Published in final edited form as:

Clin Imaging. 2016 ; 40(5): 936–943. doi:10.1016/j.clinimag.2016.04.013.

Normative reference values of thoracic aortic diameter in American College of Radiology Imaging Network (ACRIN 6654) arm of the National Lung Screening Trial

Barbara L. McComb, MD¹, Reginald F. Munden, MD DMD MBA², Fenghai Duan, PhD³, Amanda A. Jain³, C Tuite⁴, and Caroline Chiles, MD⁵

¹Department of Radiology, Mayo Clinic Florida, 4500 San Pablo Road, Jacksonville, FL 32224, Office: 904-953-0143, Fax: 904-953-2804

²Houston Methodist Hospital and Research Institute, Houston, TX

³Department of Biostatistics and Center for Statistical Sciences, Brown University School of Public Health, Box G-S121-7, 121 S. Main Street, Providence, RI 02912; Office: 401-863-2175 (FD); 401-863-9182 (AAJ)

⁴American College of Radiology Imaging Network, 1818 Market Street, Philadelphia, PA 19063

⁵Department of Radiology, Wake Forest Health Sciences Center, Medical Center Boulevard, Winston-Salem, NC 27157

Abstract

Purpose—This study aims to establish reference values for thoracic aortic diameter (AD) in participants in the National Lung Screening Trial.

Methods—Thoracic AD on 322 prevalence computed tomography was recorded at the sinotubular junction, mid-ascending, transverse arch, mid-descending, and diaphragmatic hiatus. We conducted univariate and multivariate analysis to detect AD-associated risk factors.

Results—Mean AD and upper limits of normal for men and women were recorded for each location. Smoking did not correlate with AS. Age, gender, and body surface area (BSA) were the most significant factors.

Conclusions—Thoracic AD reference values are reported. They do not correlate with smoking, but do age, gender, and body surface area (BSA).

Keywords

Aorta; aortic aneurysm; screening CT; NLST

Introduction

Screening for lung cancer with low-dose CT (LDCT) has been shown to reduce deaths from lung cancer by 20%.¹ Recent endorsements for LDCT lung cancer screening from the

United States Preventive Services Task Force, and a number of medical and surgical societies, are increasing acceptance of LDCT as a screening tool by both patients and health care providers.²⁻⁴ Equally important for increasing lung cancer screening in the U.S. is the recent decision by the Center for Medicare and Medicaid Services to approve funding of lung cancer screening.⁵

Although there are guidelines for reporting and management of pulmonary nodules encountered on screening CT, there are as yet no existing guidelines for the reporting and management of incidental findings. Thoracic aortic aneurysm is an uncommon incidental finding in patients undergoing LDCT screening for lung cancer, occurring in 0.2% to 0.4%.^{6,7} An aortic aneurysm is defined as a permanent localized dilation of the aorta, with at least a 50% increase in diameter compared with the normal expected diameter.⁸ With this in mind, our goals were to establish normative reference values for thoracic aortic diameter, and to evaluate the effect of smoking pack years on aortic diameter as measured on LDCTs of participants in the National Lung Screening Trial (NLST). Defining the normal aortic diameter on LDCT scans performed for lung cancer screening will affect the use of the term “aneurysm”, which is defined as a permanent localized dilation of the aorta with at least a 50% increase in diameter compared with the expected normal diameter⁸.

Methods

Study Cohort

All subjects were enrolled in the National Lung Screening Trial (NLST), a randomized controlled trial with the primary objective of determining if low-dose helical CT reduces lung cancer deaths relative to chest radiography. This trial was a collaborative effort of the American College of Radiology Imaging Network (ACRIN), sponsored by the NCI Division of Cancer Treatment and Diagnosis, Cancer Imaging Program and the Lung Screening Study (LSS), administered by the NCI Division of Cancer Prevention. All subjects in this aortic study were participants in the ACRIN arm (ACRIN 6654). We retrospectively analyzed ungated, low-dose non-contrast CT scans of 354 participants, each of whom underwent prevalence CT scans during the period of 2002 to 2004 at one of twenty-three institutions. Participants ranged in age from 55 to 74 years and had a significant smoking history (current or previous cumulative cigarette smoking history of > 30 pack years).

Data collection

Three board certified, experienced (>20 years) thoracic trained radiologists (BC, RM, CC) independently evaluated the prevalence CT scans in two different sessions. An initial training session included 24 CT scans; twelve studies were randomly selected from participants with aortic abnormalities recorded at the time of the screening CT, and another 12 studies from participants without documented aortic abnormality.

The main study included CT scans of 330 participants, divided among the three readers (110 scans each). The 330 scans were randomly selected from populations stratified by gender, geographical region (4 regions) and age group (55-59, 60-64, 65-74) to ensure proportional sampling. The data are reported by age groups 55-59, 60-64 and 65-74. Within the NLST

overall, 42.8% of participants were 55-59, 30.6% were 60-64, 17.8% were 65-69 and 8.8% were 70-74. For our analysis, the older 2 quartiles were combined to create 3 age groups of similar size⁹. Participants were identified as either current or former smokers. Former smokers had quit within the past 15 years. Smoking history was quantified in number of pack-years [years smoked $\times$ (number of cigarettes smoked per day) /20]. The presence or absence of hypertension and diabetes was based on participant self-report at time of the NLST prevalence screen, as determined by yes/no answers on questionnaires that asked "Have you ever been diagnosed with ...". Participant weight and height were recorded at the time of registration. Body surface area (BSA) was calculated using both the Dubois and Mosteller methods.¹⁰

We also queried the NLST database for aortic disease as a cause of death, using the ICD-10 codes of I710 through I719, and a data freeze date of 1/31/2011. The cause of death was determined by the death certificate, or by a search of the National Death Index when the death certificate was not available.

