

Do fluoroscopic and radiographic images underestimate pin protrusion in paediatric supracondylar humerus and distal radius fractures? A synthetic bone model analysis

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Abstract

Purpose Fluoroscopy is commonly used to confirm acceptable position of percutaneously placed pins when treating paediatric fractures. There is a paucity of literature investigating the accuracy of fluoroscopic imaging when determining pin position relative to the far cortex of the fixated bone. The purpose of this study was to evaluate the accuracy of fluoroscopic and radiographic imaging in measuring smooth pin protrusion from the far cortex of a bone model.

Methods Eight bone models were implanted with smooth pins and anteroposterior fluoroscopic and radiographic studies were obtained. All images were evaluated by orthopaedic attending physicians, residents and medical students. The length of pin protrusion from the model surface was estimated on fluoroscopic imaging and measured on radiographs and compared with actual lengths measured on the bone models.

Results 20 evaluators took a total of 320 pin measurements on images of 8 models. There was a significant difference between fluoroscopic measurements compared to radiographic measurements and actual pin lengths. There was no significant difference between radiographic measurements and actual pin lengths. Level of training of examiner was not statistically significant. On average, fluoroscopic estimations of pin protrusion were 1.53 mm shorter than the actual measured length.

Conclusion Fluoroscopic images underestimate the length of smooth pins protruding from a bone model surface when compared with radiographs and actual measurements.

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Orthopaedic surgeons using fluoroscopy should be aware of this discrepancy when assessing intraoperative fluoroscopic images to decide on acceptable implant position.

Level of Evidence: Level V

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Introduction

Paediatric supracondylar humerus and distal radius fractures are common injuries making up 17% and 23% of all paediatric fractures, respectively.¹ When these fractures are treated operatively, percutaneous skeletal fixation with smooth pins is a commonly employed modality.² Advantages of closed reduction and percutaneous pin fixation when compared with open reduction often include a smaller incision, shorter operative theater times,³ more rapid return of movement, and less formation of heterotopic ossification.⁴ However, these procedures rely on intraoperative fluoroscopic imaging to determine appropriate smooth pin placement.

When compared with direct visualization, fluoroscopic imaging may distort, overestimate,⁵ or underestimate the true pin position when performing fracture fixation.⁶ Smooth pins that are left unnecessarily proud or short could potentially cause local damage to soft tissue and other vital structures near pin exit sites⁷ or compromise fixation, respectively. Other surgical risks of percutaneous pin fixation have been well studied and include superficial infection,⁸⁻¹⁰ pin migration,¹¹ secondary displacement,¹² ulnar nerve damage with medial pin placement in the case of supracondylar humerus fractures,^{12,13} and tendon rupture in distal radius fractures.¹⁴ To avoid these complications, implanted pin position must be as precise as possible and confirmed on intraoperative imaging modalities with even the smallest of errors having the potential

for serious complications. There is a paucity of literature comparing the accuracy of orthopaedic implant position on imaging studies compared with actuality for supracondylar and distal radius fractures. The purpose of this study was to compare the apparent length of smooth pin protrusion on fluoroscopic images and measured length on radiographs with the actual length of protruding pin on a synthetic bone model.

Materials and methods

In all, 16 2-mm smooth skeletal fixation pins were placed in eight adult human SAWBONES models (Vashon Island, Washington). The eight models consisted of four humeri and four radiuses. All of the models of each bone were identical. Two pins were placed in each distal humerus and each distal radius in a standard pattern¹⁵ used when fixing paediatric supracondylar humerus fractures and distal radius fractures¹⁶ (Fig. 1). Anteroposterior (AP) fluoroscopic (Fig. 2) and radiographic images (Fig. 3) were taken of each bone model and uploaded to our institution's picture archiving communication system (PACS) (Sectra AB, Linköping, Sweden). AP images were taken with the bone models lying flat on the radiograph plates and operating room table in order to standardize position and to eliminate variation due to model position. A radiopaque ruler was placed in the field beside the bone models and were equidistant from the fluoroscopic machines as the bone models.

Independent orthopaedic attending physicians, resident physicians in their post-graduate year (PGY) one through to five (PGY1 to PGY5) and medical students

measured or estimated the distance each pin was protruding from the bone model surface and recorded their findings on a data sheet that was provided to them. A co-investigator (SK) was present during the recording of the data to ensure it was done accurately. When evaluating the fluoroscopic images, the radiopaque ruler was used as a legend on the side of each image and each interpreter used this ruler to estimate the length of pin protruding from the bone model surface. When



Fig. 1 Photograph of a distal humerus bone model with smooth pins protruding from the far cortex.

