A phantom study for the comparison of different brands of CT scanners and software packages for EVAR sizing and planning

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Abstract

Objective: Correct sizing of endoprostheses used for the treatment of abdominal aortic aneurysms (AAA) is important to prevent endoleaks and migration. Sizing requires several steps and each step introduces a possible sizing error. The goal of this study was to investigate the magnitude of these errors compared to the golden standard: a vessel phantom. This study focuses on the errors in sizing with three different brands of Computed Tomography Angiography (CTA) scanners in combination with three reconstruction software packages.

Methods: Three phantoms with a different diameter, altitude and azimuth were scanned with three CT scanners; Toshiba Aquilion 64-slice, Philips Brilliance iCT 256-slice, and Siemens Somatom Sensation 64-slice. The phantom diameters were determined in the stretched view after Central Lumen Line (CLL) reconstruction by three observers using Simbionix PROcedure Rehearsal Studio (PRORS), 3mensio and TeraRecon planning software. The observers, all novices in sizing endoprostheses using planning software, measured 108 slices each. Two senior vascular surgeons set the tolerated error margin of sizing on ± 1.0 mm.

Results: In total, 11.3% of the measurements (73/648) were outside the set margins of ± 1.0 mm from the phantom diameter, with significant differences between the scanner types (14.8%|12.1%|6.9% for the Siemens scanner, Philips scanner and Toshiba scanner, respectively, p-value=0.032), but not between the software packages (8.3%|11.1%|14.4%, p-value=0.141) or the observers (10.6%|9.7%|13.4%, p-value=0.448).

Conclusions: It can be concluded that the errors in sizing were independent of the used software packages, but the phantoms scanned with Siemens scanner were significantly more measured incorrectly than the phantoms scanned with the Toshiba scanner. Consequently, awareness on the type of CT scanner and CT scanner setting is necessary, especially in complex AAA sizing for fenestrated or branched EVAR if appropriate the sizing is of upmost importance.

Keywords

Aneurysm, Endovascular aneurysm repair, Diameter, Stent-graft, Endoleak.

Introduction

Endovascular aneurysm repair (EVAR) of aneurysms of the abdominal aorta (AAA) is an established alternative to open surgical repair.[1] Appropriate pre-operative sizing of an endoprosthesis is the first essential step in successful endovascular treatment of AAA.[2,3] The preferred imaging modality for sizing is Computed Tomography Angiography (CTA). CTA offers post-imaging processing techniques, and provides all necessary detailed anatomical information for pre-EVAR planning.[4,5] In the conventional axial CTA slides, an error can be introduced when the measurements are not perpendicular to the vessel wall. Center-lumen-line (CLL) reconstruction is a software method which automatically generates a plane perpendicular to the vessel wall. The 3D CTA semi-automated CLL analysis is the most reliable AAA sizing method with minimum intraobserver and interobserver variability in diameter and length measurements.[6–8]

Combinations of CT scan hard- and software and the used AAA sizing software package might introduce errors in obtained measurements and thus the chosen endoprosthesis, because each step in the sizing chain is an approximation of reality to some extent. In a previous clinical study we concluded that the CLL software packages Simbionix PROcedure Rehearsal Studio (PRORS) (Simbionix USA Corp., Cleveland, OH, USA), 3mensio (Pie Medical Imaging BV, Maastricht, the Netherlands) and TeraRecon (Aquarius, Foster City, California, USA) did almost perfectly correlate to each other with an Intraclass Correlation Coefficient (ICC) above the 0.80[9]. A study limitation was the use of patient CTAs, of which we do not know the real diameters. Therefore, in our current study a ground truth tool, a vessel phantom, is introduced. With help of a vessel phantom, it is possible to calculate the real deviation between the measured value and the golden standard. The focus of this manuscript is to study the influence on sizing of three commercially available CT-scanners in combination with three sizing software packages on the real vessel phantom measurements.