CT imaging protocol

CT scans were performed on multi-channel helical scanners that allowed the retrospective reconstruction of image data into data sets of different spatial quality and image characteristics. CT acquisition parameters were based on a standard protocol, including 120 kVp, 40 - 80 mAs, and detector collimation of 0.5-2.5 mm.¹¹ Examinations were considered acceptable if all images of the thoracic aorta were intact and available with soft tissue window settings.

Reader measurements

For both the training session and the main study, measurements from outer wall to outer wall of thoracic aortic diameter were taken perpendicular to the axis of blood flow on axial images and from sagittal oblique reformatted images generated on TeraRecon thin client workstations. On TeraRecon workstations, each reader generated sagittal oblique views using Maximum Intensity Projection (MIP) images, beginning at a 45-degree angle and then adjusting from that position to best display the ascending, transverse, and descending portions of the thoracic aorta. For each imaging plane, aortic diameters were measured at five levels: 1) sinotubular junction, 2) mid-ascending aorta, halfway between the sinotubular junction and aortic arch, at the level of the right pulmonary artery, 3) transverse aortic arch, 4) mid-descending aorta (at the same level as the sinotubular junction measurement) and 5) distal descending thoracic aorta at the diaphragmatic hiatus (Figs. 1, 2). A total of 10 measurements of thoracic aortic diameter were collected from each participant's CT scan. The order and time interval between reads was not specified, but to prevent bias in measurements of each plane, each reader measured the aorta at the five locations on axial images before creating sagittal oblique views and obtaining second measurements. The readers did not alternate between axial and sagittal images. In the NLST, CT slice thickness was standardized at 2.0 – 2.5 mm depending on the CT vendor, therefore this served as the source data for sagittal reconstructions.

Statistical analyses

We used the interclass correlation coefficient (ICC) proposed by Shrout and Fleiss to assess the inter-rater reliability (IRR) for the data collected in the training session. The ICC measure was used with the assumption that readers were a random subset of all possible readers.¹² Meyers considered the following scale of ICC to determine the extent of IRR: poor (ICC<0.7), fair (0.7 ICC<0.8), good (0.8 ICC<0.9), high (ICC 0.9).¹³

For the main study, we evaluated correlation between thoracic aortic diameter measurements recorded on axial images and on sagittal oblique reformatted images; we used the Pearson partial correlation to control for the reader's effect. We conducted univariate and multivariate analyses to study aortic diameter and its risk factors. For the univariate analysis, we produced frequency tables and descriptive statistics (mean, standard deviation, unpaired t-test, pairwise t-test, one-way ANOVA) to explore the data. The predictors that were significantly associated with the outcome were used for the subsequent multivariate analysis. For the multivariate analysis, a linear mixed effect model was fitted to take into account the correlation introduced by collecting multiple measurements from the same participant. Specifically, baseline smoking status (current/former), smoking history (in pack years), age (in yrs), gender, diabetes (yes vs. no), hypertension (yes vs. no), one body mass measure (BMI, Dubois BSA, Mosteller BSA), and reader were modeled as fixed effects, whereas view (axial vs. sagittal oblique) and anatomic level (5 levels, see above) were modeled as random effects. The interactions were also evaluated in the model. All data were analyzed using SAS Version 9.2 (SAS Inc.).

RESULTS

Training session

Of the 24 CT studies, 23 were acceptable for interpretation in the training session. IRR was good among three readers (average interclass correlation (ICC) 0.83), although variability existed by imaging plane and level: sinotubular junction axial 0.958, sagittal oblique 0.788; mid-ascending axial 0.935, sagittal oblique 0.914; transverse arch axial 0.794, sagittal oblique 0.597, mid-descending axial 0.886, sagittal oblique 0.778; diaphragmatic hiatus axial 0.806, sagittal oblique 0.834. IRR was higher on axial images than on sagittal oblique reformations across all anatomic levels, with the exception of the distal descending thoracic aorta at the diaphragmatic hiatus.

Main study

There were 322 total evaluable CT examinations (8 were deemed unsatisfactory due to missing images or patient motion). The extent of correlation between the two views for the main study images was very good (overall Pearson's partial correlation coefficient = 0.89). Correlation was highest at mid-ascending aorta (Pearson's correlation coefficient = 0.91) followed by mid-descending aorta and diaphragmatic hiatus (Pearson's partial correlation coefficient = 0.89), and was lowest at sinotubular junction and transverse aorta (Pearson's partial correlation coefficient = 0.82 and 0.83, respectively).

Baseline demographic and clinical characteristics of the population for the main study are presented in Table 1.

The mean and standard deviation for the 10 measurements of aortic diameter, on both axial and sagittal oblique images, are presented in Table 2.

Table 3 shows aortic diameter stratified by age, gender, geographic region, hypertension, diabetes, baseline smoking status, smoking quantification (categorized into five groups), BMI and BSA (using Mosteller method and dichotomized at the medians). Smoking quantification was a marginally significant predictor only at the level of the diaphragmatic hiatus ($p = 0.051$ on axial; $p = 0.055$ on sagittal oblique). Age, gender, BSA, and self-reported hypertension, and diabetes were significant predictors of aortic diameter.

