ORTHOPAEDIC SURGERY

Intraoperative ultrasound-guided reduction of femoral shaft fractures using intramedullary nailing: a technical note

Zhao Zhe[1] · Zhu Jianjin[1] · Song Fei[1] · He Dawei[1] · Deng Jiuzheng[1] · Chen Fang[2] · Pan Yongwei[1]

Abstract

Objectives Intramedullary (IM) nailing is the preferred method for treatment of femoral shaft fractures. However, for the surgical staff and the patients, exposure to large dose of X-rays is inevitable during the procedure. In this paper, a new technique based on ultrasound is proposed to guide the reduction of femoral fractures, reducing radiation exposure.

Methods and results By means of particular continuous transverse and multiplanar longitudinal scanning, the deformity pattern information of the fracture could be efficiently acquired. Adequate reduction could be achieved under the real-time guidance of intraoperative ultrasound.

Conclusions Intraoperative ultrasound can guide the reduction of femoral shaft fracture using IM nailing, and reduce the radiation exposure of medical staff and patients.

Keywords Intraoperative ultrasound · Femoral fractures · Reduction · Intramedullary nailing

Introduction

Adequate reduction is a guarantee for the successful treatment of fractures. Intramedullary (IM) nailing is preferred for treating femoral shaft fractures, because that yields high union rates and low complication rates [1]. However, before reaming and the insertion of intramedullary nail (IMN), deforming forces causing the femoral shaft fracture interferes with the reduction procedure. Despite that considerable efforts are made to overcome the forces, including traction, positioning, and closed manipulation of the thigh during operation, adequate reduction may still fail. This problem is incurred by the usages of intraoperative percutaneous

reduction tools including bone hooks, ball spikes, F-tools, and finger reduction tools under intraoperative fluoroscopy [2]. To achieve accurate reduction and realignment, a great quantity X-ray is commonly unavoidable, resulting in considerable radiation exposure of both surgical staff and patients [3, 4]. In addition, frequent change of the C-arm position between the anterior–posterior (AP) and the lateral views lengthens the operation procedure, thus potentially increasing blood loss and infection rate. Musculoskeletal ultrasonography is real-time, non-radioactive, and easy to use. Owing to these characteristics, it has progressively become an established imaging technique for evaluating peri-articular and intra-articular structures in recent years [5]. Grechenig et al. reported ultrasound-detected fracture gap of 1 mm or more [6]. Several studies demonstrated that ultrasonography facilitates diagnosis of pediatric clavicle and forearm fractures [7–9] and that it was used to guide the reduction of pediatric forearm fractures in the emergency department [7, 10]. In adult spinal burst fracture, intraoperative ultrasonography could also assist the guidance of fracture repositioning [11, 12]. In addition, intraoperative ultrasonography was also used to guide the reduction of zygomatic fracture [13, 14]. Yet, to our best knowledge, there is no research about the intraoperative ultrasound-guided reduction of femur shaft fracture. In this work, we describe a method which uses intraoperative ultrasound to

✉ Pan Yongwei
ywpan2013@163.com

1 Department of Orthopaedics, Beijing Tsinghua Changgung Hospital, School of Clinical Medicine, Tsinghua University, No. 168, Li Tang Road, Changping District, Beijing 102218, China

2 Department of Computer Science and Engineering, Nanjing University of Aeronautics and Astronautics, Nanjing 210016, China

guide IM nailing in the reduction of femoral shaft fractures, including antegrade IM nailing with fracture table and retrograde IM nailing without fracture table, thus effectively reducing radiation exposure.

Methods

Preparation

For the intraoperative ultrasound examination, a P7, Portable Color Doppler Ultrasound System (Beijing East Whale Image Technology Co., Ltd, Beijing, China) with a curve transducer (C2-5) was employed. The frequency was set between 3 and 5 MHz depending on the depth of the soft tissue and the required image quality. For intraoperative use under sterile conditions, the transducer was coated with a sterile endoscope cover. We used iodophor or normal saline as ultrasonic couplants. Correct instrument setting would markedly increase the sensitivity of the equipment; thus, the depth and gain of scanning need to be fine adjusted preoperatively.

Scanning technique and displacement detection

Transverse and multiplanar longitudinal scanning of musculoskeletal anatomic structures were performed to acquire maximal morphological information.