Methods

Phantoms were created to simulate diameters of infrarenal aortic neck and iliac outflow in AAA. Three phantoms with diameters of 10.0 mm, 20.0 mm and 30.0 mm were fabricated from a polymethyl methacrylate (PMMA) bar, from which a cylindrical bore was removed to mimic a flow lumen. Plugs to close the lumen on both sides were made of Dacron. Figure 1 shows the three phantoms. PMMA was chosen because of the transparency and Hounsfield Unit (HU) range of 92 to 137 which corresponds to abdominal tissue.[10,11] The phantoms were placed consecutively in a bearer and a container. The bearer was used to create an altitude (α) and/or an azimuth (ϒ), as depicted in Figure 2, the used combinations are shown in Table 1. The altitude and azimuth were created in order to make a CLL reconstruction necessary. The altitude and/or azimuth results in an axial coupe which is difficult to assess without a CLL reconstruction, because the CT slice is not perpendicular to the vessel wall. The bearer was fixed to the container, which was filled with water to simulate the abdominal tissue around the PMMA.[10]

The phantoms were scanned with three different CT scanners; Toshiba Aquilion 64-slice (Toshiba, Tokyo, Japan), Philips Brilliance iCT 256-slice, set as a 64-slice (Philips, Eindhoven, The Netherlands) and Siemens Somatom Sensation 64-slice (Siemens, Erlangen, Germany). Except of the reconstruction kernel (also known as filter or algorithm), all of the scanner parameters were set at the same value for the three scanners. It was not possible to choose the same kernel because a kernel is brand-specific. The scanner parameters are presented in Table 2. The scanning parameters were chosen because they are corresponding with the recommended preoperative EVAR scanning protocol of the involved institutions and the international guidelines.[12]

Each phantom was filled with a water dilution of intravenous iodine. The concentration was chosen per scanner to reach a HU of 250-300 which is equivalent to the HU in the arterial phase. In the Toshiba scanner a concentration of 8 mg iodixanol/ml and in the Philips and Siemens scanner a concentration of 10 mg iodixanol/ml was needed. The scans of the same phantom by the different scanners do show a small variation in HU.

CLL reconstructions were created by one of the authors (JFV) using the Simbionix, 3mensio and TeraRecon AAA sizing software. The reconstructed CTAs were presented in random order to three observers who had no clinical experience in sizing endoprosthesis using planning software. The randomization key was created using http://www.random.org/sequences/. Observers were blinded to each other's measurements and to earlier measurements when using different software packages. The order of the software systems was different for each observer. All three observers received a training session of one hour and practiced at least 2 supervised measurements per software package to familiarize with the protocol and the three software packages. The scans were evaluated according to a protocol of two measurements per phantom: anterior-posterior and left-right in one plane in the middle of the phantom, the lengths were not assessed. The observers did not know the true value of the diameters. During measurements there were no time constraints. The used laptops were identical and had equal monitor settings for all observers (Dell Mobile Workstation M6600 Essential).

Statistical analysis

Two senior vascular surgeons set the clinical tolerable error margin of sizing on ± 1.0 mm. A Pearson's chi-squared test was used to compare the amount of measurements inside and outside the set margins among scanner types and software packages. Differences were considered statistically significant at p values <0.05. The Holm-Bonferroni method was used to counteract the problem of multiple comparisons in post-hoc analyses. Statistical analyses were performed using SPSS for Windows version 22 (SPSS, Chicago, IL, USA).

Results

In total, 11.3% of the measurements (73/648) were outside the set margins of ± 1.0 mm from the phantom diameter. The amount of measurements outside the margins per CT scanner-software package combination is presented in Table 3. The amount of measurements outside the margins was significantly different between the scanner types: 14.8% with the Siemens scanner, 12.1% with the Philips scanner and 6.9% for the Toshiba scanner (p-value=0.032). Comparing the scanner types, the Siemens scanner was significantly different from the Toshiba scanner (14.8%|6.9%, p-value=0.009). The other comparisons were not significantly different (Siemens|Philips; 14.8%|12.1%, p-value=0.397) (Philips|Toshiba; 12.1%|6.9%, p-value=0.071). The number of measurements outside the margins was not significantly different between the software package: 8.3% with the Simbionix software package, 11.1% with the 3mensio software package and 14.4% for the TeraRecon software package (8.3%|11.1%|14.4%, p-value=0.141). The amount of measurements outside the margins was not significantly different between the observers (10.6%|9.7%|13.4%, p-value=0.448).