Table 4 presents the results of multivariate analysis from fitting the linear mixed model. The interaction between level and smoking status shows that the aortic diameter for the diaphragmatic hiatus might be larger in current smokers than in former smokers ($p = 0.0693$). Similar to the univariate analyses, we found that older age, male gender, greater BSA (Mosteller method), and hypertension were significant predictors of aortic diameter. However, diabetes was not a significant predictor under the multivariate setting ($p = 0.26$). Further study showed that the primary confounders for diabetes were age and gender. In fact, after adjusting for the effect of age, the association of diabetes with aortic diameter dropped by about 30% when comparing the diabetes' coefficient estimates between the model with the age adjustment and the model without the age adjustment. In addition, Diabetes was significantly associated with age and with gender when regressing diabetes on these variables.

Table 5 presents the mean diameters for five levels of the thoracic aorta, by gender, age and BSA in the 55 to 74 year old age group eligible for lung cancer screening. These mean diameters are used to show upper limits of normal (mean + 2 standard deviations) and thresholds for reporting thoracic aortic aneurysm (mean $\times 1.5$). For example, in men, considering any body surface area and a male 70 – 74, the mid-ascending aorta mean aortic diameter is 3.57 cm, the upper limit of normal is 4.14 cm and the aneurysm threshold is 5.35 cm. In women, considering any body surface area and a age 70 – 74, the mid-ascending aorta mean aortic diameter is 3.44 cm, the upper limit of normal is 4.12 cm and the aneurysm threshold is 5.16 cm.

Aortic disease as a cause of mortality

Aortic disease was coded as a cause of death in 38 NLST participants, including aortic dissection ($n = 10$), thoracic aortic aneurysm, ruptured ($n = 3$), thoracic aortic aneurysm without mention of rupture ($n = 4$), abdominal aortic aneurysm, ruptured ($n = 12$), abdominal aortic aneurysm without mention of rupture ($n = 4$), aortic aneurysm of unspecified site, ruptured ($n = 2$), and aortic aneurysm of unspecified site, without mention of rupture ($n = 3$). These 38 deaths represented 3.91% (38/972) of all cardiovascular deaths in the NLST.

DISCUSSION

In addition to being effective for lung cancer screening, LDCT also provides an opportunity to detect other asymptomatic diseases within the thorax, including thoracic aortic aneurysm. Normal values for the thoracic aorta in the population have been evaluated by a number of investigators. Kalsch et al reported “normal” aortic size stratified by age and gender of a European cohort in the Heinz Nixdorf Recall study. This study showed ascending thoracic aorta diameter to be larger than the descending thoracic aorta as well as larger in men than women: reported sizes were ascending aorta: 3.71 cm (men) vs 3.45 cm (women) and descending aorta: 2.82 cm (men) vs 2.54 cm (women).¹⁴ Wolak reported in a group undergoing coronary artery calcium scoring that mean aortic diameters was 3.3 cm for men and 2.4 cm for women with upper limits of normal reported as 4.1 cm and 3.0 cm respectively.¹⁵ This was further defined by sex, with mean ascending aortic diameters of 3.40 cm (men) and 3.18 cm (women), and mean descending aortic diameters of 2.56 cm and 2.30 cm.¹⁵

In our study, we determined the mean aortic diameter for the NLST population and established upper limits of normal for five thoracic aorta segments. We propose using gender, age and BSA-based upper limits for aortic diameter of normal (mean + 2 standard deviations) and for thoracic aortic aneurysm diagnosis (mean $\times$ 1.5) to guide reporting of thoracic aortic diameter in lung cancer screening patients. (Table 5) Our results are consistent with thoracic aortic diameters reported in the Framingham heart study, based on ECG-gated, non-contrast-enhanced MDCT scans.¹⁶ In this study, the authors measured the mean of the transverse and anteroposterior diameters in 3,431 participants, and stratified these by gender, age and BSA. Applying the characteristics of our screening population to their results yields the following: women with a mean age of 61.3 years, and a BSA of 1.8 m², mid-ascending aorta 3.35 cm, mid-descending aorta of 2.40 cm; men with a mean age of 62.0 and a BSA of 2.1 m², mid-ascending aorta 3.68 cm and mid-descending aorta of 2.77 cm.

In order to reduce confusion in terminology, aortic diameters greater than the upper limits of normal, but not meeting criteria for aneurysm, should be described as dilated. The term aneurysm is reserved for diameters that are 150% of normal. The distribution of thoracic aortic aneurysm has been reported as ascending or aortic arch (40%), descending alone (31%) and both (29%).¹⁷ The mean aortic diameter at the level of the diaphragm, in our screening population is 2.5 cm. The term aneurysm would therefore be used at aortic diameters of 3.75 cm and greater at the level of the diaphragm. It is important that measurements of the thoracic aorta be accurately performed because the ascending aorta is not truly vertical, and its obliquity complicates measurement of aortic diameter on axial images.¹⁸ When the cross-section of the aorta appears elliptical, the short axis diameter is likely the true diameter, with the longer axis diameter artificially created by the oblique axis. For this reason, we recommend utilizing the 2010 recommendations of the American College of Cardiology Foundation/American Heart Association Task Force on Practice Guidelines for reporting aortic diameters on CT, such that the external diameter is measured perpendicular to the longitudinal or flow axis of the aorta.¹⁹ Of interest, in our training dataset analysis, IRR was higher on axial images than on reconstructed sagittal oblique

images. While this not conclusive because of the small numbers of cases, it has clinical implications because lung cancer screening CT examinations are performed in axial plane and sagittal reconstructions are not performed.

