Direct measurement of ascending aortic diameter by intraoperative caliper assessment

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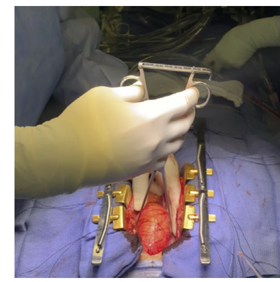


The technique of intraoperative caliper measurement.

CENTRAL MESSAGE

We confirm the accuracy of and concurrence between preoperative CT and TTE with direct intraoperative caliper measurements of ascending thoracic aortic aneurysms.

See Commentaries on pages e147 and e148.

Video clip is available online.

ADULT

Thoracic aortic aneurysm (TAA) is a silent but virulent disease. Ascending TAAs grow roughly 0.1 cm/y and as they grow, silently, the risk of dissection and death increases significantly, making this a potentially lethal disease.[1] Fortunately, surgical intervention can prevent catastrophic events and essentially restore patient survival to normal.[2] The single most predictive factor for an acute aortic event is the aortic diameter. Consequently, surgical decision making is predicated on aortic dimensions.

The accuracy of measuring the maximum aortic diameter is of upmost importance because it determines the timing of prophylactic surgical repair.[3] Aortic measurements are made using a variety of different imaging modalities, including but not limited to, computed tomography (CT) and transthoracic (TTE) or transesophageal (TEE) echocardiography (ECHO), and magnetic resonance imaging (MRI).[4] Each modality has its own strengths and limitations. However, discrepancies of aortic measurements occur both within and between modalities.[5] The advent of computerized methods has further complicated assessment of true diameter and interpretation of results. Toward greater clarity, in this study, we assess the maximal ascending aortic diameter intraoperatively through the use of a caliper tool and compare our findings to CT and ECHO measurements.

METHODS

Our cohort was composed of 35 patients undergoing ascending TAA replacement. Patients gave informed consent for participation. We documented the maximal diameter of the ascending aorta by direct intraoperative caliper measurement. All patients experienced aneurysms in zone 0, the segment of the aorta between the sinotubular junction and the innominate artery. Once the aorta was exposed, a measuring caliper was used to directly measure maximum aortic diameter. We assessed measurements during both systole and diastole. The diastolic values were used for all statistical comparisons because these correspond to the phase in which our institution, and most others, take CT measurements (because wall movement is minimal in end-diastole). For these aneurysmal, noncompliant aortas, differences between systole and diastole were rarely >1 to 2 mm.

In addition to the caliper measurements, patients underwent preoperative TTE and CT measurements as well as intraoperative TEE measurements (we rarely use TEE preoperatively). In CT scans, the diameters were determined by a radiologist based on orthonormal 3-dimensional measurements, which ensure that measurements are taken at right angles to the long axis of the aorta. Also, the senior author and surgeon (JAE) measured preoperative aortic dimensions using the axial technique. The axial measurements were done by taking a line perpendicular to the long

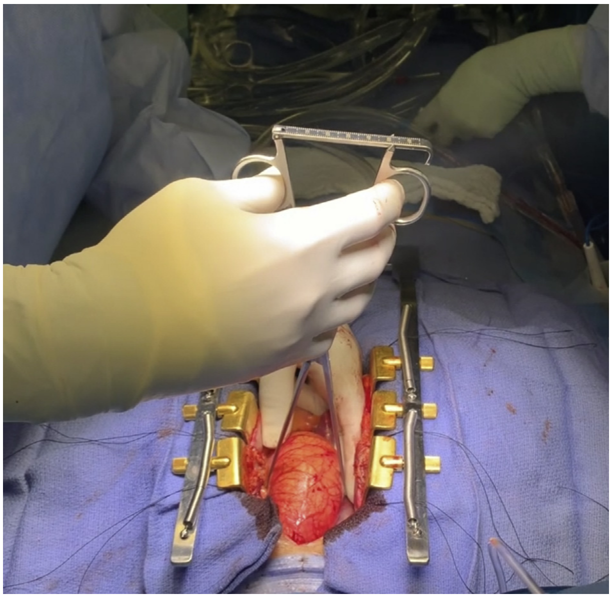
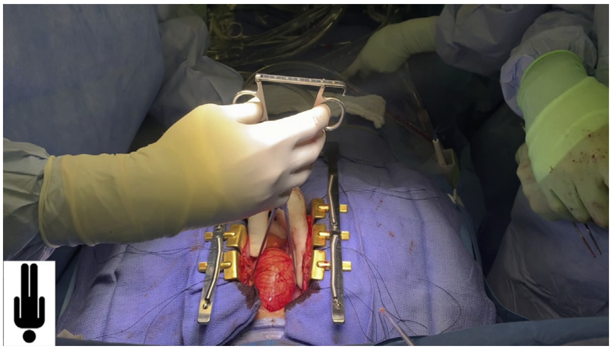