Discussion

The current phantom study showed that the number of CT-based phantom diameter measurements outside the margins (± 1.0 mm) after center lumen line reconstructions was around 10% and independent of the used AAA sizing software packages. It can be concluded that the errors in sizing were independent of the used software packages. But, comparing the scanner types, significant differences were observed, the phantoms scanned with Siemens scanner were significantly more measured outside the clinical tolerable margin of 1mm than the phantoms scanned with the Toshiba scanner.

There are several possible explanations for the differences between the Siemens and Toshiba results. First, it was not possible to choose the same kernel because a kernel is brand-specific. A different kernel can influence the sharpness of the edges of the scan. All of the applied kernels were according to the instruction for use in a preoperative EVAR scanning protocol. Second, the concentration of iodixanol was chosen per scanner to reach a HU of 250-300 which is equivalent to the HU in the arterial phase. It could be possible that this was not the best method to choose the concentration of iodixanol, which may have led to imperfect images which could have made the correct sizing difficult. Third, another difficult issue regarding the CT scanners is the Partial Volume Effect (PVE). With our settings, an intrinsic error of 0.8 mm is present which is caused by the PVE and the voxel size (three-dimensional pixel) of the scan (Table 2). For all three scanners, the x- and y-dimension of the voxel is 0.781 mm. The z-dimension of the voxel is equal to the reconstruction increment of 0.8 mm. The Partial Volume Effect results in blurred edges, because the CT scanner is unable to distinguish different attenuation coefficients within a voxel. During the reconstruction it is assumed that the attenuation is distributed homogenous within each voxel. Therefore, the PVE is most present at edges between regions with difference in Hounsfield Units (.i.e. the region of interest: the vessel lumen-vessel wall interface).[13,14]

Fourth, it remains that the appropriate representation of the ground truth is brand-specific, due to several small differences in the hard- and software of the CT scanners itself.

No other study observed the effect of the type of CT scanner in combination with AAA sizing software on 3D CLL measurements using a phantom. Previous studies with different AAA sizing software only used one type of CT scanner. Recently, Corriere and coworkers concluded that similar results can be obtained from different image processing programs TeraRecon, Osirix and Preview.[11] According to the study of Corriere and coworkers, the ICCs between the programs for diameter measurements were high (ICC > 0.82 for all pairwise comparisons). The ICCs for the length measurements were also high (ICC > 0.88 for all pairwise comparisons). Using a phantom for the comparison of CT's and sizing software has the benefit that the dimensions of the phantom are accurately defined and can be used as the ground truth. This has never been previously examined by phantoms.

Limitations

There are several limitations to the present study. First, the used phantoms were not tortuous as in daily clinical practice. Second, it remained difficult to evaluate the impact of small technical errors on the daily clinical practice, because the effect on the outcome is extremely multifactorial. Furthermore, the choice of "even" phantom diameters (10, 20 and 30 mm) might have biased the measurements. Finally, the phantom lengths were not assessed in the current study.

Conclusion

The type of sizing software package will not influence clinical decision making in AAA diameter sizing significantly. But the phantoms scanned with Siemens scanner were significantly more measured incorrectly than the phantoms scanned with the Toshiba scanner. Consequently, there is no need to take the software package into account. But awareness on the type of CT scanner and CT scanner setting is necessary, especially in complex AAA sizing for fenestrated or branched EVAR if appropriate the sizing is of upmost importance.

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Declaration of Conflicting Interests

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Legends for illustration

Figure 1. The three vessel phantoms, the diameters of the phantoms are accurate to one decimal.

Figure 2. 3D reconstruction of the set-up of one of the phantoms. The bearer was used to create a altitude (α) and/or an azimuth (Υ).

