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SCIENTIFIC ARTICLE

Image intensifier distortion influences a surgeon's ability to aim guidewires during orthopaedic procedures

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Abstract

Objective Accurate insertion of a guidewire under image intensifier guidance is a fundamental skill required by orthopaedic surgeons. This study investigated how image intensifier distortion, which is composed of pin-cushion and sigmoidal components, changed the apparent trajectory of a guidewire, and the resulting deviation between the intended and actual guidewire tip position.

Materials and methods Intraoperative image intensifier images for 220 consecutive patients with hip fractures were retrospectively corrected for distortion using a global polynomial method. The deviation between the intended and actual guidewire tip positions was calculated. Additional distortion parameters were tested using an image intensifier produced by a different manufacturer, and a flat-panel c-arm.

Results Deviation was approximately 1 cm if the guidewire was aimed from the extremity of the image and almost 0 if the entry point was only 20% from the centre ($p < 0.001$). The direction of deviation was different for left and right hips, with average deviations measuring 3 mm proximal and 5 mm distal respectively ($p < 0.001$). The flat-panel c-arm almost completely eliminated distortion.

Conclusions Image intensifier distortion significantly altered the intended trajectory of a guidewire, with guidewires aimed from the image periphery more affected than guidewires aimed from the centre. Furthermore, for right hips, guidewires should be aimed distal to their intended position, and for left hips they should be aimed proximal to achieve their desired position. The flat-panel c-arm eliminated the effect of distortion; hence, it may be preferable if precision in guidewire positioning is vital.

Keywords Distortion · Orthopaedics · Hip fractures · Fluoroscopy · Image intensifier

Introduction

A fundamental skill required by every orthopaedic surgeon is to accurately insert a guidewire into a bone under image intensifier (II) guidance. Incorrect insertion leads to delays in operations, unnecessary entry holes, increased radiation doses, or improper placement of implants [1–3]. A surgeon's ability to insert a guidewire is dependent on a number of factors, including imaging quality [4], which may be influenced by distortion, a phenomenon intrinsic to IIs.

Image intensifier distortion is manifest in two main forms: pin cushion distortion, which is due to the curved surface of the II, and sigmoidal (or s-shaped) distortion, which is reported to be influenced by the earth's magnetic field (Fig. 1) [5–7]. Correcting distortion has been the subject of ongoing research, resulting in the development of either global or local distortion correction methods, which are used to remove image distortion [5, 6, 8, 9]. However, such methods have rarely been incorporated into clinical practice, although new flat panel c-arms, an alternative to standard IIs, are reported to remove distortion completely [10].

Distortion affects the periphery of an image more than the centre, which is why it poses a particular problem when aiming guidewires into bones because the standard technique often consists of the surgeon beginning along the periphery of the image with the target located a distance away from the start

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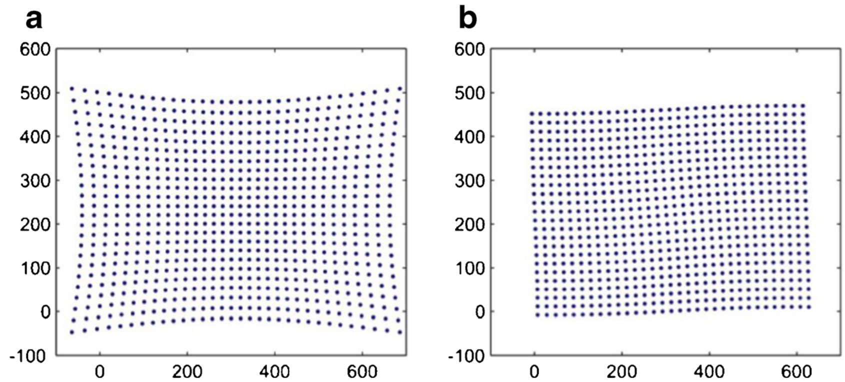

Fig. 1 Examples of a regular grid of beads subjected to **a** pin cushion distortion and **b** sigmoidal distortion

point. It is likely that a guidewire's apparent trajectory from the periphery is very different to its actual trajectory, as demonstrated in Fig. 2. If this deviation were quantified, it may help in a number of ways. First, if there are consistent patterns governing how guidewires deviate from their initial trajectory, surgeons may be able to account for this distortion by altering their technique. Second, if distortion causes significant deviation, it may encourage manufacturers to incorporate distortion correction into their image processing algorithms. Third, accounting for distortion is important in surgical navigation systems, as their guidance algorithms can be modified to account for distortion [3, 11, 12].

