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A Comparison of Accuracy of Image- versus Hardware-based Tracking Technologies in 3D Fusion in Aortic Endografting

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WHAT THIS PAPER ADDS

Fusion imaging is recognized as an important tool in complex aneurysm repair to improve the success of implantation and decrease radiation dose and contrast use. It has been previously impossible to compare the accuracy of fusion systems because they require fixed hardware, but a new cloud-based system is now available. We compare the accuracy of two different types of fusion imaging. If confirmed, these preliminary results could change clinical practice by encouraging further development of automated image base tracking fusion process.

Objectives: Fusion of three-dimensional (3D) computed tomography and intraoperative two-dimensional imaging in endovascular surgery relies on manual rigid co-registration of bony landmarks and tracking of hardware to provide a 3D overlay (hardware-based tracking, HWT). An alternative technique (image-based tracking, IMT) uses image recognition to register and place the fusion mask. We present preliminary experience with an agnostic fusion technology that uses IMT, with the aim of comparing the accuracy of overlay for this technology with HWT.
Method: Data were collected prospectively for 12 patients. All devices were deployed using both IMT and HWT fusion assistance concurrently. Postoperative analysis of both systems was performed by three blinded expert observers, from selected time-points during the procedures, using the displacement of fusion rings, the overlay of vascular markings and the true ostia of renal arteries. The Mean overlay error and the deviation from mean error was derived using image analysis software. Comparison of the mean overlay error was made between IMT and HWT. The validity of the point-picking technique was assessed.
Results: IMT was successful in all of the first 12 cases, whereas technical learning curve challenges thwarted HWT in four cases. When independent operators assessed the degree of accuracy of the overlay, the median error for IMT was 3.9 mm (IQR 2.89—6.24, max 9.5) versus 8.64 mm (IQR 6.1—16.8, max 24.5) for HWT ($p = .001$). Variance per observer was 0.69 mm^2 and 95% limit of agreement ± 1.63.
Conclusion: In this preliminary study, the error of magnitude of displacement from the "true anatomy" during image overlay in IMT was less than for HWT. This confirms that ongoing manual re-registration, as recommended by the manufacturer, should be performed for HWT systems to maintain accuracy. The error in position of the fusion markers for IMT was consistent, thus may be considered predictable.

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INTRODUCTION

Endovascular interventions have expanded the treatment opportunities available to patients with aortic disease and have become progressively complex.[1—3] When repair includes coverage of the visceral aortic segment, accurate device deployment and efficient catheterization of target vessels is critical. Fluoroscopic techniques require frequent contrast administration and high-quality image recording Digital Subtraction Angiography (DSA) to visualize key structures, resulting in exposure of the patient and surgeon to considerable radiation,[4] and may be associated with deterioration in renal function.[5,6]

Endovascular image fusion refers to the process of merging preoperative imaging with intraoperative imaging to provide a three-dimensional (3D) vascular mask.[7,8] Several studies using commercially available devices have documented variable reduction in radiation exposure, and significant reduction in contrast usage.[9—12] All commercially available systems to date use hardware-based tracking to position the mask on the fluoroscopic image. Not all fixed imaging systems require cone beam computed tomography (CBCT) to perform fusion imaging, but at our institution, CBCT is used to create an intra-operative 3D volume that is co-registered with preoperative

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imaging. The CBCT data provide the basis for a 3D coordinate reference frame that is automatically registered with fluoroscopic imaging, but also incorporates positional data for the vascular landmarks acquired on preoperative imaging. By combining both soft and bony landmarks for registration, this technique should be superior to those using registration of bony landmarks alone. The position of the image intensifier and operating table are tracked with respect to the coordinate reference frame, allowing for appropriate vascular landmark representation when the fluoroscopic image is changed.[13,14] The reliability of this technique depends on the accuracy of "hardware tracking" and the stability of the patient's position on the table once rigid co-registration has been performed.[15] Furthermore, considerable user interaction is required to define the vascular landmarks on a workstation preoperatively, manually register the images, and correct registration errors intraoperatively that may arise from patient movement.