While the prevalence of thoracic aortic aneurysm is low, even in the lung cancer screening population, it is not negligible. Priola et al reported finding two thoracic aortic aneurysms at baseline examinations in 519 participants (0.38%) in a lung cancer screening program.⁷ The prevalence in the general population is estimated at 1.25%, but may be as high as 3 to 4% in patients older than 65.²⁰ Clouse et al reported an overall incidence rate, age- and sex-adjusted to the 1990 US white population, of 10.4 per 100,000 person-years¹⁷ and more recently, Benedetti reported the prevalence of incidental ascending aortic dilation in a population of 55 – 80 years olds, which is similar age group in the NLST, to be 2.7%.²¹

In a landmark article appearing in JAMA in 1958, Hammond and Horn compared death rates in cigarette smokers with those in never smokers, linking cigarette smoking with an increased number of deaths from lung cancer, cancers in other sites, pulmonary disease, and coronary artery disease. They also noted 68 deaths from aortic aneurysm compared with 25 expected deaths, and were thus the first to associate smoking with aortic aneurysm.²² Wilmink et al reported a strong association with cigarette smoking and abdominal aortic aneurysm (AAA) with a 7.6-fold increase in the incidence of AAA in current smokers.²³ They noted that the duration of smoking played a pivotal role, with each year of smoking increasing the relative risk of AAA by 4%. An association between cigarette smoking and thoracic aortic aneurysm is less clear. It is now thought that thoracic and abdominal aortic aneurysms are different entities, with different risk factors and histologies.²⁴ Whereas atherosclerotic risk factors, including male gender, age, smoking, and hypertension, are strongly associated with AAA, genetic predisposition plays a larger role in the development of TAA.

Cigarette smoking is a well-recognized risk factor for the development of atherosclerosis. Smoking also affects elastin degradation in the vascular wall. However, we found poor correlation with aortic diameter and either smoking status or smoking history in pack-years, er, except at the level of the diaphragmatic hiatus, where the thoracic aorta transitions into the abdominal aorta. This is consistent with current understanding of aneurysm formation in the thoracic aorta as a distinct entity, dissimilar from abdominal aortic aneurysm.

While we performed analysis (hypertension, age, gender, BSA) similar to previous reports on aortic diameter, our study is unique in that we only evaluated heavy cigarette smokers (minimum of 30 pack-year history) who underwent low-dose screening CT for lung cancer. This CT technique is optimized for lung evaluation, not for cardiovascular or other soft tissue organs and certainly not ideally designed for aorta evaluation. Nevertheless, radiologists reading lung cancer screening examinations will be held responsible for reporting aortic aneurysm. Therefore, establishing a normative aortic size in this specific population is important to the lung cancer screening community. While it could be assumed that aortic dimensions reported from other studies of different populations and CT techniques are applicable to the lung cancer screening population, it is possible these

measurements would not be accurate and thus could result in adverse assessment of the effectiveness and overall expense of low dose CT lung cancer screening.

This study is subject to limitations of retrospective analysis, small sample size relative to the overall NLST population, and lack of a non-smoking control group. Using non-gated CT may be a limitation based on reports by Parodi et al that measurements of the descending thoracic aorta could differ by as much as 22.6% between peak systole and end diastole in electrocardiographically (ECG)-gated scans²⁵. However, our intent was to determine aortic measurements on examinations done for lung cancer screening and to provide guidelines for the lung cancer screening population. Reconstructions of the aorta were performed on a single vendor platform and thus slight variations in AD measurements could occur with other systems. We note that current multidetector CT scans are capable of reconstruction of the imaging data to thinner slice thicknesses than was possible at the time of the NLST, which would improve the spatial resolution of reformatted images. An additional limitation of our analysis is that we were unable to determine the prevalence of non-fatal aortic aneurysm in the NLST population without retrospective review of a much larger sample size.

While thoracic aortic aneurysm is an uncommon cause of death in the lung cancer screening population, it occurs. We provide upper limits of normal for aortic diameter and thresholds for aortic aneurysm diagnosis as measured in the axial plane at five levels of the thoracic aorta, for both men and women who are eligible for lung cancer screening on the basis of age and smoking history [sinotubular junction 4.08(M)/3.83(F), mid-ascending aorta 4.15(M)/3.99(F), transverse aorta 3.45(M)/3.16(F), mid-descending aorta 3.26 (M)/2.94(F), and diaphragmatic hiatus 3.16(M)/2.90(F); all measurements in cm].

Acknowledgments

The American College of Radiology Imaging Network component (ACRIN 6654) of the National Lung Screening Trial (NLST) was funded through grants (U01-CA-80098 and U01-CA-79778) under a cooperative agreement with the Cancer Imaging Program, Division of Cancer Treatment and Diagnosis. The authors gratefully acknowledge the ACRIN 6654 participating institutions, site principal investigators, and research coordinators. We also thank the many other radiologists, radiologic technologists, referring clinicians, and site administrative staff at the participating sites, as well as the ACRIN staff who supported the study at ACRIN headquarters in Philadelphia, PA and the Biostatistic and Data Management Center at Brown University in Providence, RI. Without the diligent efforts of these many individuals, this study would not have been possible.

