Impact of contrast injection and stent-graft implantation on reproducibility of volume measurements in semiautomated segmentation of abdominal aortic aneurysm on computed tomography

Florence Morin-Roy • Claude Kauffmann • An Tang • Sofiane Hadjadj • Olivier Thomas • Nicolas Piché • Stéphane Elkouri • Dan Yang Yang • Éric Therasse • Gilles Soulez

Abstract

Purpose To assess the impact of contrast injection and stent-graft implantation on feasibility, accuracy, and reproducibility of abdominal aortic aneurysm (AAA) volume and maximal diameter (D-max) measurements using segmentation software.

Materials and methods CT images of 80 subjects presenting AAA were divided into four equal groups: with or without contrast enhancement, and with or without stent-graft implantation. Semiautomated software was used to segment the aortic wall, once by an expert and twice by three readers. Volume and D-max reproducibility was estimated by intraclass correlation coefficients (ICC), and accuracy was estimated between the expert and the readers by mean relative errors.

Results All segmentations were technically successful. The mean AAA volume was 167.0±82.8 mL and the mean D-max 55.0±10.6 mm. Inter- and intraobserver ICCs for volume and D-max measurements were greater than 0.99. Mean relative errors between readers varied between −1.8±4.6 and 0.0± 3.6 mL. Mean relative errors in volume and D-max measurements between readers showed no significant difference between the four groups ($P \geq 0.2$).

Conclusion The feasibility, accuracy, and reproducibility of AAA volume and D-max measurements using segmentation software were not affected by the absence of contrast injection or the presence of stent-graft.

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Key points

- AAA volumetry by semiautomated segmentation is accurateon CT following endovascular repair.
- AAA volumetry by semiautomated segmentation is accurateon unenhanced CT.
- Standardization of the segmentation technique maximizesthe reproducibility of volume measurements.

Keywords

Aortic aneurysm · Computed tomography · Contrast media · Stents · Image processing · Computer-assisted

Introduction

The current indication for abdominal aortic aneurysm (AAA) elective repair relies on the main predictors of rupture risk: the measurement of the maximal diameter (D-max) and its expansion rate [1–5]. AAA endovascular repair (EVAR) was recently found to provide long-term survival comparable to that of open repair among younger patients [6]. After EVAR, the follow-up of patients is based on CT angiography (CTA) to detect and classify endoleak and endotension [7, 8]. D-max progression is one of the main criteria upon which a diagnosis of EVAR failure is made [7, 8]. For some patients, measurement of AAA volume is more sensitive than diameter measurements in detecting subtle changes in AAA size [9–12]. Investigators have suggested different ways to implement AAA volume measurement in the follow-up of patients after EVAR [7–9, 13–15].

AAA manual segmentation is a tedious and time-consuming process which can require 15–45 min [10, 16, 17]. Recently, a more efficient method was developed allowing semiautomated segmentation of AAA on CTA in less than 5 min [18]. This method is based on automatic lumen extraction followed by a semiautomated segmentation processed on cranio-caudal reformations along this center line. The validation of accuracy and reproducibility of D-max and volume measurements with this software was assessed on AAA patients with contrast-enhanced study before endovascular repair [18, 19].

A recent study reported that 36–54 % of patients requiring AAA repair are suffering from renal impairment [20]. Those patients are susceptible to develop contrast-induced nephropathy [20–22]. Since after EVAR patients require a life-long imaging follow-up, there is a need for an accurate imaging follow-up independent of contrast injection.

Some researchers recently suggested a manual segmentation method for unenhanced CT, providing reproducible volume measurements comparing favourably to measurements obtained on CTA [23]. The main limitation is the time-consuming manual disk summation approach (slice by slice segmentation). On the other hand, to our knowledge, there is no published validation of segmentation methods of AAA on unenhanced CT studies after endovascular repair. To overcome those limitations, we optimized a piece of dedicated segmentation software to enable fast and robust segmentation of AAA on unenhanced CT studies and in the presence of stent-graft (Object Research System, Montréal, Canada).

