Spatial Frame in the treatment of pediatric and adolescent tibial shaft fractures. J Pediatr Orthop. 2006;26:164–70.
28. Gantsoudes GD, Fragomen AT, Rozbruch SR. Intraoperative measurement of mounting parameters for the Taylor Spatial Frame. J Orthop Trauma. 2010;24:258–62.
29. Park DH, Bradish CF. An intraoperative method of calculating the mounting parameters for the Taylor Spatial Frame using the image intensifier. Ann R Coll Surg Engl. 2011;93:260–1.
30. Sokucu S, Demir B, Lapcin O, et al. Perioperative versus postoperative measurement of Taylor Spatial Frame mounting parameters. Acta Orthop Traumatol Turc. 2014;48:491–4.

Figures

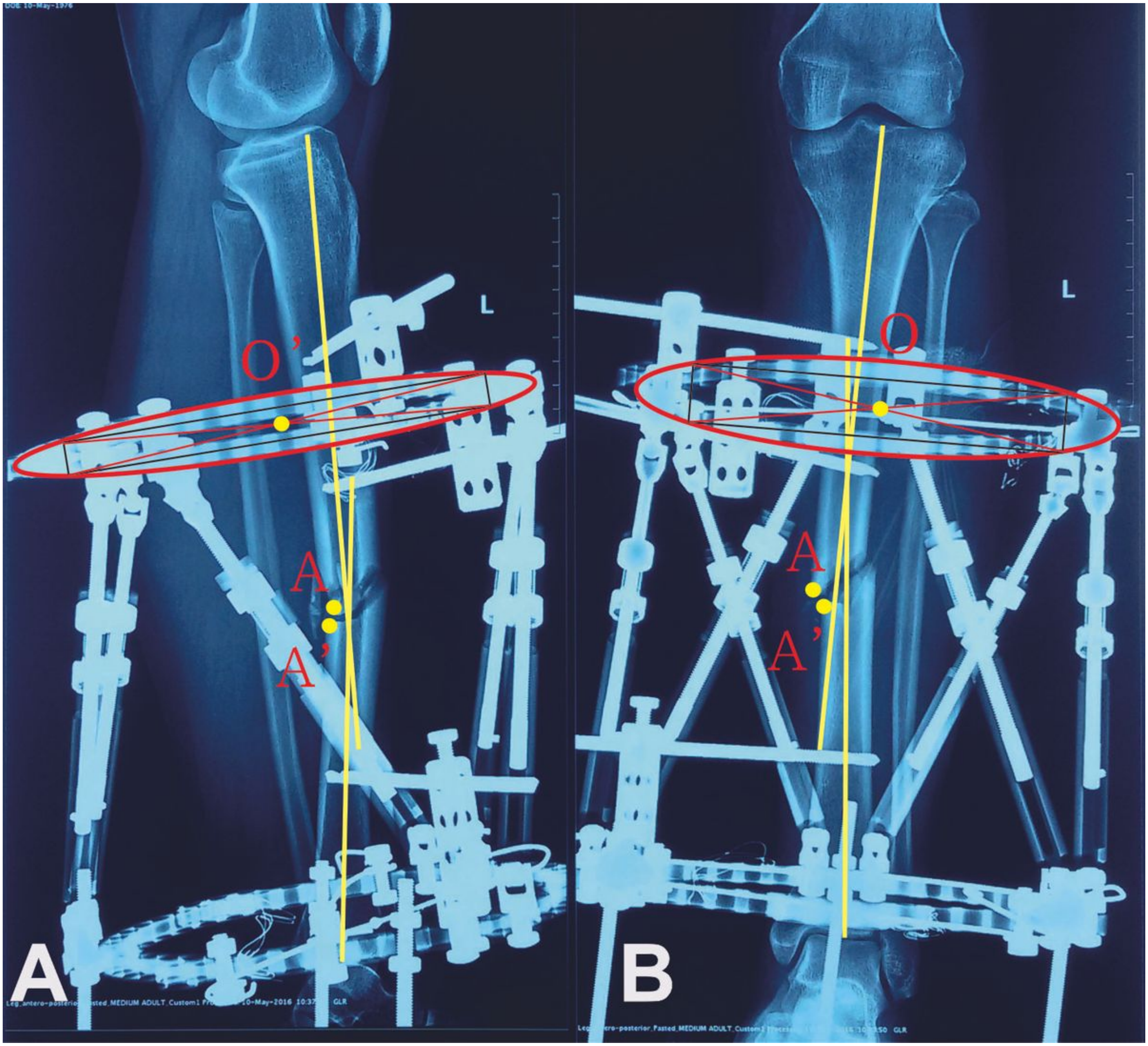

Figure 1

a Measurements of the lateral view. b Measurements of the anteroposterior view. The yellow line indicates the anatomical axis. The red ellipse indicates the reference ring. The yellow point O and O’ indicates the center of the reference ring. The yellow point A indicates the origin point. The yellow point A’ indicates the corresponding point.

