Source of Errors and Accuracy of a Two-Dimensional/Three-Dimensional Fusion Road Map for Endovascular Aneurysm Repair of Abdominal Aortic Aneurysm

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ABSTRACT

Purpose: To evaluate the accuracy and source of errors using a two-dimensional (2D)/three-dimensional (3D) fusion road map for endovascular aneurysm repair (EVAR) of abdominal aortic aneurysm.

Materials and Methods: A rigid 2D/3D road map was tested in 16 patients undergoing EVAR. After 3D/3D manual registration of preoperative multidetector computed tomography (CT) and cone beam CT, abdominal aortic aneurysm outlines were overlaid on live fluoroscopy/digital subtraction angiography (DSA). Patient motion was evaluated using bone landmarks. The misregistration of renal and internal iliac arteries were estimated by 3 readers along head-feet and right-left coordinates (z-axis and x-axis, respectively) before and after bone and DSA corrections centered on the lowest renal artery. Iliac deformation was evaluated by comparing centerlines before and during intervention. A score of clinical added value was estimated as high (z-axis < 3 mm), good (3 mm $\leq$ z-axis $\leq$ 5 mm), and low (z-axis > 5 mm). Interobserver reproducibility was calculated by the intraclass correlation coefficient.

Results: The lowest renal artery misregistration was estimated at x-axis = 10.6 mm $\pm$ 11.1 and z-axis = 7.4 mm $\pm$ 5.3 before correction and at x-axis = 3.5 mm $\pm$ 2.5 and z-axis = 4.6 mm $\pm$ 3.7 after bone correction ($P = .08$), and at 0 after DSA correction ($P < .001$). After DSA correction, residual misregistration on the contralateral renal artery was estimated at x-axis = 2.4 mm $\pm$ 2.0 and z-axis = 2.2 mm $\pm$ 2.0. Score of clinical added value was low (n = 11), good (n= 0), and high (n= 5) before correction and low (n = 5), good (n = 4), and high (n = 7) after bone correction. Interobserver intraclass correlation coefficient for misregistration measurements was estimated at 0.99. Patient motion before stent graft delivery was estimated at x-axis = 8 mm $\pm$ 5.8 and z-axis = 3.0 mm $\pm$ 2.7. The internal iliac artery misregistration measurements were estimated at x-axis = 6.1 mm $\pm$ 3.5 and z-axis = 5.6 mm $\pm$ 4.0, and iliac centerline deformation was estimated at 38.3 mm $\pm$ 15.6.

Conclusions: Rigid registration is feasible and fairly accurate. Only a partial reduction of vascular misregistration was observed after bone correction; minimal DSA acquisition is still required.

ABBREVIATIONS

2D = two-dimensional, 3D = three-dimensional, AAA = abdominal aortic aneurysm, DSA = digital subtraction angiography, EVAR = endovascular aneurysm repair, FEVAR = endovascular aneurysm repair with fenestrated stent graft, ICC = intraclass correlation coefficient, SCAV = score of clinical added value

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Endovascular aneurysm repair (EVAR) is the predominant technique for repair of abdominal aortic aneurysm (AAA) in patients with intermediate and high operative risk (1–3). Measures that are less invasive than open repair should be taken to preserve renal function in this high-risk population (4–7). The EVAR procedure is planned with contrast-enhanced multidetector computed tomography (CT) based on specific anatomic criteria (8). No soft tissue differentiation is available during the intervention performed under fluoroscopic guidance, and data such as thrombus and aneurysm extension close to proximal and distal landing zones are lacking. Knowledge of the vascular geometry is mandatory to locate specific vascular landmarks (renal arteries, ostia, aortic and iliac bifurcations) crucial for the placement of the stent graft. Because of patient motion and vessel deformation secondary to the delivery device, accurate deployment of the stent graft during the EVAR procedure requires iterative injections of contrast agent before releasing each component of the stent graft. This contrast enhancement is even more critical for EVAR in an angulated neck or endovascular aneurysm repair with fenestrated stent graft (FEVAR) or EVAR with branched stent graft (9–12).