FIGURE 1. Demonstration of intraoperative aortic measurement with the caliper. The caliper is placed at the belly (ie, the largest portion) of the ascending aorta. Measurements are taken in systole and diastole.

axis of the aorta by CT or TTE. For all radiographic measurements, we took the highest value at the belly (ie, the largest part) of the aneurysm (Figure 1 and Video 1). The operative measurements were also taken at the belly of the aneurysm and recorded in systole and diastole. The intraoperative measurements were confirmed by 2 separate observers. The more compliant the aorta, the greater the variability between systole and diastole. Patients were under general anesthesia and closely monitored while measurements were taken just before aortic cannulation and institution of cardiopulmonary bypass. Arterial pressures were kept in a normotensive range for good clinical care of aneurysm patients undergoing aortic surgery.

The distribution for each dataset was tested with Kolmogorov Smirnov normality test. All of the different measuring modalities (surgeon-generated measurements, preoperative CT, preoperative MRI, and intraoperative TEE) were independently compared to the caliper measurements. An independent Student *t* test was used to compare means between normally distributed data. Mann Whitney *U* test was used to compare datasets that showed not normally distributed data.



VIDEO 1. Video of intraoperative ascending aortic measurement with the caliper. The oscillation of the marker on the scale can be seen, corresponding to systole and diastole. Video available at: https://www.jtcvs.org/article/S0022-5223(20)32265-0/fulltext.

RESULTS

Table 1 depicts patient characteristics, including presence of bicuspid aortic valve, abnormal branching of the aortic arch, presence of aneurysm family history, and the aortic measurements for each modality. Additionally, 28 patients underwent whole exome sequencing (WES). Out of these, 6 were found to have a positive WES, meaning that either a genetic mutation known to be associated with TAA or a variant of unknown significance related to aneurysm disease was found. For patients with a positive WES the affected gene is noted in Table 1.

Five to 5.5 cm diameter is our usual criterion for intervention (Table 2) (modified by aortic height index for small or very large patients).[1] For 13 patients in this study with somewhat smaller aortic dimensions, drivers for surgery included the following: aortic valve disease (aortic stenosis/aortic insufficiency/other) in 4 patients, abnormal genes on WES (3 patients), high aortic/height index (2 patients), aortic replacement at time of coronary artery bypass graft (1 patient), and family history of arterial rupture or aortic surgery by our team (3 patients). There were no mortalities in these patients. We generally resect the ascending aorta when it exceeds 4 cm when we are there for another indication, usually aortic valve disease.

