Arch Orthop Trauma Surg (2013) 133:953–959
DOI 10.1007/s00402-013-1765-y

TRAUMA SURGERY

Intraoperative panoramic image using alignment grid, is it accurate?

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Received: 6 February 2013 / Published online: 1 May 2013

Abstract
Background Minimally invasive orthopedic trauma surgery relies heavily on intraoperative fluoroscopic images to evaluate the quality of fracture reduction and fixation. However, fluoroscopic images have a narrow field of view and often cannot visualize the entire long bone axis.
Objectives To compare the coronal femoral alignment between conventional X-rays to that achieved with a new method of acquiring a panoramic intraoperative image.
Materials and methods Twenty-four cadaveric femurs with simple diaphyseal fractures were fixed with an angulated broad DCP to create coronal plane malalignment. An intraoperative alignment grid was used to help stitch different fluoroscopic images together to produce a panoramic image. A conventional X-ray of the entire femur was then performed. The coronal plane angulation in the panoramic images was then compared to the conventional X-rays using a Wilcoxon signed rank test.
Results The mean angle measured from the panoramic view was 173.9° (range 169.3°–178.0°) with median of 173.2°. The mean angle measured from the conventional X-ray was 173.4° (range 167.7°–178.7°) with a median angle of 173.5°. There was no significant difference between both methods of measurement ($P = 0.48$).
Conclusion Panoramic images produced by stitching fluoroscopic images together with help of an alignment grid demonstrated the same accuracy at evaluating the coronal plane alignment of femur fractures as conventional X-rays.

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Keywords Intraoperative panorama · Image stitching · Alignment grid · Coronal plane malalignment

Introduction

Modern minimally invasive osteosynthesis has forged itself into a popular option for the treatment of fractures. The paramount importance of achieving a well-aligned reduction equates to a heavy reliance on the intraoperative images. Malalignment after long bone fracture fixation has been reported to be up to 28 % [1]. It is most often due to insufficient intraoperative visualization of the entire limb axis. Even non-collimated intraoperative fluoroscopic images are small, often failing to provide a view of the entire long bone axis. Revision surgery to correct the malalignment has additional cost, leads to a longer hospital stay, more pain and discomfort as well as more radiation exposure.

Several clinical techniques to help determine intraoperative alignment have been demonstrated. Saleh et al. [2] reported on the treatment of diaphyseal tibial fractures using an external fixator combined with an alignment grid to help fine tune varus and valgus alignment. Farouk et al. [3] described "the cable technique" to determine intraoperative varus or valgus deformity of the lower limb by simulating the patients' mechanical axis with a cautery cable and fluoroscopy. Liodakis et al. [4] introduced the axis board for intraoperative assessment of lower limb alignment. However, limb positioning, obesity and human technical error provide potential sources of error, making it unjustified to rely purely on this technique. Therefore, accurate intraoperative visualization of the entire bone axis is strongly desirable.

Nowadays panoramic images can be created with a digital camera using photostitch software. Panoramic X-ray images of the entire length of the long bone are very helpful in evaluating limb axis during surgery. Yaniv et al. [5] described a method of producing an undistorted panoramic view from a composition of individual overlapped fluoroscopic images.

Messmer et al. [6] proposed an image fusion technique using new software and an X-ray translucent panel with a radio-opaque marker. Wang et al. [7] presented a novel method to generate parallax-free panoramic X-ray images by enabling the C-arm to rotate around its X-ray source center, relative to the patient's table. However, all of these proposed methods need new software, complex instruments or a modification of the fluoroscopic unit. We present a simple technique employing the use of an alignment grid whereby four C-arm images are stitched together without the need of software or any C-arm modifications. The purpose of this study was to compare the accuracy of this technique to conventional X-ray images.