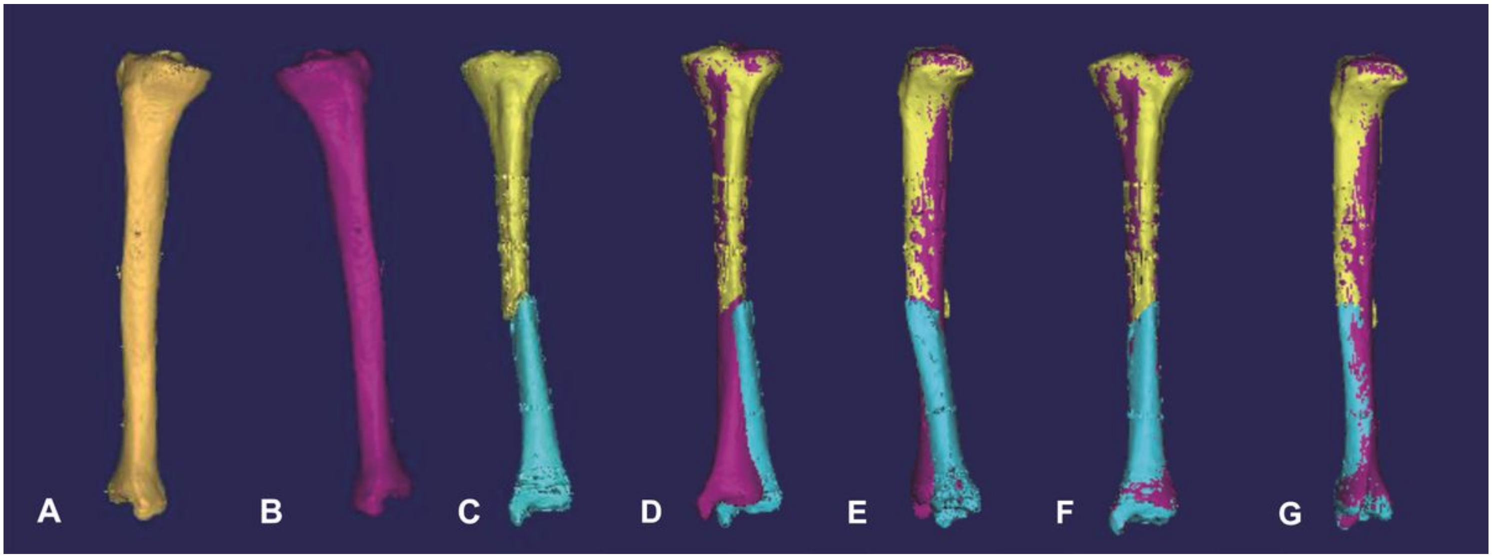

Figure 2

Images of original 3D reconstruction and bone reduction. a 3D image of the contralateral tibia. b Mirrored image of the contralateral tibia. c 3D image of the affected tibia (reference fragment and distal fragment). d AP view before the reduction. e Lateral view before the reduction. f AP view after the reduction. g Lateral view after the reduction.