The aim of this study was to assess the impact of contrast injection and stent-graft implantation on the feasibility, accuracy, and reproducibility of AAA volume and maximal diameter (D-max) measurements on CT studies with this dedicated segmentation software. Potential sources of measurement errors during segmentation were also analysed.

Materials and methods

Study design and patient selection

This retrospective, cross-sectional, single-site study was approved by the institutional review board, which waived patient consent. This study included 80 subjects selected from the radiological PACS database at our institution.

We recruited subjects presenting AAA equal to or larger than 3.9 cm on abdominal CT with 5.0-mm maximal slice thickness. We defined four groups of subjects depending on whether the CT was contrast-enhanced or not (C+ or C–) and if the subject was treated with stent-graft (SG+ or SG–). The four groups are as follows: SG+C–, SG+C+, SG-C–, and SG-C+. We reviewed the radiological reports of abdominal CT retrospectively, from December 2010 back to January 2003, to recruit 20 consecutive patients in each group. Select- ed CTs were anonymized and transferred to the research PACS for post-processing and data analysis.

MDCT protocols

The 80 examinations were performed on four different multi-detector CTs (Somatom Sensation 4, 16, 64, Siemens, Erlangen, Germany; Lightspeed 16, General Electric, Milwaukee, Wis). The imaging parameters were pitch 1–1.5, slice thick-ness 0.75–5.0 mm, collimation 0.75–1.5, field of view 240–320 cm. Intravenous non-ionic contrast media was given in C+ studies with a flow rate of 3–5 mL/s, for a total of 80– 120 mL. Image acquisition was started 5 s after automatic triggering of contrast bolus arrival in the proximal portion of the abdominal aorta. The field of view and coverage included the abdomen and pelvis from the thoraco-abdominal junction to the femoral bifurcations.

Measurement methods

Segmentations were performed by four readers: one experienced senior reader (E), and three medical students (R1, R2, R3). All readers were blinded to previous radiological reports and to each other. All medical students underwent 5 days of training during which they learned CT anatomy of abdominal aorta, iliac arteries and surrounding structures. They manipulated the software with iterative feedback sessions from the expert using a database of 20 AAA subjects not included in this study. All segmentations were performed using semiautomated software validated with C+CT (Object Research, System, Montreal, Canada); the segmentation steps and algorithm are described in detail elsewhere [18, 19]. The main steps of the segmentation method are the following (Fig. 1): on contrast-enhanced CTs, based on lumen extraction, a path is automatically created along the AAA lumen. On unenhanced CTs, the reader manually defines a path by placing several points along the lumen of the aorta. For all examinations, the path started at the level of the celiac trunk and ended in one distal common iliac artery selected by the reader (iliac path). Then, the outer wall of the AAA was segmented using an active-contour meth-od on eight radial cranio-caudal reformations (half-plane) along this path with a real-time quality control on the native axial slices. Then, an automatic 3D model of the AAA outer wall was computed. The reader defined the superior and inferior limits of AAA volume calculation by placing two markers: one proximal at the level of the lowest renal artery and one distal at the aortic bifurcation. Finally, the software automatically measured AAA volume within defined limits and the maximal diameter orthogonal to the path defined earlier (D-max).

Software validation

For each subject, the expert performed a segmentation used as the reference standard, and the students performed two segmentations with a minimum interval of 1 month between the first and second segmentations to prevent recall bias. The second segmentation was used to assess intraobserver reproducibility. All readers were blinded to each other.

We used a standardized method to maximize measurement reproducibility. All segmentations were performed selecting the same iliac path (right or left) and the limits of AAA volume (proximal and distal markers) as defined by one reader (R1) were registered on the segmentations performed by other readers.

Impact of iliac path and volume limits standardization on volume measurement reproducibility

We assessed the variability of volume measurement related to iliac path selection (ipsilateral or contralateral). This was estimated by comparing the volumes generated following the segmentation of one reader (R1) with an ipsilateral or contralateral path.

