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Zonal variation in atheroscleric aorta: Is it a fact?

Anupama Barua, Christopher Dadnam, Sapna Puppala

ABSTRACT

Aims: The diameter of ascending aorta changes in different stages of cardiac cycle in normal, dissected and aneurysmal aorta. The differences in size of arch of aorta during cardiac cycle in atherosclerotic patients are not well established. Here we studied the long and short axis diameter of arch of aorta in atherosclerotic patients to assess the differences in diameter in different stages of cardiac cycle. Methods: This study involved evaluation of retrospective data, for patients who underwent retrospectively gated cardiac computed tomogrphy (CT) scan examinations for various indications. Zones 0–4 were identified from CT scan as per Shin Ishimaru's division of arch of aorta. The short axis and long axis, along with the average of the two, were obtained both in systole and diastole, at the same level. The measurements were taken from outer wall to outer wall of the aorta. Results: Data from 27 patients (11 females and 16 males) was reviewed. The age range was 50–89 years. A total of 135 zones were identified and axial diameters (short and long axes) were measured. The average zone variation between the long axis and short axis diameter during systole and diastole did not exceed 1 mm (max = 2.9 mm, min = 0.0 mm) for any zone. The largest difference in average variation was noted in zone 4; 0.58 mm, although this was not statistically significant. Conclusion: Our study suggested that the variation of atherosclerotic aorta is minimal in different phases of cardiac cycle. This should be considered for endovascular intervention in atherosclerotic arch of aorta.

Keywords: Aorta, Atherosclerosis, Endograft

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INTRODUCTION

Ishimaru has described the division of arch of aorta in 2001 [1]. This innovation has significant clinical implication in mapping of landing zone for endograft. It not only helps to evaluate the arch of aorta during the treatment but also assists in monitoring the outcome of treatment in follow-up scan. Proximal placement of endograft on a sufficient long segment of healthy aorta (landing zone) is vital for successful endovascular management of aneurysm of arch of aorta. Figure 1 shows the division of zone 1, zone 2, and zone 3 distal to each branch of aortic arch and zone 4 correlates to the straight part of thoracic aorta up to the lumber region of abdominal aorta and zone 0 is proximal to the arch innominate branch.

Aortic distension is a physiological phenomenon, occurring in different phases of cardiac cycle due to vessel wall elasticity or compliance [2]. The aortic displacement is most prominent near the heart due to transmission of kinetic movement of pericardium during cardiac cycle [3]. Windkessel's principle shows that distension of aorta during systole and recoil in diastole reduces the pulse pressure and maintains the continuous blood flow throughout its length. This elastic property of the aorta allows the vessel to work as a buffering chamber [4]. Two different disease processes affect the aortic wall elasticity: arteriosclerosis and atherosclerosis. Arteriosclerosis is progressive loss of elasticity and distension of the vessel wall due to aging [5]. Atherosclerosis happens due to inflammatory process followed by lipid accumulation resulting in structural weakness in tunica media [6].

Over last three decades, endovascular grafting has become the mainstay of treatment for thoracic and abdominal aortic aneurysm. To size the optimal endograft, multidetector computed tomography and magnetic resonance angiography are used to assess the anatomy of diseased aorta. Multidetector computed tomography has high spatial resolution with high specificity and sensitivity both for diagnosis and sizing [7, 8]. It offers accurate depiction of branch vessel anatomy along with aneurysm and dissection configuration [9, 10]. However, MDCT involves high levels of ionizing radiation and iodinated contrast causes nephrotoxic changes leading to contrast induced nephropathy [11, 12]. Another limitation of MDCT is motion artefact usually present in the aortic root and ascending aorta. Some studies suggest that the degree of motion artefact is most pronounced in proximal aorta zone 0–zone 1 during systole and diastole [13]. Up to 17.8% difference in diameter occurs during different phases of cardiac cycle. Electrocardiographic-gated computed tomography scan utilizes MCDT in correlation with cardiac cycle requiring higher radiation dose. It can be performed in two ways: retrospective and prospective. Retrospective gating uses continuous modulated or unmodulated X-ray throughout cardiac cycle (R-R interval), whereas prospective gating takes images at approximately 70% cardiac cycle (late diastolic phase) (Figure 2).