Materials and methods

Simple transverse shaft fractures were created in 24 cadaveric femurs. Longitudinal K-wires were attached to the surface of both the proximal and distal fracture fragments. They served as reference lines for judging the longitudinal femoral shaft axis. The fractures were then fixed with angulated 10-hole broad DCPs to produce malalignment in the coronal plane. Less than 20° of varus and valgus angulation was produced.

An alignment grid was created that consisted of a piece of Perspex, measuring 200 × 450 × 5 mm, with grooves impregnated with K-wires, functioning as reference lines. A grid was fashioned from perpendicular regularly spaced parallel lines, at 2.5-cm intervals, and two longitudinal lines (Fig. 1). The alignment grid was placed in a box. The femurs were secured and placed over the alignment grid inside the box with the use of foam. The foam functionally minimized the motion of the fracture model and also served to represent soft tissues (Fig. 2).

The box was placed on an operating table. The distance to the image intensifier and C-arm was standardized at 17 and 28 inches, respectively. Four images overlapping each other, at least 25 % of femoral length, were taken with the C-arm starting at the hip. As the C-arm was moved distally it was kept parallel to the box. Images were saved and printed out on thermal paper. After folding the upper and lower parts of the printouts the center part of all four images were aligned using the transverse K-wires as reference markers. It was of utmost importance to maintain parallelism of the transverse K-wire markers while the longitudinal axis of the femoral cortex or plate was being aligned (Fig. 3).

Fig. 1 The alignment grid

Three repeated angular measurements of femoral longitudinal alignment were taken and averaged. The averaged value represented the coronal plane angulation of the panoramic image (Fig. 4a). The box with the same bone and alignment grid was then brought to the radiology department for a conventional X-ray. A standardized distance of 40 inch from the X-ray tube was used. The angulation was measured three times using the Panacea Vision workstation software. The averaged value represented the angulation of the conventional X-ray (Fig. 4b).

Statistical analysis

Data analysis was analyzed using STATA version 12.0 (Stata Corp., College Station, Texas). We used a Wilcoxon signed rank test to compare the angulation measured from both methods because the distribution of the data was not normal. *P* value <0.05 was set as the level of significance.

Results

The age of the cadaveric femurs ranged from 20 to 79 years of age. There were 12 left-sided and 12 right-sided femurs. The mean angle measured from the panoramic view was 173.9° (range 169.3°–178.0°) and the median angle was

Fig. 2 The angulated femur fixed with broad DCP was placed in the *box* over the alignment grid

