Accurate assessment of abdominal aortic aneurysm with intravascular ultrasound scanning: Validation with computed tomographic angiography

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Purpose: **The purpose of this study was to assess the accuracy of intravascular ultrasound (IVUS) parameters of abdominal aortic aneurysm, used for endovascular grafting, in comparison with computed tomographic angiography (CTA).**

Methods: **This study was designed as a descriptive study. Between March 1997 and March 1998, 16 patients with abdominal aortic aneurysms were studied with angiography, IVUS (12.5 MHz), and CTA. The length of the aneurysm and the length and lumen diameter of the proximal and distal neck obtained with IVUS were compared with the data obtained with CTA. The measurements with IVUS were repeated by a second observer to assess the reproducibility. Tomographic IVUS images were reconstructed into a longitudinal format.**

Results: **IVUS results identified 31 of 32 renal arteries and four of five accessory renal arteries. A comparison of the length measurements of the aneurysm and the proximal and distal neck obtained with IVUS and CTA revealed a correlation of 0.99 ($P < .001$), with a coefficient of variation of 9%. IVUS results tended to underestimate the length as compared with the CTA results (0.48 ± 0.52 cm; $P < .001$). A comparison of the lumen diameter measurements of the proximal and distal neck derived from IVUS and CTA showed a correlation of 0.93 ($P < .001$), with a coefficient of variation of 9%. IVUS results tended to underestimate aneurysm neck diameter as compared with CTA results (0.68 ± 1.76 mm; $P = .006$). Interobserver agreement of IVUS length and diameter measurements showed a good correlation (r = 1.0; $P < .001$), with coefficients of variation of 3% and 2%, respectively, and no significant differences (0.0 ± 0.16 cm and 0.06 ± 0.36 mm, respectively). The longitudinal IVUS images displayed the important vascular structures and improved the spatial insight in aneurysmal anatomy.**

Conclusion: **Intravascular ultrasound scanning results provided accurate and reproducible measurements of abdominal aortic aneurysm. The longitudinal reconstruction of IVUS images provided additional knowledge on the anatomy of the aneurysm and its proximal and distal neck. (J Vasc Surg 1999;29:631-8.)**

The feasibility of endoluminal stent grafts in the treatment of abdominal aortic aneurysms has been shown.[1-4] The success of this technique is closely related to the accurate knowledge of the critical parameters of aortic morphology. Intravascular ultrasound scanning (IVUS) is acknowledged as an important imaging technique to provide information on lesion characteristics and vessel dimensions of the coronary and peripheral arteries and of the abdominal aorta.[5-7] Although IVUS is used currently for the intraoperative imaging of abdominal aortic aneurysm during endovascular treatment, no study has focused on the clinical validation of IVUS para-

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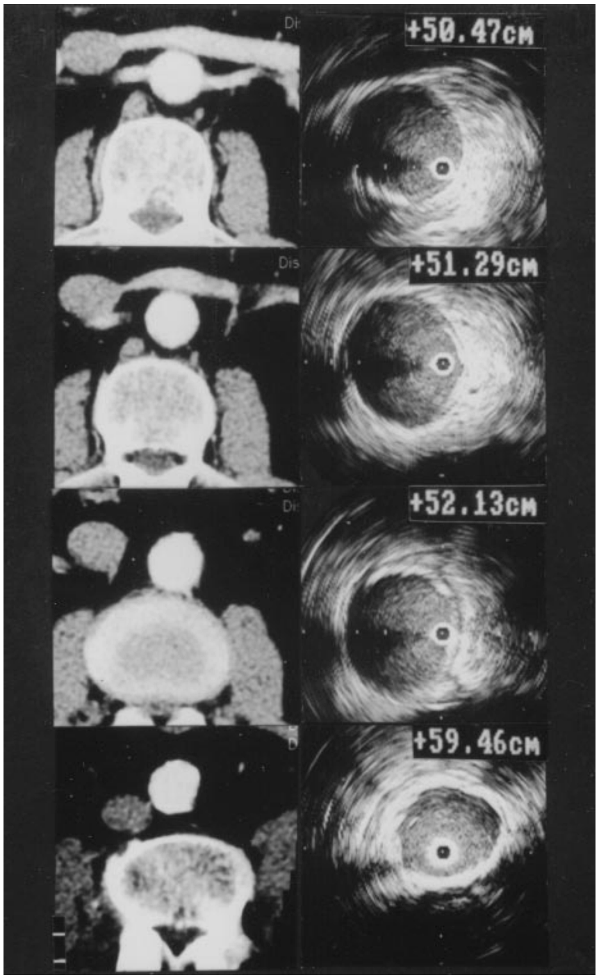