Endograft sizing is vital to ensure adequate functioning and to minimize potential complication. Most clinicians oversize the endograft by 10–15% [14]. Alongside size, as opposed to abdominal aortic aneurysms (AAA's), the thoracic aorta, particularly the aortic arch with a natural curvature can be problematic when sizing and planning for endovascular repair [15]. Furthermore, the morphological and hemodynamic characteristics of the thoracic aorta need to be considered. Undersizing as well as oversizing can lead to complications such as migration, collapse, pseudocoarctation, infolding and endoleaks (particularly type 1) [16, 17]. Furthermore, the pressure or radial force exerted by some stent graft designs, along with excessive oversizing, can lead to further deterioration of already diseased aortic walls. The decision regarding the degree of oversizing is still debatable. Most clinicians oversize the measurement by 10–20%. Excessive oversizing has shown conflicting results, with the possibility of greater associated increased tendency for specific complications [17–19].

The purpose of this study was to assess the expansile differences during the cardiac cycle, in the various Ishimaru zones of the aortic arch. We focused on patients that have atherosclerotic disease and not have previously undergone endovascular repair procedures.

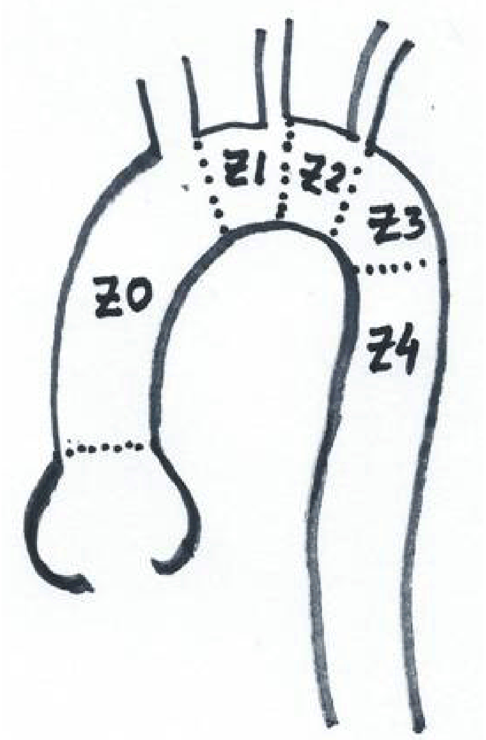

Figure 1: The Ishimaru zones.

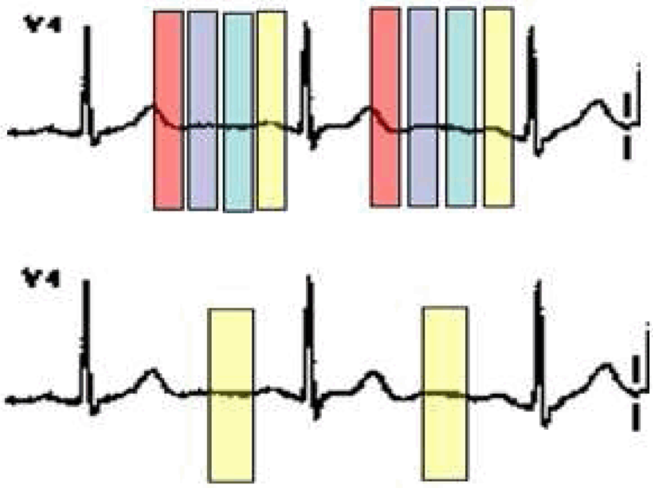

Figure 2: The retrospective and prospective electrocardiographic-gated computed tomography scan.

MATERIALS AND METHODS

This study involved prospective evaluation of retrospective data, for patients who underwent retrospectively gated cardiac CT examinations for various indications. Individuals with evidence of atherosclerotic disease, identified by the presence of atherosclerotic plaques, calcification of the vessel wall, and elevated serum levels of cholesterol or lipids, were included. Patients with acute aortic syndrome, previous aortic rupture, and connective tissue disorders were excluded as these patient groups may have reduced aortic compliance leading to confounding data. All scans were performed with retrospective CT cardiac gating. Standard axials were acquired, at 0.75 mm thin slices, using a dual source Siemens CT scanner, without the usage of β-blockers. Contrast used for these procedures was; 90 ml of 350 strength Iodine (Optiray covidien) at the rate of 5 ml/sec followed by 30 ml of normal saline chase at 4 ml/sec using a pump injector. The standard set of axial data was analyzed using the VOXAR 3D workstation (equipment/software). Oblique sagittal slices were obtained from the standard axial slices were used to derive true axial projections orthogonal to aortic centreline as shown Figure 3. The short axis and long axis, along with the average of the two, were obtained both in systole and diastole, at the same level. The measurements were taken from outer wall to outer wall of the aorta.

