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Potential for Reducing Radiation Dose in Proximal Tibia Plate Fixation Using Depth Camera Augmented Fluoroscopy (DeCAF)

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Abstract

Mobile C-arm x-ray machines are commonly used in orthopaedic trauma surgeries to visualize internal anatomy. However, the use of scouting images to aid C-arm positioning during these procedures can prolong operating time and increase radiation exposure. Our Depth Camera Augmented Fluoroscopy (DeCAF) device is designed to reduce the number of x-ray images needed by overlaying the fluoroscopic images onto a live video of the patient's surface anatomy. In this study, we demonstrate in a simulated operating room (OR) environment that the DeCAF system has clinically acceptable overlay accuracy (1.3 ± 0.2 mm) and allowed the surgeon to substantially eliminate use of x-rays while fixing proximal tibial plates in acceptable positions without significantly changing the time required ($p = 0.72$). This justifies proceeding to live clinical evaluations.

1 Introduction

In orthopedic trauma surgery, C-arm fluoroscopes play a crucial role in determining the relative positions of surgical tools and anatomical structures. However, the frequent use of these machines for positioning purposes can prolong surgical time and subject both the patient and the surgical team to increased radiation exposure.

Efforts have been made to address the challenge of connecting the information in x-ray images of hidden anatomy with the surgical scene using x-ray overlays. The first example of such an overlay system is known as CamC, which included the use of a camera and double-mirror structure placed at the source side to align the viewpoints of the camera and x-ray (Navab 2010). CamC offered submillimetric overlay accuracy and demonstrated a 46% reduction in the number of x-ray shots in a clinical trial (von der Heide 2018). However, the device requires using the C-arm in an inverted configuration, leading to 60-65% more radiation scatter (Tremains 2001), and it significantly restricts the surgeon's work area. Subsequent iterations of CamC have proposed using a depth camera at the detector side. Most recently, Hosseinian (2019) presented an improved calibration procedure for a depth-camera-based system. However, no further studies have been conducted to assess the clinical efficacy of the system. Simultaneously, our group presented a prototype of a similar system with a depth camera on the detector side (Hickey 2019), but did not demonstrate the accuracy or utility of the system in user trials. We hypothesize that the DeCAF system has the potential to substantially reduce radiation exposure and potentially enhance workflow efficiency in selected orthopaedic trauma procedures. Here we present an updated version of the system and evaluate its potential clinical value in a proximal tibia plate fixation procedure performed on anatomic models in a simulated OR environment.

2 Method

Our Depth Camera Augmented Fluoroscopy (DeCAF) system uses a 3D depth camera affixed to the image intensifier tube of a C-arm machine (see Figure 1) to create an augmented reality view that overlays a recently acquired x-ray image onto a live video feed (Hickey, 2019) to allow the surgeon to more intuitively understand the relationship between the patient's surface anatomy, surgical tools in the operating field, and interior anatomical structures.

After mounting the depth camera, the system is pre-operatively calibrated by aligning a calibration object with the C-arm's laser crosshair. Using a tracking module which tracks the corners of each marker on the calibration object, the software uses geometric data from the depth camera to display a real-time video feed in a perspective aligned with the C-arm's viewing direction. The system uses a scannable pointer tool to indicate the target anatomy plane and compute its depth in order to determine the proper scale for the overlay (since, in contrast to the Cam-C system, with DeCAF, the x-ray emitter and the depth camera are positioned on opposite sides of the patient).

To evaluate the potential clinical utility of DeCAF, we simulated a proximal tibia plate fixation procedure using 20 Synbone tibia models embedded in a foam wrapping representing the surrounding soft tissues. An experienced trauma surgeon inserted three screws under the tibial plateau in each model, in half of the cases using the conventional fluoroscopic method, and in the other half using the DeCAF system with no imaging taken after the initial shot, except to confirm final placement. We measured the number of x-rays taken in the conventional procedure, the time required for each step, and the depth of the exit points of the screws relative to the joint surface.