Transverse scanning

This was the first scanning pattern we used. The transducer was placed anterior to the thigh at the proximal end. The typical signal of femur in transverse section should be a hyperechoic arc with acoustic shadow. After detecting the proximal fragment, we slid the transducer distally along the femur. The discontinuity of the femoral signal or the double arc sign revealed the fracture site for the deformity type (Fig. 1a, b; video in the Supplementary Material 1). The translational displacement including medial or lateral, anterior or posterior, and shortening or lengthening could be recognized approximately. Then, we marked the fracture site on patient's skin, and rotated the transducer 90° clockwise to start the sagittal scanning.

Sagittal scanning

The following cases were observed in sagittal scans: an angulation deformity (flexion or extension) when the proximal and distal segments were seen in the same section, but there was an angle between the two parts, the apex towards or against the transducer indicating extension or flexion deformity, respectively (Fig. 1c, d); medial or

lateral displacement when the proximal and distal segments could not be seen in the same section, but the displacement was indicated by the order in which segments appeared if moving the transducer from medial to lateral (Fig. 1e–g; video in Supplementary Material 2); anterior or posterior displacement when the proximal and distal segments were seen in the same section, but the displacement was indicated by the different distances between segments and the transducer (Fig. 1h, i); or complex deformity in the combination of above cases.

Coronal scanning

We slid the transducer 90° from the sagittal pattern along the longitudinal axis of femur for coronal scanning. The basic technique applied here was the same as that in sagittal scanning. However, angulation deformities in the coronal plane (adduction and abduction) could only be seen in coronal scans, and medial or lateral displacement was measured accurately in this pattern. The deformity was cross-validated by both sagittal and coronal scans (Fig. 1h–j). Scanning in other directions is also recommended to provide more information, which is suggested to be performed if necessary.

Artifacts

The interface between muscle and bone was highly reflective, resulting in linear artifacts called reverberation artifacts. These artifacts appeared as a series of echogenic lines that were parallel to one another and to the transducer face. In addition to that, the amplitudes of echogenic lines diminished at greater depths (Fig. 2).