Fig 1. Intravascular ultrasound scan cross sections and computed tomographic angiography counterparts of proximal and distal neck of abdominal aortic aneurysm. *Upper panel* shows cross section 0.2 cm below the most distal renal artery. *Second panel* shows cross section halfway in the proximal neck. *Third panel* shows cross section 0.2 cm proximal to the aneurysm. *Lower panel* shows cross section 1 cm distal to the aneurysm. *Inserts* show readings from displacement sensing device. Calibration on computed tomographic angiography, 10 mm. Calibration on intravascular ultrasound scan, 5 mm.

meters.[8-10] The purpose of this study was to assess the accuracy of the IVUS parameters of abdominal aortic aneurysm with a comparison with computed tomographic angiography (CTA).

METHODS

Patients. Between March 1997 and March 1998, 17 consecutive patients with abdominal aortic aneurysms who were scheduled for operations were asked to participate in the study. One patient refused. The remaining 16 patients (12 men, four women; mean age, 68 years; age range, 42 to 84 years) underwent studies with routine angiography, IVUS, and CTA. The study was approved by the Local Committee on Human Research, and written consent was obtained from all the patients.

Subtraction angiography. Routine anteroposterior views were obtained with a pigtail catheter (Royal Flesh II pigtail aneurysm swing catheter, WA Cook Pty Ltd, Queensland, Australia) that was placed at the level of the renal arteries via a common femoral artery puncture. A single bolus of 35 mL of contrast fluid (Omnipaque, Nycomed Ltd, Cork, Ireland) was injected at 14 mL/s with a power injector. Then, the catheter was placed above the aortic bifurcation and a second bolus of contrast was injected.

Intravascular ultrasound scanning. An HP-Sonos Intravascular Imaging System (Hewlett Packard, Andover, Mass) was used with a mechanically driven, Sonicath Side-Saddle, 12.5 MHz, 6.2F catheter (Boston Scientific Corp, Watertown, Mass). The catheter was introduced over a 0.025-in, angled, hydrophilic coated guidewire (Terumo Europe NV, Leuven, Belgium) through an 8F sheath into the aorta up to the level of the celiac trunk. To monitor the position of the IVUS catheter, a displacement sensing device was used. This device consisted of a small, sterile, disposable sensing unit. The movement of the catheter activates a rotating wheel that converts the linear movement into an electronic pulse train signal so that the advancement or the withdrawal of the catheter is digitized and wirelessly registered by a sterilizable unit to which the sensing unit is mounted.[11] The display of the displacement of the IVUS catheter tip in steps of 0.01 cm was mixed together with the ultrasound scan information on the video screen. IVUS images were stored on videotape (S-VHS) for further quantitative analysis and longitudinal reconstruction.

Longitudinal intravascular ultrasound scan reconstruction. The IVUS images were digitized off line at a resolution of 800 × 600 × 8 bits with a frame grabber (DT-3852, Data Translation, Inc, Marlboro, Mass) and were aligned and stacked longitudinally.[12] As many as 200 images were acquired with a given interval (0.5 to 1.0 mm). In the resulting model, two panels parallel to the vessel axis were selected to create longitudinal images.

Computed tomographic angiography. Spiral CTA was performed with a Siemens Somatom 4 Scanner (Siemens Medical Systems, Iselin, NJ). After frontal scout projection, a single dose of 130

