Accuracy of Fluoroscopy in the Treatment of Intra-articular Metacarpal Fractures

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Abstract

The purpose of this study was to determine the accuracy of fluoroscopic imaging during closed reduction and percutaneous fixation of intra-articular thumb metacarpal fractures. Closed reduction and percutaneous fixation was assessed in eight simulated intra-articular thumb metacarpal fractures, using fluoroscopy and digital radiographs. Displacement and fracture step-off were measured during fluoroscopy, on plain radiographs, and by direct visualization after careful dissection. Displacement on fluoroscopy was 0.8 (SD 1.0) mm and 1.2 (SD 1.4) with radiographic imaging. Direct visualization showed displacement of 0.9 (SD 1.2) mm. Intra-articular step-off on fluoroscopy was 0.8 (SD 1.0) mm and 0.8 (SD 0.8) with radiographic imaging. Direct visualization showed an intra-articular step-off of 0.8 (SD 1.2) mm. Statistical analysis showed excellent compatibility between fluoroscopy and direct visualization. Fluoroscopic visualization during surgery provides an adequate assessment of articular step-off and displacement in comparison with radiographs and direct visualization.

Level of Evidence: **Anatomical / Technical study**

Introduction

An intra-articular fracture at the base of the thumb metacarpal (Bennett's fracture) is the most common fracture in the carpometacarpal joints [27, 103]. Post-traumatic deformity of the joint surface may result in osteoarthritis, causing a painful joint and decreased function in the hand [20, 27, 104, 105].

Surgical treatment aims to prevent these problems by anatomical reduction of the fracture fragments [24, 29, 49, 104, 106].

During closed reduction and percutaneous fixation, fluoroscopic imaging can be used to assess the reduction. However, limited data are available on the accuracy of fluoroscopy in hand surgery. Only one study describes the accuracy of fluoroscopy in the treatment of intra-articular fractures of the hand [32]. This study showed significant differences in the accuracy of fluoroscopy in comparison with radiography and direct visualization. The authors concluded that fluoroscopy is often in error in comparison with radiography and direct examination when gap, step-off, and displacement are assessed. This would mean that the use of fluoroscopy during hand surgery is unreliable.

The alternative to closed reduction and percutaneous fixation is open reposition and internal fixation. The advantages of open reposition and fixation are a more rigid fixation and the possibility of starting early mobilization. The disadvantages are the necessity for extra exposure, which is associated with extra tissue damage and risk of complications. Open reduction also causes the formation of scar tissue, resulting in loss of function (Fusetti et al., 2002). Unnecessary exposure could be avoided if closed reduction can be determined accurately by intra-operative fluoroscopy.

The purpose of this study was to compare the accuracy of fluoroscopic imaging with radiography and direct visualization during closed reduction and percutaneous fixation in the treatment of simulated Bennett fractures.

Materials and methods

The study was done on preserved specimens from persons who had voluntarily consented to have their bodies used for medical research and died at age of 75 years or older. During life none had experienced arthritis or previous trauma of the hand.

In eight preserved forearms, an intra-articular thumb metacarpal fracture was made with an osteotome. Intact arms were used. An incision was made on the dorso-medial side of the thumb metacarpal. All osteotomies were identically performed with an osteotome at an angle of 30° to the thumb metacarpal. In all eight hands, this resulted in an intra-articular fracture at the base of the thumb metacarpal with only one intra-articular fragment at the ulnar side. In all eight hands, this fragment consisted of at least 5 mm of the shaft and one-third of the joint surface, consistent with a Bennett fracture (**Figure 1**).

Figure 1 Simulated intra-articular thumb metacarpal fracture.
(Detail of fluoroscopic image of the hand)

All eight Bennett fractures were treated using closed reduction and percutaneous fixation with two parallel-positioned 1.6 mm Kirschner wires between the thumb and index metacarpal shaft [11, 31, 42, 53, 56]. Fluoroscopic images were taken in two directions (anteroposterior [59] and lateral) to determine the quality of the reduction (**Figure 2**). The quality of the fixation was assessed by moving the thumb, during which any movement of the fracture fragments was noted using constant fluoroscopic imaging. A stable fixation was defined as one in which no displacement of the fracture fragments occurred.