Close reduction

First, we used inline traction with or without fracture table and then checked the reduction using ultrasonography again. We manipulated the distal segment with towel pumps or hands. If an adequate reduction is not achieved, we would adopt percutaneous Schanz pins to facilitate reduction. After achieving satisfactory realignment, we were able to pass the finger reducer or ball-tipped guidewire into the opposite segment. If the reduction was lost to a certain extent after the insertion, the finger reducer is usually outside the femoral intramedullary cavity, and the reducer could still be found in the image (Fig. 3b, d). If the reduction was still maintained (Fig. 3e), it should be checked by double direction intraoperative fluoroscopy, because ultrasonography cannot provide sufficient information about the bone and the implant.
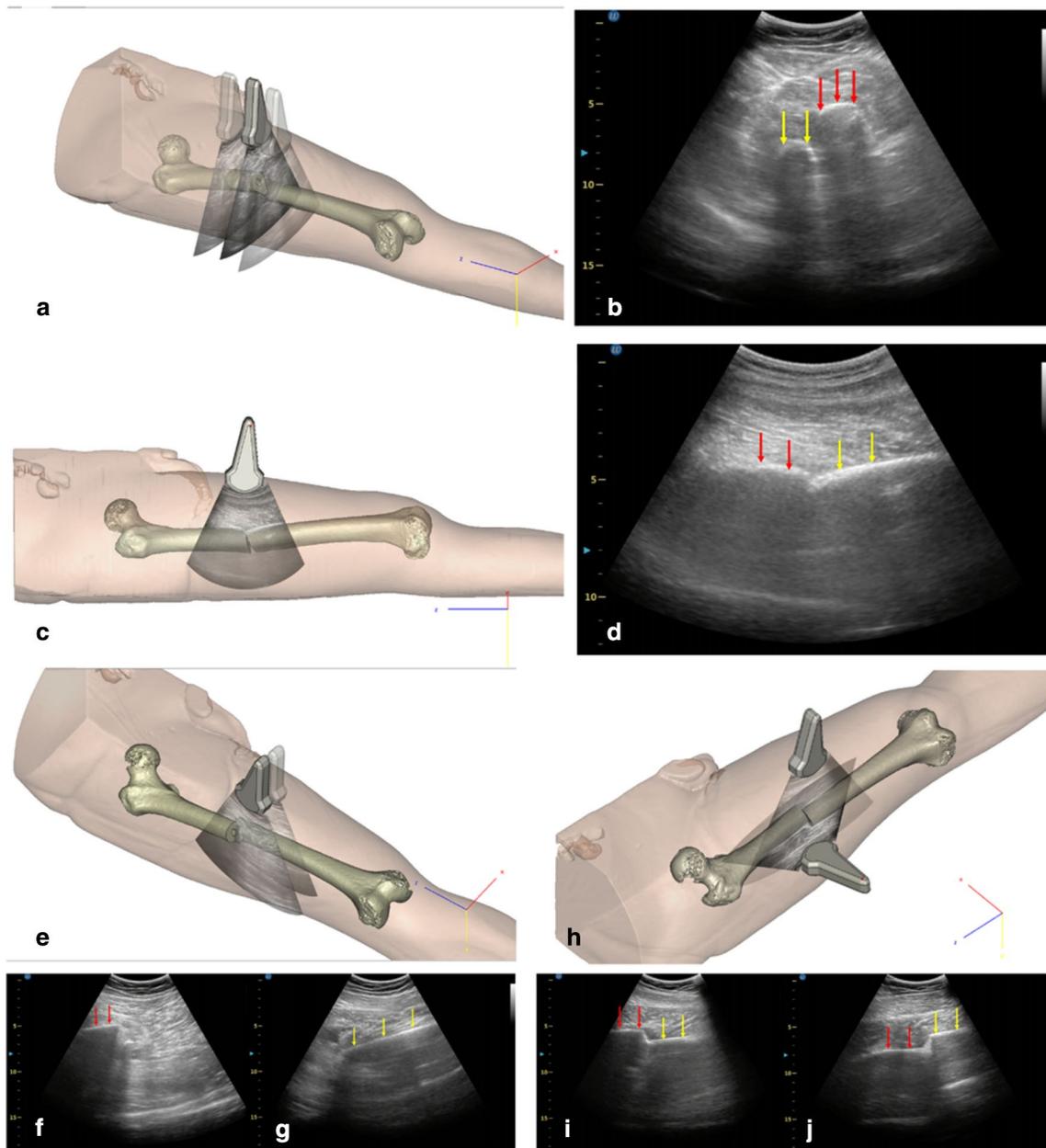
Fig. 1 **a** Sliding the transducer along the femur to locate the fracture. **b** Double arc sign indicated the fracture site. The proximal segment (red arrows) and the distal segment (yellow arrows) were shown in the same section. **c** Sagittal scanning at the fracture site revealed angulation deformity in the sagittal plane. **d** Extension deformity was shown in this section. There was an angulation, apex against the transducer, between the proximal segment (red arrows) and the distal segment (yellow arrows). **e** Medial displacement of the distal segment could be observed by moving the transducer from lateral to medial. **f** Proximal segment (red arrows) was seen first. **g** Distal segment (yellow arrows) was seen afterwards. **h** Sagittal and coronal scanning was performed on the same patient for analysis of complex displacement. **i** Sagittal scan showed that the distal segment was posteriorly (accurate) and laterally (approximately) displaced. **j** Coronal scan showed the lateral displacement of the distal segment accurately

Cases

Case one

A 17-year-old female sustained a transverse femoral shaft fracture (32-A3 according to AO/OTA classification) and a patella fracture on the same side caused by a vehicle accident (Fig. 3). The patella fracture was fixed by a tension band first, and then, the reduction of femoral fracture was under ultrasound. After failing to pass the reducer several times, intraoperative fluoroscopy was used to check, and then, the ultrasound was used at the same time as lateral
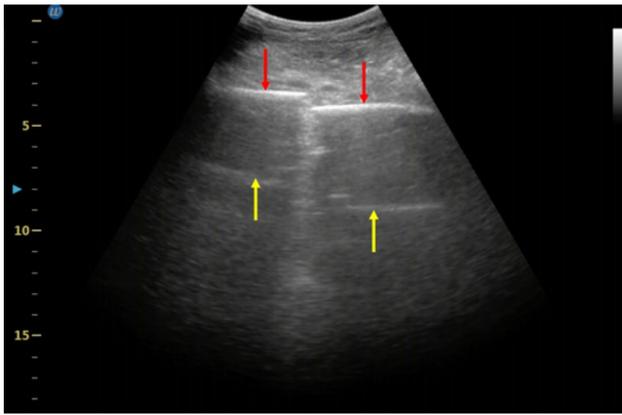
Fig. 2 Red arrows showed the surface of fractured femur, which were hyperechoic lines. The yellow arrows showed the reverberation artifacts, which were not the opposite surface of femur

view of the fracture site. The reduction time was 16 min. The radiation exposure was 20 times for reduction and 72 times in total.

