Staged correction trajectory with hexapod external fixator for the satisfactory reduction of acute long bone shaft fracture

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Research Article

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Abstract

Backgroud:

When deformity correction and fracture reduction are conducted in acute long bone shaft fracture using the hexapod external fixator, the collision and interference between the irregular bony end in the reduction process often result in an incomplete reduction and a time-consuming procedure. The purpose of this study was to present and determine the clinical effectiveness of staged correction trajectory with hexapod external fixator for the satisfactory reduction of acute long bone shaft fracture.

Methods

A total of 57 patients with acute tibial shaft fractures consented to hexapod external fixator treatment in our institution were retrospectively analyzed from June 2016 to February 2020. Thirty-one cases (Group □) underwent a conventional one-step reduction trajectory from June 2016 to July 2018. Starting in September 2018, the other twenty-six patients (Group □) all underwent staged correction trajectory (three key points reduction trajectory of “extension-rotation-reduction”). The demographic data, residual deformities before and after correction, number of repeated radiographs after the first postoperative radiograph, duration of deformity correction, and external fixation time were documented and analyzed. At the last clinical visit, the Johner-Wruhs criteria were used to evaluate the final clinical outcomes.

Results

All the 57 patients achieved satisfactory fracture reduction and bone union. There were no statistically significant differences between the two groups in demographic data, residual deformities before and after correction, external fixation time, and final clinical outcomes ($P > 0.05$). The average number of repeated radiographs after the first postoperative radiograph and mean duration of deformity correction in Group □ (1.3 times, 2.9 days) were all less than those in Group □ (2.3 times, 5.1 days) ($P < 0.05$).

Conclusion

Compared with the conventional one-step reduction trajectory, there are no statistically significant differences in the final clinical outcomes, but the staged correction trajectory is a superior method with the advantages of less repeated radiographs and reduction duration.

Background

The circular external fixators with the versatility of eliminating bending and translational shear while maintaining a degree of axial micromotion, providing a three-dimensional stable biomechanical environment that is conducive to bone healing and regenerate formation[1–3]. With the advantages of minimal soft tissue disruption and early weight-bearing, it has given satisfactory clinical outcomes especially for high-energy fractures with poor surrounding soft tissues[4–7].

Hexapod external fixation (HEF) systems, such as the Taylor spatial frame (TSF) and TrueLok-Hex (TL-Hex), are derived from the traditional Ilizarov circular external fixator[8]. The HEF is comprised of two full or partial rings connected by six telescopic struts at special universal joints, imparting the frame with six degrees of freedom. In this frame, one ring can be multidimensionally repositioned with respect to the other one by adjusting strut lengths. It, therefore, allows to simultaneously correct spatial deformities without frame modification. As the expertise of this device was gained by more general orthopedic surgeons, the hexapod external fixator had become an attractive option for trauma-control and definitive treatment of high-energy acute fractures[4, 9–12]. The stable fixation that translates all movement from the rings directly to the corresponding bony segments was needed firstly when conducting deformity correction and fracture reduction using the HEF, and followed by accurate radiographs analysis for deformity correction planning. However, the collision and interference between the irregular bony end in the process of fracture reduction often result in an incomplete reduction or failed reduction due to the conventional one-step reduction trajectory. Additionally, repeated radiographs, exposing the patient to further radiation exposure, are therefore required in the subsequently time-consuming reduction procedures.

In our department, the staged correction procedures called three key point trajectory of “extension-rotation-reduction” were applied to resolve the collision and interference between the irregular bony end during fracture reduction. The purpose of this study was to present and determine the clinical effectiveness of staged correction trajectory with hexapod external fixator for the satisfactory reduction of acute long bone shaft fracture.

Methods

This retrospective study consists of 57 patients with acute tibial shaft fractures consented to hexapod external fixator (Tianjin Xinzhong Medical Instrument Co., Ltd., Tianjin, China) treatment in our institution from June 2016 to February 2020, including 39 males and 18 females with a mean age of 41 years (range 19-65 years). The hexapod external fixation treatments were conducted due to trauma-control and multiplanar posttraumatic deformities correction in those with poor surrounding soft tissues that were not suitable for traditional internal fixation. In any anatomical plane, postoperative deformities greater than 5° or 10mm were needed to be corrected[13].