Figure 2 Fluoroscopy after closed reduction and percutaneous fixation
(Similar hand as Figure 1)

A digital image program (ImageJ; Scion Corp., Frederick, Maryland, USA) was used to measure intra-articular step-off and displacement on the fluoroscopic images. Measurements were calibrated on the thickness of the 1.6 mm K-wires. A step-off and displacement of up to 2.0 mm was accepted [47, 56]. When a Step-off or Displacement of > 2.0 mm was seen on fluoroscopy, the K-wires were removed and the closed reduction and percutaneous fixation was done again.

After closed reduction and fixation, plain AP and lateral radiographs were taken in all eight hands. The fluoroscopic images and radiographs were saved digitally. The digital measurements on fluoroscopy were done before the radiographs were taken. A different researcher measured step-off and displacement for each type of visualization. All measurements were made by either a surgical or radiology resident.

The dissection consisted of division of the abductor pollicis longus and extensor pollicis longus tendons together with the ligaments of the trapezio-metacarpal joint on the dorso-radial side. This enabled direct measurement of the fragment displacement and intra-articular step-off without applying additional force on the percutaneous fixation (**Figure 3**).

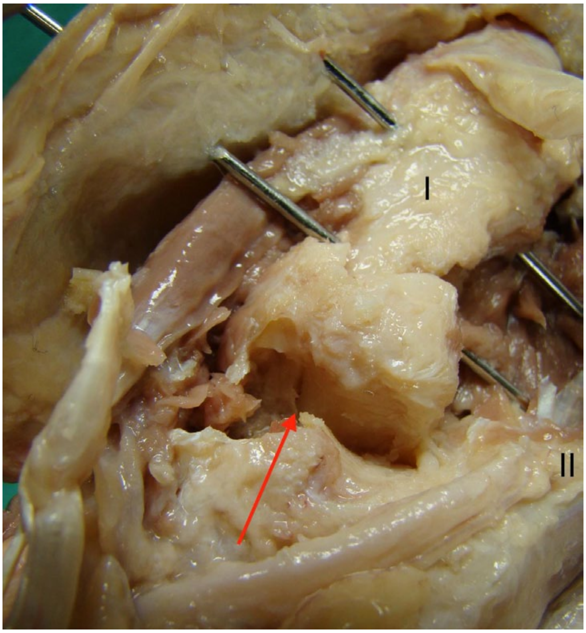

Figure 3 Open visualization of the fracture
(I = thumb metacarpal; II= index metacarpal; red arrow indicates intra- articular fracture)

Fracture displacement and step-off were measured with a precision of 0.1 mm for all three modalities (fluoroscopy, radiographs, and direct visualization). Step-off was defined as the largest intra-articular step perpendicular to the joint surface that could be measured. Displacement was defined as the largest distance between two fracture fragments that could be measured. The results of fluoroscopic imaging measurements were compared with the measurements on the plain radiographs and the results of measurements after dissection. In these comparisons, direct visualization was considered the gold standard.

Data are expressed as mean (standard deviation [SD]). Measurement results of the three visualization methods were compared using paired Student t-tests. A p value < 0.05 was considered to be statistically significant. Intraclass correlation coefficients (ICC's) were calculated to assess the agreement between the three visualization methods, using a two-way random model with measures of consistency.

Results

In all eight hands fracture reduction and percutaneous fixation was achieved. In three hands a second reduction and percutaneous fixation was necessary after measurement of displacement and step-off under fluoroscopy. After reduction and fixation, the intra-articular step-off was 0.8 (SD 0.8) mm with fluoroscopic imaging. Radiographs showed an intra- articular step-off of 0.8 (SD 1.2) mm. After dissection, direct visualization showed a step-off of 0.8 (SD 1.0) (**Table I**).