Case two

A 47-year-old male sustained bilateral femoral fracture (32-A3 of the right and 33-C1 of the left, according to AO/OTA classification) by a vehicle accident (Fig. 4). An open reduction internal fixation was performed first on the left side. Then, the right femoral fracture was fixed by a retro-intramedullary nail, and the reduction was entirely done under ultrasound. This process only took 6 min and a half for reducing and passing the finger reducer, and total intra-operative fluoroscopy exposure was 35 times.

Discussion

The main goals of using intramedullary nail fixation for femur shaft fractures contain restoration of length, alignment, and rotation of the femur through strategic intraoperative reduction techniques [15]. If the femur was reamed yet adequate reduction has not been achieved, the reamer could create an eccentric path leading to malreduction, which would result in compromised outcomes including nonunion, malunion, and dysfunction [16, 17]. Therefore, it is very important for surgeons to recognize the deformity pattern. Main segments in a diaphyseal fracture usually displace in six basic patterns, including three pairs of translational displacements and three rotations, but most fractures displace in a combination of ways [18]. All three pairs of translational displacements could be detected under intraoperative ultrasonography, and the resolution is 1 mm and more [6]. Rotations in sagittal and coronal planes could be directly detected

and measured by the integration of the device software. The most exciting character of ultrasound system is the real-time capability. Thanks to the real-time ultrasound system, surgeons could observe the translation and angulation continuously while manipulating the distal segment to reduce without any radiation exposure. The rotation along the longitude axis of femur could not be observed directly, and it is also the most difficult one to judge under intraoperative fluoroscopy. A study showed that following the closed intramedullary nailing of the femur, the torsional deformity of 4°–61° was found, and the average malrotation was 16° [16]. When the malalignment was more than 10° in femoral rotation, it would be symptomatic for the patients [19], which undoubtedly adds more importance for surgeon in correcting the rotation. During our practice, two methods could be used to evaluated of malrotation. First, the proximal and distal alignment of the intermediate fragment was evaluated separately. This technique was appropriate for 32 B2 fractures, in which the proximal and distal margins could provide enough shape information. Second, the torsional deformity could be evaluated using the technique modified from the method proposed by Ehrenstein et al. [20]. Ehrenstein et al. developed a method using a modified transducer attached with a goniometer to adjust the torsional deformity and compared the measurements of the femoral neck angle and the anterior femoral condyle angle with the data of uninjured side. We measured the angle between femoral neck line and anterior femoral condyle and compared with the opposite side. During the scan procedure, manipulator should keep the anterior condylar line and femoral neck line oriented horizontally on the ultrasound screen, and the orientation of the transducer was marked by the assist, then the angles between two position was measured (Fig. 5). This technique was appropriate for 32 B3-to-C fractures. However, in our recent practice, we still used intraoperative fluoroscopy to double check the rotation before interlocking.

Ultrasonography was used in the diagnosis of children forearm fractures, with a sensitivity of 91.5% and a specificity of 87.6%, no better or worse than X-ray [21]. This indicates its potential usage in assisting fracture reduction but with several limitations. In this work, we try to establish a practical procedure to overcome these limitations. Intraoperative ultrasonography is able to provide only two-dimensional information in a single section, which may be difficult for surgeons to get a complete impression of the fracture site and the deformity. First, the commonly used fluoroscopy penetrates bones and provides information of both the outer and inner surfaces, though the images are also two-dimensional; second, its image intensifier is relatively larger, thus displaying larger region in single exposure.