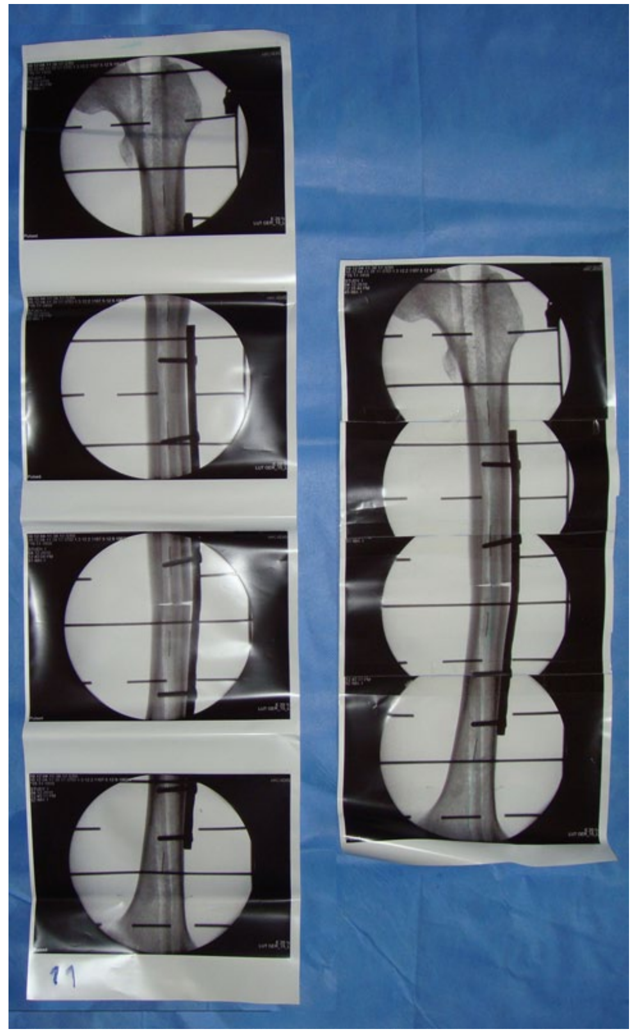

Fig. 3 Four C-arm images before and after stitching

173.2°. The mean angle measured from the conventional X-ray was 173.4° (range 167.7°–178.7°) and the median angle was 173.5° (Table 1). There were no significant differences between the both methods of measurement (Wilcoxon signed rank test, $P = 0.48$).

Discussion

Femoral malalignment after closed reduction and internal fixation has been reported to vary from 10 to 30 % [1, 8, 9]. Most surgeons use mobile C-arm to determine the relative position of implants and bones. However, current fluoroscopic imaging technology has several limitations such as the inability to demonstrate the whole bone axis, narrow viewing capabilities, limited resolution and contrast and geometric distortion. In addition, intraoperative evaluation of alignment can only be measured with indirect measurement techniques [3]. Unfortunately, malalignment is often detected postoperatively resulting in unplanned re-operation.

Panoramic X-ray imaging is a technology that can produce a single long bone image after individual images are overlapped and aligned using reference markers. The main technical issues to control with this technology are the number of images and the resulting radiation exposure, the amount of overlap and the fluoroscopic image distortion. Most existing methods to control such variable require either a modern C-arm unit or software technology and/or specially design complex instruments.

Dewaele et al. [10] described a full-leg/full-spine image stitching technology using digitized computed radiography whereby standard film cassettes were overlapped. Their setup requires that a metal grid be placed close to the object, and within the X-ray path. This method uses only a few images and can be applied to any part of the body. However, it requires film digitization, which is time consuming and cannot be used intraoperatively.

Geijer et al. [11] developed a measuring system for scoliosis using 30–40 partially overlapped digital X-ray images. The individual radiographic images are merged, using an easy vision workstation, into a panoramic image.