To quantify the effect of distortion on guidewire placement, the authors considered the common clinical scenario of inserting a guidewire into a femoral head during internal fixation of a hip fracture, which is estimated to occur millions of times annually [13]. This study investigated how distortion changed the apparent trajectory of a guidewire and the resulting distance between the intended and actual destination of the wire. The null hypothesis was as follows:

H_o: II distortion had no significant effect on guidewire trajectory during operative fixation of hip fractures.

Materials and methods

A total of 220 consecutive patients between January and December 2014 with hip fractures requiring operative fixation with either dynamic hip screws (DHSs; DePuy Synthes, West Chester, PA, USA) or cephalomedullary nails (CMNs; Gamma3 nail; Stryker, Kalamazoo, MI, USA) were included in this study. Ethics approval was obtained from the regional ethics board (approval number: 15/186). These patients had operations in one of two major metropolitan teaching hospitals (Hospitals 1 and 2) carried out by either a consultant orthopaedic surgeon, or by a registrar (trainee surgeon with 1–6 years of experience) under the supervision of a consultant.

Intraoperative images were taken using a BV Pulsera II (II_1: Philips, Amsterdam, Netherlands), with a different device of the same model at each of the two hospitals.

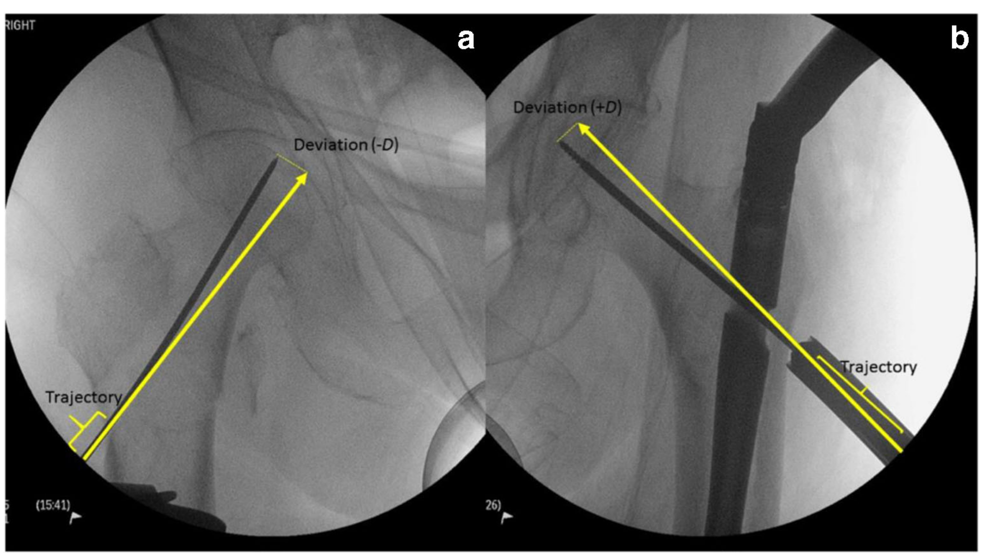

Fig. 2 **a** A guidewire placed inside a much larger diameter hole drilled in the right hip demonstrated how the trajectory of the wire at the periphery (*yellow*) significantly deviated (−*D*) from the wire's true destination. **b** Similarly, for the left hip, the trajectory of the wire at the periphery deviated (+*D*) from the actual position of the wire tip. Deviation of the trajectory proximal to the true wire destination was considered positive, and vice versa

Each II was retrospectively corrected for distortion using a custom calibration grid, constructed of a sheet of Perspex (5 mm × 400 mm × 400 mm) with a square grid (25 mm × 25 mm) of 0.5-mm holes drilled with a computer numerical controlled (CNC) drill. Tantalum beads measuring 0.5 mm in diameter were inserted and glued into each hole. With the II axis vertical (a posterior–anterior view of a supine patient), the calibration grid was placed against the surface of the cylindrical receiver of the II so that the grid was orthogonal to the axis of the II. This was done in each hospital for each fluoroscope.