The aortic dimensions assessed varied between 4.0 and 6.0 cm with a mean of 4.83 cm $\pm$ 0.47 cm when measured intraoperatively via the caliper, 4.93 cm (3.90 to 6.50 $\pm$ 0.42 cm) by surgeon-generated diameter using preoperative CT or TTE, 4.77 cm (3.3 to 5.5 $\pm$ 0.44 cm) by preoperative TTE, 4.8 cm (3.9 to 6.4 $\pm$ 0.49 cm) by preoperative CT scan, and 4.61 cm (3.5 to 6.2 $\pm$ 0.51 cm) by intraoperative TEE. Only 3 patients had MRI available, with a median of 4.6 cm and a range of 4.40 to 5.10 cm. All the different imaging modalities were comparable to the caliper measurements ($P > .05$) except the TEE intraoperative measurements. The measurements taken by TEE intraoperatively were significantly different (lower) than the caliper measurements ($P = .015$).

DISCUSSION

Ascending and aortic root TAA diameters are the best predictors for acute aortic syndrome events such as rupture and dissection, especially when corrected for body height.[1] Accurate assessment of the maximum aortic diameter is critical due to its implications on surgical decision making. Despite attempts at implementing standardized protocols, the variability between measurements obtained by various imaging modalities has raised concerns about their accuracy, creating challenges for the surgeon when deciding whether or not to proceed with surgery.

Although each modality has its limitations, CT is preferred by most surgeons because of perceived accuracy,

TABLE 1. Measurements through the different modalities

								Preoperative				Intraoperative	
No.	Gender	Age	BAV	Arch anomaly	Family history*	Positive WES	Gene	Surgeon's measurement†	TTE	CT	MRI	TEE	Caliper
1	M	71	Yes	No	No	No		5.00	5.2	4.8		5	5.3
2	M	71	No	Yes	Proven	No		5.20	4.7	4.7		4.4	5
3	F	57	Yes	No	No	No		4.00	3.3	4		4	4
4	M	30	Yes	No	Proven	Yes	NOTCH1	4.70	4.4	4.6		4.2	4.1
5	M	77	No	No	Proven	Yes	TGFBR2	5.00	5.3	4.8		4.8	5.1
6	M	62	No	Yes	Proven	–		5.00	4.8	5		4.8	5.1
7	F	53	Yes	No	Proven	No		5.19	5	4.8		4.5	4.6
8	F	71	Yes	No	No	No		4.80	4.8	4.8		4.8	5.1
9	M	46	Yes	No	No	No		4.90	4.5	4.8		4.5	4.9
10	M	58	No	No	No	–		3.90	3.9	3.9		3.5	4.1
11	M	72	No	No	No	No		4.90	4.9	5		4.5	5.1
12	M	68	No	No	No	No		5.20	5.1	5.2		4.4	5.1
13	F	58	No	No	No	No		4.70	4.2	4.1		4.16	4.6
14	F	75	No	No	Likely	–		5.73	5.5	5.4		5.1	5.9
15	F	84	No	No	No	No		5.90	5.2	5.1		5	5.5
16	F	51	Yes	No	No	No		5.00	4.9	4.9		4.7	5
17	M	59	No	No	Possible	–		4.62	4.3	4.3		3.6	4.3
18	M	61	No	No	Proven	Yes	ELN	4.62	4.7	4.5		3.9	4.4
19	M	75	No	No	No	No		6.50	4.9	6.4		6.2	4.1
20	M	53	No	Yes	Proven	No		4.50	4.9	4.7		4.4	5
21	M	56	No	No	Proven	No		5.00	4.9	5		4.9	5.1
22	M	46	No	No	No	–		4.90	4.8	5		4.2	4.5
23	M	64	No	No	Possible	No		4.60	4.9	4.5			4.8
24	M	69	No	No	Proven	No		4.70	5	4.9			4.8
25	M	66	Yes	No	Likely	–		5.00	5	4.7			4.4
26	M	81	No	No	No	Yes	PRKG1	5.00		4.7		4.4	5
27	F	75	Yes	No	No	Yes	NOTCH1	5.00		4.7		4.8	5
28	M	71	Yes	Yes	Likely	Yes	NOTCH1	4.95		4.7		5	4.8
29	M	70	No	No	Proven	No		5.00		4.3		4.7	4.7
30	M	40	Yes	No	Proven	No		5.70		5.7		5.2	6
31	M	72	No	No	Proven	No	BRCA1	5.00	4.8			4.8	5.2
32	F	89	No	No	No	No		5.00	5.2			5.1	4.9
33	M	61	Yes	No	No	No		4.60	4.6		4.6	4.3	4.5
34	F	70	No	No	Proven	–		4.90	4.7		4.4	4.7	4.5
35	M	59	Yes	No	Proven	No		5.32			5.1	4.8	4.5
						Result		5.00 (3.90-6.50)	4.77 ± 0.44	4.80 ± 0.49	4.70 (4.40-5.10)	4.61 ± 0.51	4.83 ± 0.47
						***P* value**		0.301	.747	.625	.717	.015	

