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# Dynamic Computed Tomography Evaluation of Pre and Postoperative Aortic Changes of AAA Patients Treated by Endovascular Aneurysm Repair

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## Abstract

**Objective:**

Endograft sizing has been based primarily on static CT, discounting the naturally pulsatility of the aorta. The purpose of this study was to utilize dynamic cine-CT scanning on pre- and post-operative EVAR patients to characterize cardiac induced aortic motion within the aneurysm neck, an essential EVAR sealing zone.

**Methods:**

ECG-gated CTA data sets were acquired utilizing a 64-slice Philips Brilliance CT-scanner on 15 consecutive pre- and post-operative AAA patients. Axial pulsatility measurements were taken at two clinically relevant levels within the aneurysm neck; 2 cm above the highest renal artery and 1 cm below the lowest renal artery. Changes in aortic area and diameter were determined.

**Results**:

Significant aortic pulsatility exists within the aneurysm neck during the cardiac cycle. Pre-operative aortic area increased significantly with a maximum increase of up to 12.5%. The presence of an endograft did not affect aortic pulsatility (p=NS). Post-operative area changed also significantly during heart cycle with a maximum increase of up to 14.5%. Diameter measurements demonstrated an identical pattern with significant pre- and post-operative intra-cardiac pulsatility within and above the aneurysm neck ($p<0.05$). An increase in diameter is seen with a maximum diameter change of up to 15%.

**Conclusion**:

Patients undergoing EVAR experience aortic diameter changes within and above the aneurysm neck. The presence of an endograft does not abrogate this response to intra-cardiac pressure changes. Static CT imaging may not adequately identify patients with large aortic pulsatility, potentially resulting in endograft undersizing, stent-graft migration, intermittent type 1 endoleaks, and poor patient outcomes. The current standard regime of over sizing of 10 to 15% based on static CT may be inadequate for some patients.

## Introduction

In properly selected patients, endovascular aneurysm repair (EVAR) is the preferred treatment modality for aneurysms of the infrarenal abdominal aorta[1;2]. Complications, when they occur, can negate the purported benefits of a shorter hospital stay, decreased days in the intensive care unit, less surgical morbidity, and a quicker return to normal activities. The most critical factor for determining suitability and durability of EVAR relates to the anatomy and morphology of the infrarenal aortic neck[3;4]. This is the zone where stent-graft sealing occurs. Static computed tomography angiography (CTA) is the currentˆgold standard¤ for pre- and post-operative AAA imaging [3;4-8]. Patient selection is based solely on static images, irrespective of the fact that the abdominal aorta is a three dimensional moving organ.

Aortic pulsatility may play a causative role as described in EVAR complications, such as late rupture, endoleaks, stent fracture, and stent-graft migration[9-13]. Little was known about the natural aortic motion and how the placement of an endoprothesis would effect that motion when Parodi first treated an AAA patient with an endovascular stent-graft[14;15]. Previous report of our group showed significant pulsatility at important anatomic landmarks prior to EVAR [16]. Does the presence of an endograft alter these dynamic forces? If aortic wall pulsatility is diminished by lining it with an endoprosthesis, concern over motion related complications may be lessened. However, continued pulsatility may suggest the need for oversizing greater than the typical 10-15% practiced by many clinicians.

Utilizing new dynamic imaging tools, such as cine-CTA, may provide for improved decision making regarding endovascular candidate suitability and stent-graft sizing. The purpose of this study was to utilize 64-slice dynamic CT to evaluate aortic diameter changes before and after EVAR within the aneurysm neck.

## Patients and Methods

Patients were evaluated at a single institution for AAA repair. We evaluated all patients with an aneurysm size of 5.5cm in diameter or more. Patients were rejected for EVAR with angulated necks (> 60 degrees) or aneurysm necks less then 1.5cm of length. EVAR was performed by one operating surgeon utilizing either the Excluder (n=4) (W.L. Gore, Flagstaff, AZ, USA) or Talent (n=11) (Medtronic, Santa Rosa, CA, USA) devices. CT scans used for analysis were obtained as part of the standard pre- and post-operative evaluation protocol. Endograft sizing was based on static images (untagged data). Patients were not subjected to additional CT scanning or radiation exposure.