Table I Measurement of displacement and step-off

Specimen	Dislocation			Step-off		
	Fluoroscopy	Radiography	Open	Fluoroscopy	Radiography	Open
I	0,0	0,0	0,0	0,0	0,8	0,0
II	0,0	0,0	0,0	0,0	0,0	0,0
III	0,0	1,3	0,0	0,0	0,0	0,0
IV	2,0	4,0	2,0	2,0	1,3	2,0
V	0,0	1,0	0,0	0,0	1,5	0,0
VI	2,0	2,5	2,0	2,0	2,0	1,0
VII	2,0	0,8	3,0	2,0	0,5	3,0
VIII	0,0	0,0	0,0	0,0	0,0	0,0
Mean	0,8	1,2	0,9	0,8	0,8	0,8
SD	1,0	1,4	1,2	1,0	0,8	1,2

Fl = fluoroscopic imaging, Ra = Radiological imaging, Op = Open direct visualization

Displacements measured using fluoroscopy, radiographs, and direct visualization were 0.8 (SD 1.0) mm, 1.2 (SD 1.4) mm, and 0.9 (SD 1.2) mm, respectively. Comparison of these results with the Student's t-test showed no significant difference between the measurements of displacement and step-off between the three visualization methods.

The agreement between measurements from open visualization and fluoroscopy, calculated with the ICC's, were excellent for both displacement and step- off (ICC 0.95 and 0.90, respectively; **Table II**). There was less agreement between open visualization and radiographs, and between fluoroscopy and radio- graphs (ICC 0.56 and 0.69, respectively, for displacement, and 0.22 and 0.52, respectively, for step-off).

Table II Intra-class Correlation Coefficient (ICC) with 95% CI
Comparing Displacement and Step-off using Open visualization, Fluoroscopy and Radiography

	Displacement ICC (95% CI)	Step-off ICC (95% CI)
Open vs. Fluoroscopy	0.95 (0.78 to 0.99)	0.88 (0.52 to 0.98)
Open vs. Radiography	0.56 (–0.17 to 0.89)	0.22 (–0.52 to 0.77)
Fluoroscopy vs. Radiography	0.69 (0.04 to 0.93)	0.52 (–0.23 to 0.88)

Discussion

The amount of incongruity that can be accepted after surgical treatment of intra-articular thumb metacarpal fractures is still unknown [47]. Some have shown that osteoarthritis does not occur with a step-off of up to 3 mm, whereas others accept a maximum of 1 mm [21, 56, 107]. The current study showed that step-off was adequately assessed using fluoroscopy. Using fluoroscopy, a measurement error of > 1 mm incongruity occurred in only one case. With radiography, measurement errors of > 1 mm were seen in four cases. The dis- placement and step-off found with fluoroscopy was never larger than the displacement and step-off found with direct visualization. This means that displacement is not overestimated with fluoroscopy.

Only limited data are available on the accuracy of fluoroscopy in hand surgery [32]. The current data showed an agreement between measurements with open visualization and fluoroscopy to be excellent for both displacement and step-off (**Table II**). The 95% confidence interval showed a small range for displacement and step- off when comparing open measurements with fluoroscopy. A larger range was found for displacement and step-off when radiography was com- pared with open measurement or fluoroscopy. These results are in contrast with the study by Capo et al [32]. There are several explanations for these discrepancies. Of major importance is the difference in the precision of measurements in their study. Measurements on the fluoroscopic and radiographic images were made in millimetres with a metric ruler placed on the screen. After dissection, open measurements were made in 0.01 mm with a digital calliper. These differences in measurement could have resulted in unjustifiable significances and conclusions. A further explanation for the difference in results could lie in the fact that their study used hands, which were already fully dissected. This would make the fracture fixation more prone to displacement during the experiment, because of the absence of soft tissue and its ligamentotaxis effect. During the design of the current study, these limitations were taken into consideration and accounted for. The measurements in the current study were done with equal precision (0.1 mm) in all modalities, and the experiments were done on intact hands.

We conclude that intra-operative fluoroscopic imaging provides an accurate assessment of articular step-off and displacement in comparison with radiographs and direct visualization and, therefore, intra-operative fluoroscopic imaging is an adequate tool for use in the treatment of fractures of the hand.