We also assessed the variability related to the position of the proximal and distal markers defining the superior and inferior limits of volume measurement. This was estimated by comparing the volumes generated following the segmentation of only one reader (R1) but calculated according to the marker positions defined by the three

readers (E, R1, R2).

Statistical analysis

Feasibility We recorded the proportion of CT examinationssuccessfully segmented in the four groups.

Reproducibility Interobserver and intraobserver volume andD-max measurement reproducibility were assessed for eachgroup (SG+C+, SG–C+, SG+C–, SG–C–) by the intraclass correlation coefficient (ICC).

Accuracy Bland–Altman analyses were performed to assessthe accuracy between the expert (reference standard) and thethree readers for volume and D-max measurements for the four groups. The bias was calculated as the average differencebetween the results of pairs of readers and the limits of agreement as the bias ± two standard deviations [24]. The mean relative errors for volume and D-max calculation for each group were compared using ANOVA. A linear mixed model was performed to identify the factors that could induce systematic volume and D-max measurement variations. Theclustered structure of the data was taken into account withineach study group. Since there were repeated measurements in the same patients by the expert and three students, the calculation of mean relative errors for volume and D-max were considered as paired data. The clustered structure of the datawas also taken into account for the comparison between the four study groups (i.e. enhanced CT before SG implantation;unenhanced CT before SG implantation; enhanced CT withSG; and unenhanced CT with SG), which were treated as independent clusters and unpaired data.

Sources of measurement error The mean variations of volumes according to path selection and marker limits positionwere calculated as relative errors and percentage.

Results

Subjects

Eighty subjects were divided into four equal groups (SG+C–, SG+C+, SG–C–, and SG–C+). All patients were included inthe analysis. There was no repetition of subjects between groups. The mean age was 76 years old (range 58–90). Seventy subjects were male (87.5 %).

Software validation

Feasibility All segmentations were successful. Paths were computed with automatic lumen extraction for 38 of the C+CTs, and semiautomatically for 40 C–examinations and two C+because of the high tortuosity of those two AAAs. Among the four readers, mean AAA volume was 167.0 ± 82.8 mL (min 41.3 mL, max 441.0 mL) and mean D-max 55.0 ± 10.6 mm (28.9 mm, max 87.0 mm). The mean volumes by group were 153.8 mL for SG–C+, 147.4 mL for SG–C–, 193.5 mL for SG+C+, and 176.4 mL for SG+C–. An illustration that shows volume-rendering of AAA seg- mentation is shown in Fig. 2.

Reproducibility The interobserver and intraobserver ICCs for volume and D-max calculation were estimated at greater than 0.99 for all groups. The intraobserver variability was judged non-significant by the linear mixed model (P=0.4).

Accuracy Bland–Altman analysis was performed for volumeand D-max measurements for each group between the expertand the three readers. The bias for volume agreement and thelimits of agreement (±2 standard deviations) ranged between –1.4 mL (95 % confidence interval [CI] –7.9, 5.1 mL) and 2.9 mL (95 % CI –4.3, 10.1 mL) and for D-max agreement between 0.1 mm (95 % CI –1.0, 1.2 mm) and 0.6 mm (95 % CI –2.4, 3.5 mm) (Fig. 3).

The mean relative errors between the expert and three studentsamong the four groups for volume measurements varied

be-tween –1.8 mL (95 % CI –3.3, –0.2 mL) and 0.0 mL (95% CI –1.3, 1.3 mL) and for D-max between –0.5 mm (95 % CI –0.7, –0.3 mm) and –0.2 mm (95 % CI –0.4, 0.0 mm) (Table 1).

Compared to the expert, the novice operators (R1, R2, andR3) slightly underestimated the volumes. Mean differences in volume and D-max reached statistical significance in some groups (Table 1). However, the magnitude of the error was low. There was no significant difference between the four groups for volume and D-max errors (between expert and readers) as defined in absolute volume (P=0.2) and D-max (P=0.5) and also in percentage error for volume (P=0.6) andD-max (P=0.5).