Fifteen consecutive patients were studied pre- and post-EVAR. The pre-EVAR scan served as the control for the identical patient’s post-EVAR scan. Data was acquired using an ECG-gated dynamic 64-slice CT scanner (Philips Medical Systems, Cleveland, OH, USA). Images were acquired during a single breath-hold phase of 20 seconds during which the entire abdomen was imaged. The imaging protocol was set at 1.25 mm collimation and a pitch of 0.25. Radiation exposure parameters were 120 kVp and 300 mAs, resulting in a CT dose index ($CTDI_{vol}$) of 21 mGy. Intravascular non-ionic contrast (120 ml) (Imerol 300, Schering, Berlin, Germany) followed by a 50ml of saline chaser bolus was injected at a flow rate of 4ml/s. The scan was started using bolus triggering software with a threshold of 100HU over baseline.

ECG triggered retrospective reconstructions were made at eight equidistant time points over the R-R cardiac cycle. The data set of each patient was loaded into a separate workstation (Extended Brilliance Workspace, Philips Medical Systems, Cleveland, OH, USA) and processed using the cardiac review program function. The gated data sets, covering the cardiac cycle, were reconstructed perpendicular to the center flow lumen of the aorta. Two relevant anatomic levels of the aorta were selected for analysis; 2cm above the highest renal artery (level 1) and 1cm below the lowest renal artery (level 2)(Figure 1). Analysis of the dynamic scans was performed using Dynamix software (Image Sciences Institute, Utrecht, the Netherlands). This software was developed to perform automated segmentation and measure changes in area and diameter at predetermined aortic levels (figure 2). Each segmentation was reviewed manually by two blinded observers independently.

Statistical analysis of changes in area and diameters were performed using a Student's *t*-test for paired data. Significance was assumed at $p< 0.05$. Data on area and diameter were expressed as mean and standard deviation. Analysis of repeatability and to compare measurements by two observers was performed according to Bland and Altman[17]

All patients underwent dynamic CT scanning for evaluation for surgical correction of abdominal aortic aneurysms. Therefore, most patients were taking beta blockers. The heart rates ranged from 63 to 106 bpm. Therefore, the reconstructed gated data set represents the average over 20 seconds and several heartbeats. It does not contain data for a single heartbeat.

## Results

### *Aortic area change*

Preoperative aortic area changed significantly during each cardiac pulsation at each of the two anatomic levels. Two cm above the highest renal artery (level 1) it changed from 464 73 $mm^2$ to 494 76 $mm^2$ per cardiac cycle ($p<.001$). One cm below the lowest renal artery (level 2) aortic area changed from 381 112 $mm^2$ to 409 118 $mm^2$ ($p< 0.001$) (Figure 3). This corresponded to a pre-EVAR mean aortic area increase of 7.0% per cardiac cycle ($p< 0.001$ for both levels). A maximal in-