A fully automated, image-based 2D—3D registration system that is independent of imaging system manufacturer has been proposed by Carrell et al.,[16] and its initial use was described in 2010. This system provides several advantages including being suitable for any theatre even those equipped with mobile C-arm; it is radiation and contrast free for the initial registration; and being fully automated makes it "user friendly" for the operator. The drawback of IMT is that it can only perform fusion on $\pm$30-degree angles from a standard anteroposterior view, and it does require additional equipment to be installed in theatre.

The aim of this study is to compare the accuracy of the fusion overlay between two systems that use different mechanisms to maintain accurate overlay of vascular markings: hardware tracking, and image-based tracking. Because most fusion systems are brand-specific, there has been no previous simultaneous comparison of accuracy between systems on the same patient in the same conditions. Thus, the accuracy of an initial manual registration was compared, followed by hardware tracking using a commercially available device, with continuously updated image-based matching in an investigative device.

MATERIALS AND METHODS

All patients undergoing aortic repair between July 2015 and September 2015 by the Aortic Team at Royal Free London were included in this study. These patients were enrolled in a pre-market trial of CYDAR software and signed consent for involvement. The study was approved by NHS England (IRAS ID 158839) and was closed on September 30, 2015, in accordance with the approved protocol.

All patients with aneurysms underwent preoperative high-resolution computed angiography (CTA) as the standard of care. All patients received stent-graft deployments with fusion assistance using two different systems: a pragmatic application of a commercially available device that uses hardware tracking (Siemens Artis Zeego, Siemens Healthcare) and a novel image-based device the Cydar EV system (Cydar Medical, Cambridge, UK) in order to allow for a comparison between the two systems. Fusion would be considered successful if the initial images were available and assisted the surgical procedure. Fusion would be considered a failure if no mask appeared on the screen, or if the position of the mask was so far removed from reality that it was not helpful in the opinion of the operating team.

Hardware-tracking fusion protocol

A hardware-tracking fusion protocol for complex aortic repair has been used at the Royal Free London since October 2014. Prior to CBCT, the surgical team imported the preoperative CTA onto the theatre-based workstation and marked the target vessels by drawing rings at the level of the vessel ostia using Syngo (Siemens Healthcare) software. After induction of general anaesthetic and after all adjustments had been made to the patient's position, the patients were fully prepared and draped to minimize any extraneous patient movement after registration. All staff retreated to a shielded and sterile control room before CBCT. A 5sDR (5-second acquisition, taking 133 frames at 30 frames/sec) was used for all procedures. Rigid co-registration of the preoperative CTA with the bony CBCT volume was then performed by the surgeon or an expert radiographer using a manual process. Target vessel rings were assessed intraoperatively on the fluoroscopy screen. Manual readjustments of the fusion overlay were not performed since the accuracy of automatic image overlay in both systems after initial co-registration was being compared.

Image-based tracking fusion protocol. For each patient the Cydar EV system was also used to generate vascular landmarks that were viewable on an additional screen. Segmentation of the aorta and relevant visceral vessels was performed from the DICOM data of CTA using a semi-automatic method (thresholding followed by region growing), and then rings were manually drawn on the rendered surface by the software provider before the day of surgery. The software provider requires 24 h to prepare the overlay mask. The software is then applied to a computational algorithm on the preoperative CT volume to generate a series of images (digitally reconstructed radiographs, DRRs) that mimic fluoroscopic images across a range of C-arm rotations and magnifications to match vertebral bodies in both images. An intensity-based registration algorithm then scanned the DRR series for images with similar pixel distributions, and automatically matched the most appropriate DRRs to the live fluoroscopic images throughout the procedure. During each fluoroscopic position, the tracking software analysed the visualized field and attempted to identify vertebrae. If two or more vertebrae were identified, the vascular overlay image created from CT angiography was projected. The algorithm assumed there was a rigid relationship between CT and fluoroscopy, since registration is based on vertebral bodies, and does not adjust for changes in spinal position.[17] The system works when the C-arm is angulated within 30° craniocaudally and 40° in an anterior-oblique direction, which is a range chosen by the