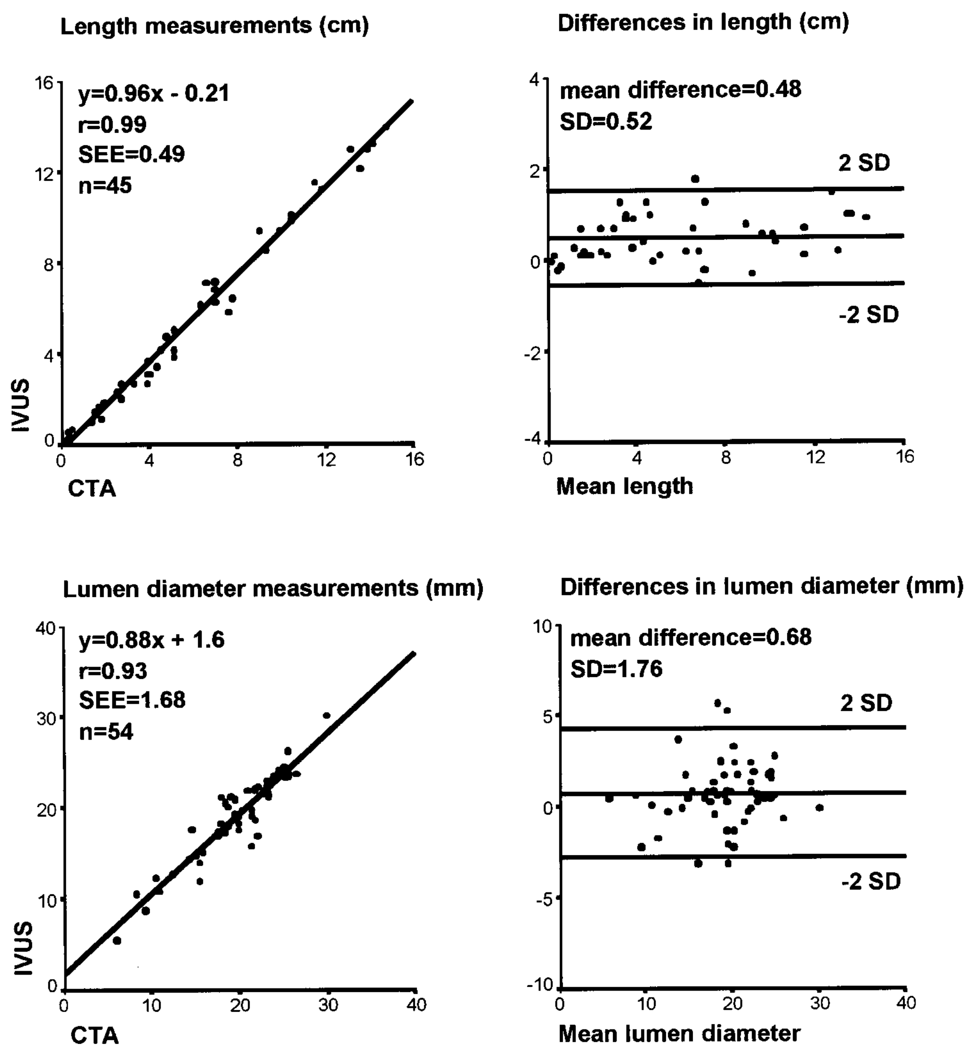

Fig 2. Comparison between intravascular ultrasound scan and computed tomographic angiography for length measurements of aneurysm, proximal, and distal neck and lumen diameter measurements of proximal and distal neck. *IVUS,* Intravascular ultrasound scan; *CTA,* computed tomographic angiography; *SEE,* standard error of estimate; *SD,* standard deviation.

mL of intravenous contrast (Omnipaque) was injected through a catheter in the antecubital vein at 2.0 mL/s with a scan delay of 35 seconds. A slice thickness of 5 mm and a table speed of 5 mm/s were chosen, with a reconstruction interval of 2 mm. The volume scanned was from the celiac axis down to the level of the proximal femur.

Data analysis. The presence of renal and accessory renal arteries was documented with angiography, IVUS, and CTA. For angiographic assessment, both the subtracted and the unsubtracted images were reviewed from film by an independent radiologist (L.C.vD.).

The length of the aneurysm and the length and diameter of the proximal and distal neck, seen with IVUS (J.A.vE.) and CTA (A.vdL.), were determined. The *proximal neck* was defined as the distance between the lower border of the most distal renal artery and the proximal border of the aneurysm. The *distal neck* was defined as the distance between the distal border of the aneurysm and the aortic bifurcation. If the aneurysm extended into the iliac arteries, the *distal neck* was defined as the distance between the distal border of the aneurysm and the iliac bifurcation at the side of access. Length measurements on IVUS were obtained with the