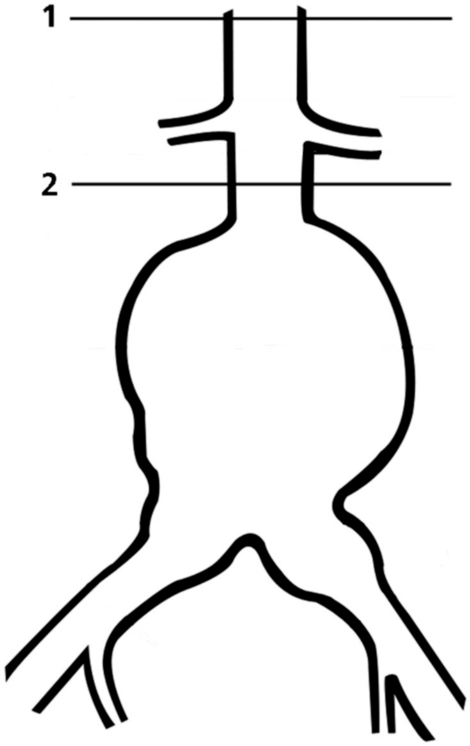


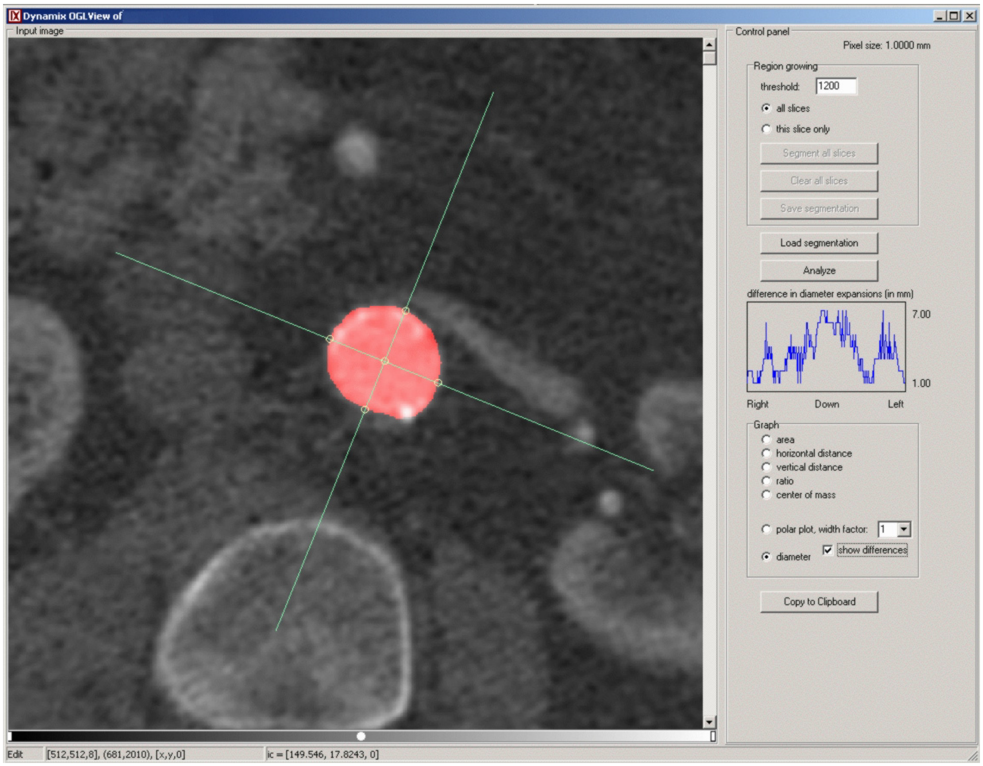
*Figure 1.*
*The two anatomic levels of the abdominal aortic aneurysm; level 1 is 2 cm above the highest renal artery. Level 2 is 1 cm below the lowest renal artery. This is the area of possible landing zone for the proximal attachment of endovascular aneurysm repair.*

crease of 12.5% was observed. The intraobserver repeatability coefficient was 35.9 $mm^2$ and the interobserver variability coefficient was 6.6 $mm^2$ indicating no significant difference within and between observers.

Postoperative aortic area also changed significantly during each cardiac cycle; from 447 63 $mm^2$ to 480 72 $mm^2$ at level 1. At Level 2 it changed from 411 109 $mm^2$ to 436 110 $mm^2$;p< 0.001 for all levels) (Figure 3). This corresponded to a post-EVAR mean aortic area increase of 7.9% per cardiac cycle (p< 0.001 for all levels), with a maximum increase of 14.5%. Post-EVAR aortic area was not statistically different from pre-EVAR aortic area changes (p=NS). Endograft placement did not significantly alter mean area change at any of the levels (Figure 3). The inter-observer repeatability coefficient was 20.8 $mm^2$ and the intra-observer repeatability coefficient was 7.8 $mm^2$ indicating no differences within or between observers.

*Aortic diameter change*

Aortic diameters changed significantly during the cardiac cycle at all measured levels. Preoperatively, mean aortic diameter changed from 24 1.8 mm to a maximum



Pixel size: 1.0000 mm

threshold: 1200

● all slices

○ this slice only

○ polar plot, width factor: 1

● diameter ☑ show differences

[512,512,8], (681,2010), [x,y,0]

ic = [149.546, 17.8243, 0]

*Figure 2.*
*The diameter and area measurements are done which the Dynamix software (Image Sciences Institute, Utrecht, the Netherlands). The program calculates in this picture the diameter in 360 degrees separately based on the earlier acquired segmentation.*

of 25 1.9 mm at level 1 (p< 0.001). The diameter changed from 21 3.3 mm to 23 3.4 mm at level 2 (p< 0.001) (Figure 4). The mean percentage change of diameter at level 1 is 6%, with a maximum increase in diameter of 11%. For level 2 the mean change is 5%, with a maximum increase of 14%. The intra-observer repeatability coefficient was 3.02 mm and the inter-observer repeatability coefficient was 3.84 mm indicating no significant differences within or between observers.