In particular, the following individuals warrant specific mention: Patricia Fox, former biostatistician; Maria Oh, protocol development; Irene Mahon, administrative.

References

1. Aberle DR, Adams AM, et al. National Lung Screening Trial Research T. Reduced lung-cancer mortality with low-dose computed tomographic screening. *N Engl J Med*. 2011; 365:395–409. [PubMed: 21714641]
2. Wender R, Fontham ET, Barrera E Jr, et al. American Cancer Society lung cancer screening guidelines. *CA Cancer J Clin*. 2013; 63:106–17.
3. Jaklitsch MT, Jacobson FL, Austin JH, et al. The American Association for Thoracic Surgery guidelines for lung cancer screening using low-dose computed tomography scans for lung cancer survivors and other high-risk groups. *The Journal of thoracic and cardiovascular surgery*. 2012; 144:33–8. [PubMed: 22710039]

4. Moyer VA. Screening for Lung Cancer: U.S. Preventive Services Task Force Recommendation Statement. *Ann Intern Med.* 2013; N/A:N/A–N/A.
5. [8/15/2015] Decision Memo for Screening for Lung Cancer with Low Dose Computed Tomography (LDCT) (CAG-00439N). 2015. (<https://www.cms.gov/medicare-coverage-database/details/nca-decision-memo.aspx?NCAId=274>.)
6. MacRedmond R, Logan PM, Lee M, Kenny D, Foley C, Costello RW. Screening for lung cancer using low dose CT scanning. *Thorax.* 2004; 59:237–41. [PubMed: 14985561]
7. Priola AM, Priola SM, Giaj-Levra M, et al. Clinical implications and added costs of incidental findings in an early detection study of lung cancer by using low-dose spiral computed tomography. *Clinical lung cancer.* 2013; 14:139–48. [PubMed: 22868220]
8. Hiratzka LF, Bakris GL, Beckman JA, et al. ACCF/AHA/AATS/ACR/ASA/SCA/SCAI/SIR/STS/SVM Guidelines for the diagnosis and management of patients with thoracic aortic disease. A Report of the American College of Cardiology Foundation/American Heart Association Task Force on Practice Guidelines, American Association for Thoracic Surgery, American College of Radiology, American Stroke Association, Society of Cardiovascular Anesthesiologists, Society for Cardiovascular Angiography and Interventions, Society of Interventional Radiology, Society of Thoracic Surgeons, and Society for Vascular Medicine. *Journal of the American College of Cardiology.* 2010; 55:e27–e129. [PubMed: 20359588]
9. Aberle DR, Adams AM, et al. National Lung Screening Trial Research T. Baseline characteristics of participants in the randomized national lung screening trial. *Journal of the National Cancer Institute.* 2010; 102:1771–9. [PubMed: 21119104]
10. Mosteller RD. Simplified calculation of body-surface area. *N Engl J Med.* 1987; 317:1098. [PubMed: 3657876]
11. Aberle DR, Berg CD, et al. National Lung Screening Trial Research T. The National Lung Screening Trial: overview and study design. *Radiology.* 2011; 258:243–53. [PubMed: 21045183]
12. Shrout PE, Fleiss JL. Intraclass correlations: uses in assessing rater reliability. *Psychol Bull.* 1979; 86:420–8. [PubMed: 18839484]
13. Meyers, C. Measurement in physical education. New York, USA: Ronald Press; 1974.
14. Kalsch H, Lehmann N, Mohlenkamp S, et al. Body-surface adjusted aortic reference diameters for improved identification of patients with thoracic aortic aneurysms: results from the population-based Heinz Nixdorf Recall study. *International journal of cardiology.* 2013; 163:72–8. [PubMed: 21641667]
15. Wolak A, Gransar H, Thomson LE, et al. Aortic size assessment by noncontrast cardiac computed tomography: normal limits by age, gender, and body surface area. *JACC Cardiovascular imaging.* 2008; 1:200–9. [PubMed: 19356429]
16. Rogers IS, Massaro JM, Truong QA, et al. Distribution, determinants, and normal reference values of thoracic and abdominal aortic diameters by computed tomography (from the Framingham Heart Study). *The American journal of cardiology.* 2013; 111:1510–6. [PubMed: 23497775]
17. Clouse WD, Hallett JW Jr, Schaff HV, Gayari MM, Ilstrup DM, Melton LJ 3rd. Improved prognosis of thoracic aortic aneurysms: a population-based study. *Jama.* 1998; 280:1926–9. [PubMed: 9851478]
18. Eleftheriades JA, Farkas EA. Thoracic aortic aneurysm clinically pertinent controversies and uncertainties. *J Am Coll Cardiol.* 2010; 55:841–57. [PubMed: 20185035]
19. Hiratzka LF, Bakris GL, Beckman JA, et al. ACCF/AHA/AATS/ACR/ASA/SCA/SCAI/SIR/STS/SVM guidelines for the diagnosis and management of patients with Thoracic Aortic Disease: a report of the American College of Cardiology Foundation/American Heart Association Task Force on Practice Guidelines, American Association for Thoracic Surgery, American College of Radiology, American Stroke Association, Society of Cardiovascular Anesthesiologists, Society for Cardiovascular Angiography and Interventions, Society of Interventional Radiology, Society of Thoracic Surgeons, and Society for Vascular Medicine. *Circulation.* 2010; 121:e266–369. [PubMed: 20233780]
20. Castellano JM, Kovacic JC, Sanz J, Fuster V. Are we ignoring the dilated thoracic aorta? *Ann N Y Acad Sci.* 2012; 1254:164–74. [PubMed: 22548582]