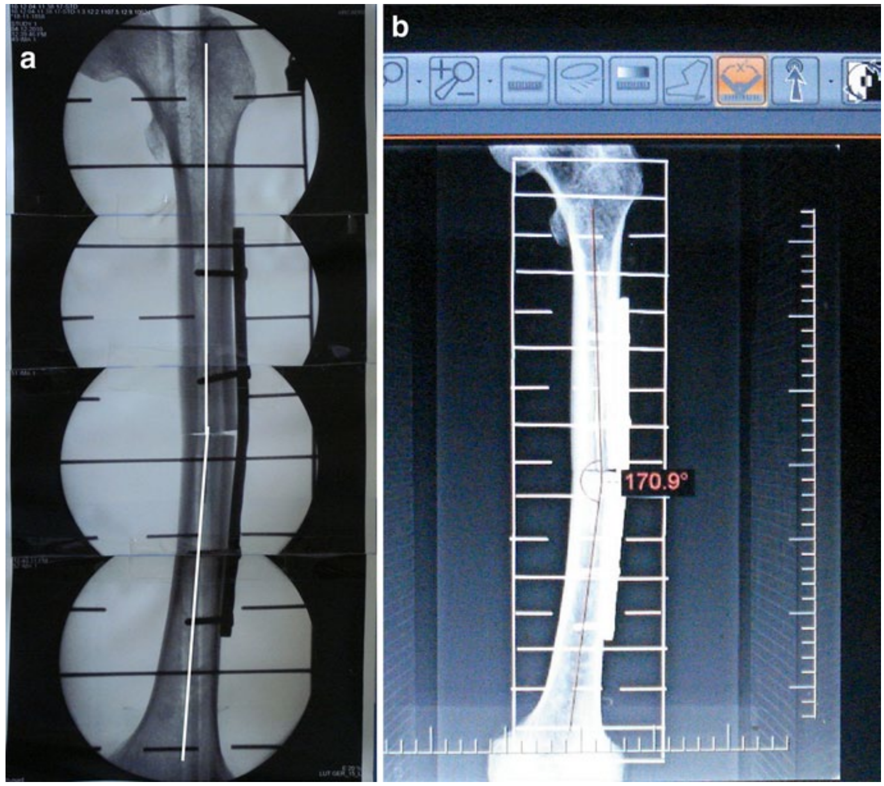

Fig. 4 **a** The angulation of the femur from panoramic image was measured using the marker on the femur. **b** The angulation of the femur from conventional X-ray was measure using the Panacea Vision workstation

Table 1 The angulation measured from the panoramic image compare to conventional X-ray and the difference

No	Panoramic image	Conventional X-ray	Difference (°)
1	173	173.3	−0.3
2	175.3	175.3	0
3	178	178	0
4	169.7	168.7	1
5	170	169	1
6	172	174.3	−1.3
7	171.7	170.7	1
8	178	173.7	4.5
9	171.7	173	−1.3
10	177	178.7	−1.7
11	172.3	172.3	0
12	171.3	175	−3.7
13	173	171.3	1.7
14	169.3	170.3	−1
15	173.3	171.3	2
16	171.7	174.3	−2.6
17	177.7	172	5.7
18	178	175	3
19	176.7	172.7	4
20	174.7	176	−1.3
21	173.7	167.7	6
22	178	176.7	1.3
23	171.3	177.6	−6.3
24	176.7	175.7	1

This technology produces high-quality undistorted panoramas with little parallax and is suitable for any part of the body. However, it requires special hardware, cannot be used in the operating room and employs a large dose of radiation.

Yaniv and Joskowicz [5] described a method for creating a panoramic image of a long bone from several C-arm images using a sterile metal reference ruler placed alongside the limb. They also used a custom dewarp grid mounted on a C-arm image intensifier to correct geometric distortion. After a sequence of 4–10 images, with 20–60 % overlap, is acquired and a panoramic image is created by computed distortion correction, image alignment and image composition. This method requires a dewarp grid, a computed imaging procedure and large radiation exposure.

Messmer et al. [6] presented a new software prototype using an absolute reference panel placed under the limb to generate a panoramic picture. Prior to image fusion, the software applies non-linear distortion, picture scaling and de-rotation algorithms to the C-arm images. The image processing occurs within seconds. The setup is simple, applicable in the operating room and suitable for deployment in a hospital with a limited budget and small space. Unfortunately, no method was proposed to solve the parallax effects and this software is still not available for clinical use.

Wang et al. [7] presented a parallax-free intraoperative X-ray image stitching method using a camera augmented mobile C-arm (CamC) and a visual planar marker pattern.