The concept of two-dimensional (2D)/three-dimensional (3D) fusion is based on the importation of a preoperative CT or 3D angiography image in the coordinate space of the angiography system and merging it with perioperative fluoroscopy (13). Cone beam CT acquisitions provide a perioperative 3D volume that serves as a reference to register the preoperative CT volume and then generate a 2D/3D fusion with an overlay of the preoperative model on the live fluoroscopy image. Bone landmarks or vascular landmarks such as vessel wall and calcifications can be used to register preoperative CT with the cone beam CT acquisition (14–16). Several series reported clinical experience with this approach for standard EVAR and FEVAR (14–16). In these series, a CT volume rendering of the AAA lumen was used for the 2D/3D registration, and there was limited information on the magnitude and source of error.

Software for semiautomated segmentation of AAA (AAA3Dmax; Object Research System, Montreal, Quebec, Canada) was developed allowing the creation of lumens, iliac arteries, and outer aortic wall 3D meshes and lumen centerlines extraction (1,17). Expected gains are the improvement of visual information and the possibility to perform real-time registration corrections. The aims of the present validation study were to evaluate the registration errors during rigid 3D fusion of cone beam CT and 3D meshes extracted from preoperative multidetector CT during EVAR of AAA and to discriminate the three components of overall misregistration: patient movement, rigid vascular displacement, and vascular deformation. A secondary objective was to evaluate the correction of the registration process based on bone and DSA alignment.

MATERIALS AND METHODS

Study Design and Patient Population

This study was compliant with the Health Insurance Portability and Accountability Act and was approved by the institutional review boards of the participating hospitals. All patients signed an informed consent form. The study included 16 subjects (12 men and 4 women) with a mean age of 77 years (range, 66–85 y) undergoing EVAR (between August 2011 and April 2013) in the interventional suite where the AAA interventional guidance tool prototype was installed.

Preoperative Multidetector CT Protocols and Image Segmentation and Registration

The 16 multidetector CT examinations were performed on different scanners, with a collimation ranging from 0.75–1.5 mm and slice thickness of 1–2 mm, after injection of a nonionic iodine contrast agent (1.5 mL/kg) at a flow rate of 3–5 mL/s. The basic workflow illustrated in Figure 1 can be divided in six sequential steps. Before the procedure (step 1), the 3D morphology of AAA components (lumen, thrombus, and outer wall) was extracted from preoperative enhanced multidetector CT. All segmentation and mesh creations were performed using a semiautomated software method previously validated for maximal diameter and volume measurements (18–20). The centerlines of right and left renal arteries were also extracted.

The planning (step 2) was performed on the AAA interventional guidance tool prototype Leonardo syngo Workplace (Siemens AG, Healthcare Sector, Forchheim, Germany) and consisted of the following: (*a*) loading and visualizing the preoperative multidetector CT, AAA and iliac meshes, and centerlines; (*b*) automatic detection of the ostia of renal arteries by centerline analysis; (*c*) manual positioning of one landmark at the aortoiliac bifurcation and two landmarks at the origin and midportion of the right and left internal iliac arteries; (*d*) manual positioning of additional landmarks at the origin of the celiac trunk and superior mesenteric arteries for FEVAR; and (*e*) proposal of working projections orthogonal to the centerline of the lower renal artery and the proximal portion of the right and left internal iliac arteries by the software.

At the onset of the EVAR procedure (step 3), unenhanced cone beam CT was acquired after induction of general (n = 12) or local anesthesia (n = 4) and before patient draping with an 8-second rotational acquisition (AXIOM Artis dTA; Siemens AG, Medical Solutions, Forchheim, Germany). During patient draping, a 3D/3D registration (step 4) between cone beam CT and preoperative CT angiography was performed manually, first based on spine alignment and then based on the best superimposition of aortic wall, calcifications, renal branching, and iliac bifurcation. The 3D registration matrix and the vascular landmarks of EVAR planning were sent to the angiography system.