Thirty-one cases (Group □) underwent a conventional one-step reduction trajectory from June 2016 to July 2018. Starting in September 2018, the other twenty-six patients (Group □) all underwent staged correction trajectory (three key points reduction trajectory of “extension-rotation-reduction”). All the treating procedures were performed by the same medical team. The demographic data, residual deformities before and after correction, number of repeated radiographs after the first postoperative radiograph, duration of deformity correction, and external fixation time in all cases were documented and analyzed. All patients consented to record and publish their information in the present study. This study was approved by the Ethical Committee of our institution.

Deformity correction and fracture reduction procedures

The residual deformities were evaluated by the immediately postoperative orthogonal anteroposterior (AP) and lateral radiographs, followed by the application of total residual program in the HEF system. Any deformities were corrected within three days by gradual strut adjustment according to the electronic prescription, and oral analgesics were used for pain management. Repeated radiographs and electronic prescriptions were performed until satisfactory reduction was achieved. All radiographs were justly taken for clinical reasons rather than the purpose of this study.

In Group □ (conventional one-step reduction trajectory), all deformity parameters (angulation and translation in the anteroposterior, lateral, and axial view) were inputted into the HEF system program at once, and the deformity correction was then performed according to the electronic prescription.

As for Group □ (staged correction trajectory), three key points reduction trajectory was performed (Figure 1-2). A translation parameter in the axial view (within 10mm according to our experience) was inputted into the HEF system program firstly to determine the lengthening of the given case, while the other five deformity parameters were set to zero. The first step of fracture reduction was performed according to the electronic prescription of the “extension” key point (Figure 2b and 2f). Subsequently, the five deformity parameters according to the postoperative radiographs (including angulation and translation in the AP and lateral view, angulation in the axial view) were inputted to determine rotation, while the translation parameter in the axial view was set to zero. The second step of fracture reduction was conducted depending on the electronic prescription of the “rotation” key point (Figure 2c and 2g). Finally, a translation parameter in the axial view (original deformity combined with the “given” deformity in the first step) was inputted to determine the shortening, the other five deformity parameters were set to zero at the same time. The final fracture reduction was achieved using the electronic prescription of the “reduction” key point (Figure 2d and 2h).

Clinical effectiveness evaluation

The reduction effectiveness was evaluated by the translation and angulation in the AP and lateral view, according to the standard orthogonal radiographs after the final reduction. The residual deformities were calculated by the same observer who is experienced in musculoskeletal radiology using CorelDRAW X7(Corel, Canada).

The patients were followed up monthly during the fracture healing time. The hexapod external fixation was terminated when radiographs showed sufficient union (corticalization in 3 of 4 cortices). All patients were followed up at a minimum of 12 months after the fixator removal. The final clinical outcomes were evaluated by the Johner-Wruhs criteria[14] at the last clinical visit.

Statistical analysis

The SPSS 22.0(IBM Corp, USA) was used for statistical analysis. Continuous variables were analyzed by Independent-samples T-tests, expressing as the mean and range of the observations. Count variables were analyzed by the Chi-square or Fisher's test, representing as a number. A statistically significant difference was set at $P < 0.05$.

Results

All the 57 patients achieved satisfactory fracture reduction and bone union. The average follow-up after hexapod external fixation termination was 17.9 months (12–26 months), and no case was lost. No reduction loss, neurovascular injury, and refracture were observed. Activities of daily life without significant difficulty were performed in all patients at the last seen.

There were no statistically significant differences between the two groups in demographic data, residual deformities before and after correction, and external fixation time ($P > 0.05$). The average number of repeated radiographs after the first postoperative radiograph and mean duration of deformity correction in Group □ (1.3 times, 2.9 days) were all less than those in Group □ (2.3 times, 5.1 days) ($P < 0.05$). (Typical cases are shown in Fig. 3 and Fig. 4)

Based on the Johner-Wruhs criteria, in Group □, there were excellent in 23 cases, good in 6 cases, and moderate in 2 cases. Excellent in 19 patients, good in 5, and moderate in 2 were observed in Group □. There were no statistically significant differences between the two groups ($P > 0.05$). (More details are shown in Table 1 and Table 2)