To compensate the limitations, in this work, we propose a practical solution for intraoperative ultrasonography-assisted fracture reduction, which moves the transducer in particular
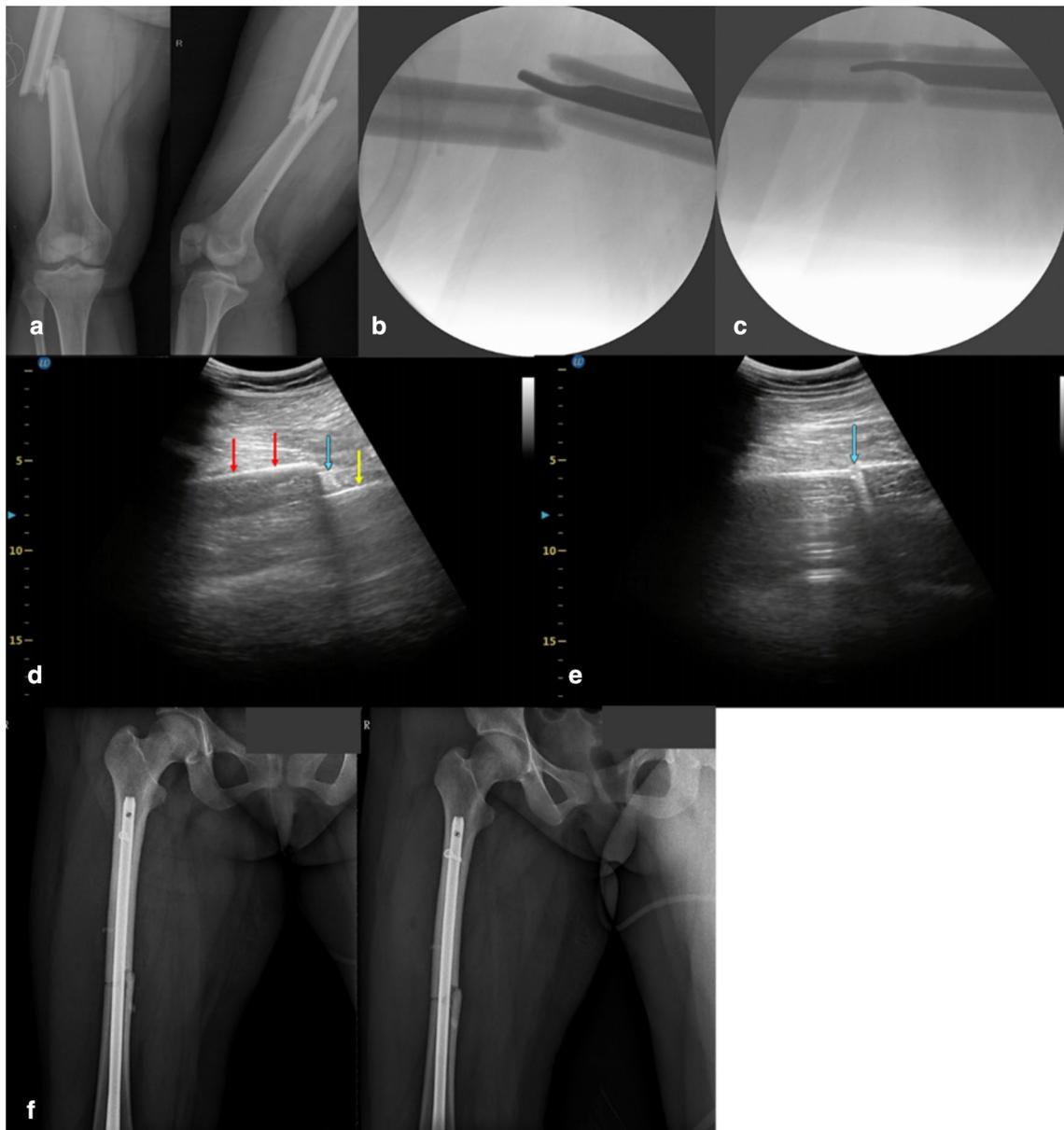
Fig. 3 **a** X-ray showed that there was a transverse fracture on left femoral shaft. **b** AP view of X-ray showed the lost reduction. **c** X-ray confirmed the finger reducer passed into the opposite segment. **d** Coronal scan showed the lost reduction ate the same time with **b**, but the reducer (blue arrow) could be found coming out from the proxi-mal segment (red arrows) outside the distal segment (yellow arrow). **e** Confirming image showed that the reduction was satisfactory, and the fracture line was marked by the blue arrow. **f** AP and lateral X-ray after surgery

ways to provide three-dimensional scans for surgeons. Although ultrasound cannot penetrate bones and the image only contain information of the bone surface, scans obtained from three planes can help the surgeon to build a precise judgement of the displacement. This solution requires that the manipulator is experienced in operating ultrasound devices and good at employing spatial intelligence. In the future, new technologies such as the phase-array ultrasonic imaging can also be used to generate three-dimensional

images of the fracture site in real time and in continuity, which possibly would make the procedure more visualized and easier.

