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Technical note

Augmented reality fluoroscopy simulation of the guide-wire insertion in DHS surgery: A proof of concept study

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ABSTRACT

Background: Hip fractures contribute to a significant clinical burden globally with over 1.6 million cases per annum and up to 30% mortality rate within the first year. Insertion of a dynamic hip screw (DHS) is a frequently performed procedure to treat extracapsular neck of femur fractures. Poorly performed DHS fixation of extracapsular neck of femur fractures can result in poor mobilisation, chronic pain, and increased cut-out rate requiring revision surgery. A realistic, affordable, and portable fluoroscopic simulation system can improve performance metrics in trainees, including the tip-apex distance (the only clinically validated outcome), and improve outcomes.
Method: We developed a digital fluoroscopic imaging simulator using orthogonal cameras to track coloured markers attached to the guide-wire which created a virtual overlay on fluoroscopic images of the hip. To test the accuracy with which the augmented reality system could track a guide-wire, a standard workshop femur was used to calibrate the system with a positional marker fixed to indicate the apex; this allowed for comparison between guide-wire tip-apex distance (TAD) calculated by the system to be compared to that physically measured. Tests were undertaken to determine: (1) how well the apex could be targeted; (2) the accuracy of the calculated TAD. (3) The number of iterations through the algorithm giving the optimal accuracy–time relationship.
Results: The calculated TAD was found to have an average root mean square error of 4.2 mm. The accuracy of the algorithm was shown to increase with the number of iterations up to 20 beyond which the error asymptotically converged to an error of 2 mm.
Conclusion: This work demonstrates a novel augmented reality simulation of guide-wire insertion in DHS surgery. To our knowledge this has not been previously achieved. In contrast to virtual reality, augmented reality is able to simulate fluoroscopy while allowing the trainee to interact with real instrumentation and performing the procedure on workshop bone models.

1. Introduction

Hip fractures contribute to a significant clinical burden globally with over 1.6 million cases per annum [1]. Domestically, 70,000 patients fracture their hip in the UK each year, resulting in £2 billion of care [2]. These fractures carry a high morbidity and mortality, with up to a 30% mortality rate within 1 year [3–6]. Additionally, after hip fracture, patients are five times more likely to be institutionalised at one year than their age-matched controls [7]. Extracapsular fractures account for a significant subsection of neck of femur fractures.

Extracapsular neck of femur fractures can be treated with a fixed angle sliding screw device, better known as a sliding, compression or dynamic hip screw (DHS). However, mechanical failure rates of up to 20% have been reported [8–11]. The tip-apex distance (TAD: the sum of the distance between the tip of the lag screw to the apex of the femoral head on both the antero-posterior [AP] and cross table lateral [CTL] radiographs) is considered to be the strongest predictor for screw cut-out, necessitating further surgery and increasing morbidity or mortality [12]. Studies have found that the optimal TAD needs to be less than 20 mm for reducing the risk of cut-out and mechanical failure [12]. To achieve this optimal TAD during surgery, intraoperative fluoroscopy is used to position a guide-wire which forms the trajectory along which the implant is placed.

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It is becoming increasingly difficult for trainee surgeons to gain exposure to these operations early on in their career [13,14] resulting in less practice and ultimately poorer outcomes owing to poor technique, poor implant placement, and increased procedural time. Poorly performed procedures can result in poor mobilisation increasing the risks associated with co-morbidities, chronic pain, and higher cut-out rates requiring revision surgery. Simulation is a well-recognised teaching adjunct to train high-risk tasks within a safe and controlled environment to prevent harm to patients [15–20]. Simulation in orthopaedic surgery can be divided into three broad categories: 1) low-fidelity saw bones (dry-lab) 2) virtual reality (VR) and 3) cadaveric (wet-lab) simulation [21–25].

In spite of DHS surgery being one of the more common lower limb trauma procedures worldwide, there are very few resources available to simulate DHS surgery. In the aforementioned methods of simulating DHS surgery, the placement of the guide-wire to achieve an optimal TAD of less than 20 mm, arguably the most crucial part of the procedure, is unrealistic. Current methods may teach the principle of the procedure, however the practical tasks involved are far removed from reality due to either the lack of fluoroscopy or actual tools which reduces the fidelity and realism of the simulation. Fluoroscopy is usually not permitted in simulation due to the exposure of radiation. A realistic, affordable, and easily accessible simulation of DHS surgery would provide a useful step in developing and perfecting the practical implementation to the operating theatre that will inevitably enhance patient safety.