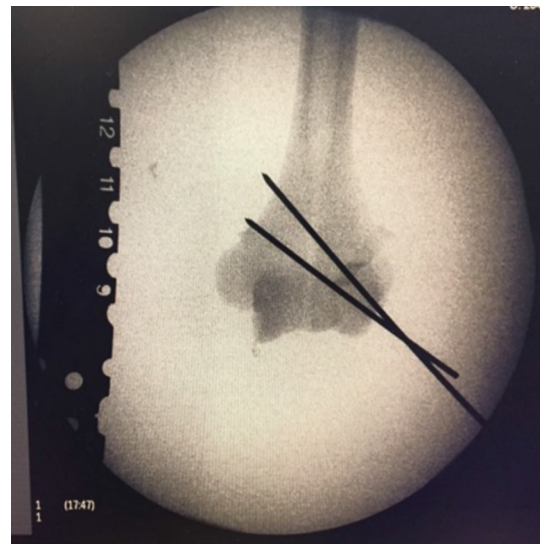


Fig. 2 Anteroposterior fluoroscopic image of a synthetic bone model with pins placed in a manner typical for fixing supracondylar humerus fractures.

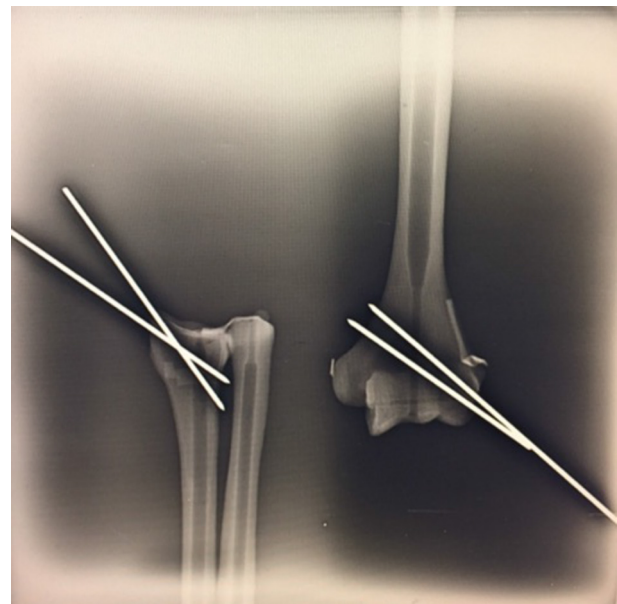


Fig. 3 Anteroposterior radiographic image of two synthetic bone models with pins placed in a manner typical for fixing supracondylar humerus and distal radius fractures.

evaluating radiographic images, the measurement tool on the PACS programme was used to measure each pin length protruding from the bone model surface. Actual distances of pin protrusion from the surface of the bony models were measured and recorded as the standard reference.

The mean and absolute differences between lengths estimated on fluoroscopic images, measured on radiographic images and actual measurements were calculated. Average measurements were broken down by level of training (attending, PGY year and student). Intraobserver reliability was calculated by having each participant read the same images twice and comparing the obtained values and reported as a correlation coefficient. Interobserver reliability was calculated between all subjects and reported as a correlation coefficient.

This study was submitted to our facility's Institutional Review Board and the study was granted exempt status before data collection. Comparisons between average actual, fluoroscopic, and radiographic measurements were performed utilizing analysis of variance with Bonferroni *post hoc* comparisons. The analysis was also performed separately for each level of training group. Data was checked for normality and homogeneity of variances. Inter- and Intraobserver reliability was determined by calculating the intraclass correlation coefficient (ICC). The following convention was utilized to evaluate reliability: < 0.5 = poor reliability, 0.5 and 0.75 = moderate reliability, 0.75 and 0.9 = good reliability, > 0.90 = excellent reliability.¹⁷ Alpha was set at $p < 0.05$ to declare significance and all analyses were performed utilizing Statistical Package for the Social Sciences version 24 (IBM, Armonk, New York, New York).

Results

In all, 20 independent orthopaedic professionals and students (four attending physicians, three PGY5, three PGY4, two PGY3, three PGY2, three PGY1 residents and two third-year medical students) measured the distance each pin was protruding from the bone model surface. A total of 320 radiographic and fluoroscopic measurements were made. There was a significant difference between estimated pin lengths on fluoroscopic images (average 4.29 mm, SD 2) versus the actual measured lengths on the bone models (average 5.47 mm, SD 1.3) ($p < 0.0001$). There was also a significant difference between estimated lengths on fluoroscopic images (4.29 mm, SD 2) versus radiographic images (5.46 mm, SD 1.4) ($p < 0.0001$). There was no significant difference between pin length measured on radiographic images (5.47 mm, SD 1.4) and actual measurements taken from bone models (5.47 mm, SD 1.3) ($p = 0.99$).

The mean absolute error between lengths estimated on fluoroscopic images compared with actuality was 1.53 mm (SD 0.96). The mean absolute error between lengths measured on radiographic images and actuality was 0.64 mm (SD 0.55).

Intraobserver reliability was good (ICC = 0.87) and excellent (ICC = 0.95) between fluoroscopic estimations and radiographic measurements respectively. Interobserver reliability was moderate (ICC = 0.7) and good (ICC = 0.8) between fluoroscopic estimations radiographic measurements, respectively. There was no trend of more accurate fluoroscopic pin length estimation with increasing level of training. All levels of training showed the same pattern as the overall cohort except for the PGY2 group which showed no significant difference between fluoroscopic estimations, radiographic measurement and actuality.