Between 40 and 60 beads were identified in each calibration image using a semi-automated method, and these coordinates were then used to correct image distortion using a third-order global polynomial correction method, implemented in MATLAB (Mathworks, Natick, MA, USA). Residuals from the polynomial fitting, which characterised the error of the correction, were calculated in each case.

To calculate the deviation (D) between the intended and actual guidewire trajectories, three points were used: the tip of the screw in the femoral head, the centre of the screw shaft where it left the lateral femoral cortex and a point along the same line, either 3 cm lateral to the lateral femoral cortex, or the periphery of the image, whichever was closer to the lateral femoral cortex. Distortion correction was applied to the three abovementioned points to define the "undistorted" trajectory. The Euclidean distance between the tips of the distorted and original trajectories defined the deviation (D) introduced by distortion (Fig. 2). If the distorted trajectory travelled proximal to the original tip, D was positive, if it travelled distally, D was negative. The distances between points were calibrated according to the known dimensions of the thread diameter of the DHS (12.7 mm) and CMN (10.5 mm).

Additional variations in the distortion parameters were tested in this study. The calibration grid was imaged when the II was tilted 10° from vertical (10º), and in the lateral position (Lat). An II produced by a different manufacturer (II_2: Fluorostar, GE Healthcare, Chicago, IL, USA) and a flat panel c-arm (FP: Veradius, Philips, Amsterdam, Netherlands) were also used to image the calibration cage. Distortion parameters from each of these abovementioned settings (10°, Lat, II_2, FP) were applied to all 220 images, and D was calculated in each.

A prospective validation of this method was performed intraoperatively by imaging a straight guidewire placed into the hole left after reaming for screw insertion, in 19 subjects. The reason for placing the guidewire into the larger hole drilled for the screw was to ensure that any apparent non-linear deviation of the guidewire was due to distortion and not mechanical deflection of the wire off the calcar. Using the method outlined above, the predicted D was calculated and compared with the actual deviation (D_a) observed for this guidewire from its trajectory on the lateral femur.

Statistical analysis was performed in MATLAB and in SPSS (version 23; IBM, Armonk, NY, USA). Linear regression was performed relating D to the radial distance from the centre of the image of both the entry point into the lateral femur (d_e) and the tip of the screw (d_t) as a proportion of the image radius. Linear regression was also used to relate D to D_a in the prospective validation. A linear mixed model was used to assess if D (the response variable) was influenced by side (L or R) or device (DHS or CMN), which were fixed effects, and hospital (Hospital 1 or Hospital 2) as a random effect. A linear mixed model was also used to assess if D was influenced by side (L or R) or II position (II_1, II_2, 10^o, Lat, FP), which were fixed effects, and image number (1 to 220) as random effects.

Results

Of the 220 subjects studied, the mean age was 83.3 years (SD 10.8). The group comprised more women (151) than men (69), more right (123) than left (97) hips and more CMN (173) than DHS (47) prostheses (Table 1). Six subjects were excluded from the study, 3 of whom were imaged using a different II, 1 had no images saved and image quality was inadequate in 2.

After each II was calibrated, average root mean squared residuals varied from 0.37 mm (10° tilt) to 0.63 mm (Hospital 2).

Significant differences in D existed between left (2.9 mm) and right (−4.9 mm) sides ($p < 0.001$; Fig. 3). No significant differences in deviation were found between DHS and CMNs.

Comparison of D across the five additional scenarios (II_1, II_2, 10°, Lat, FP), revealed a consistent pattern of positive D for left hips and negative for right ($p < 0.001$), although for the flat panel II, D was minimal (average of 0.01 mm for left and −0.44 mm for the right; Fig. 4). Average D in the lateral images was lower than in the other scenarios, except for the flat panel.