Sources of measurement errors

The mean variation between volumes generated from segmentation centred on the same iliac artery was –0.7±3.1 mL (min –8.9 mL, max 6.6 mL) or 0.3±1.9 % (min –5.13 %, max 4.7 %) and was not statistically significant (P=0.9). The mean variation between volumes generated from opposite iliac arteries was –2.1±4.8 mL (min –10.9 mL, max 17.8 mL) or 1.0 ±3.0 % (min –10.1 %, max 7.6 %) and was statistically significant (P=0.0002) (n=79). For one AAA contralateral segmentation was not technically successful because of a tortuous geometry. Comparison of volume-rendering after AAA segmentation from opposite iliac arteries paths is shownin Fig. 4.

The mean volume variation induced by superior and inferior volume limits definition between the expert and the readers was estimated at 1.6±4.2 mL (min –20.8 mL, max 17.7 mL) or –1.0±2.3 % (min –8.0 %, max 8.4 %) and wasstatistically significant (P=0.0006, P=0.0001) (n=80).

Discussion

This study confirmed the feasibility of AAA segmentation on unenhanced CT and after EVAR. We found high inter- and intraobserver reproducibility on volume and D-max measurements without significant difference in measurement variability between the four study groups according to contrast ad- ministration and stent-graft implantation. AAA volumes in all groups according to contrast ad- ministration and stent-graft implantation. AAA volumes in all groups were slightly underestimated by the students when compared to the expert. However, the magnitude of this underestimation was not clinically relevant and could be at- tributed to a learning curve effect.

The results confirmed the importance of the standardization of the segmentation method to reduce measurement variations. Definition of the volume limits is a source of measurement error. Thus, in the case of patient follow-up, we recommend registering the limit of AAA volume between examinations. The variability related to the selection of iliac path side is explained by the tortuous geometry of distal aorta and common iliac arteries. Thus, when follow-up studies are per- formed the same iliac path should be selected between base- line and follow-up studies to minimize variability.

We found that the volume measurements were highly reproducible with ICCs greater than 0.99 for all groups consistent with those previously reported on C+CT [18]. It also compares favourably to the study of Nambi et al. reporting an ICC of more than 0.9 after manual segmentations performed on unenhanced CT [23]. Moreover, to our knowledge, this is the first study to systematically evaluate the accuracy of AAA volume depending on contrast injection or SG implantation. This is clinically relevant as AAA volumetric evaluation based on unenhanced stud- ies for EVAR follow-up is now proposed by several investigators [9, 20, 23]. The variability of segmentation performed by novice readers was minimal in our study. Caldwell et al. reported a larger volume variation (6 %) in novice readers using a manual segmentation [25]. This better reproducibility can be attributed to the semiautomated approach and real-time quality control. Thus we can expect a good external validity as

technicians operating the software may not necessarily be highly experienced in AAA segmentation. Our study has a larger sample size than previous studies dealing with the validation of AAA volume measurement. Nambi et al. evaluated the impact of contrast- enhancement on volume measurement variability in 16 subjects, whereas Caldwell et al. studied the impact of operator experience on the variability of volume measurements in only 10 subjects [23, 25].

Different suggestions of how to use volume measurements to detect endoleaks after EVAR have been made [7, 9–13]. Bley et al. suggested that AAA presenting volume growth of 2 % or more on an unenhanced CT at follow-up should undergo contrast-enhanced CT for endoleak detection [9].

However, in that study a single expert reader performed measurements, thus there was no evaluation of measurement variability. They proposed a 2 % intraobserver variation based on Caldwell et al.'s study [9, 25]. However, Caldwell et al. report different volume variability depending on the experience of the observer. For all observers, the mean intraobserver error was estimated at 4.1 % and a mean interobserver error at 7.2 % [25]. Interobserver variability must be considered as EVAR patients are followed for several years and it is likely that different observers will be involved in volume measurements. Even with an interobserver error as low as 0.9 ± 2.1 % found in our study, a 2 % variation of AAA volume is still within the range of measurement variability. On the other hand, 5 % or 5 mm D-max growths are currently used as diagnostic criteria for EVAR failure, endotension and clinical- ly significant type II endoleaks [7]. As volume variation is more sensitive to detect AAA growth than D-max variation, a 5 % volume growth could be a sensitive diagnostic criterion for endoleak and was previously suggested by Chaikof et al. [7]. This cut-off value would be easily detected with our software in a clinical setting.