Table 1
Demographic data of the two groups

	Group [illegible]	**Group [illegible]**	**Statistical value**	**P value**
Patients				
Male	21	18	0.015	0.904
Female	10	8		
Age (year)	40.6 ± 11.9	41.1 ± 9.9	-0.170	0.865
Injury mechanism				
Road traffic accident	20	18	1.380	0.531
Fall from height	4	5		
Crushing injury	7	3		
Open/closed fracture				
Open	22	16	0.566	0.575
Closed	9	10		
OTA classification of fractures				
A	11	6	1.251	0.599
B	16	17		
C	4	3		
Time elapsed since the injury to HEF installation (day)	3.3 ± 1.4	3.1 ± 1.1	0.332	0.741

Table 2
Clinical outcomes of the two groups

	Group ▯	Group ▯	Statistical value	P value
Residual deformities before correction				
T1(mm)	9.6 ± 5.6	8.5 ± 5.2	0.745	0.459
A1(°)	5.5 ± 2.5	5.1 ± 3.3	0.596	0.553
T2(mm)	8.3 ± 3.3	8.9 ± 5.1	-0.505	0.616
A2(°)	3.8 ± 1.9	4.4 ± 2.1	-1.204	0.234
Residual deformities after correction				
T1(mm)	1.8 ± 1.3	1.2 ± 1.1	1.748	0.086
A1(°)	0.7 ± 0.8	0.6 ± 0.8	0.720	0.475
T2(mm)	1.2 ± 1.1	0.9 ± 1.3	0.859	0.394
A2(°)	0.8 ± 0.9	0.7 ± 0.9	0.777	0.441
N (time)	2.3 ± 1.0	1.3 ± 0.5	4.572	P < 0.001
Duration of deformity correction (day)	5.1 ± 1.9	2.9 ± 1.1	4.914	P < 0.001
External fixation time (week)	27.9 ± 4.9	27.2 ± 1.9	0.543	0.589
Follow-up (month)	18.3 ± 3.7	17.5 ± 4.7	0.699	0.488
Johner-Wruhs criteria				
Excellent	23	19	0.212	1.000
Good	6	5		
Moderate	2	2		
Poor	0	0		

T1: Residual translation in the coronal plane

A1: Residual angulation in the coronal plane

T2: Residual translation in the sagittal plane

A2: Residual angulation in the sagittal plane

N: number of repeated radiographs after the first postoperative radiograph

Discussion

Combined with the Ilizarov circular external fixator and the Chasles theorem of six-axis motion[15,16], the hexapod external fixator has played an important role in orthopedic and reconstructive surgery due to the advantages of simultaneous correction of multiplanar spatial deformities without frame modification[4,7,8,10,12,17–19]. Initially developed for gradual deformity correction, the hexapod external fixator expanded to conduct the management of fracture and bone nonunion[11,12,19–21].

The high theoretical accuracies of 1/1000000 inch and 1/10000 degrees are extreme for clinical practice, but with approximate correction accuracies of 1mm and 1° using the hexapod external fixator[15,22]. Accurate radiographic analysis of deformity and mounting parameters are crucial for the success of hexapod external fixation treatment. Although lots of satisfactory clinical outcomes have been manifested in the HEF treatment, no technique is perfect in fact, as most parameter measurement techniques are subjective and heavily depend on human evaluators. Malcorrection, insufficient correction, or unexpected translation-angulation can be presented by subtle errors in the parameter definition. Lots of previously published methods have been described to improve parameter accuracy, including CT scans, intraoperative fluoroscopy, postoperative radiography, and determination of the radiographs' orthogonality[15,23–29].

Gantsoudes et al.[15] utilized equipment that already available in a TSF treatment would be used to obtain intraoperative orthogonal images, they thought their technique was quick, cheap, and easily reproducible. Ahrend et al.[29] taken postoperative radiographs with the help of a rotation rod, the results manifested that the variability of rotation on radiographs was lower with the rotation rod, and more reproducibly comparable radiographs can be obtained. Kanellopoulos et al.[25] described a noninvasive technique using a specifically designed radiolucent frame to determine the reference ring perfectly orthogonal in single exposures for each radiographic view. Deakin DE et al.[26] acquired perfectly aligned radiographs with the help of a frame-mounted spirit level. Wright et al.[28] described a silhouette technique to produce adequate orthogonal imaging. Kucukkaya et al.[24] introduced a technique for determining the mounting parameters using computed tomography, and it is especially advantageous for cases with rotational deformity. Liu et al.[27] precisely measured the deformity and mounting parameters with the help of the elliptic registration technique and three-dimensional reconstruction. Gessmann et al.[30] declared that the mounting parameters can be accurately measured with radiographic techniques when using calibration markers and a software calibration tool.