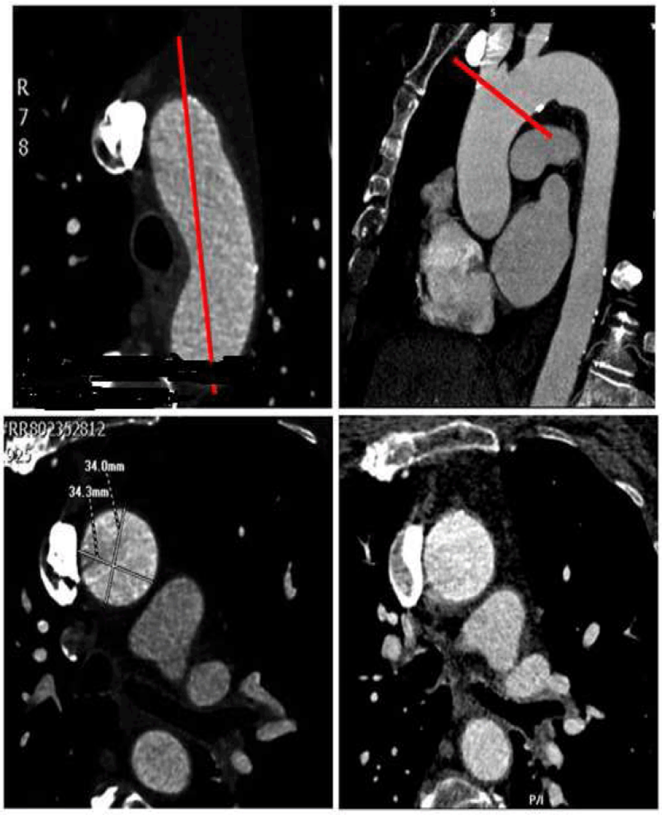

Figure 3: The methodology used to obtain true axial slices from the original data using VOXAR 3D workstation. The raw axial data is used to reformat the oblique sagittal from which true axials were obtained.

RESULTS

Data from 27 patients (11 females and 16 males) was reviewed. Of these, 20 had calcification in the arch and seven had calcification either within the coronary arteries or the aortic valves. The age range was 50–89 years. A total of 135 zones were identified and axial diameters (short and long axes) were measured. The average zone variation between the long axis and short axis diameter during systole and diastole did not exceed 1 mm (max = 2.9 mm, min = 0.0 mm) for any zone (Table 1). The largest difference in average variation was noted in zone 4; 0.58 mm, although this was not statistically significant. There was no significant difference in aortic diameter variation during cardiac cycle for any zone (Table 2).

DISCUSSION

This study demonstrates that the expansile nature of the aorta, during the cardiac cycle, is reduced when the artery becomes atherosclerotic. The results showed no statistically significant variation in aortic diameter in any of the individuals observed. The maximum variation seen in both the long axis and short axis is in zone 4 (p-value = 0.46 and 0.48, respectively). We could not find any specific reason for greater expansile nature in zone 4. Indeed our expectations were that zone 4 may have the least distensibility being furthest from the heart. It might be related to the atherosclerotic nature of the disease and plaque distribution. In a study by Parodi et al., the variation in dimensions between systole and diastole in the descending thoracic aorta were noted similar to our study which also revealed a near significant variation in size in zone 4 [20]. Future studies in this area will be able to justify this finding and show any distinct comparison between the anatomical zones of the aorta or demonstrate anatomical anomaly. As mentioned in the results, the p-values for long and short axes in zone 0 and zone 1 have shown the least significance.

The introduction of electrocardiographic (ECG) cardiac-gating CT, both prospective and retrospective, has enable reduction of movement artefact. As mentioned, the main implication that exists with using MDCT imaging is ionizing radiation exposure which in the younger atherosclerotic patients is relevant due the risk associated with the amount of X-ray radiation exposure leading to lifetime risk of developing cancer [21]. This aspect applies particularly to the organs within the region being scanned, for instance effective dose radiation form a 64-slice MDCT of the chest for female breast tissue is 10–30 times greater than that received from mammography screening [21]. This issue is carefully considered when introducing CT-gating, as relative exposure can increase dramatically. Many studies have observed the efficacy and use of specific types of CT gating techniques, questioning quality over radiation exposure.