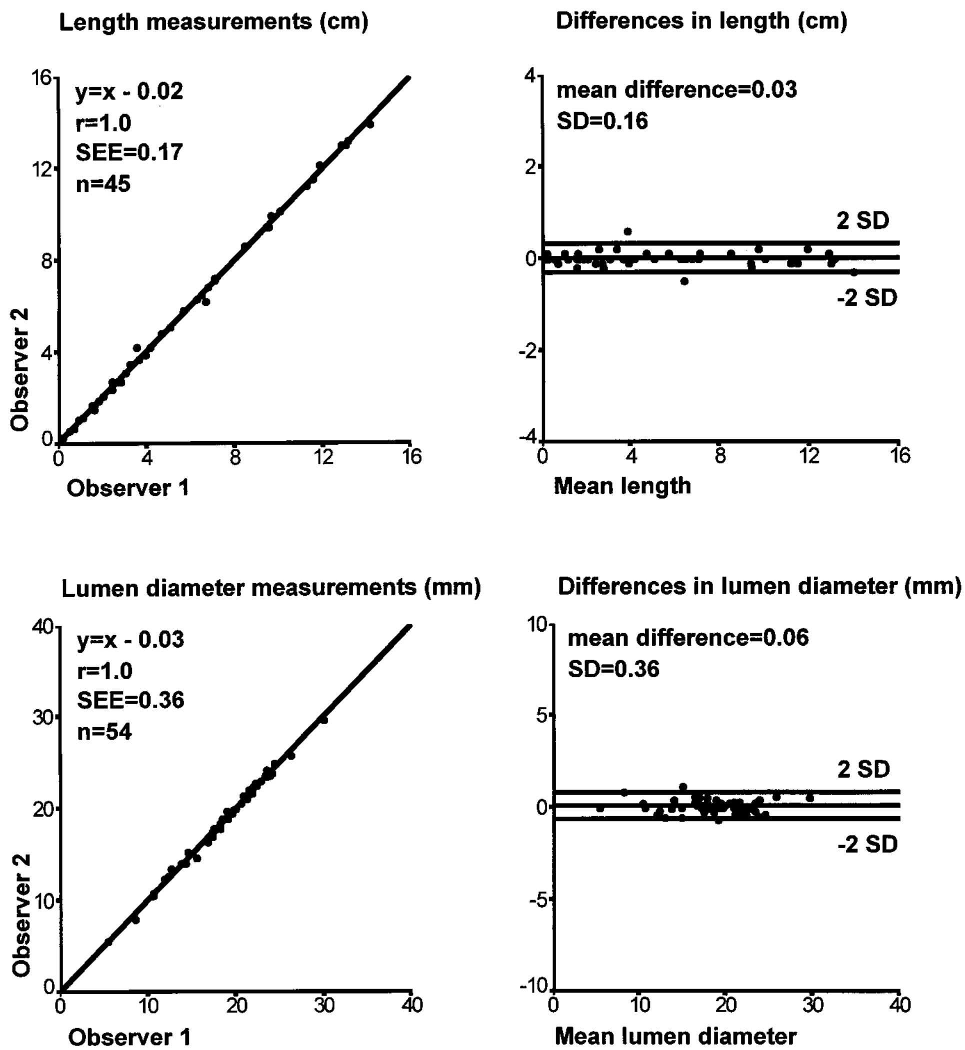

Fig 3. Comparison between observers 1 and 2 for length and lumen diameter measurements. *SEE,* Standard error of estimate; *SD,* standard deviation.

information provided with the displacement sensing device. Length measurements with CTA were performed on a Siemens Magic View Workstation (Sienet VA 31B, Siemens Medical Systems) with multiplanar reformats. The length was determined by manually counting the number of steps, which were 1 mm apart, that were necessary to cross the distance to be investigated (ie, the neck, the aneurysm, the iliac artery) along the central lumen line.

In the presence of a proximal neck that was more than 1 cm in length on CTA, the lumen diameter was measured with IVUS and CTA at the following three positions: 0.2 cm distal from the renal artery, in the mid portion of the proximal neck, and 0.2 cm proximal from the aneurysm (Fig 1). If the proximal neck was less than 1 cm in length on CTA, only one cross section, taken 0.2 cm distal from the renal artery, was selected for lumen diameter assessment. The diameter of the distal neck was measured 1 cm distal from the distal border of the aneurysm in the aorta. If the distal aortic neck was more than 1 cm in length on CTA, the cross section selected for analysis was 1 cm distal from the aneurysm in the aorta. In the presence of a distal aortic neck that was too short (<1 cm) and not suitable for endograft placement, the diameter of the iliac artery was measured 1 cm distal from the bifurcation. If the aneurysm extended into the iliac arteries, the selected cross section was 1 cm distal from the aneurysm in the iliac artery.