The aforementioned techniques all concentrated on precise parameter calculation, none of them focused on the influence of the bony ends' movement trajectory on the correction effectiveness during the fracture reduction process. At present, the mainstream hexapod external fixation system all performed one-step reduction trajectory, the inherent limitation is that the collision and interference between the irregular bony end in the process of fracture reduction often result in an incomplete reduction or failed reduction. In those complex cases, this drawback always results in repeated radiographs which expose the patient to further radiation exposure and make the reduction procedure time-consuming.

In the present study, the three key points reduction trajectory of “extension-rotation-reduction” was used to resolve this problem. In the whole process, the crucial step is “extension” to provide sufficient space for the relative movement of the two bony ends. Notably, accurate parameter measurements are equally important. In this series of 57 patients with tibial shaft fractures treated by the HEF, there were no statistically significant differences between the two groups in the final clinical outcomes. Although both groups achieved satisfactory outcomes, the average number of repeated radiographs after the first postoperative radiograph and mean duration of deformity correction in Group □ were all less than those in Group □. Repeated reduction may aggravate the internal soft tissue damage which is not beneficial for fracture healing, and the long duration of fracture reduction will make patients uncomfortable. Therefore, according to our experience, the three key point trajectory of “extension-rotation-reduction” is recommended due to the shorter reduction duration with lower potential radiation exposure, especially for those complex fractures with irregular bony ends.

The present study had several limitations. First of all, considering the small sample size in a single-center, a conservative attitude should be adopted regarding the interpretations of our results. Besides, compared with the conventional one-step reduction trajectory, this three key point trajectory is relatively tedious but the results manifest the superiority.

Conclusion

Compared with the conventional one-step reduction trajectory, there are no statistically significant differences in the final clinical outcomes, but the staged correction trajectory is a superior method with the advantages of less repeated radiographs and reduction duration.

Abbreviations

HEF: hexapod external fixator

TSF: Taylor spatial frame

AP: anteroposterior

Declarations

Ethics approval and consent to participate

All methods in this study were carried out in accordance with the Declaration of Helsinki. This 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 competing interests.

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Authors' Contributions

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

WF: Interpreted and analyzed the data. Edited the manuscript.

KL: Created and statistical analyzed the data. Edited the manuscript.

FYC: Conducted the study and provided the data.

XPZ: Conducted the study and prepared figures 1-2.

HL: Conducted the study and prepared figures 3-4.

TZ: Provided theoretical guidance. Reviewed the manuscript.

AY: Planned the project. Reviewed the manuscript.

Yanshi Liu and Fei Wang contributed equally to this study.

All authors read and approved the final manuscript.