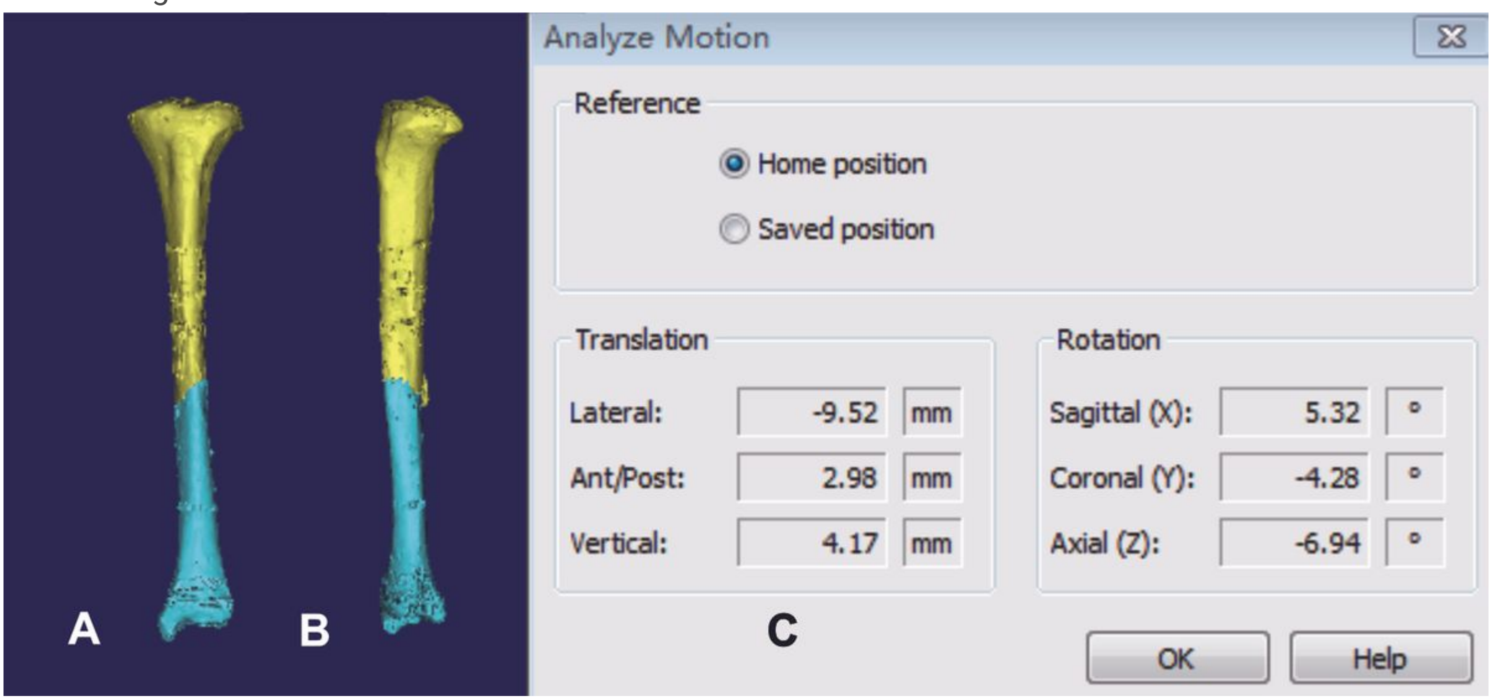

Figure 3

Information of position change related to the distal fragment. a AP view after the reduction. b Lateral view after the reduction. c Data of spatial position change calculated by Mimics.