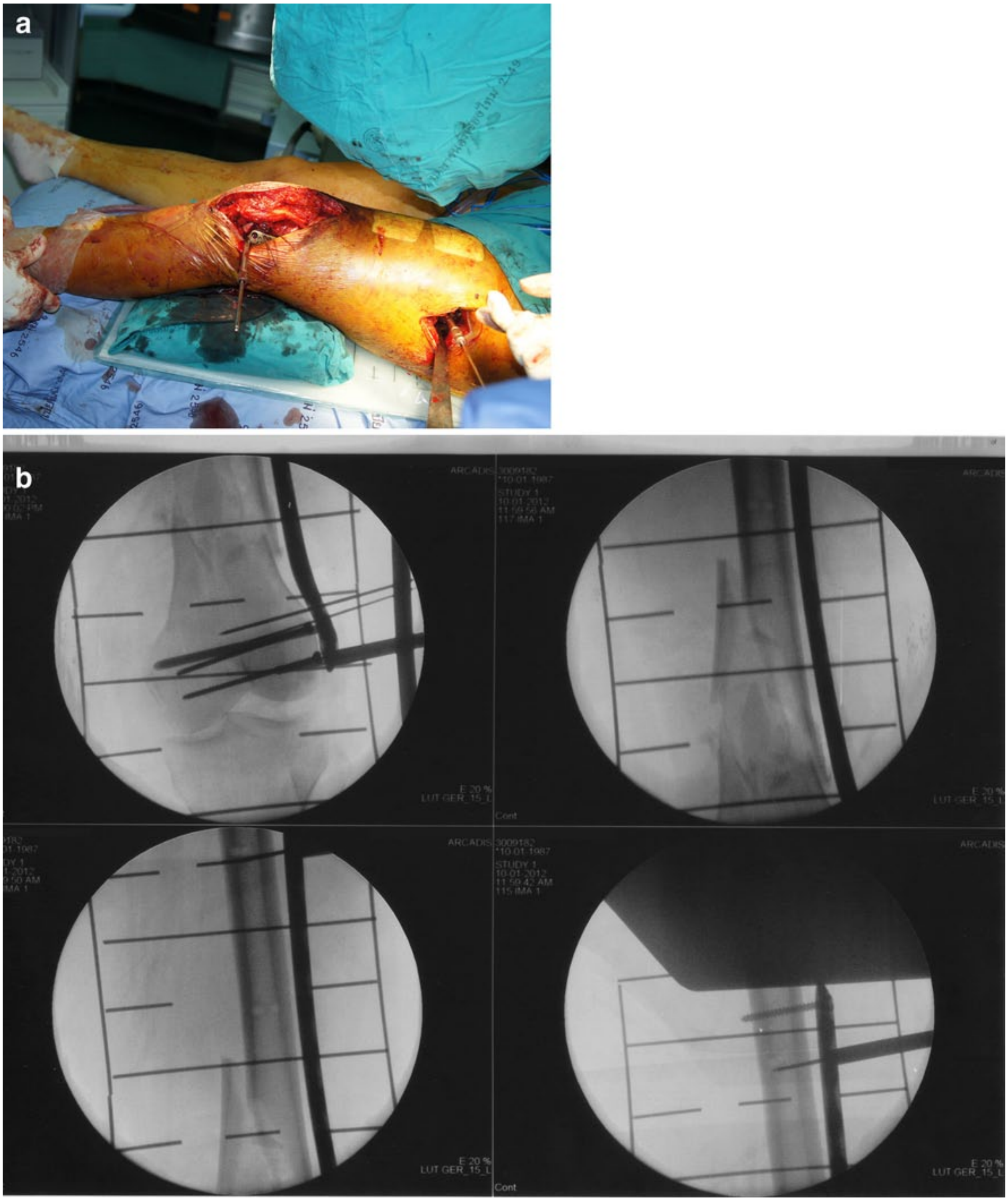

Fig. 5 **a** A 25-year-old woman with comminuted supracondylar fracture of left distal femur fix with minimally invasive plate osteosynthesis (MIPO) technique; the intraoperative alignment was evaluated using the panoramic image. The alignment grid was placed under the femur. **b** Four C-arm images were printed out on thermal paper. **c** Panoramic image after stitching. **d** Post-operative radiograph of the fracture after fixation

Their method does not require that C-arm images be overlapped or that special X-ray markers be used. Instead, it uses video images in combination with a visual marker pattern to estimate the planar transformation for creating panoramic image. The main advantages over the previous C-arm base solutions are reduced radiation exposure and independence from fronto-parallel C-arm setup. However, it needs a special camera and visual planar marker.