21. Benedetti N, Hope MD. Prevalence and significance of incidentally noted dilation of the ascending aorta on routine chest computed tomography in older patients. *Journal of computer assisted tomography*. 2015; 39:109–11. [PubMed: 25319605]
22. Hammond EC, Horn D. Smoking and death rates; report on forty-four months of follow-up of 187,783 men. I. Total mortality. *J Am Med Assoc*. 1958; 166:1159–72. [PubMed: 13513334]
23. Wilbanks TB, Quick CR, Day NE. The association between cigarette smoking and abdominal aortic aneurysms. *J Vasc Surg*. 1999; 30:1099–105. [PubMed: 10587395]
24. Guo DC, Papke CL, He R, Milewicz DM. Pathogenesis of thoracic and abdominal aortic aneurysms. *Ann N Y Acad Sci*. 2006; 1085:339–52. [PubMed: 17182954]
25. Parodi J, Berguer R, Carrascosa P, Khanafer K, Capunay C, Wizauer E. Sources of error in the measurement of aortic diameter in computed tomography scans. *J Vasc Surg*. 2014; 59:74–9. [PubMed: 23958070]

(A)

(B).

(C)

(D)

Figure 1.

Axial images showing the 4 levels of aortic diameter measurement. (A) Sinotubular junction and mid-descending aorta. (B) mid-ascending aorta (C) Transverse aortic arch (D) Diaphragmatic hiatus.

Figure 2.
Sagittal reconstruction of aorta showing the 5 levels of aortic diameter measurements.

Table 1

Baseline Demographic and Clinical Characteristics of the Main Study Population.

	Overall (n=322)		Female (n=145)		Male (n=177)		P value
	N	Estimate	N	Estimate	N	Estimate	
Age (yrs): Mean +/- Standard Deviation	322	61.7 +/- 5.1	145	61.3 +/- 5.0	177	62.0 +/- 5.3	0.215 9
BSA (m2): Mean +/- Standard Deviation	321 *	2.0 +/- 0.2	144	1.8 +/- 0.2	177	2.1 +/- 0.2	<.000 1
BMI (kg/m2): Mean +/- Standard Deviation	321 *	27.8 +/- 4.9	144	27.3 +/- 4.9	177	28.1 +/- 4.9	0.170 8
Smoking (pack-years): Mean +/- Standard Deviation	322	54.8 +/- 22.5	145	50.6 +/- 22.2	177	58.3 +/- 22.1	0.002 1
Current Smoker: Frequency (%)	322	163 (50.6%)	145	73 (50.3%)	177	90 (50.8%)	0.928 5
Diabetes: Frequency (%)	320	37 (11.6%)	144	10 (6.9%)	176	27 (15.3%)	0.019 5
Hypertension: Frequency (%)	322	117 (36.3%)	145	52 (35.9%)	177	65 (36.7%)	0.873 0

BSA = body surface area (Mosteller's method); BMI = body mass index.

* one patient did not report weight.

two patients did not report diabetes status.

Table 2

Measure (in centimeters) of Aortic Diameter at Various Anatomic Levels from Axial and Multiplanar Reformats in the Sagittal Oblique Plane

	Axial CT			Sagittal Oblique			Difference	
	N*	Mean	Standard Deviation	N**	Mean	Standard Deviation	N	P-value
Sinotubular junction	321	3.28	0.38	320	3.20	0.39	320	<.0001
Mid-Ascending Aorta	321	3.38	0.38	320	3.33	0.38	320	<.0001
Transverse Aorta	321	2.78	0.29	320	2.73	0.28	320	<.0001
Mid-Descending Aorta	321	2.59	0.29	320	2.62	0.28	320	<.0001
Diaphragmatic Hiatus	322	2.53	0.28	320	2.51	0.28	320	0.0241

* There are 321 observations reported in this table (as opposed to 322 in the analysis set) for all levels except Diaphragmatic Hiatus for Axial due to one image that only had a measurement for Diaphragmatic Hiatus on Axial.

** There are 320 observations reported for Sagittal Oblique (as opposed to 322 in the analysis set) due to two images (including the 1 mentioned in the previous footnote) that did not have any measurements recorded for the sagittal oblique plane.

