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● *Original Contribution*

ABDOMINAL AORTIC ANEURYSM IMAGING WITH 3-D ULTRASOUND: 3-D-BASED MAXIMUM DIAMETER MEASUREMENT AND VOLUME QUANTIFICATION

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Abstract—The clinical reliability of 3-D ultrasound imaging (3-DUS) in quantification of abdominal aortic aneurysm (AAA) was evaluated. B-mode and 3-DUS images of AAAs were acquired for 42 patients. AAAs were segmented. A 3-D-based maximum diameter (Max3-D) and partial volume (Vol30) were defined and quantified. Comparisons between 2-D (Max2-D) and 3-D diameters and between orthogonal acquisitions were performed. Intra- and inter-observer reproducibility was evaluated. Intra- and inter-observer coefficients of repeatability (CRs) were less than 5.18 mm for Max3-D. Intra-observer and inter-observer CRs were respectively less than 6.16 and 8.71 mL for Vol30. The mean of normalized errors of Vol30 was around 7%. Correlation between Max2-D and Max3-D was 0.988 ($p < 0.0001$). Max3-D and Vol30 were not influenced by a probe rotation of 90°. Use of 3-DUS to quantify AAA is a new approach in clinical practice. The present study proposed and evaluated dedicated parameters. Their reproducibility makes the technique clinically reliable. (E-mail: along@chu-reims.fr or anne.long@wanadoo.fr)

Key Words: **Aortic aneurysm, Abdominal, Ultrasonography, Imaging, Three-dimensional, Partial volume.**

INTRODUCTION

Abdominal aortic aneurysm (AAA) is a permanent and local dilation of the aorta. The definition recommended by the European Society for Vascular Surgery is an abdominal aortic diameter of 3.0 cm or more in either the antero-posterior or transverse plane (Moll et al. 2011). Principal risk factors are advanced age, male gender, smoking and a family history of AAA. Prevalence is about 5.5% in men older than 65 y (Lindholt and Norman 2008). AAAs tend to expand with time, generally without symptoms, with a mean annual growth rate ranging from 1.8 mm for AAAs 30–34 mm in diameter to 5.02 mm for AAAs 45–49 mm in diameter (Powell et al. 2011b). The main risk is AAA rupture, which is associated with an overall mortality around 80%–90% (Moll et al. 2011). The rupture rate ranges from 0 to 1.61 ruptures per 100 person-year (Powell et al. 2011a). Risk of rupture increases with maximum diameter and expansion rate (Moll et al. 2011). Therefore, small AAAs require regular monitoring of maximum diameter, and preventive open surgery or endovascular repair (EVAR) is proposed when an AAA reaches a maximum diameter of 55 mm (50 mm in women), grows rapidly (>1 cm/y) or becomes symptomatic (Moll et al. 2011). Screening programs have been shown to decrease AAA-related mortality (Lindholt and Norman 2008), and national screening programs have been implemented in the United States and some European countries. Maximum diameter is thus an essential parameter for diagnosis, follow-up before treatment, indication for repair and follow-up after EVAR.

The imaging technique most commonly to measure AAA diameter is 2-D ultrasound (2-D US), closely followed by computed tomography (CT) and, more rarely,

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magnetic resonance imaging (MRI). US is the reference technique for screening and monitoring the growth of small AAAs, and has also been advocated for follow-up after EVAR. CT is performed mainly when AAA repair is being considered and remains the technique of reference for follow-up after EVAR. MRI is reserved for patients with contraindications to CT and is not discussed further in this article.

Because AAA is a 3-D (3-D) disease, the clinical interest in AAA volume measurement lies in enabling better prediction of the evolution of small AAAs and of AAAs post-EVAR. AAA volume estimation has previously been reported with CT acquisitions combined with post-processing (Bargellini et al. 2005; Fillinger 2006; Kauffmann et al. 2011; Kauffmann et al 2012; Kritpracha et al. 2004; Lee et al. 2003; Parr et al. 2011; Prinssen et al. 2003; Renapurkar et al. 2012; Wever et al. 2000a). Nevertheless, this technique is not routinely used in clinical practice. Compared with US, CT presents drawbacks such as exposure to radiation, injection of iodine contrast medium and higher costs.

