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Orthogonal Rings, Fiducial Markers, and Overlay Accuracy When Image Fusion is Used for EVAR Guidance

G. Koutouzi [a,*], C. Sandström [a], H. Roos [b], O. Henrikson [a], H. Leonhardt [a], M. Falkenberg [a]

[a] Institute of Clinical Science, Department of Radiology, Sahlgrenska Academy, University of Gothenburg, Gothenburg, Sweden
[b] Department of Vascular Surgery, Sahlgrenska University Hospital, Gothenburg, Sweden

WHAT THIS PAPER ADDS
This study points out possible pitfalls in 3D image fusion for EVAR guidance. Methods for visualization and correction of anatomical landmarks are suggested, and causes for suboptimal accuracy are investigated.

Objective: Evaluation of orthogonal rings, fiducial markers, and overlay accuracy when image fusion is used for endovascular aortic repair (EVAR).
Methods: This was a prospective single centre study. In 19 patients undergoing standard EVAR, 3D image fusion was used for intra-operative guidance. Renal arteries and targeted stent graft positions were marked with rings orthogonal to the respective centre lines from pre-operative computed tomography (CT). Radiopaque reference objects attached to the back of the patient were used as fiducial markers to detect patient movement intra-operatively. Automatic 3D-3D registration of the pre-operative CT with an intra-operative cone beam computed tomography (CBCT) as well as 3D-3D registration after manual alignment of nearby vertebrae were evaluated. Registration was defined as being sufficient for EVAR guidance if the deviation of the origin of the lower renal artery was less than 3 mm. For final overlay registration, the renal arteries were manually aligned using aortic calcification and vessel outlines. The accuracy of the overlay before stent graft deployment was evaluated using digital subtraction angiography (DSA) as direct comparison.
Results: Fiducial markers helped in detecting misalignment caused by patient movement during the procedure. Use of automatic intensity based registration alone was insufficient for EVAR guidance. Manual registration based on vertebrae L1-L2 was sufficient in 7/19 patients (37%). Using the final adjusted registration as overlay, the median alignment error of the lower renal artery marking at pre-deployment DSA was 2 mm (0—5) sideways and 2 mm (0—9) longitudinally, mostly in a caudal direction.
Conclusion: 3D image fusion can facilitate intra-operative guidance during EVAR. Orthogonal rings and fiducial markers are useful for visualization and overlay correction. However, the accuracy of the overlaid 3D image is not always ideal and further technical development is needed.

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INTRODUCTION

Three dimensional (3D) image fusion is an advanced imaging tool that helps the operator, providing useful anatomical information for guidance during endovascular procedures. Several authors have reported their clinical experience with fused imaging during endovascular aortic repair (EVAR), suggesting that the method is feasible[1] and that it can reduce both radiation[2—5] and contrast dose.[6,7] Visualization of anatomical positions derived from pre-operative imaging can be achieved by projecting volume rendered (VR) images or specific marks on the live fluoroscopy screen. For image registration the commercially available systems require either an acquisition of CBCT (3D-3D fusion) or two fluoroscopic orthogonal images (2D-3D fusion) intra-operatively.

However, 3D roadmaps derived from image fusion are not always precise.[8] There are several potential sources of errors: pre-operative computed tomography (CT) and intra-operative cone-beam CT (CBCT) are performed at different time points, on different tables, and with the patient in different body positions. An automatic algorithm can be used for 3D-3D registration of the two datasets, or this can be performed manually. Automatic registration is usually based on image intensity, and it can be used either as the definitive registration or as a first rough estimate before manual adjustments are started. Manual registration is most easily done by aligning highly attenuating bony

* Corresponding author. Department of Radiology, Sahlgrenska Academy, University of Gothenburg, Bruna stråket 11 B, SE-413 45 Gothenburg, Sweden.
E-mail address: giasemi.koutouzi@vgregion.se (G. Koutouzi).
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structures, but outlines of vessels and calcifications also can be used.

During EVAR, the introduction of medical devices can deform the arteries.[9,10] Breathing movements may cause misalignment. The patient may be pushed, pulled, or tilted during the procedure, especially if it is prolonged in time. Lastly, inaccuracy in the mechanical C-arm/table system may contribute to registration errors.

This study describes the use of 3D-3D image fusion for intra-operative guidance during EVAR. The aims were to evaluate orthogonal rings for visualization of anatomical locations during EVAR and to evaluate the use of easily spotted radiopaque points of reference for detection of intra-operative patient motion. Sources of registration and overlay errors also were determined.