Table 3

Association of aortic diameter with risk predictors from univariate analysis

(A) On axial image		Sinotubular junction			Mid-Ascending Aorta			Transverse Aortic Arch			Mid-Descending Aorta			Diaphragmatic Hiatus		
		Mean (Std. Dev.)	P Value		Mean (Std. Dev.)	P Value		Mean (Std. Dev.)	P Value		Mean (Std. Dev.)	P Value		Mean (Std. Dev.)	P Value	
Age Level	55-59	3.22 (0.38)	0.0593		3.29 (0.38)	0.0001		2.72 (0.26)	0.0056		2.50 (0.27)	<.0001		2.44 (0.26)	<.0001	
	60-64	3.33 (0.35)			3.40 (0.37)			2.81 (0.29)			2.60 (0.27)			2.53 (0.27)		
	65-74	3.32 (0.40)			3.50 (0.34)			2.83 (0.31)			2.71 (0.30)			2.64 (0.30)		
Gender	Male	3.39 (0.38)	<.0001		3.48 (0.36)	<.0001		2.87 (0.29)	<.0001		2.70 (0.28)	<.0001		2.64 (0.26)	<.0001	
	Female	3.15 (0.34)			3.27 (0.36)			2.68 (0.24)			2.46 (0.24)			2.40 (0.25)		
Region of Registering Site	Northeast	3.36 (0.37)	0.0724		3.41 (0.37)	0.5134		2.80 (0.29)	0.1316		2.60 (0.25)	0.7666		2.52 (0.26)	0.9740	
	Midwest	3.21 (0.40)			3.37 (0.40)			2.73 (0.26)			2.56 (0.27)			2.54 (0.27)		
	South	3.29 (0.38)			3.40 (0.37)			2.82 (0.29)			2.60 (0.30)			2.52 (0.29)		
	West	3.23 (0.35)			3.30 (0.34)			2.75 (0.29)			2.58 (0.38)			2.53 (0.35)		
Hypertension	Yes	3.37 (0.34)	0.0011		3.50 (0.36)	<.0001		2.84 (0.28)	0.0068		2.67 (0.29)	0.0003		2.58 (0.29)	0.0070	
	No	3.23 (0.39)			3.32 (0.37)			2.75 (0.29)			2.55 (0.28)			2.50 (0.28)		
Diabetes	Yes	3.43 (0.37)	0.0132		3.51 (0.35)	0.0279		2.87 (0.26)	0.0498		2.69 (0.32)	0.0190		2.61 (0.26)	0.0475	
	No	3.26 (0.38)			3.37 (0.38)			2.77 (0.29)			2.58 (0.29)			2.52 (0.28)		
Current Smoker	Yes	3.25 (0.36)	0.1428		3.37 (0.36)	0.3571		2.75 (0.28)	0.0452		2.57 (0.30)	0.2530		2.51 (0.30)	0.3055	
	No	3.31 (0.40)			3.40 (0.39)			2.82 (0.29)			2.61 (0.28)			2.54 (0.27)		
Pack-Year Groups	30 to < 40 pack years	3.27 (0.39)	0.1835		3.37 (0.40)	0.6383		2.77 (0.27)	0.6552		2.56 (0.29)	0.2755		2.47 (0.27)	0.0508	
	40 to < 50 pack years	3.21 (0.37)			3.34 (0.37)			2.78 (0.30)			2.57 (0.32)			2.52 (0.30)		
	50 to < 60 pack years	3.31 (0.35)			3.44 (0.39)			2.76 (0.32)			2.62 (0.27)			2.57 (0.29)		
	60 to < 70 pack years	3.35 (0.42)			3.40 (0.39)			2.75 (0.31)			2.57 (0.29)			2.50 (0.22)		
	70+ pack years	3.34 (0.38)			3.41 (0.35)			2.82 (0.26)			2.65 (0.26)			2.59 (0.28)		
BMI (Categorized)	At or Below Median	3.22 (0.36)	0.0013		3.31 (0.37)	0.0009		2.73 (0.27)	0.0002		2.53 (0.28)	<.0001		2.47 (0.28)	0.0004	
	Greater than Median	3.35 (0.39)			3.45 (0.37)			2.84 (0.29)			2.65 (0.29)			2.58 (0.28)		