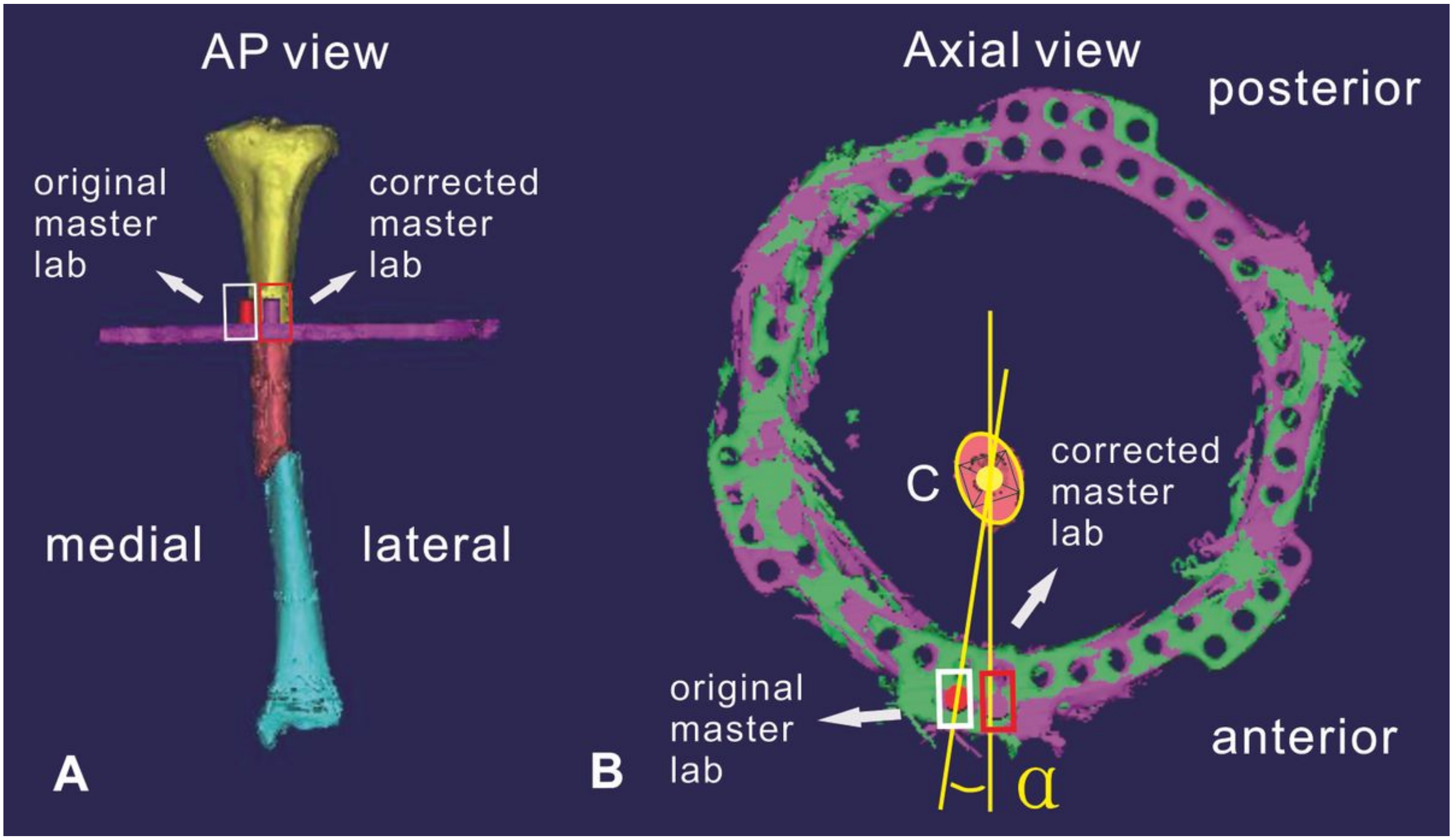

Figure 4

Measurement of the rotary frame angle. a AP view of the reference ring. b Axial view of the reference ring. The original master lab indicates the original position of the reference ring on the axial view. The corrected master lab indicates the standard position of the reference ring on the axial view. The yellow point C indicates the center of the reference fragment. The angle α indicates the rotary frame angle.