Table legends

Table 1. Twelve combinations were made out of the different diameter, altitude (α) and azimuth (ϒ).

Combination	Diameter	Altitude (α)	Azimuth (ϒ)
1	10.0	0°	0°
2	10.0	0°	45°
3	10.0	10°	0°
4	10.0	10°	45°
5	20.0	0°	0°
6	20.0	0°	45°
7	20.0	10°	0°
8	20.0	10°	45°
9	30.0	0°	0°
10	30.0	0°	45°
11	30.0	10°	0°
12	30.0	10°	45°

Table 2. The scanner parameters for the three CT scanners.

	Toshiba Aquilion	Philips Brilliance iCT	Siemens Somatom Sensation
Slices	64-slice	256-slice, set as 64-slice	64-slice
Kernel	FC12	Kernel B	B30f
Tube voltage	120kV	120kV	120kV
Tube current	100 mA	100 mA	100 mA
Pitch factor (table mm / beam mm)	0.828	0.828	0.828
Slice thickness	1 mm	1 mm	1 mm
Reconstruction increment	0.8 mm	0.8 mm	0.8 mm
Rotation time	0.5 s	0.5 s	0.5 s
Field of view	400 mm	400 mm	400 mm
Matrix size [r x c]	512 x 512	512 x 512	512 x 512

Table 3. The numbers of measurements for which the deviation is outside the set margins. The software packages are presented in the first row and the CT scanners are presented in the first column.

	Simbionix	3mensio	TeraRecon	**Total**
Siemens	7 (9.7%)	7 (9.7%)	18 (25.0%)	**32 (14.8%)**
Philips	5 (6.9%)	12 (16.7%)	9 (12.5%)	**26 (12.0%)**
Toshiba	6 (8.3%)	5 (6.9%)	4 (5.6%)	**15 (6.9%)**
Total	**18 (8.3%)**	**24 (11.1%)**	**31 (14.4%)**	**73 (11.3%)**

Table 1

Combination	Diameter	Altitude (α)	Azimuth (ϒ)
1	10.0	0°	0°
2	10.0	0°	45°
3	10.0	10°	0°
4	10.0	10°	45°
5	20.0	0°	0°
6	20.0	0°	45°
7	20.0	10°	0°
8	20.0	10°	45°
9	30.0	0°	0°
10	30.0	0°	45°
11	30.0	10°	0°
12	30.0	10°	45°

Table 2

	Toshiba Aquilion	Philips Brilliance iCT	Siemens Somatom Sensation
Slices	64-slice	256-slice, set as 64-slice	64-slice
Kernel	FC12	Kernel B	B30f
Tube voltage	120kV	120kV	120kV
Tube current	100 mA	100 mA	100 mA
Pitch factor (table mm / beam mm)	0.828	0.828	0.828
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Matrix size [r x c]	512 x 512	512 x 512	512 x 512