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Not applicable

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Figures

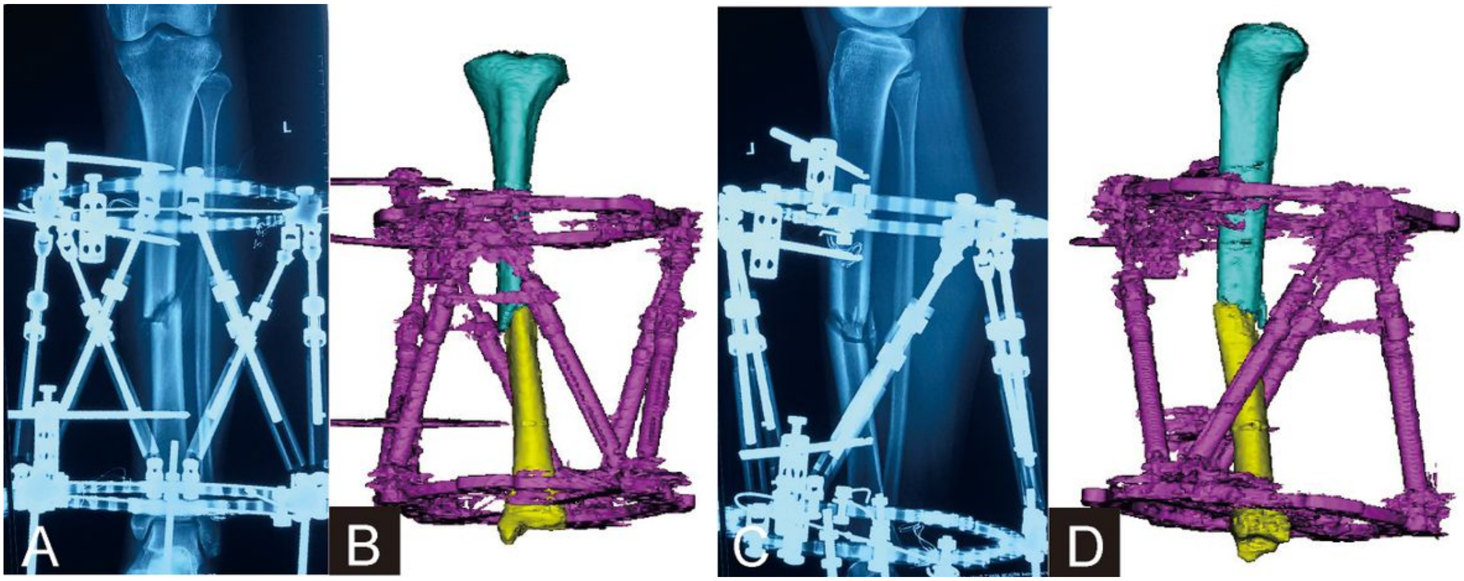

Figure 1

A 41-year-old man with posttraumatic multidimensional deformities in tibia treated by the hexapod external fixator, and underwent staged correction trajectory. a and b Radiographs immediately after the operation and three-dimensional reconstruction in the AP view. c and d Radiographs immediately after the operation and three-dimensional reconstruction in the lateral view.