D increased as the entry point on the lateral femur approached the image periphery (increased d_e) at both Hospital 1 and Hospital 2 ($R^2 = 0.588$ and 0.352 respectively, $p < 0.001$; Fig. 5). D decreased as the position of the tip approached the image periphery (increased d_t), but was only statistically significant for Hospital 2 ($R^2 = 0.571$, $p < 0.001$).

Table 1 Subject population according to gender, side (left or right) and prosthesis type. *DHS* dynamic hip screw, *CMN* cephalomedullary nail

Group		Number	Total
Gender	Female	151	220
	Male	69	
Side	Left	97	220
	Right	123	
Prosthesis	DHS	47	220
	CMN	173	

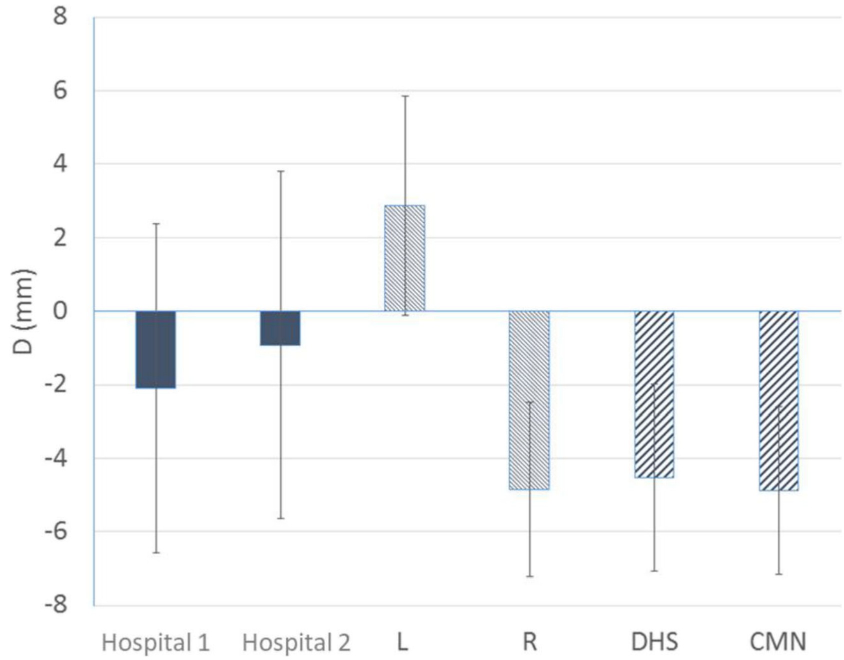

Fig. 3 Deviation (D) in II_1 according to hospital (Hospital 1 and Hospital 2), side of the body (left, *L*, or right, *R*) and type of device (dynamic hip screw, *DHS*, or cephalomedullary nail, *CMN*)

In the prospective validation test, the actual (D_a) and predicted deviations (D) matched closely ($r^2 = 0.98$, $p < 0.001$; Fig. 6).

Discussion

Image distortion significantly affected a surgeon's ability to place guidewires during hip fracture fixation, resulting in rejection of the study's null hypothesis. There are two main findings that may help to guide clinical practice. First, the direction of guidewire deviation was different for the left and right hips. For the left and right hips, average deviations were approximately 3 mm proximal and 5 mm distal respectively, an example of which is evident in Fig. 2 for both a right and a left hip. The variation in guidewire deviation between the left and right sides suggested that sigmoidal distortion might be predominantly responsible, rather than pin cushion distortion. Sigmoidal distortion causes a rotational warping of the image (Fig. 1b), which explains why a straight trajectory from either the bottom left- or bottom right-hand corner of the image would deviate in a different direction, as opposed to pin-cushion distortion, which would cause deviation in the same direction. In practical terms, this finding suggests that for the right hip, surgeons must aim distal to their desired position, whereas for the left hip, they must aim proximal.