Table 1: Zonal size variation between diastole and systole for both long and short axes

Ishimaru zone	Average variation	Maximum variation	Minimum variation
0	0.17 mm	1.9 mm	0.15 mm
1	0.0 mm	2.9 mm	0.05 mm
2	0.38 mm	2.5 mm	0.0 mm
3	0.24 mm	2.1 mm	0.0 mm
4	0.58 mm	2.2 mm	0.1 mm

Table 2: Mean axial length of the zones and calculated p-values

Ishimaru zone	Short axis systole	Short axis diastole	p-value	Long axis systole	Long axis diastole	p-value
0	32.36 mm	32.65 mm	0.7	34.72 mm	34.78 mm	0.9
1	29.52 mm	29.46 mm	0.94	31.96 mm	32.02 mm	0.93
2	27.80 mm	27.42 mm	0.65	30.71 mm	30.33 mm	0.64
3	26.20 mm	26.12 mm	0.92	29.02 mm	28.61 mm	0.63
4	26.49 mm	25.94 mm	0.48	28.04 mm	27.42 mm	0.46

Retrospective gating involves continuous, intensity-modulated, X-ray imaging throughout the cardiac cycle (R-R interval), whereas perspective gating invokes on a step-and-shoot model, where around 26% of the cardiac cycle (late diastolic phase) is imaged [22, 23]. Numerous studies have focused on the effective dose implications and quality of images produced [24–26]. There has been little difference, in terms of image quality, between the two techniques. However, some studies reveal marked differences in effective dose, up to 77% less radiation exposure in prospective gating [26]. Though this is the case, there are limitations imposed on prospective gating, including image quality which is severely affected if heart rate is >70 bpm. This statement, regarding quality, is particularly notable with images of the coronary arteries and not with the aorta. It should be noted that the implications for using ECG gating are not limited to aortic malformations. Indeed some authors discuss a triple rule-out technique, allowing emergency imaging evaluation of the pulmonary and coronary arteries, as well as the thoracic aorta, in response to chest pain. This technique is performed with retrospective gating, as opposed to prospective, due to relative speed acquired to image these areas whilst the contrast is still present.

This finding is crucial for clinicians when performing endovascular repair, in relation to landing zone choice. Currently the use of retrospective cardiac CT-gating, in endograft repair, allows acquiring the relevant information needed to select the most appropriate endograft size. The results in this study, however, demonstrate that the difference in the aortic diameter, throughout the cardiac cycle, is not significant enough to affect endograft sizing, in the zones of the arch of aorta as compared to descending aorta.

Furthermore, since the majority of the clinicians who perform this procedure oversize the aortic diameter by 10–20%, to achieve better endograft apposition to aortic wall, for the endograft used, the discrepancy between the aortic sizes would seem insignificant. This prospect is important to consider in terms of diagnostic benefits against patient risk. Another important consideration is motion artefact, caused by cardiac movement. This can affect the quality of the axial images produced in normal CT scans particularly when observing zone 0 and zone 1, as they are closest to the heart. Indeed we have considered this aspect in the clinical setting. When significant motion artefact generated during CT scan, we recommend that prospective cardiac CT-gating is performed to limit image distortion. Though we appreciate that the level of radiation, using prospective CT-gating, is higher than that of normal spiral CT scan it is significantly lower than the volume of radiation used for retrospective CT-gating.

Limitations

The study was carried out with retrospectively ECG gated CT scan in atherosclerotic patients. This was a retrospective study with a small group of patients, the implications to perform higher quality studies is, however, questionable due to the ethical implications concerning ionizing radiation. Certain variables were not considered, including patient medication such as beta blockers, smoking history (which reduces expansible nature of blood vessels), and low cardiac output patients related to cardiac failure or aortic stenosis (low cardiac output would not cause large distension of the aorta). Finally, the study did not evaluate pre- and post-stenting procedures for the patients. This needs to be documented in the study as it can have significant effect on the results.

CONCLUSION

We conclude that routine cardiac gating, both computed tomography (CT) scan and magnetic resonance imaging (MRI) scan, is not required for endovascular repair of arch in atherosclerotic patients. For stent in or near zone 0, the use of prospective CT gating allowing for a more accurate depiction of the aortic walls is substantial, whilst acquiring lower radiation dose than retrospective CT gating. Current oversizing by 10–20% would be sufficient to compensate for the minimal changes that occur during aortic distension in different phases of cardiac cycle.

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Author Contributions

Anupama Barua – Substantial contributions to conception and design, Acquisition of data, Analysis and interpretation of data, Drafting the article, Revising it critically for important intellectual content, Final approval of the version to be published
Christopher Dadnam – Substantial contributions to conception and design, Acquisition of data, Analysis and interpretation of data, Drafting the article, Revising it critically for important intellectual content, Final approval of the version to be published
Sapna Puppala – Substantial contributions to conception and design, Acquisition of data, Analysis and interpretation of data, Drafting the article, Revising it critically for important intellectual content, Final approval of the version to be published

Guarantor

The corresponding author is the guarantor of submission.

Conflict of Interest

Authors declare no conflict of interest.

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