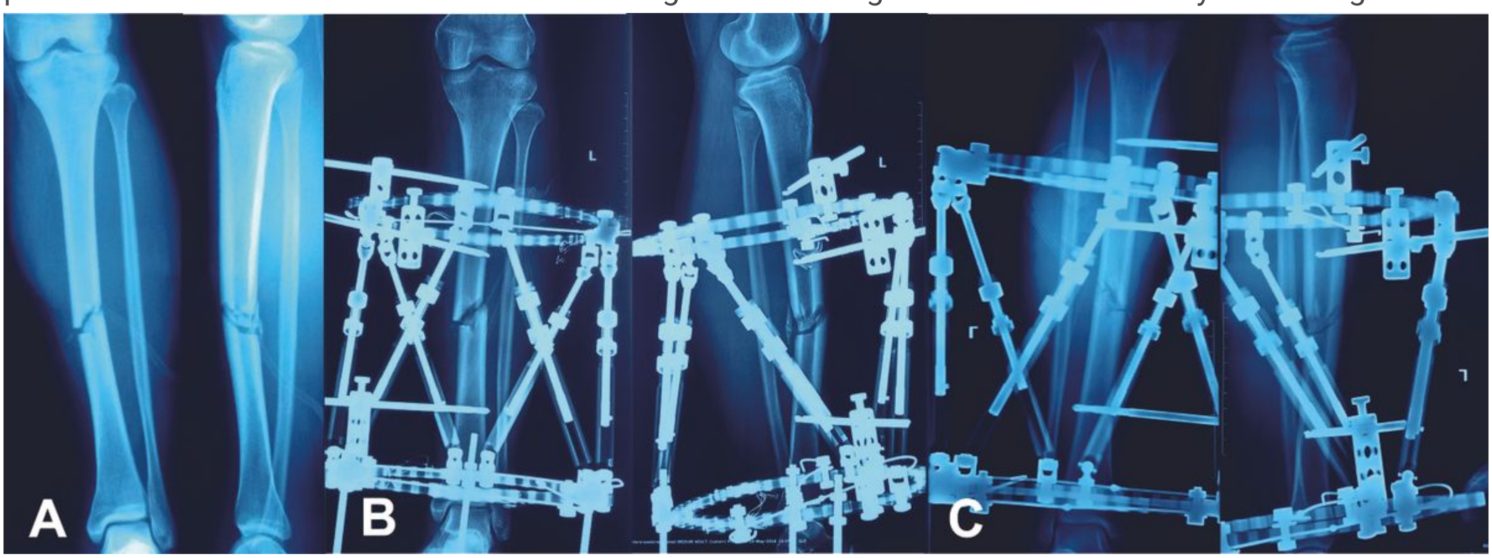

Figure 5

Images of the patient with a posttraumatic multidimensional deformity in tibia treated by the TSF. a Preoperative AP and lateral views of X-rays. b Postoperative AP and lateral views of x-rays. c AP and lateral views of x-rays after reduction.

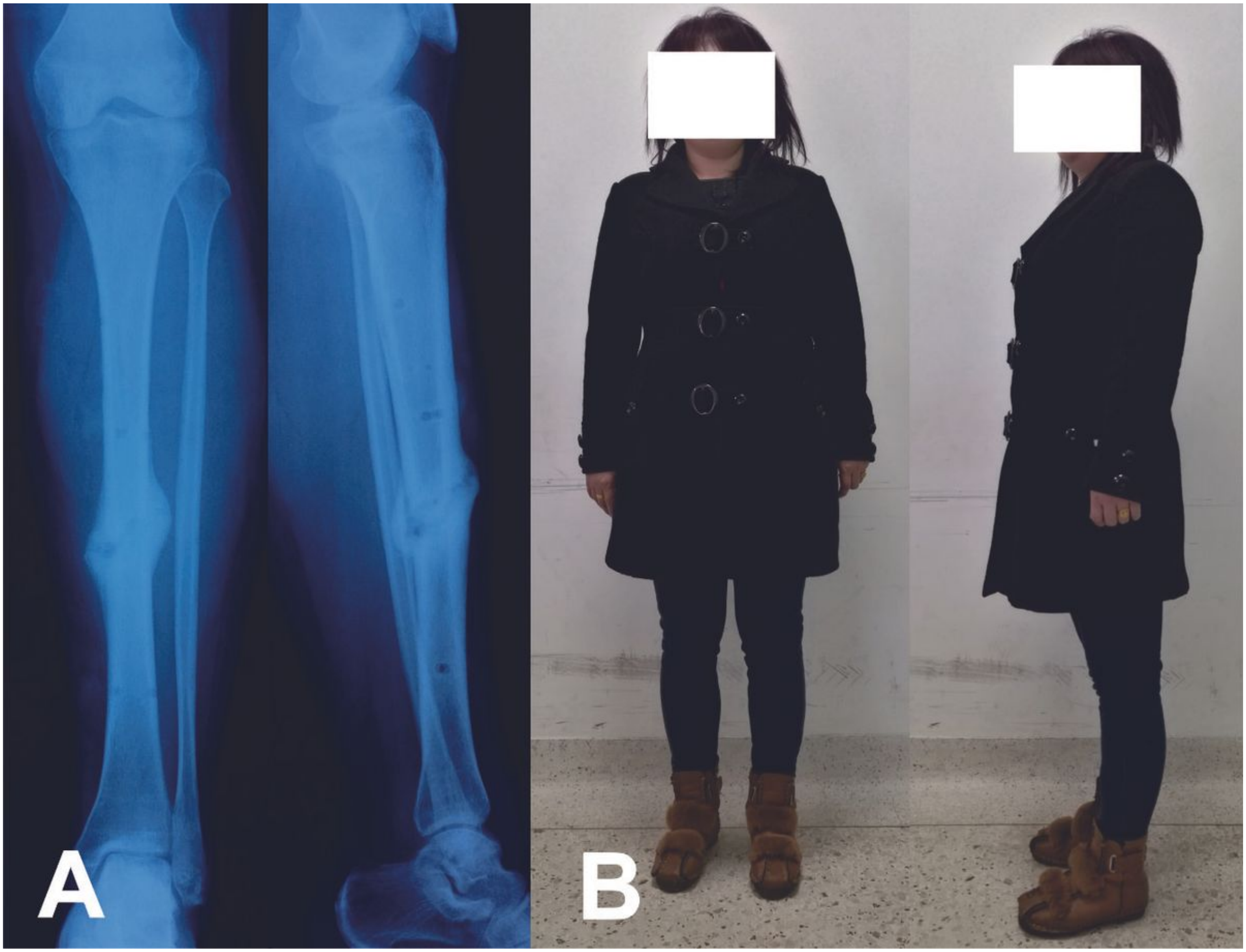

Figure 6

a AP and lateral x-rays after removal of TSF. b General AP and lateral images twelve months later after removal of TSF.