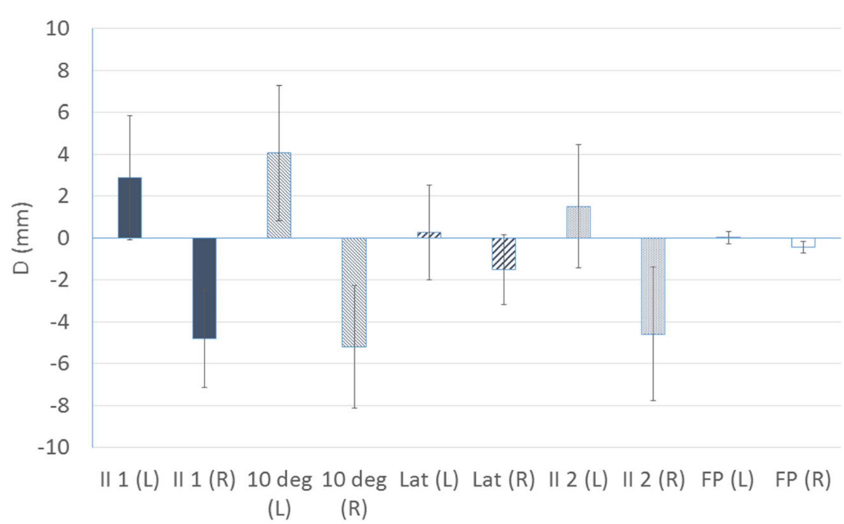

Fig. 4 Deviation of guidewire tip according to either original pooled data (II_1), 10° tilted fluoroscope, laterally tilted fluoroscope (*Lat*), a different model (II_2: Fluorostar) and flat panel (*FP*), for left (*L*) and right (*R*) hips

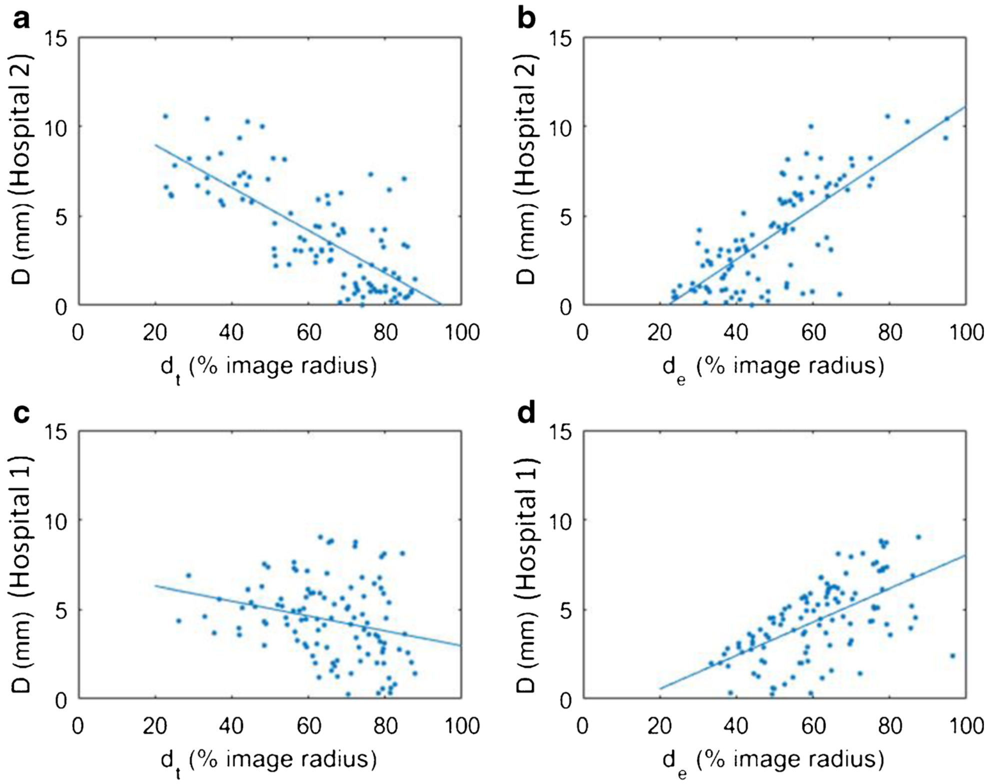

Fig. 5 **a** At Hospital 2, deviation varied according to tip screw position (d_t; $R^2 = 0.571$; $p < 0.001$) and **b** the entry position (d_e; $R^2 = 0.588$; $p < 0.001$). **c** Similarly, for Hospital 1, deviation varied according to tip position (d_t; $R^2 = 0.07$; $p = 0.2$), and **d** the entry position (d_e; $R^2 = 0.352$, $p < 0.001$)