Progress in US probe technology has led to the development of new means of acquiring AAA volumes. Three-dimensional imaging of AAAs with US has previously been reported in a few studies (Abbas et al. 2012; Causey et al. 2013; Leotta et al. 2001; Nyhsen and Elliott 2007; Rouet et al. 2010; Vidakovic et al. 2006, 2007). Most of the authors used volumetric acquisitions to determine aortic diameter, and only Causey et al. (2013) quantified AAA volume.

We propose here a novel approach to extract more information from 3-D US acquisitions obtained with a volumetric probe, by combining the recorded volume with a dedicated post-processing software that makes it possible to extract the surface of the AAA and its centerline.

The first novelty of this study is to show that it is possible to automatically extract the maximum diameter of the AAA in any direction, perpendicular to the centerline, from the 3-D US AAA segmentation. Our proposed approach, namely, extracting the maximum diameter from 3-D ultrasound, is wholly oriented toward improving patient care. In this article, we present the technical validation of this approach. The clinical interest would be to provide a unified definition of the maximum AAA diameter. As recently underlined (Long et al. 2012), the lack of standardization for AAA diameter measurement affects the reproducibility of techniques, hinders comparisons between US and CT and, ultimately, affects patient care. Improving the quality of measurements is aimed primarily at improving patient care over the successive stages of the disease, namely, screening, decision for intervention and follow-up after EVAR procedures.

The second novelty is that we propose an original volumetric parameter to assess AAA volume. Using CT acquisitions, the volume is measured between two anatomic landmarks (the ostium of the lower renal artery and the aortic bifurcation). In the case of large and extended AAAs, a 3-D US acquisition performed with 3-D mechanical or matrix array US probes will generally not contain these landmarks because of the limited field of view (Fig. 1). We proposed to solve this issue by defining a volumetric parameter called *partial volume*, which may be measured in the absence of standard visible landmarks (Fig. 2).

The aim of the study was to validate this novel approach using two steps. First, the reproducibility of the 3-D-based maximum diameter and the partial volume were evaluated. Secondly, the 3-D-based maximum diameter was compared with the standard diameter measured on 2-D US acquisitions. Because the small AAA included in this study did not present any indications for CT scans, none were performed, and thus, volume comparisons between 3-D US and CT could not be performed.

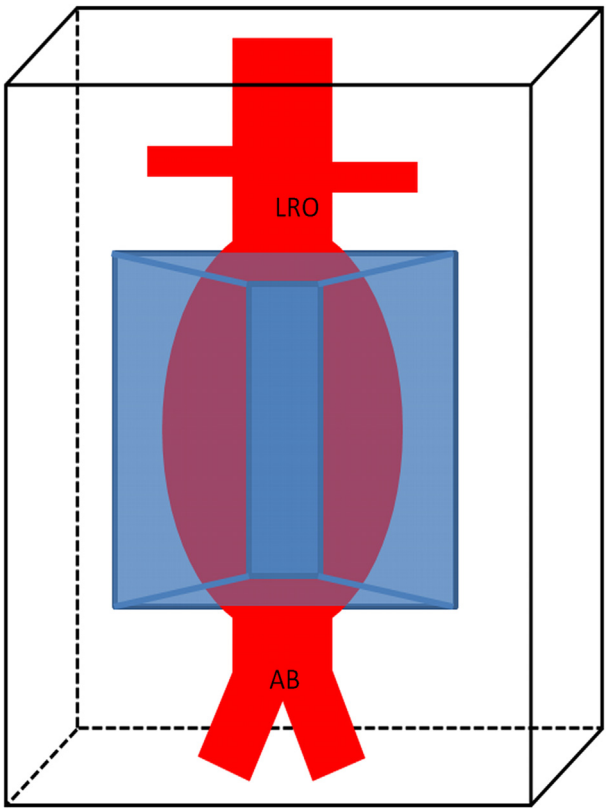

Fig. 1. Schematic comparative view of the volumes acquired with computed tomography (full cube) and 3-D ultrasound (gray pyramidal volume). Landmarks corresponding to the lowest renal artery ostium (LRO) and the aortic bifurcation (AB) are included in the computed tomography field of view, but not necessarily in the ultrasound field of view.