The selected IVUS cross sections were digitized, and the minimum lumen diameter was calculated

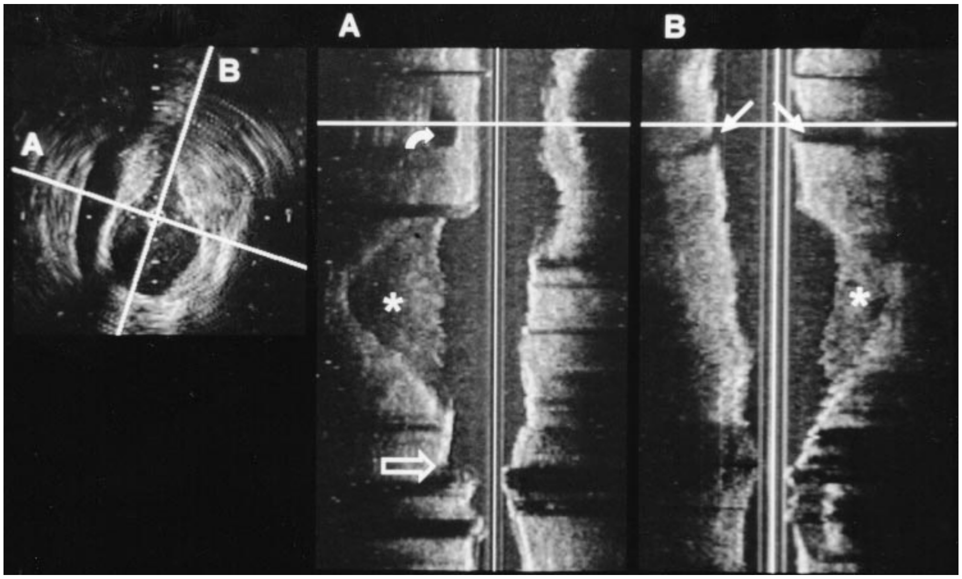

Fig 4. Longitudinal intravascular ultrasound scan reconstructions of aneurysmal aorta. *Lines A* and *B* represent longitudinal reconstructed sections *(right panels)*, which stand perpendicular to each other, as shown in axial image *(left panel)*. Both renal arteries are visible *(small arrows)*, as are the renal vein *(curved arrow)*, thrombus in aneurysm *(*)*, and aortic bifurcation *(large arrow)*.

from the manually traced lumen area contour and its geometric center with a digital video analyzer.[12] The minimum lumen diameter was used for analysis because the IVUS catheter could have been in a noncoaxial position: such a cross section would have had an oval shape instead of a circular one. As a consequence, the mean lumen diameter of such a cross section may have overestimated the lumen dimension. On CTA, the lumen diameter measurements were performed on cross sections taken perpendicular to the central lumen line, with electronic calipers on the Siemens Workstation. For every cross section, the diameter was measured in four directions. The mean lumen diameter was taken. To assess the interobserver variability of IVUS measurements, the images were reviewed by a second independent observer (P.C.H.).

Statistical analysis. Linear regression analysis was performed to assess the strength of the relationship between IVUS and CTA measurements and between the observer's measurements. Systematic differences between the IVUS and CTA measurements and between the observer measurements were analyzed with the Student t test for paired observations. The agreement was expressed as a *coefficient of variation*, defined as the standard deviation of the paired differences divided by the mean of the absolute value.[14] A P value of less than .05 was considered statistically significant.

RESULTS

In 15 patients, the data that were obtained with angiography, IVUS, and CTA were complete. In one patient, CT scanning was only performed from the celiac trunk down to the aortic bifurcation.

With angiography, 32 renal arteries and two accessory renal arteries were identified. IVUS results identified 31 renal arteries and four accessory renal arteries: one renal artery was missed on IVUS because of the shadow of the guide wire. CTA results identified 32 renal arteries and five accessory renal arteries.

A distinct aneurysm was identified angiographically in 12 patients. In four patients, the angiogram results showed a local dilatation and the elongation of the abdominal aorta, which was suspective of aneurysmal disease. Both IVUS and CTA results showed a distinct abdominal aortic aneurysm in all 16 patients. On IVUS and CTA, the length of the proximal neck was more than 1 cm in 13 patients and less than 1 cm in three patients. Similarly, the length of the distal aortic neck was more than 1 cm in five patients and less than 1 cm in two patients who both had normal iliac arteries. In six other patients, the aneurysm extended from the aorta up to the aortic bifurcation with a normal iliac artery. In the three remaining patients, the aneurysm extended down to the iliac bifurcation.