Second, deviation between the intended and actual path of the guidewire was more significant if the guidewire was aimed from the periphery of the image, not just because there was less of the guidewire to help to visualise a trajectory, but because this was the most distorted part of the image. An entry point that was only 20% of the radius from the centre of the field of view resulted in almost zero deviation (Fig. 5), whereas an entry point 90% of the radius from the centre resulted in 10-mm deviation, most likely requiring repositioning of the guidewire.

Similar guidewire deviation patterns were observed for the pooled images from both hospitals (II_1), for the II tilted 10º and for the II produced by a different manufacturer (II_2), suggesting that these findings might be generalizable to other IIs positioned to take posterior–anterior images of a supine patient. The flat panel c-arm almost completely eliminated distortion as mean errors were similar to the distortion correction residuals. Distortion in the lateral image caused less deviation, on average, than the other positions. Given that sigmoidal distortion is reported to be affected by the earth's magnetic field, and that distortion characteristics change with II rotation [14], the effect of sigmoidal distortion may have been minimised in the lateral position.

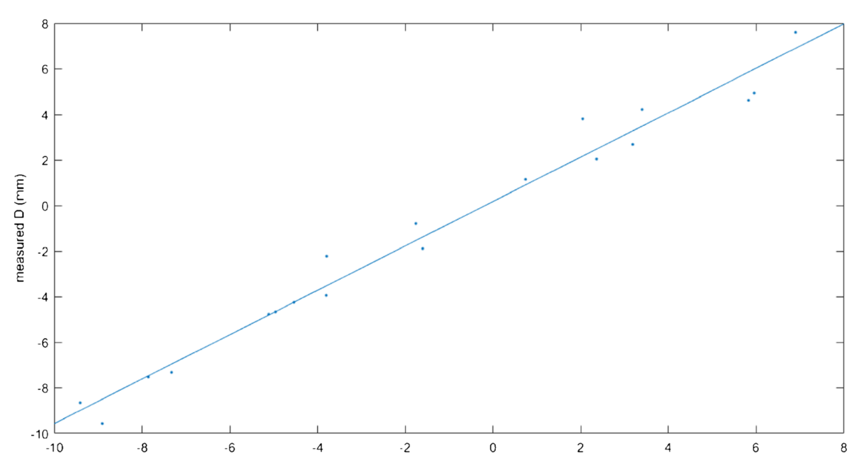

Fig. 6 The actual deviation (D_a) and predicted deviation (D) of a guidewire were measured for 19 subjects in whom a guidewire was inserted into the hole drilled for the screw before screw insertion

This study was subject to a number of limitations. The distortion parameters of each fluoroscope were calibrated retrospectively; hence, it was possible that variations occurred in the distortion characteristics over time and with variations in positioning. However, the prospective validation revealed close agreement between the deviation predicted by the current method and the actual deviation measured in images of the guidewires inserted into the drilled holes in the femoral head (Fig. 6).

To summarise the clinical relevance of this study, for the right hip, surgeons should aim distal to their intended position, and for the left hip they should aim proximal. Furthermore, if guidewire placement is particularly critical, surgeons should try to position the II such that the lateral femoral entry point is near the centre of the image, or consider using a flat panel c-arm. If II is to be used as part of a surgical navigation system, it would be highly beneficial to incorporate distortion correction into the imaging processing steps.

Compliance with ethical standards

Conflicts of interest The authors report that they have no conflicts of interest.

Ethical approval All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Declaration of Helsinki and its later amendments or comparable ethical standards.

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