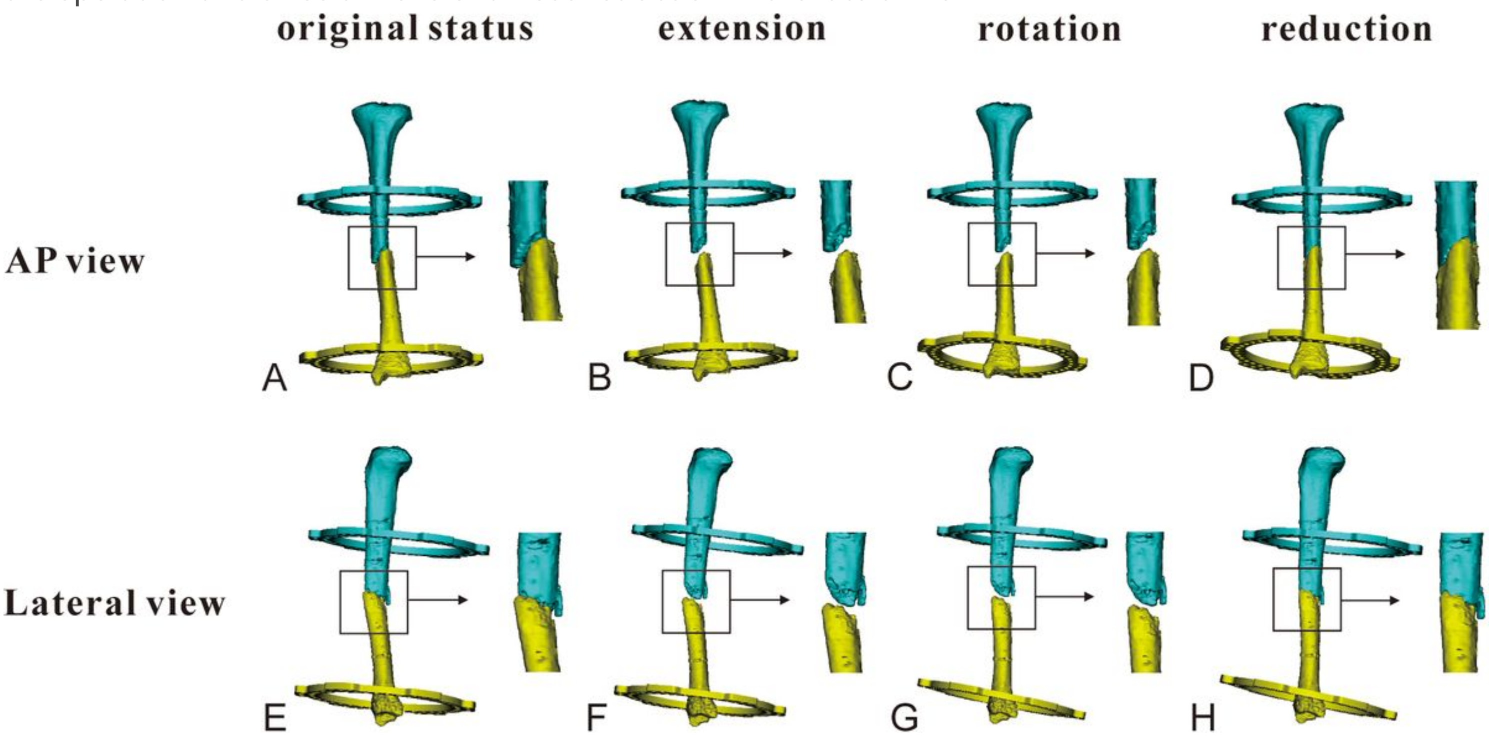

Figure 2

Schematic diagram of the staged correction trajectory for the case shown in figure 1. a and e Original status of the whole model. b and f “Extension” key point, the distal part was moved at an appropriate distance to the distal end, providing sufficient space for the relative movement of the two bony ends. c and g “Rotation” key point, the distal part was moved and rotated in multiple planes to correct the spatial deformities. d and h “Reduction” key point, the two bony ends were docked and the final fracture reduction was achieved.

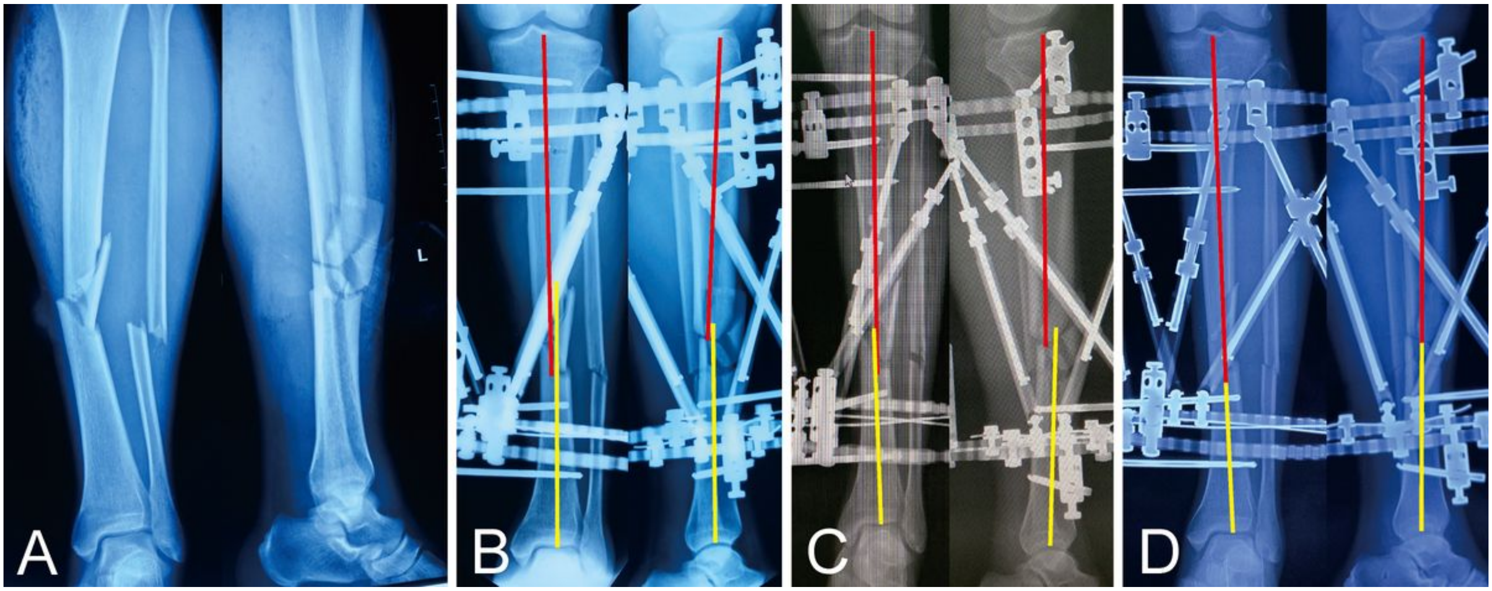

Figure 3

A 49-year-old man with posttraumatic multidimensional deformities in tibia treated by the hexapod external fixator, and underwent conventional one-step reduction trajectory. This patient underwent two repeated radiation exposure after the first postoperative radiograph, and the duration of deformity correction was six days. a Posttraumatic radiographs. b Radiographs immediately after operation. c Radiographs immediately after the first correction. d Radiographs immediately after the second correction.

