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Use of three-dimensional fluoroscopy to determine intra-articular screw penetration in proximal humeral fracture model

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Background: Proximal humeral locking plates have significantly improved the treatment of proximal humeral fractures in recent years; however, they are not devoid of complications. Inadvertent screw penetration into the joint is a well-documented complication. Intraoperative 3-dimensional (3D) imaging may assist in detecting intra-articular implant penetration. This study compared the performance of a standard C-arm fluoroscope with a novel 3D imaging fluoroscope in detecting penetrating implants in a proximal humeral fracture model.

Methods: Zinc-sprayed proximal humerus sawbones were affixed with a proximal humeral locking plate. Six different constructs were assembled. In each specimen, 1 screw, 2 screws, or no screws were inserted 2-mm proud of the articular surface. Each specimen was imaged with a conventional fluoroscope and a 3D imaging fluoroscope. Overall, 36 image sets were prepared for each modality. These were evaluated by 2 fellowship-trained surgeons for intraobserver and interobserver reliability as well for the accuracy of detecting prominent implants in the 2 imaging methods.

Results: Overall accuracy for observer A was 89.9% compared with 100% for C-arm fluoroscopy and 3D imaging fluoroscopy ($P < .01$) and for observer B was 91.1% and 100% ($P = .01$), respectively. The κ values were 0.74 with C-arm fluoroscopy and 1.0 for the 3D imaging fluoroscopy for observer A, and 0.93 and 1.0, respectively, for observer B.

Conclusions: In a proximal humeral fracture model, C-arm fluoroscopy is a highly accurate imaging modality that can minimize the incidence of penetrating screws into the joint. Further clinical studies are required to establish this modality.

Level of evidence: Basic Science Study, Imaging, Surgical Technique.

Keywords: Proximal humeral fracture; intra-articular implants; three-dimensional fluoroscopy

The incidence of proximal humeral fractures had increased in recent years.[1,6] Although nonoperative treatment can be offered to most patients,[18] many fractures require surgical management. Because fixation techniques have evolved recently, especially with regards to fixed-angle devices such as locked plates, the option of open

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reduction and internal fixation (ORIF) of proximal humeral fractures has gained popularity.[1,6,13]

ORIF has achieved excellent results in many patients; however, many recent reports describe a considerably high complication rate, especially in treating 3-part and 4 part-fractures with ORIF.[2,7,8,19,23] These complications include loss of reduction, varus collapse, avascular necrosis, and screw cutout of the humeral head.[7,8,15] The latter complication can occur as a primary complication or secondary to fracture settling due to medial instability.[9] The screws in some patients, however, are originally placed penetrating into the glenohumeral joint, with a reported incidence of up to 10% to 15%.[7,15] Because most of these procedures rely on conventional C-arm fluoroscopy as the single means of intraoperative imaging, missing intra-articular screw penetration is not avoidable.

In recent years, more sophisticated intraoperative imaging devices emerged that have enabled 3-dimensional (3D) imaging using specialized fluoroscopes. These were most useful in delineating the complex anatomy of intra-articular fracture reduction[10,16,22] but also assisted in detecting inadvertent violation of joint spaces by screws.[3] However, despite the potential advantages, clinicians did not commonly use these systems, probably due to their high cost, inferior image quality, and the at time, considerable radiation dose delivered to the patient and staff during each scan.[21]

Recently, a prototype software module, C-InSight (Mazor Surgical Technologies, Caesarea, Israel), has emerged that allows the use of a conventional 2-dimensional C-arm fluoroscope, coupled with a target array, to capture and produce 3D fluoroscopic images similar to the ones produced by currently available 3D devices such as the Siremobil ISO-C3D (Siemens, Erlangen, Germany). Thus, intra-operative 3D imaging can now be performed with conventional fluoroscopes with the potential advantages of decreased cost and reduced radiation time. The goal of this study was to assess the accuracy and feasibility of the use of intraoperative 3D fluoroscopy compared with conventional 2D fluoroscopy in detecting intra-articular screw penetration in a proximal humeral fracture model.

Materials and methods

Zinc sprayed humeral sawbones (Sawbones, Vashon, WA, USA) were used. A PHILOS proximal humeral locking plate (Synthes, Oberdorf, Switzerland) was fixed to the bone using 6 locking screws inserted through its proximal part through holes designated A-I (Fig. 1).

Overall, 6 different constructs were created. Four constructs were made with a single, predefined screw (A, B, E, or I) inserted 2-mm proud of the articular surface, as measured using a caliper. The fifth construct had 2 predefined screws (F and H) inserted 2-mm proud of the articular surface, and the sixth construct had no penetrating screws.

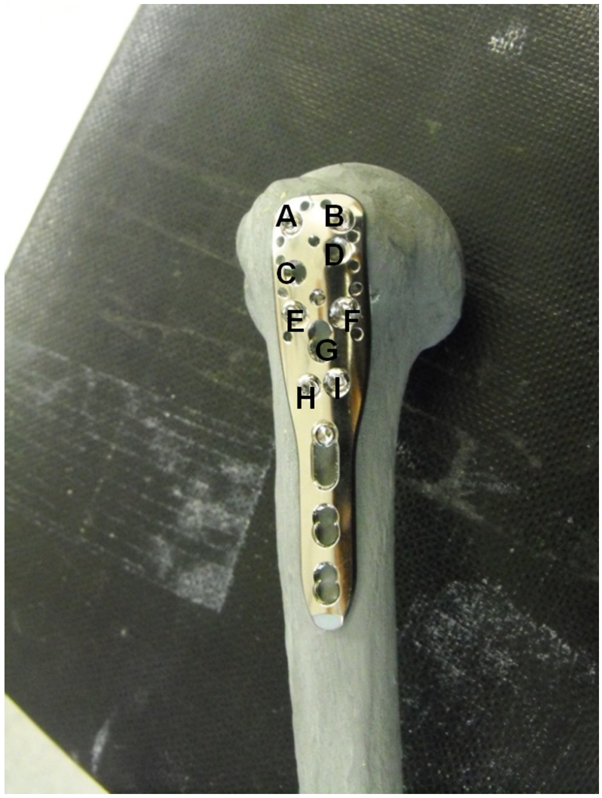

Figure 1 A zinc sprayed sawbone with 6 screws fixed to the bone. The screws were designated A-I. Overall, 6 such constructs were assembled.

Each construct underwent C-arm fluoroscopy with a 12-inch OEC 9800 fluoroscope (GE, St. Giles, UK) using an anteroposterior, lateral, and 2 oblique views of 45° (Fig. 2).

3D fluoroscopic process

The C-InSight system consists of a computer station that feeds directly from the video output to a conventional C-arm unit, an image adaptor that mounts onto the C-arm image intensifier, and a multiuse plastic target, draped in a disposable sterile sheath, which is placed over the anatomic region of interest (Fig. 3). This plastic target is identical to the one placed during spine robotic surgery[4] and was successfully tried clinically in our center in other anatomic regions such as the pelvis and wrist.

A continuous 20-second fluoroscopic scan is performed as the C-arm is moved through its entire arc of rotation (120°), while translating the C-arm forwards or backwards to keep the target at the image's center. The software then calculates the position of the scanned anatomic object relative to the plastic target array. During the C-InSight scan, the system captures a real-time video stream of X-ray scans, and the frames are processed sequentially to determine the target array location because the region of interest may shift due to C-arm rotation. Once all frames are processed, the system can colocate them in space relative to the target array. Then, the image reconstruction process iteratively builds slabs similar to computed tomography (CT). Volume reconstruction and reformatting produces axial, sagittal, and coronal images as well