In recent years, the electromagnetic navigation technique is proved effective and has the potential to prevent ionizing radiation exposure [22, 23]. However, during the reduction and insertion of the IMN, the hands of surgeon unavoidably enter the primary beam, whose dose is 100 times higher than the dose received at distance of 15 cm from the beam [24]. In
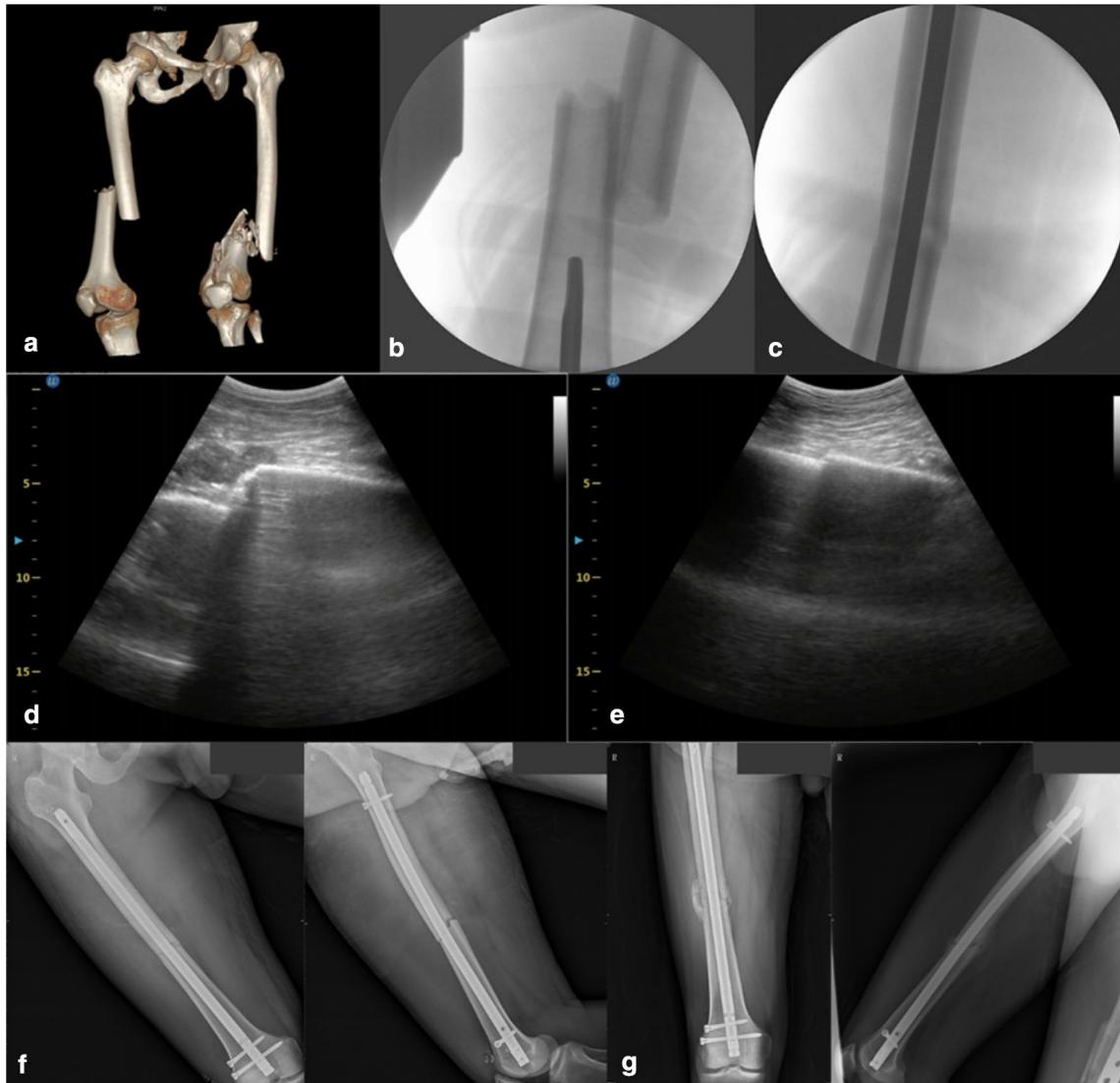
Fig. 4 **a** CT reconstruction showed that there were a transverse fracture on left femoral shaft and a comminuted fracture on right distal femur. **b** Intraoperative X-ray view before reduction. **c** Intraoperative X-ray view after passing the finger reducer. **d** Ultrasonic finding before reduction. **e** Ultrasonic finding after reduction. **f** AP and lateral X-ray after surgery. **g** Callus could be found in the X-ray after 6 weeks