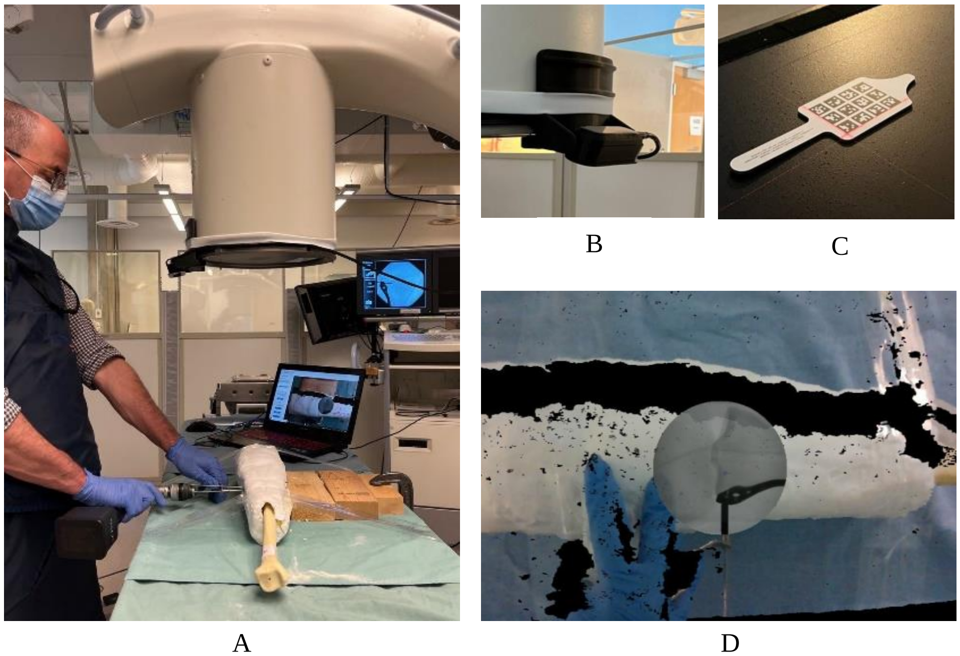

Figure 1. (A) Surgical setup for testing DeCAF in proximal tibia plate fixation while using the overlay for drilling, B) Camera Assembly, C) Calibration Tool, and (D) x-ray overlay view while the surgeon holds a surgical drill

3 Results

The DeCAF overlay accuracy calculated by the distance between corresponding points on the x-ray and video images using a calibration object was 1.3 ± 0.2 mm within ±50 mm of the calibration plane. Figure 2A shows the exit hole depths for the three screw positions. No breaches occurred with either technique. On average, the surgeon inserted the screws deeper when using DeCAF (2.91 ± 1.79 mm, $p < 0.05$). There was a statistically detectable influence of screw position on depth, with the anterior screw being slightly deeper than the other two, but no statistically significant difference in change of depth across methods for the different screw positions (changes in depth for anterior, middle, and posterior screws were 3.22 ± 1.79 mm, 3.06 ± 1.45 mm, and 2.45 ± 2.08 mm, respectively).

Figure 2B shows the times required for each procedural step in the conventional and DeCAF approaches. The average total procedure time was not significantly shorter when using DeCAF (487s vs 499s). Two-sided t-tests showed no detectable differences between the DeCAF and conventional method in the total procedure time ($p = 0.72$), nor in the individual steps including K-wire insertion ($p = 0.77$), middle screw placement ($p = 0.19$), anterior screw placement ($p = 0.59$), and posterior screw placement (p-value = 0.49). Finally, the average number of x-ray shots using the conventional method was 39.2 ± 5.1 (vs 0 with DeCAF, $p<0.05$).