Table 3

	Simbionix	3mensio	TeraRecon	**Total**
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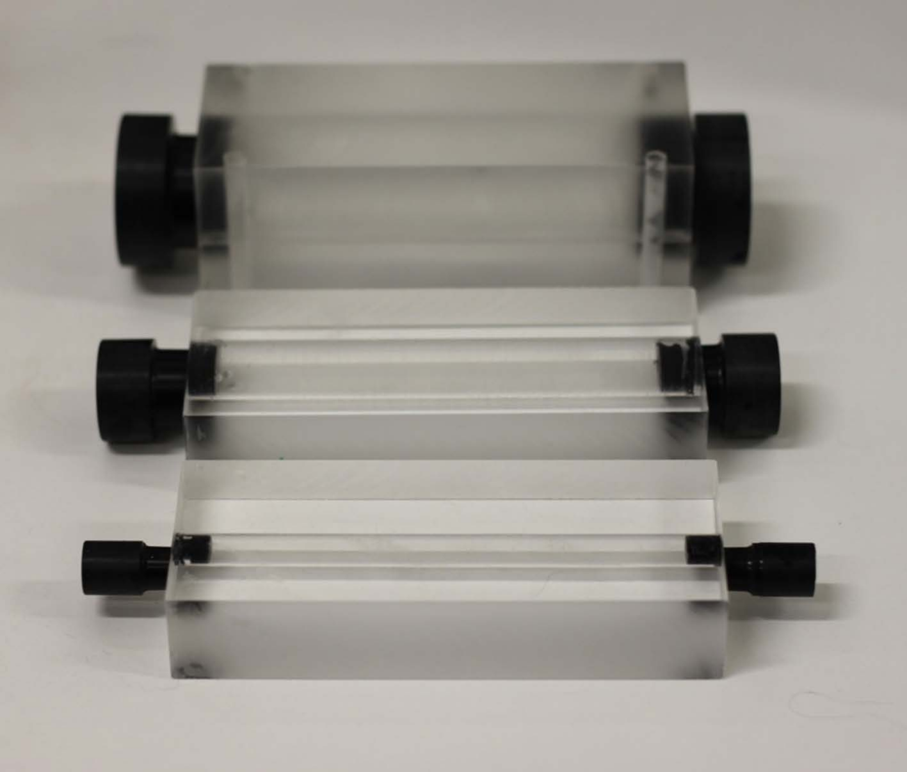
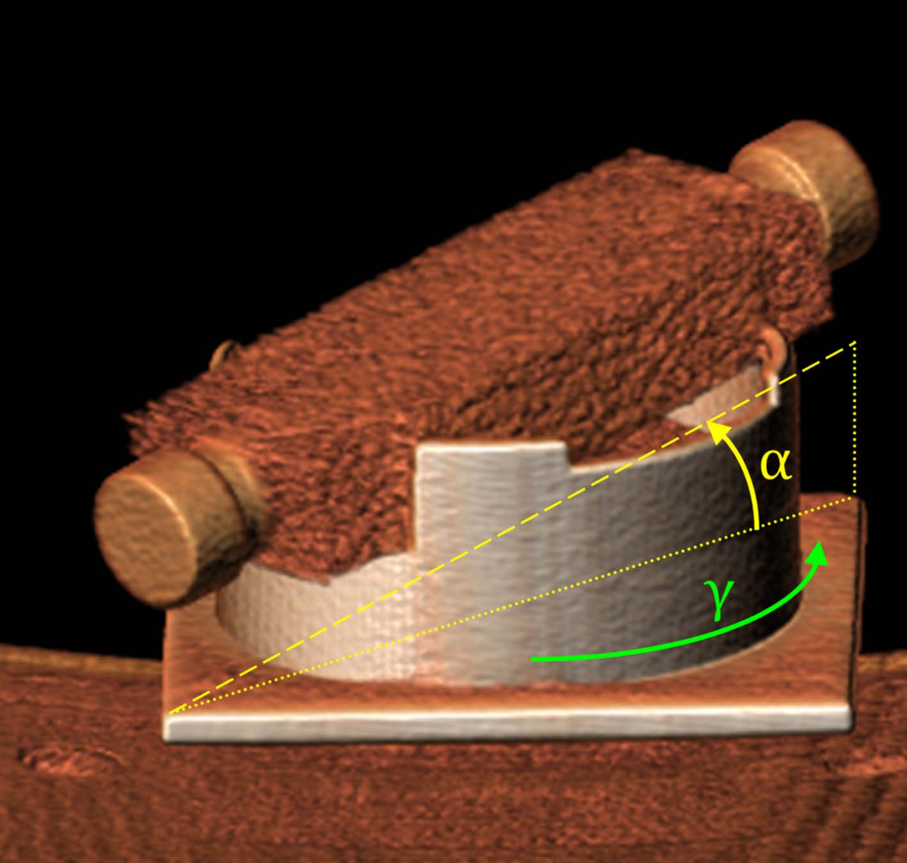
Total	**18 (8.3%)**	**24 (11.1%)**	**31 (14.4%)**	**73 (11.3%)**




α
γ