Our study has several limitations due to its retrospective nature. Comparison of volume measurements on C−and C+ and CT acquisitions of the same AAAs during the same examination would have allowed us to perform a paired comparison. Unfortunately, this was not possible because in our institution unenhanced examinations were not acquired routinely before contrast injection in order to minimize radiation exposure. However, despite the inclusion of four different patient populations with different AAA geometries reproducibility and accuracy remained excellent. For three subjects unenhanced CTs were performed with low dose protocols and slice thickness of 5.0 mm. The slice thickness did not affect the reproducibility of D-max and volume measurements. This finding suggests that we could consider low dose unenhanced CT to follow patients after EVAR and significantly reduce radiation dose as compared to CTA.

We defined the AAA volume as the whole infra-renal aorta volume. Thus detection of focal growth in a saccular aneurysm could be overlooked. However, standardization of the measurement method is of paramount importance to ensure measurement reproducibility, but definition of the limits of a saccular dilatation would induce variations in measurements. We are presently working on another direction, which consists of detecting localized surface deformation or volume increase by calculation of specific parameters.

Finally, we did not evaluate the time of processing in this study; however, this was previously done by our team (mean processing time of 227.3±70.5 s) [18].

In conclusion, this dedicated software enables successful AAA segmentation in unenhanced studies and in the presence of stent-grafts. It provides the possibility of volumetric follow- up in a larger population, including patients with renal failure and patients who underwent EVAR. We are currently studying the impact of volumetric follow-up in a cohort of subjects after EVAR.

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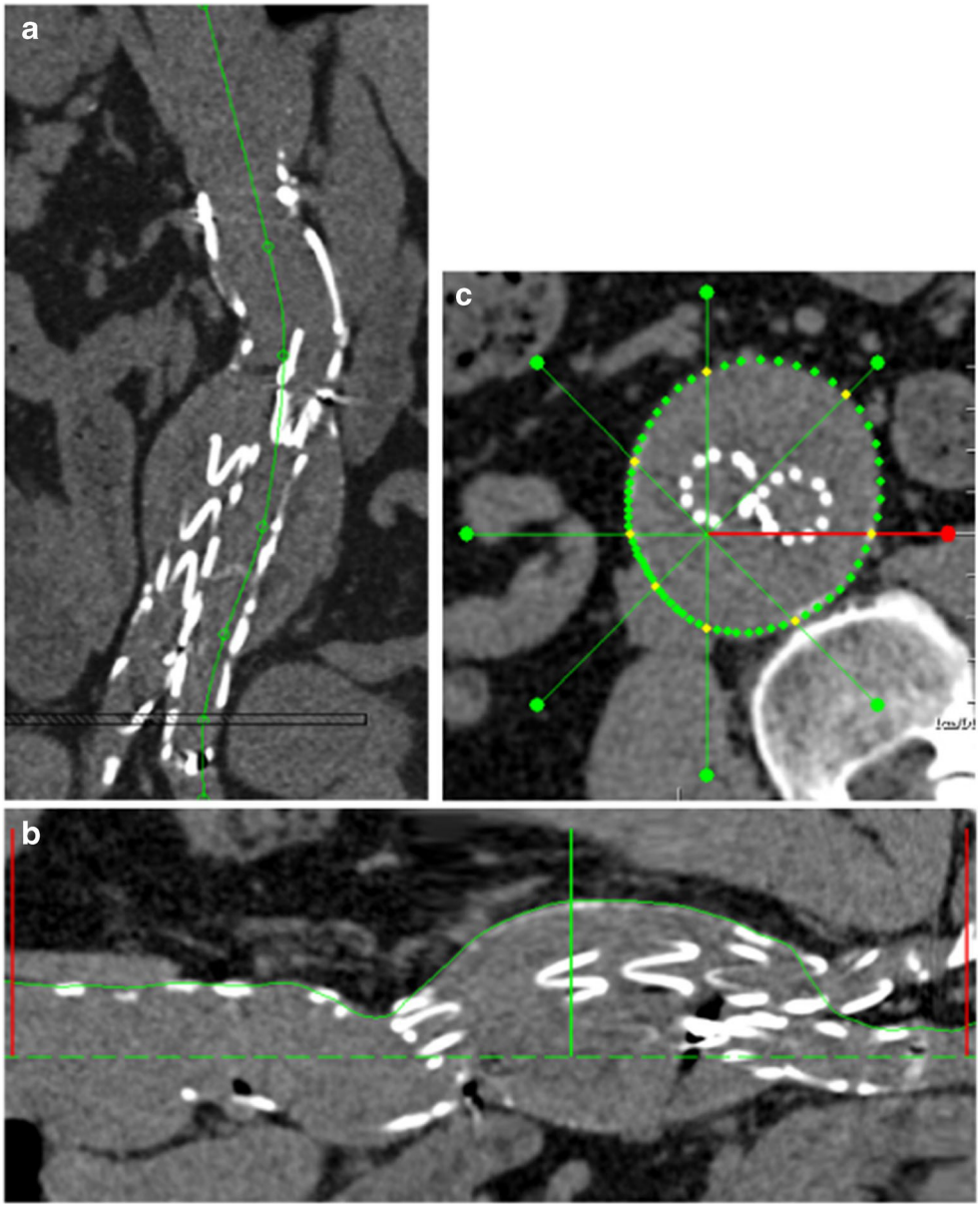