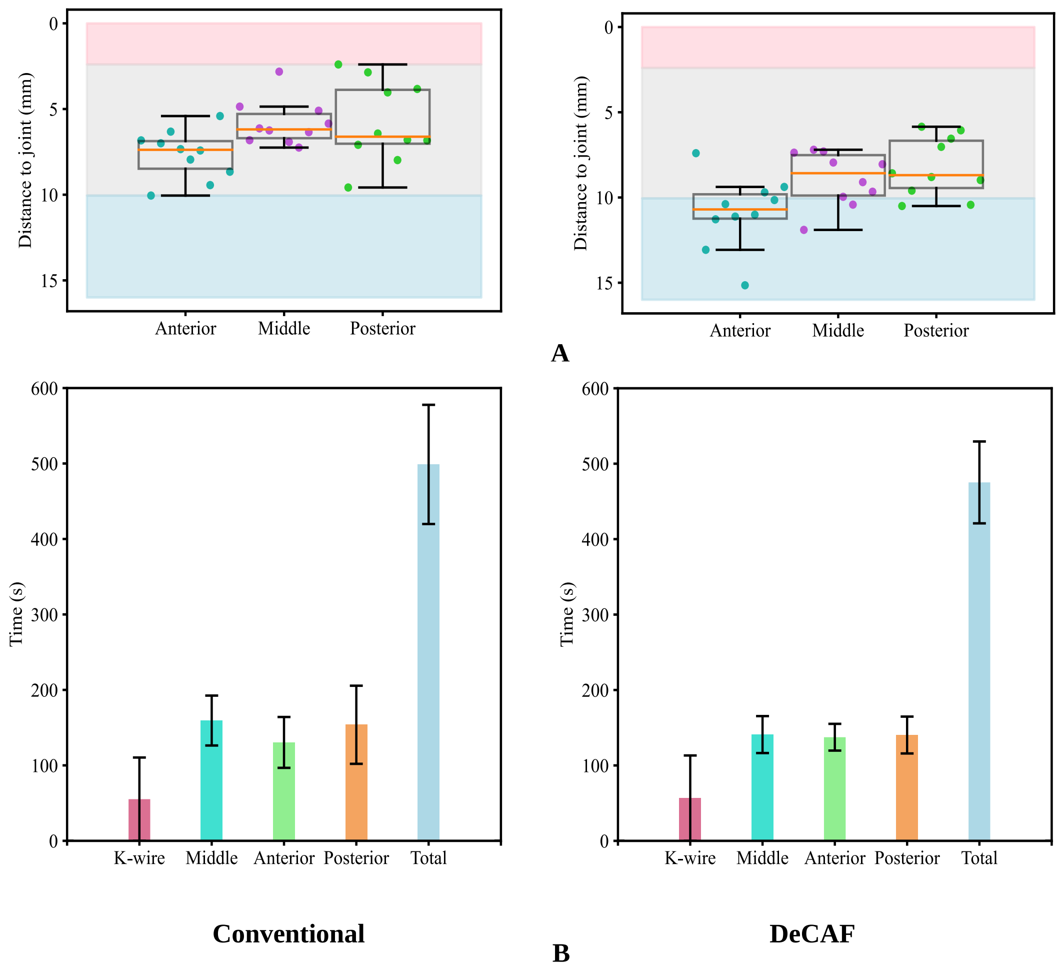

Figure 2. A) Exit hole depths using the conventional (left) and DeCAF (right) approaches. Points are sorted by the order of completed cases from left to right. B) Time required for each category in proximal tibia plate fixation using the conventional approach and the DeCAF approach. The categories are sorted based on the order of their occurrence from left to right.

4 Discussion and Conclusion

The overlay accuracy for DeCAF of 1. 3 ± 0.2 mm is consistent with accuracies reported in related studies (Navab 2010, Habert 2015) and is likely acceptable for clinical applications. Despite acquiring only one x-ray of the proximal tibia, the surgeon was able to appropriately place all screws without breaching and in times comparable to the conventional method. Overall, screws inserted with DeCAF were placed ~3 mm deeper than with the conventional method but were generally still within or close to the normally targeted depth zone. These results justify moving to deploy and test DeCAF in live surgical scenarios.

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