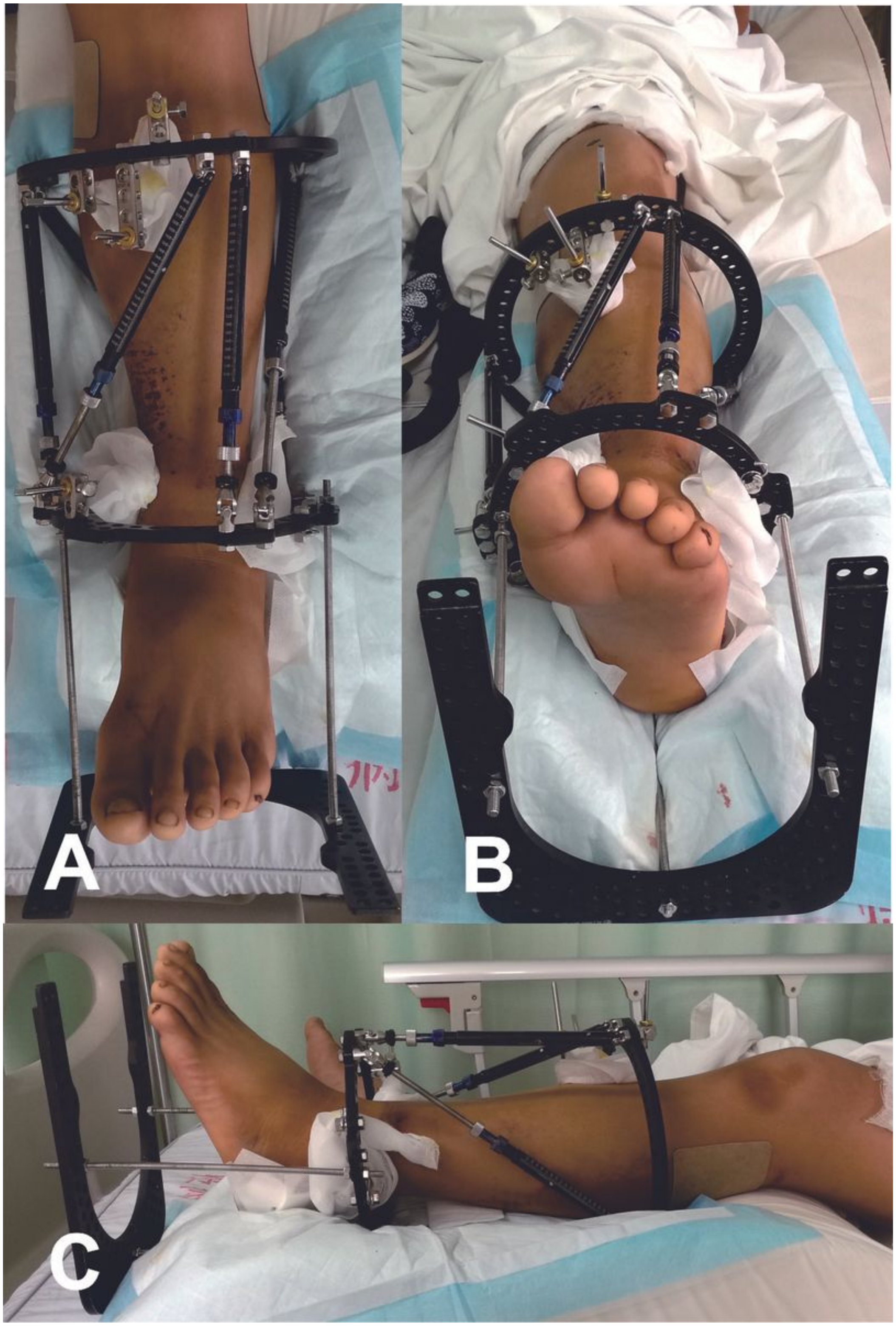

Figure 7

Foot ring used for the standard orthogonal AP and lateral X-rays. a AP view. b Axial view. c Lateral view.