Fig. 1 Segmentation process on a non-contrast CT of an AAA treated with stent-graft. a MPR view of the endoluminal path defined manually by placing several points along the lumen of the aorta. The path ends in one common iliac artery selected by the reader. This path may be edited, if needed. b Stretched cranio-caudal view of the path- based image, with semiautomatic segmentation of the AAA wall. The vertical green line represents the level of the corresponding axial view. c Axial view shows AAA path and semiautomated segmentation of aneurysm wall. The red line represents the corresponding active stretched cranio-caudal view. The green lines represent the planes that can be edited in the cranio-caudal views.

Fig. 2 Volume-rendering of an AAA with stent-graft on a contrast- enhanced CT (Sg+C+). The AAA lumen is shown as red mesh and theAAA wall is shown as blue mesh, the limits of volume measurement are proximally the lowest renal artery and distally the aortic bifurcation

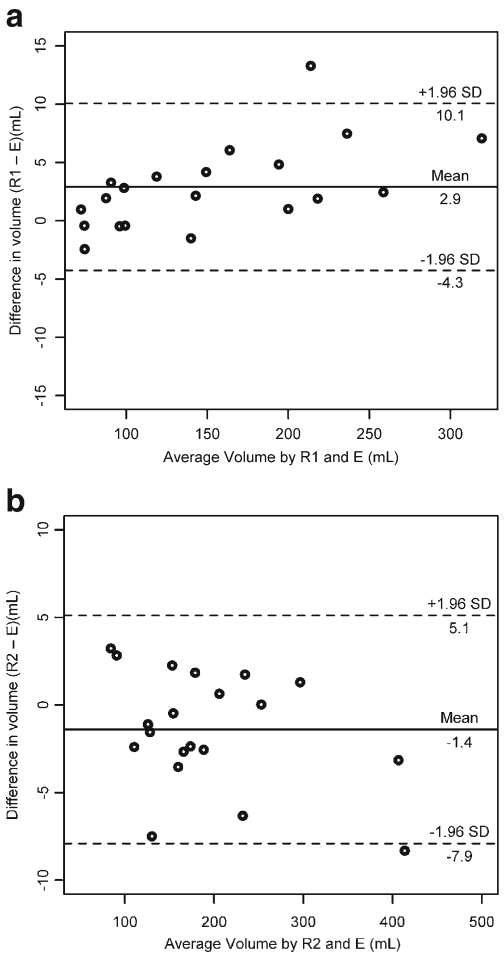

Fig. 3 Bland–Altman plots showing the lowest and highest bias between the readers and the expert for volume measurements vs. their mean. Range of agreement (dashed lines) was defined as the bias±2 standard deviations. a Bland–Altman plot of the difference between volume measurements of readers R1 and E vs. their mean for the group Sg–C+. b Bland–Altman plot of the difference between volume measurements of R2 and E vs. their mean for the groups SG+C+. SG+ with stent-graft, SG – without stent-graft, C+ with contrast administration, C– without contrast administration, SD standard deviation