Discussion

Paediatric supracondylar and distal radius fractures are common injuries¹⁸ that, when requiring operative treatment, are often fixed with percutaneous smooth pin fixation.¹⁹ This study shows that intraoperative fluoroscopic images tend to underestimate actual lengths of smooth pin protruding from bony surfaces by a mean of 1.5 mm. This underestimation was present even when the participants making the measurements had a fluoroscopic ruler on the image to make their estimate, a luxury which is not routinely used intraoperatively when taking fluoroscopic images. However, radiographic measurements using the measurement tool on the PACS system tended to be a more accurate way to estimate the true length of pin protruding from the bony surface.

Inaccuracy of 1.5 mm may not pose as much of a risk to surrounding structures if smooth pins are left just beyond the bony surface. However, many surgeons decide not to change pins that are further beyond the far cortex when they are initially placed. This study may help surgeons understand that they may want to retract their pins to a position closer to the bony cortex because they are likely to be underestimating how far they are really beyond the surface of the bone. Additionally, this study may help validate surgeons who, by tactile feedback, feel that their pins are across the far cortex but on confirmatory imaging find that it is not clear whether the pins are fully penetrated through the far cortex.

Many vital structures including nerves, arteries, veins, as well as soft tissues may lie in close proximity to sharp pins protruding from bony surfaces.⁷ These structures may be at risk of temporary or permanent damage if implanted pins are left unnecessarily long. This is especially true in children where the distance from bone to vital structures

is less than that in adults. Findings from this study may aid surgeons intraoperatively when making decisions about whether pins appear to be of adequate length for stable fracture fixation while taking care not to leave implants too proud to avoid complications.

The inaccuracy of fluoroscopy has been studied in the past. One such study looked at fracture reduction appearance on fluoroscopy compared with radiographs and actuality in percutaneous fixation of metacarpals in a cadaveric model.⁶ This study found that fracture articular step off and displacement was underestimated on fluoroscopic images compared with radiographs and direct examination. In conjunction, a recent study on slipped capital femoral epiphysis looking at the accuracy of fluoroscopy when determining acceptable screw to subchondral bone distance found fluoroscopy to be less accurate than other modalities such as computed tomography (CT).⁵ These studies together support the current findings that fluoroscopy is not the most accurate method for determining acceptable implant position or fracture reduction intraoperatively.

Our custom and practice when treating orthopaedic injuries with percutaneous pinning has been to strive to have the length of pin protruding from a given bony surface no more than 1 mm to 2 mm. Another frequent practice when using the most common pin sizes (1.6 mm or 2.0 mm) is to have the length of protruding pin to be no more than the diameter of the pin. While studies have been conducted looking at fracture reduction maintenance¹² and biochemical strength²⁰ based on pin configuration,^{21,22} currently we are not aware of a study that describes how far a pin must be through the far cortex in order to maximize biomechanical integrity while not putting local structures at risk. Future areas of research could include an investigation on the biomechanical stability of fractures fixed with smooth pins with different lengths of pin protruding from the far cortex of the bone. This type of study may help validate the clinical significance of a small difference, even that of 1.5 mm, if the biomechanical strength of the construct was significantly altered by changing the length of pin protrusion from the far cortex by 1 mm to 2 mm.

Strengths of this study include the fact that the injuries and treatment modalities discussed are some of the most common orthopaedic procedures that are performed. Also, there are no other studies to our knowledge that have investigated fluoroscopic image accuracy in treating these fractures with percutaneous skeletal fixation. Limitations of this study include the use of bone models to simulate actual bony anatomy. In addition, the use of bony models made it impossible to measure the distances between pins that are placed in typical positions and surrounding neurovascular structures. Also, all images taken for this study were AP images and not oblique images. It can be argued that oblique images may have been more

orthogonal to implanted pins and may have allowed participants to get a truer reading on the actual length of the protruding pin. However, this seems to be less of a concern as radiographic measurements of the same image were able to more accurately estimate the true length than fluoroscopic images taken in the same view.

In conclusion, estimated smooth pin lengths protruding from bony surfaces when treating supracondylar humerus and distal radius fractures tend to be underestimated on fluoroscopic images when compared with actuality. However, radiographic images reviewed with a computerized measuring tool tended to be more accurate in judging true pin length. Surgeons performing these procedures can use these findings when placing percutaneous pins and judging appropriate pin length.

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COMPLIANCE WITH ETHICAL STANDARDS

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OA LICENCE TEXT

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ETHICAL STATEMENT

Ethical approval: This study was submitted to our Institutional Review Board and was granted 'exempt' status. 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 Helsinki declaration and its later amendments or comparable ethical standards. This article does not contain any studies with animals performed by any of the authors.

Informed consent: Informed consent was obtained from all individual participants included in the study.

ICMJE CONFLICT OF INTEREST STATEMENT

The authors declare no conflict of interest.

AUTHOR CONTRIBUTIONS

SK: literature review, project design, data collection, manuscript writing and editing, submission process.

JS: project oversight, project design, manuscript writing and editing.

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