In the 12 patients with angiographic results that identified an aneurysm, seven of nine proximal necks were seen that were 1 cm or more. In one of three patients in whom the proximal neck was absent on IVUS and CTA, the neck was deemed to be present angiographically. IVUS and CTA results showed thrombus obscuring the lumen of the aneurysm. Angiography failed to identify three of five distal necks that were 1 cm or more. Four of the necks that were missed on the angiogram findings showed a conical shape on IVUS and CTA and were considered part of the aneurysm on angiography.

A comparison of IVUS and CTA measurements on the length of the aneurysm and the proximal and distal neck revealed a correlation of 0.99 ($P < .001$). Student t test results showed a significant difference between the measurements of 0.48 ± 0.52 cm ($P < .001$). IVUS tended to underestimate the length as compared with CTA. The coefficient of variation was 9% (Fig 2). A comparison between IVUS and CTA results for total measured length in all the patients revealed a correlation of 0.96, a difference of 1.2 ± 0.9 cm, and a coefficient of variation of 6%. A comparison of the lumen diameter obtained revealed a correlation of 0.93 ($P < .001$). The difference between the measurements was 0.68 ± 1.76 mm ($P = .006$). Diameters derived from IVUS tended to underestimate as compared with CTA. The coefficient of variation was 9% (Fig 2). Interobserver IVUS measurements revealed a correlation of 1.0 ($P < .001$) for both length and lumen diameter measurements, with a difference of 0.0 ± 0.16 cm and 0.06 ± 0.36 mm and a coefficient of variation of 3% and 2%, respectively (Fig 3).

Longitudinal reconstruction. The creation of longitudinal reconstructions of IVUS data that were available required 3 minutes. In the longitudinal images, the renal arteries, the proximal neck, the aneurysm, and the distal neck were manifest (Fig 4). Compared with the single cross sectional images, the transition from neck into aneurysm was better appreciated in the longitudinal images, especially when the neck showed a more conical shape. The longitudinal reconstructions contributed to a better understanding of the aneurysmal anatomy.

DISCUSSION

Endovascular grafting of abdominal aortic aneurysms presents a minimally invasive technique in which the accurate visualization of the abdominal aorta before, during, and after placement of a stent graft is of eminent importance. Currently used techniques are angiography, IVUS, and CTA. Angiography allows a broad imaging field and is easily accessible but shows only the vessel lumen. Measurements of the length and diameter of the proximal and distal attachment sites may be influenced by the presence of thrombus, parallax, and foreshortening. Therefore, caution should be applied when sizing the stent graft solely on angiographic measurements.[15] In contrast, CTA is a noninvasive technique that provides relevant parameters for the selection of patients who are suitable for endovascular treatment and for the decision on the dimensions of the stent graft to be used.[16] However, CTA can not be used during intervention. Recently, IVUS has been introduced as an alternative method to be used during endovascular treatment.[8-10] In a recent validation study, we have shown that IVUS can provide accurate information on the morphology and quantitative dimensions of abdominal aortic aneurysms in vitro.[7] However, no study has focused on the validation of this technique in a clinical situation.

This study confirms the insufficiency of angiography to adequately determine the morphology of the aneurysm. Although the angiographic results revealed a distinct aneurysm in 12 patients and abnormalities suspective of aneurysmal disease in four other patients, a precise determination of the nature of the proximal and distal neck failed in five patients (three proximal and four distal). Although calibrated angiography may be unsuitable to determine the length of the individual segments of the aneurysm, in practice, it can be used to determine the distance between the renal and iliac arteries.

This study shows the capability of IVUS to identify pertinent structures, such as renal arteries, aneurysm, and aortic bifurcation. A comparison of the length measurements of the aneurysm and the proximal and distal neck revealed a difference of 0.48 ± 0.52 cm between IVUS and CTA results, with IVUS measurements being smaller than those of CTA. Both the stiffness and the noncoaxial position of the IVUS catheter may be responsible for the fact that the path of the IVUS catheter does not correspond with the path of the central lumen line: the endograft may not follow either path. Although a significant difference was found between the IVUS and CTA length measurements, the coefficient of variation indicates a good agreement and the differences encountered may be a consequence of measurement faults of both imaging methods. The difference in length encountered between IVUS and CTA results indicates that device sizing on the basis of IVUS measurements will be appropriate, given that stent graft sizes are determined by the centimeter and that, in practice, only the minimum length to cross the aneurysm into the iliac arteries is necessitated. The appropriate length of the stent graft may be assessed with either a displacement sensing device or a sterile ruler held along the IVUS catheter.