Postoperatively, mean aortic diameter also changed significantly during each cardiac cycle. At level 1 it changed from 23 1.6 mm to 25 1.8 mm. At level 2 mean diameter changed from 22 2.9 mm to 24 2.9 mm (p< 0.001 for both levels) (Figure 4). This change corresponded with an increase in mean aortic diameter for level 1 of 7% with maximum increase up to 11%. Level 2 showed a mean increase of 6% with a maximum increase up to 15%. Post-EVAR diameter changes were not different from pre-EVAR changes (p=NS). Stent graft placement did not significantly alter mean diameter change at any of the levels (Figure 3). The intra-observer repeatability coefficient was 0.42 mm and the inter-observer repeatability coefficient was 1.62 mm. Again, intra- and interobserver variability showed no significant differences within or between the observers.

### Discussion

To our knowledge this is the first study utilizing a 64-slice CT-scanner (Brilliance 64, Philips Medical Systems, Best, The Netherlands) to evaluate the effect of EVAR on the natural pulsatility of the aortic neck. This new imaging tool provides a unique opportunity to evaluate the dynamic aortic environment into which endografts are placed. With the advent of 64-slice CT scanners, the entire abdomen can be imaged with retrospective ECG gating during a single breathhold, providing for excellent special and temporal resolution. Reconstruction of several phases of the RR-interval yields a 4-dimensional dataset which allows for the creation of cine loops and dynamic structural evaluation. Recent publication reports about pulsatility measurements based on the use of dynamic MRA scanning[18] There are some disadvantages of using MRA. Well known disadvantages are noisiness and

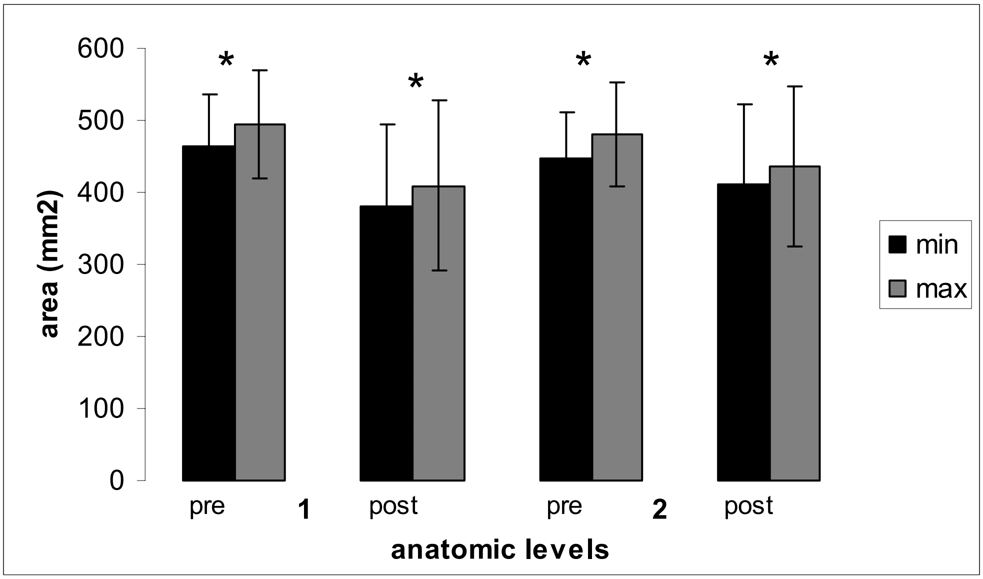


*Figure 3.*

*The pre and postoperative mean area are shown here. There is a significant change in the mean area during a heart cycle at anatomic levels 1 and 2 (* p<0.001) in the pre-operative group and post-operative group. There is no significant change between both groups.*