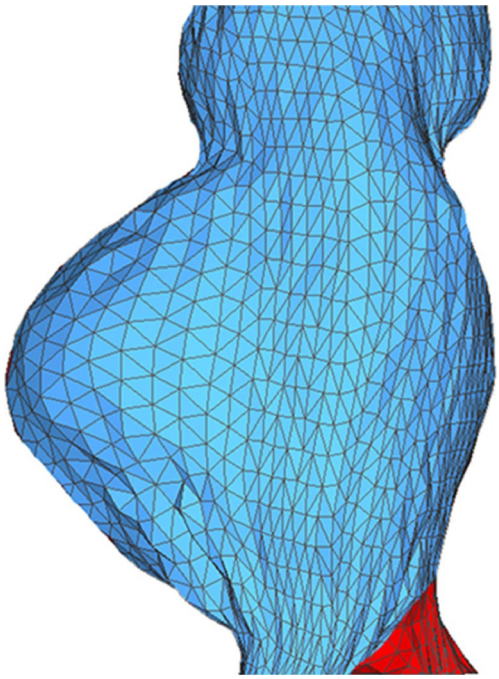

Fig. 4 Comparison of volume-rendering of two segmentations of the same AAA. The blue mesh is computed with an endoluminal path ending in the right common iliac artery. The red mesh is the volume difference at the aortic bifurcation when segmented from the left side. The volume difference between both segmentations is 16 mL (5.7 %).

Table 1 Volume and diameter measurements between the expert and the readers for each AAA group presented as mean error.

Volume (mL)				
	Mean (mL)	SD (mL)	95 % CI (mL)	*P* value
SG−C−	−1.2	2.9	−1.9, −0.4	0.003
SG−C+	−1.8	4.6	−3.0, −0.6	0.004
SG+C−	−1.0	3.1	−1.8, −0.2	0.015
SG+C+	0.0	3.6	−0.9, 1.0	0.945
D-max (mm)				
	Mean (mm)	SD (mm)	95 % CI (mm)	*P* value
SG−C−	−0.3	0.8	−0.5, −0.1	0.017
SG−C+	−0.5	0.8	−0.7, −0.3	0.000
SG+C−	−0.4	1.4	−0.7, −0.0	0.030
SG+C+	−0.2	0.8	−0.4, 0.0	0.087
Volume (%)				
	Mean (%)	SD (%)	95 % CI (%)	*P* value
SG−C−	−0.9	2.1	−1.5, −0.4	0.001
SG−C+	−0.8	3.1	−1.6, 0.0	0.060
SG+C−	−0.8	2.4	−1.4, −0.2	0.011
SG+C+	−0.2	2.26	−0.8, 0.4	0.521
D-max (%)				
	Mean (%)	SD (%)	95 % CI (%)	*P* value
SG−C−	−0.5	1.4	−0.9, −0.1	0.012
SG−C+	−0.9	1.6	−1.3, −0.5	0.000
SG+C−	−1.0	3.4	−1.8, −0.1	0.034
SG+C+	−0.3	1.3	−0.6, 0.0	0.077

D-max maximum diameter orthogonal to path, SG+ with stent-graft, SG- without stent-graft, C+ with contrast administration, C- without contrast administration, SD standard deviation, CI confidence interval.

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