A comparison between IVUS and CTA results revealed a small, yet significant, difference for lumen diameter. IVUS diameters tended to be 3.5% smaller than the diameters seen with CTA. This may be due to the fact that the minimum lumen diameter was chosen for the IVUS cross sections and no correction was used for systolic and diastolic changes. It should be emphasized that we used the minimum lumen diameter to correct for the noncoaxial position of the IVUS catheter during imaging. However, if the mean lumen diameter was used for analysis, the difference found between IVUS and CTA results was 1% (0.22 ± 1.9 mm) and was not significant, showing an identical correlation (r = 0.93) and a coefficient of variation (9.4%) as found for minimum lumen diameter. Another factor that may contribute to the difference in lumen diameter obtained with IVUS and CTA may be that CTA can overestimate the diameter because of the slice thickness and filtering techniques. When the difference in diameter of 3.5% between IVUS and CTA results and the selection of 10% to 15% oversized stent grafts commonly used for implantation are taken into account, we opine that IVUS can be used in a clinical setting to determine the appropriate stent graft diameter.

Longitudinal IVUS imaging enhanced the spatial insight in the aneurysm by showing the continuity between consecutive images. These longitudinal images used as a quick reference in the interpretation of the axial cross sections may have an additional value in the interpretation of IVUS images in the clinical setting. The recognition of the shape of the aortic neck may improve and the transition from the neck into the aneurysm may be clarified.[18] In case of a conical-shaped neck, the transition from the neck into the aneurysm may be obscured. Conical-shaped necks also may present difficulties in sizing the appropriate endograft. With longitudinal imaging, a cut-off point may be chosen where the neck stops and the aneurysm starts.

It should be remembered that the longitudinal IVUS images are reconstructed relative to the catheter tip. They do not represent a true three-dimensional view of the aorta. It should be acknowledged that three-dimensional reconstruction with CTA will show the angulation of the iliac arteries and necks in relation to the aneurysm, which are features that cannot be obtained with IVUS.

In other studies, the use of IVUS to assess the dimensions of abdominal aortic aneurysm and to guide stent graft delivery have been described.[8-10] In 1997, Lyon et al[8] reported the use of IVUS after endovascular procedures and found that IVUS was more sensitive than angiography to detect arterial and graft lesions (92% vs 50%). On the basis of IVUS, additional intervention was necessitated in 33% of the lesions detected. IVUS was, however, less sensitive in detecting endoleaks as compared with postoperative CTA. White et al[9] reported the use of IVUS before and after intervention. They concluded that "IVUS was the most accurate way to determine the morphology of vascular structures (ie, calcium, thrombus)."[9] In addition, the final choice of device dimensions and fixation sites was determined with IVUS interrogation. Finally, Vogt et al[10] reported the use of IVUS before, during, and after intervention. Before the stent graft placement, the location of the renal arteries and the renal vein was determined with IVUS and the position of the catheter tip on fluoroscopy in relation to a radiopaque ruler was documented. After the deployment, the expansion and the adaptation of both the distal and the proximal stents were evaluated, as was the position of the proximal stent in relation to the renal arteries. IVUS showed to be unsuitable for the monitoring during stent graft deployment.

Nowadays, most stent grafts are modular systems, which allows the interventionalist to select the appropriate modules during the intervention. Therefore, an intraoperative imaging technique that can accurately quantitate the dimensions of the stent graft may be profitable.[17] The present study indicates that IVUS used for endovascular treatment for abdominal aortic aneurysms can provide relevant information on the parameters necessary to exclude the aneurysm successfully. After the intervention, IVUS may be used to document the position and to assess the proper deployment of the device. Future clinical studies have to prove the efficacy of IVUS during intervention for the benefit of the individual patient.

CONCLUSION

IVUS provides accurate and reproducible information on the dimensions of abdominal aortic aneurysm. Longitudinal reconstruction provides additional knowledge on the anatomy of the aneurysm.

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