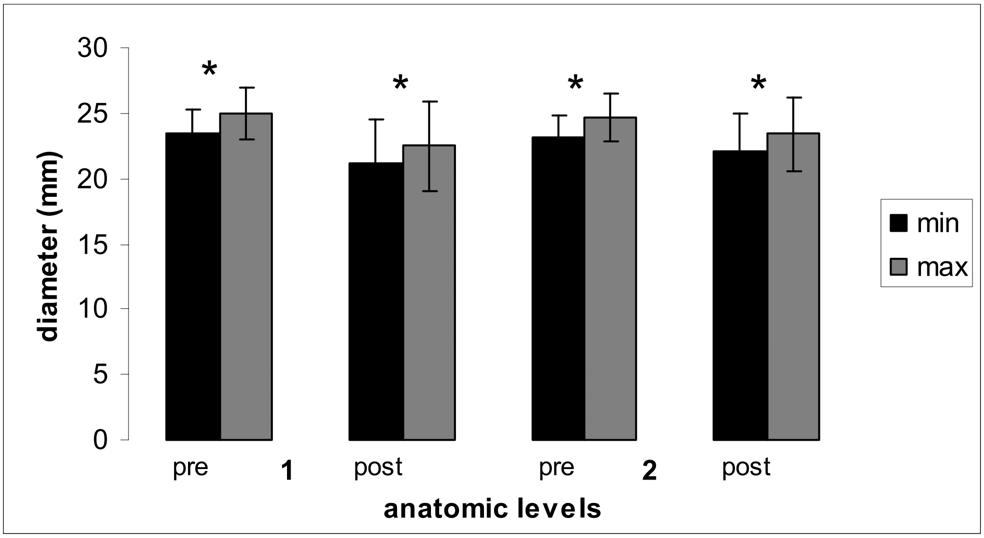


*Figure 4.*
*The pre and postoperative mean diameter are shown here. There is a significant change during a heart cycle in diameter at both anatomic level 1 and 2 (* p<0.001). Again there is no significant change in diameter between the pre-operative group and post-operative group.*

not every endoprothesis is compatible for MRA use[19]. The authors performed dynamic MRA on predetermined levels with significant time of scanning. We showed shorter time of scanning and we are able to measure the pulsatility on any level of the abdominal aorta.

The areas above and just below the renal arteries are important for adequate sealing of the proximal attachment system of EVAR. Appropriate sealing is determines the success and durability. Although this study was not designed to determine clinical outcomes secondary to pulsatility, we can speculate on the potential implications of our findings. We have shown that pulsatility continues in the aortic wall despite the implantation of a relatively stiff and non-porus endograft. Individual patients exhibited diameter increases of up to 15%, stressing the importance of endograft oversizing. Risk factors for type I endoleaks are well known, and include mural thrombus, calcification and angulated necks[20]. Currently, there is no evidence of that these risk factors affect pulsatility. We do know that pulsatility may be affected by clinical parameters such as blood pressure, calcification, smoking, etc[21;22].

Limitations in this study exist. There are other important levels of the aorta that we could have measured. Certainly it would have been interesting to determine pulsatility within the aneurysm sac and at the level of distal sealing within the iliac arteries. Future studies may be directed at these questions. We acknowledge the potential drawback of performing measurements utilizing a two dimensional approach. It is inadequate to completely characterize complex 3D aortic movement. Volumetric evaluation may provide a more complete analysis, but at the present time this technology is unavailable to us. We are developing the resources required for such and endeavour.

We studied patients who underwent implantation with one of two commercially available stent-grafts. This study was not powered to determine differences between stent-grafts, but every reason exists to believe that differences may exist. Various fixation systems (hooks, barbs, radial force, etc.) may result in altered forces on the aortic wall and subsequent differences in pulsatility. Dynamic cine-CT provides valuable insight into the dynamic environment into which endografts are placed. Any differences that might exist would be interesting when contemplating future stent-graft design. Our finding of continued motion following EVAR has implications for endograft complications such as stress related stent fractures and fabric durability.

This study introduces the feasibility of cine-CT imaging on dynamic aortic wall motion pre- and post-EVAR at the level of the aneurysm neck. Understanding the pulsation in this area where aortic stent-graft fixation occurs could be relevant in future designs. The native aorta exhibits significant pulsatility and this phenomenon is preserved after endograft implantation. Morphological changes are very complex, but this study gives early insight into aortic pulsatility in the aneurysm neck. Future studies utilizing dynamic CT to determine rupture risk, effects of different endografts, volumetric analysis and even consequences for endograft efficacy and durability are anticipated.

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