Mean ± standard deviation was reported for normally distributed data and median (range) for not normally distributed data. *BAV*, Bicuspid aortic valve; *WES*, whole exome sequencing; *TTE*, transthoracic echocardiogram; *CT*, computed tomography; *MRI*, magnetic resonance imaging; *TEE*, transesophageal echocardiogram. *Patients with family members with proof of aneurysmal disease were classified as proven family history, those with sudden death in the family of individuals aged ≤50 years were considered likely, and patients with sudden death in the family of individuals aged >50 years were considered possible. †Refers to surgeon-generated diameter using existing CT or TTE imaging.

ADULT

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TABLE 2. Procedures performed. Three operations were redo, and 2 required associated coronary artery bypass graft

Procedure	No. performed
Ascending	10
Ascending/aortic valve replacement	9
Aortic root	6
Ascending/aortic valve replacement/hemiarch with DHCA	5
Ascending/hemi-arch with DHCA	3
Total arch	2

DHCA, Deep hypothermic circulatory arrest.

wide availability, and user friendly readability.[3,4] TAA dimensions by CT have traditionally been measured through an axial dimension, when the measurement is taken perpendicular to the long axis of the aorta. More recently, 3-dimensional orthonormal measurements have become center stage.[5] Radiology departments at multiple institutions, such as ours, have adapted this methodology as standard practice. The introduction of this new way of accessing CT measurements has raised questions about discrepancies between the 2 modalities.

In this study looking for the presence and extent of these discrepancies, we have demonstrated close concordance of aortic measuring modalities with the direct intraoperative caliper measurement. We believe that the slightly smaller measurements obtained by intraoperative TEE likely reflect interference by the tracheal air column, preventing the probe from seeing high enough to assess the largest belly of the aneurysm.[5]

Current intervention guidelines have emerged from data wherein aneurysm measurements were done using the traditional axial measurement.[6] This raises the question of degree of correspondence with orthonormal measurement methods. Would discrepancies between traditional and orthonormal measurements require adjustment of intervention criteria?

This study provides substantial reassurance that all types of measurements studied cluster closely around direct physical measurement. The exception is that intraoperative TEE underestimates the other modalities mildly, reflecting the restriction of the TEE by the tracheal air column preventing it from seeing the belly of the aneurysm in certain cases.

It is interesting to note that prior caliper studies of the abdominal aorta did, similarly to our study of the ascending aorta, confirm accuracy of preoperative radiographic assessments (eg, ECHO, CT, and MRI).[7,8]

Limitations of this study include the relatively small sample size. Another limitation is that the caliper measurements, by their very nature, include the aortic wall, which is usually 1 to 2 mm thick. CT contrast imaging excludes the aortic wall (although noncontrast images include the wall). TTE splits the difference, by convention including the anterior aortic wall but excluding the posterior (the so-called leading edge to leading edge convention). Also, in the present study, we have deliberately excluded the aortic root, which is especially complex to measure. How does one even define diameter in a cloverleaf, let alone an asymmetric cloverleaf? We address these complex general imaging issues in a separate very recent publication.[5]

CONCLUSIONS

We have confirmed accuracy and concurrence between preoperative CT and TTE with intraoperative caliper measurements of the ascending aorta.

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