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Computer-assisted surgery: The use of stored intraoperative images for accurate restoration of femoral length and rotational alignment after fracture

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ABSTRACT

Most femoral fractures are now managed with minimally invasive internal fixation. In the absence of formal exposure of the fracture lines, these procedures make heavy use of C-arm fluoroscopy to allow both fracture reduction and placement of implants, at the expense of measurable radiation exposure to both patient and surgeon. Although this technology has been commercially available for over a decade, it has not yet been widely accepted by the Orthopaedic community.

Introduction

Orthopaedic surgeons are experienced in using two-dimensional image data from arthroscopy or fluoroscopy during minimally invasive surgery. CAS takes this a step further, by providing access to multiple simultaneously-displayed stored two-dimensional (2D) fluoroscopic images. Synonyms for this particular type of CAS are surgical navigation, image-guided surgery (IGS), C-arm navigation, virtual fluoroscopy, and 2D fluoroscopic navigation. The surgeon may store multiple 2D images of each area of interest, allowing accurate assessment of fracture reduction and alignment in three dimensions. Most current systems use an optical tracking system to follow both the position of the patient and special surgical instruments during the course of the procedure. These optical systems offer a large effective working distance, and appear to be best suited for trauma applications. In all types of IGS systems, the predicted position of the surgical instruments and fracture fragments are displayed on a computer monitor relative to the position of the patient's skeletal anatomy on the stored images.

Surgical navigation in the treatment of long bone fractures

Nearly all femoral fractures, from the femoral neck to the distal metaphysis, are now managed with minimally invasive techniques that do not require direct exposure of the fracture. Closed antegrade or retrograde intramedullary nailing of diaphyseal femoral fractures (OTA 32-A–C) allows minimally invasive stabilization of these injuries at the expense of significant ionizing radiation exposure to both the patient and the operative team. The procedure typically requires several minutes of fluoroscopy time. Most surgeons feel very comfortable performing this procedure using C-arm guidance alone, without the use of navigation. As navigation may add time to the surgical procedure, it is probably not necessary for all femoral fractures, although early experience suggests great decreases in radiation exposure when using navigation. The biggest advantage of navigation is the ability to accurately restore not only axial alignment, but also anatomic length and rotational alignment to match the injured femur to the uninjured side[1,2]. In comminuted fractures, this is otherwise difficult to do using standard non-navigated technique (Fig. 1). Although a variety of techniques have been described to compare anteversion of the femur to the contralateral side using intra-operative imaging, these techniques are not entirely reliable, and length remains particularly difficult to judge [3]. Femoral malrotation is an underappreciated problem in trauma care. While rotational variation up to 10° is common in uninjured femora, a rotational difference of 15° or more is considered malreduction [4]. When femoral rotation (version) is critically assessed with computed tomography (CT) following locked nailing of femoral fractures, it appears that surgeons leave the injured femur malrotated by over 15° in 20–30% of cases [5]. According to the AAOS Closed Claims survey (1985–1998), femoral fractures

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Fig. 1. A and B depict an example of a femoral fracture in which it may be difficult to restore anatomic length and alignment without using the contralateral normal side as a model.

accounted for more malpractice claims than any other diagnosis [6].

Multiple C-arm images are usually obtained during the critical portions of the femoral nailing procedure:

- Identification of the proper skin incision site, and the insertion site for the femoral nail in the proximal femur.
- Reduction of the fracture, followed by passage of a reduction rod and/or guide wire across the fracture.
- After axial alignment is corrected by passage of the intramedullary device, the final reduction involves restoration of normal length and rotational alignment. This step in particular is difficult without navigation.
- Interlocking of the nail.

The total radiation exposure has historically been approximately four minutes of fluoroscopy time during these steps, and over one hundred individual images are often obtained. Many of these images must be obtained with the surgeon's hands in the radiation field, particularly during starting point preparation, reduction and guide wire passage, and freehand locking. Virtual fluoroscopy allows the performance of the critical portions of the femoral nailing procedure with as few as 12 individual stored images, and only a few seconds of fluoroscopy time [7]. As both the C-arm and the patient are tracked during the navigated procedure, the computer can accurately determine femoral length and rotational alignment on the uninjured side, and the surgeon can then match the anatomy of the injured to the uninjured side prior to definitive locking [8]. The surgeon may be well away from the radiation beam during imaging, and no additional imaging is required during the procedure, although several confirmatory images are usually obtained. A fluoroscopic CAS technique for femoral nailing, including fracture reduction, is described below.

Surgical technique

Preoperative CT is not required when using the 2D navigation workflow; all of the images are obtained intraoperatively, and normal femoral length and rotation is calculated using C-arm images of the uninjured extremity. A standard C-arm unit is retrofitted with a calibration target to allow tracking of the unit by the computer system, and optical correction of any distortion in