this study, we hope to develop a method using ultrasonography during the reduction and insertion of the IMN to avoid radiation exposure of hands and fingers of surgeons and assistants. The disadvantage of this technique is the need of an additional assistant to handle the transducer that will add additional cost. At the present stage, we do not expect an entire replacement of fluoroscopy by ultrasonography because of the limitations described above.

Conclusion

Intraoperative ultrasonography can be used to observe femoral fracture clearly. Following a particular procedure of scanning, the manipulator could establish the deformity pattern of the fracture, which helps in reducing the fracture. Characterized as real time, continuous, and radiation
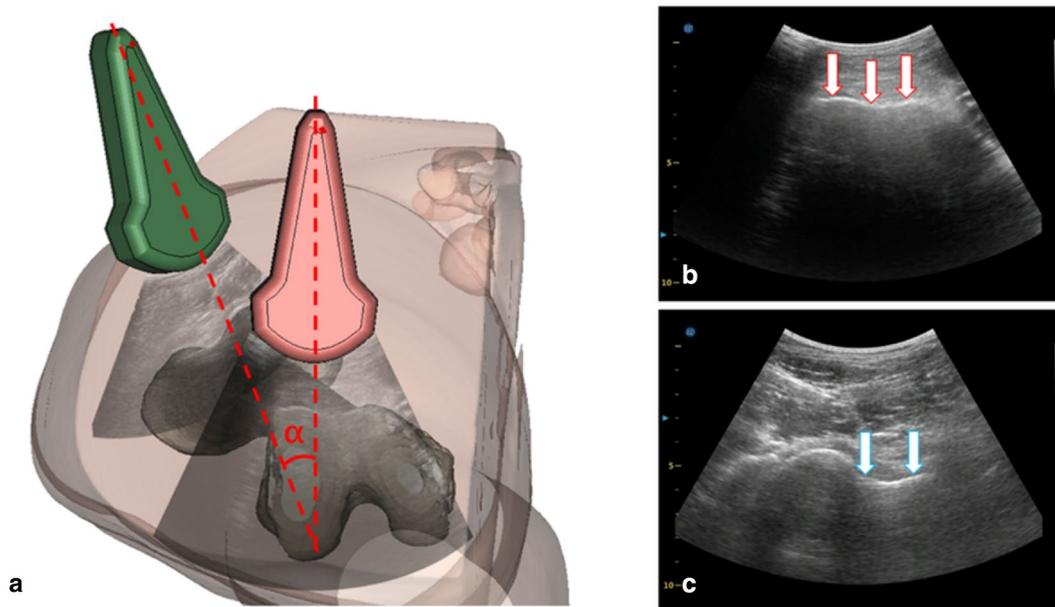
Fig. 5 **a** Before interlocking, the torsional deformity was evaluated, and the angle (α) between the two positions of the transducer was compared with the uninjured side. The two positions were determined by setting the anterior condylar line and femoral neck line oriented horizontally on the ultrasound screen. **b** Ultrasound scan of the seagull-like pattern of the anterior condylar line (red hollow arrow) oriented horizontally on the ultrasound screen. **c** Ultrasound scan of the femoral neck line (blue hollow arrow) oriented horizontally on the ultrasound screen

free, ultrasonography can partially substitute fluoroscopy to reduce the potential hazard of radiation exposure for medical staff and patients.

Compliance with ethical standards

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

Research involving human participants and/or animals This article does not contain any studies with human participants or animals performed by any of the authors.

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