MATERIALS AND METHODS

The study was approved by the regional ethical review board in Gothenburg.

Patient population

Nineteen patients who underwent standard EVAR between March 2014 and June 2015 (15 men and 4 women with a mean age of 76.2 years [SD $\pm$ 6.5]) were included in this prospective single centre study. Median body mass index (BMI) was 25.6 kg/m^2 (range 21.7—35.9), median weight was 83 kg (range 52—105), and median sagittal abdominal diameter (SAD) measured on the axial CT plane at the L4-L5 level was 27 cm (range 19.8—35.3).

Additional patient, aneurysm, and procedure characteristics are presented in Table 1.

Technical aspects

All patients underwent a pre procedural multi-detector CT angiography with 1—3 mm slices within 8 months from the EVAR procedure (median 2.5 months, range 5 days—8 months). Thin CT slices (preferably $<$1 mm) are optimal for pre-operative planning as well as for image fusion. All EVAR procedures were performed in the same hybrid operating room, which was equipped with a multi-axis robotic C-arm system together with a tiltable angiography table and a dedicated post-processing workstation (Artis zeego and syngo XWP; Siemens Healthcare GmbH, Forchheim, Germany).

The workflow was divided into the following steps.

Case planning: orthogonal rings. Thin slices of the pre-operative contrast enhanced CT (up to 3 mm) were loaded into the post-processing workstation. Anatomical structures of interest were marked on multi-planar reconstructed (MPR) images using a 3D visualization and processing application (syngo InSpace; Siemens Healthcare GmbH). Specifically, rings were manually drawn around the origins of the renal arteries and one larger ring was drawn around the aorta, orthogonal to its centre line, at the optimal cranial extension of the aortic stent graft just below the lower renal artery (Fig. 1A).

Patient preparation. All procedures were performed under general anaesthesia. The patient, the C-arm, and the entire table were covered with sterile drapes to provide sterility, even under the table. The patient was positioned with the abdomen in the ISO-centre of the system for CBCT acquisition.

Fiducial markers. To detect patient movements that could affect the accuracy of the overlay during the procedure, fiducial markers were attached to the patient. Fiducial markers are objects placed in the field of view (FOV) and used as reference points. In the current study, one or two ECG monitoring electrodes were attached on the back of the patient close to the anatomical area of treatment, between Th12 and L4. These electrodes consist of a radiolucent adherence tape and a round metal stud (diameter 1 cm). The stud is radiopaque and therefore clearly visible, both in live fluoroscopic imaging and in CBCT. The fiducials were depicted in CBCT and rings were manually drawn around them in the post-processing workstation, to mark their position—similar to the orthogonal rings used for the marked anatomical locations (Fig. 1B).

The ECG electrodes are inexpensive, disposable, and readily available in the hospital. They can be attached easily to the skin and did not cause any skin irritation in the present study patients. There were no significant artefacts related to the fiducial markers that affected the accuracy of the 3D-3D image fusion.

Intra-operative CBCT. Cone beam CT without contrast was performed after the patient had been positioned and draped on the operating table, just before vascular access. During acquisition, the C-arm rotates around the patient on a 200° trajectory. The CBCT protocol used (5s DCT Body Care) acquires 248 projection images at a configured detector dose of 0.36 µGy. The images are automatically transferred to the workstation, where they are reconstructed to CT-like images (Fig. 2). The cylindrical volume captured by a CBCT unit has a diameter of 25 cm and a height of 19 cm. To capture both the aorta and the fiducial markers in the volume, the table was centred so that the iliac spines were visible at the caudal end of a frontal view, with the lumbar vertebrae and the fiducial markers being visible in the lower aspect of a lateral view.

3D-3D fusion. Fusion of the datasets was performed with dedicated 3D-3D registration software (syngo InSpace 3D-3D Fusion; Siemens Healthcare GmbH) in a semi-automatic procedure. First, an automatic registration was activated, using an intensity value based on a normalized mutual information algorithm. Second, manual registration was done based on the alignment of vertebrae L1 and L2. This registration was done for investigational purposes to determine whether there was a change in aortic position in relation to nearby vertebrae between the CT and the CBCT. Finally, a manual registration was done using aortic calcifications and vessel outline, to align the renal artery ostia in two 3D datasets (Fig. 3). This final 3D-3D registration was used to create the 2D-3D overlay during the procedures.

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