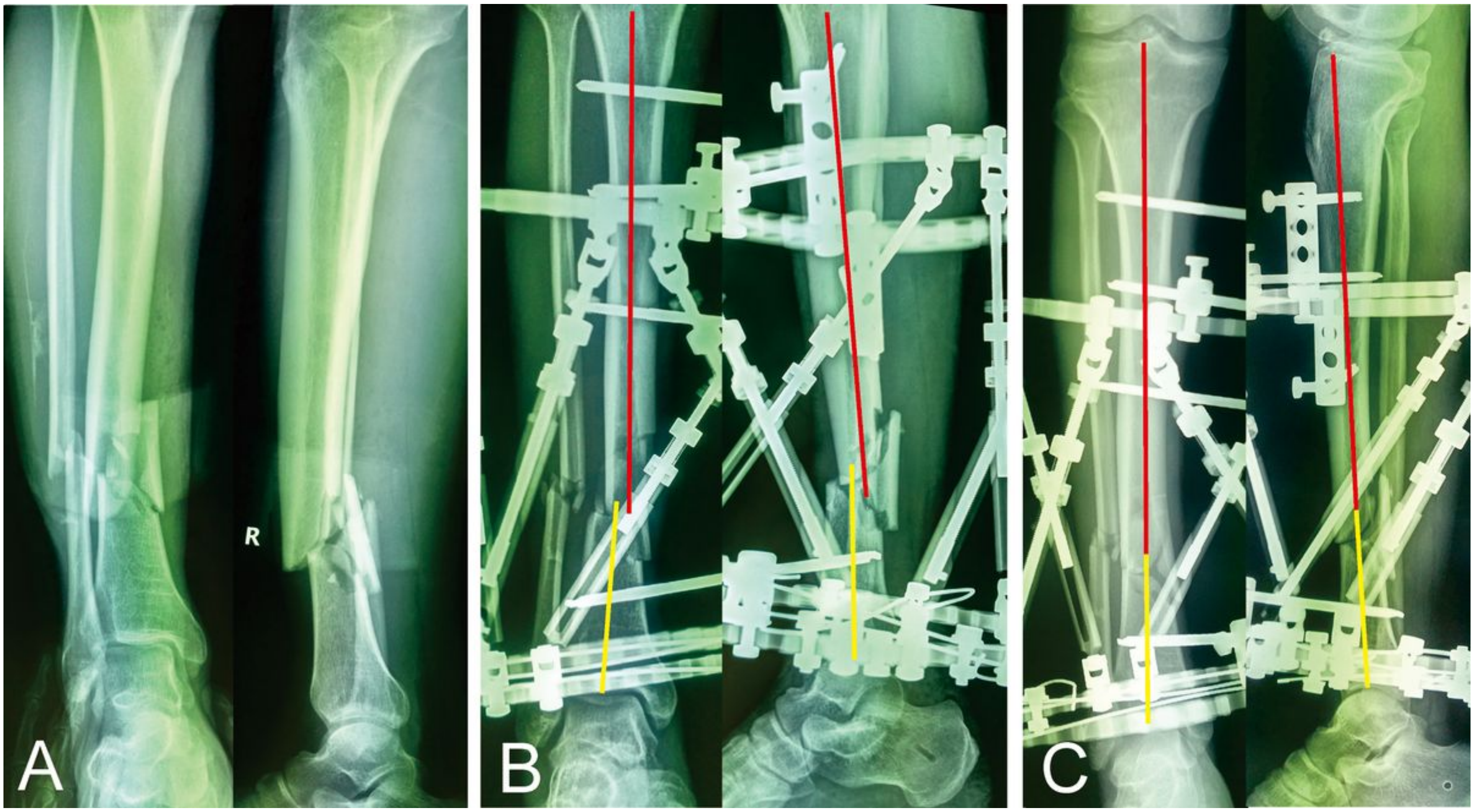

Figure 4

A 52-year-old man with posttraumatic multidimensional deformities in tibia treated by the hexapod external fixator, and underwent staged correction trajectory. This patient underwent one repeated radiation exposure after the first postoperative radiograph and a three-day deformity correction duration. a Posttraumatic radiographs. b Radiographs immediately after operation. c Radiographs immediately after the first correction.