All of the above-mentioned techniques require new hardware, software, C-arm modification, C-arm technician, and/or computerized or physical background personnel. Our idea was to develop a simple alignment marker

Fig. 5 continued

that could be used to provide reference points for stitching intraoperative fluoroscopic images. In addition, our goal was that this instrument would be uncomplicated and would be applicable to most hospitals. A tibial alignment grid was described by Saleh et al. [2]. It consisted of a piece of Perspex with grooved lead-impregnated longitudinal and perpendicular parallel reference lines. It was used to evaluate tibial alignment in fracture reduction and malunion correction. This method is only applicable to tibial diaphyseal pathology and cannot be used for femurs. We have adopted the alignment grid idea, but modified the grid to produce several small rectangular blocks created from horizontal lines separated 2.5 cm apart. We also present a method of composing a panoramic image from individual overlapped images.

Our proposed simple technique of creating a panoramic image requires that the alignment grid be placed under the operating table padding or that it be draped into the sterile field and placed under the limb. The alignment grid then provides intraoperative reference points to judge alignment. As the C-arm is moved distally it must be kept parallel to the limbs long axis and four separate C-arm images with overlap are captured. We accept that there exists image distortion or a parallax effect when the images are stitched together. To examine the true effect of image distortion we built an angulated femoral shaft fracture model. We then simulated an intraoperative setting and measured the alignment of the fracture model using our technique of acquiring a panoramic image and then compared it to the alignment measured from a conventional X-ray, simulating the post-operative setting. Our hypothesis was that the panoramic image would produce the same assessment of alignment as a conventional X-ray.

The developed fracture model used a box with foam to simulate soft tissue thickness and to keep the position of the femur in the box constant during both simulated measurement conditions. The results of this study revealed that the mean coronal plane angulation of the angulated femur measured in the panoramic image was 173.9° and the mean angle measured from the conventional X-ray was 173.4°. There existed no significant difference.

Our method is simple in that most orthopedic surgeons are familiar with C-arm image printouts and simple stitching techniques. The technique may have some parallax effect and distortion of the overlapped images but using the parallelism of the transverse grid compensated for the C-arm distortion, as shown in Fig. 5. Nowadays, the C-arm produces digital images which can be store digitally and export to the PC. It is simple to stich and measure the angulation using the photoediting software, e.g. the photoshop. By drawing a 'line' with the ruler, then hold down Alt and draw a new line starting from the end of the first, then an angle was measured on the control strip. The accumulative dose for four C-arm images was 0.054 mGy (range 0.017–0.087) which is very low radiation exposure.

The economical issue is also an important factor to consider. Most hospitals that have a C-arm unit would be able to process a panoramic image using our described technique. It only requires a printer to print four images to allow stitching and therefore provides a low-cost solution. In cases where the C-arm unit has no printer, the image files can be exported from the C-arm and processed with the computer. This solution has a high potential to be introduced into routine orthopedic practice. The alignment grid is a simple instrument, which can be made using the plastic plate or polypropylene board stick with multiple parallel K-wire. The alignment grid can be placed under the operating table padding or be draped into the sterile field and placed under the limb. This technique is applicable to both femoral and tibial fractures.

Our technique has some limitations in that the C-arm must be kept parallel to the operating table and the limb. In addition, the C-arm images need to overlap at least 25 % of the length of the bone being imaged.

Conclusions

We believe that our method of using an alignment grid to help guide the creation of a panoramic image from individual fluoroscopic views is a simple method that has advantages over previously described methods of producing panoramic images. It requires no additional hardware or software and can be performed by most C-arm units. The accuracy for detecting coronal plane angulation is not statistically different to that of conventional X-rays. Malalignment can be detected intraoperatively and corrected, potentially reducing re-operation rates for unanticipated malreductions.

Acknowledgments We thank Dr. Ryan Martin from Calgary, Canada, for his kind review of our paper.

Conflict of interest None.

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