Training will be improved by developing an affordable and high-fidelity modality to simulate the fluoroscopic guidance used within orthopaedic theatres. In this paper we present a novel augmented reality fluoroscopic simulator to simulate the insertion of the guide-wire during DHS surgery. To our knowledge this has not been previously achieved. The proposed device makes use of visual tracking using two video cameras in conjunction with image processing algorithms, to overlay the guide-wire position on corresponding fluoroscopic images. Additionally, we present results obtained while testing the accuracy of the proposed fluoroscopic simulator.

2. Methods

2.1. Design

In order to achieve a realistic simulation of the fluoroscopy used to guide placement of guide-wire placement in theatre, a method to simulate the fluoroscopic imaging was developed.

A prototype of this technology was developed and is described here to illustrate the methodology. To track the instrument (specifically the guide-wire), two orthogonally placed cameras are used to detect coloured markers attached to the guide-wire. Two Logitech c920 cameras (Logitech, Romanel-sur-Morges, Switzerland) were used; one placed in a position to capture the cross table lateral (CTL) and the other placed to capture the anterior-posterior (AP) view, as would be the case when using a single fluoroscopic C-arm. The cameras were placed at fixed positions ([0,500,0] & [500,0,0] for AP and CTL cameras respectively) from the centre of calibration (see Fig. 1a).

Two coloured (green and yellow) markers were attached to the guide-wire (Figs. 1a and 3). The CTL and AP camera images of the femoral head of a workshop bone (3B Scientific, Hamburg, Germany) were mapped onto previously obtained genuine fluoroscopic CTL and AP images using an affine transformation matrix. Three points on each camera image (AP: tip, lesser trochanter, greater trochanter CTL: tip, inferior neck, superior neck) and the corresponding points on the fluoroscopic images were selected using a graphical user interface (GUI). Fig. 2a–d illustrates the corresponding points between video and fluoroscopic overlay images used as inputs. The corresponding points were used to calculate an affine transformation matrix which then allowed for the mapping of points from the camera images to corresponding points on the fluoroscopic images in real time.

The position of the guide-wire in the camera images was determined based on tracking the attached coloured markers. To obtain the marker positions, the recorded RGB (red, green, blue) colour space images were converted to HSV (hue, saturation, value) colour space images and a threshold filter (minimum and maximum thresholds for hue, saturation, and value for ambient light conditions were predetermined by the user) were used to isolate the coloured pixels for each marker individually [26]. The images were processed prior to segmentation using a Gaussian filter (5 pixel radius). A best fit circle was then fitted to the identified pixels and the centre of the circle was used as the marker position (see Fig. 1). To minimise positional variation due to ambient light conditions, the position of the marker was averaged over multiple images; a variable specified by the user. Averaging over a larger number of images resulted in a more stable marker position but a slower computation time.

Knowing the position of the guide-wire tip relative to the markers meant that the guide-wire position could be mapped onto the corresponding fluoroscopic image as an overlay. The use of two markers, at predetermined positions from both each other and relative to the tip, made it possible to calculate the wire trajectory taking into account the effect of out of plane motion on the two-dimensional image representation [27]. Application of the calculated affine transformation matrix to the trajectory allowed for an image of the guide-wire to be overlaid on the fluoroscopy image, to simulate a fluoroscopic environment without being exposed to harmful radiation.

Python (version 2.7) and OpenCV (version 3.0.0) were used to develop the image processing algorithms used to track the coloured marker spheres as described. The system was capable of providing both static ‘snapshots’ as well as live screening as is the case in a real theatre environment. The code developed recorded a number of parameters as outputs to measure the performance of the user/trainee: the time taken, the number of images taken, the AP, CTL, and absolute distance from the tip of the wire to the apex and a calculated TAD.

2.2. Testing

Three tests were performed to assess the accuracy of the system: (1) absolute accuracy under laboratory conditions. (2) Accuracy convergence with number of images. (3) In use accuracy when the simulation was used by naïve subjects.

2.3. Absolute accuracy

To test the accuracy, or how well the system represents reality, a specialised ’marker jig’ and a ’drilling block’ were built (Fig. 3). The system was set up with a right sided proximal femur and the pointer of the maker jig was placed at the apex of the femoral head (Fig. 3a). The system was then calibrated to determine the affine transformation matrix. Once calibrated the femur was removed and replaced by the drilling block (Fig. 3b) and this was subsequently covered to obscure the pointer marking the apex which remained in situ (Fig. 3c).

Using this setup, the guide-wire was inserted at 135° using a 135 degree guide (135° being the angle between the femur and femoral neck) under simulated fluoroscopic guidance, aiming for 18 separate points in relation to the marker, to give both a range of distances and positions from the defined ‘apex’. The position of the