(A) On axial image		Sinotubular junction		Mid-Ascending Aorta		Transverse Aortic Arch		Mid-Descending Aorta		Diaphragmatic Hiatus	
		Mean (Std. Dev.)	P Value	Mean (Std. Dev.)	P Value	Mean (Std. Dev.)	P Value	Mean (Std. Dev.)	P Value	Mean (Std. Dev.)	P Value
BSA (Mosteller Method) (Categorized)	At or Below Median	3.16 (0.35)	<.0001	3.25 (0.36)	<.0001	2.68 (0.24)	<.0001	2.47 (0.25)	<.0001	2.43 (0.27)	<.0001
	Greater than Median	3.41 (0.37)		3.52 (0.34)		2.89 (0.29)		2.71 (0.27)		2.63 (0.26)	
BSA (Dubois Method) (Categorized)	At or Below Median	3.16 (0.35)	<.0001	3.26 (0.36)	<.0001	2.68 (0.25)	<.0001	2.47 (0.25)	<.0001	2.42 (0.26)	<.0001
	Greater than Median	3.41 (0.37)		3.51 (0.35)		2.89 (0.28)		2.72 (0.27)		2.64 (0.27)	
(B) On multiplanar reformats in the sagittal oblique plane											
		Sinotubular junction		Mid-Ascending Aorta		Transverse Aortic Arch		Mid-Descending Aorta		Diaphragmatic Hiatus	
		Mean (Std. Dev.)	P Value	Mean (Std. Dev.)	P Value	Mean (Std. Dev.)	P Value	Mean (Std. Dev.)	P Value	Mean (Std. Dev.)	P Value
Age Level	55-59	3.13 (0.39)	0.0407	3.21 (0.38)	<.0001	2.65 (0.25)	<.0001	2.54 (0.27)	<.0001	2.43 (0.27)	<.0001
	60-64	3.22 (0.36)		3.35 (0.37)		2.75 (0.27)		2.62 (0.26)		2.52 (0.26)	
	65-74	3.26 (0.41)		3.46 (0.35)		2.81 (0.32)		2.72 (0.27)		2.61 (0.28)	
Gender	Male	3.32 (0.38)	<.0001	3.41 (0.37)	<.0001	2.83 (0.26)	<.0001	2.72 (0.26)	<.0001	2.60 (0.26)	<.0001
	Female	3.05 (0.35)		3.22 (0.38)		2.61 (0.26)		2.49 (0.24)		2.40 (0.26)	
Region of Registering Site	Northeast	3.24 (0.41)	0.5057	3.35 (0.37)	0.7311	2.75 (0.26)	0.5260	2.64 (0.23)	0.3351	2.51 (0.27)	0.9552
	Midwest	3.15 (0.38)		3.30 (0.44)		2.69 (0.27)		2.57 (0.26)		2.52 (0.25)	
	South	3.21 (0.39)		3.33 (0.37)		2.74 (0.30)		2.64 (0.29)		2.50 (0.28)	
	West	3.18 (0.35)		3.29 (0.32)		2.74 (0.33)		2.62 (0.35)		2.51 (0.34)	
Hypertension	Yes	3.27 (0.38)	0.0131	3.42 (0.39)	0.0014	2.78 (0.28)	0.0136	2.70 (0.26)	<.0001	2.58 (0.28)	0.0011
	No	3.16 (0.39)		3.27 (0.37)		2.70 (0.28)		2.58 (0.27)		2.47 (0.27)	
Diabetes	Yes	3.32 (0.37)	0.0495	3.41 (0.36)	0.1563	2.81 (0.29)	0.0546	2.73 (0.27)	0.0109	2.63 (0.27)	0.0054
	No	3.18 (0.39)		3.31 (0.39)		2.72 (0.28)		2.60 (0.27)		2.49 (0.27)	
Current Smoker	Yes	3.16 (0.38)	0.0699	3.31 (0.35)	0.4105	2.71 (0.27)	0.1349	2.61 (0.28)	0.5675	2.51 (0.28)	0.8948
	No	3.24 (0.40)		3.34 (0.41)		2.75 (0.30)		2.63 (0.27)		2.51 (0.27)	
Pack-Year Groups	30 to < 40 pack years	3.17 (0.41)	0.5227	3.33 (0.40)	0.8397	2.73 (0.29)	0.3175	2.59 (0.26)	0.1098	2.46 (0.27)	0.0549
	40 to < 50 pack years	3.16 (0.37)		3.29 (0.39)		2.69 (0.29)		2.58 (0.29)		2.50 (0.30)	

(A) On axial image		Sinotubular junction		Mid-Ascending Aorta		Transverse Aortic Arch		Mid-Descending Aorta		Diaphragmatic Hiatus	
		Mean (Std. Dev.)	P Value	Mean (Std. Dev.)	P Value	Mean (Std. Dev.)	P Value	Mean (Std. Dev.)	P Value	Mean (Std. Dev.)	P Value
	50 to < 60 pack years	3.25 (0.39)		3.34 (0.39)		2.71 (0.31)		2.68 (0.31)		2.53 (0.30)	
	60 to < 70 pack years	3.20 (0.43)		3.32 (0.37)		2.71 (0.26)		2.58 (0.25)		2.47 (0.23)	
	70+ pack years	3.24 (0.38)		3.36 (0.37)		2.78 (0.26)		2.67 (0.25)		2.58 (0.26)	
BMI (Categorized)	At or Below Median	3.12 (0.37)	0.0004	3.28 (0.37)	0.0304	2.69 (0.28)	0.0295	2.56 (0.26)	<.0001	2.46 (0.27)	0.0006
	Greater than Median	3.27 (0.40)		3.37 (0.39)		2.76 (0.28)		2.68 (0.28)		2.56 (0.28)	
BSA (Mosteller Method) (Categorized)	At or Below Median	3.08 (0.37)	<.0001	3.21 (0.37)	<.0001	2.63 (0.26)	<.0001	2.51 (0.24)	<.0001	2.41 (0.27)	<.0001
	Greater than Median	3.32 (0.37)		3.44 (0.36)		2.83 (0.27)		2.73 (0.26)		2.61 (0.25)	
BSA (Dubois Method) (Categorized)	At or Below Median	3.08 (0.37)	<.0001	3.22 (0.37)	<.0001	2.62 (0.26)	<.0001	2.50 (0.24)	<.0001	2.41 (0.25)	<.0001
	Greater than Median	3.32 (0.37)		3.43 (0.36)		2.84 (0.26)		2.74 (0.26)		2.62 (0.26)	

Table 4

Association of aortic diameter with risk predictors from multivariate analysis, controlling for the effect of Reader.

Predictor	Level	Estimate	Standard Error	P-Value
Intercept	–	3.2813	0.0320	<.0001
Aortic view	Sagittal oblique	-0.0383	0.0046	<.0001
	Axial	Referent Group	-	-
Aortic level	Diaphragmatic Hiatus	-0.7500	0.0213	<.0001
	Mid Descending	-0.6598	0.0213	<.0001
	Transverse	-0.4915	0.0213	<.0001
	Mid Ascending	0.0939	0.0213	<.0001
	Sinotubular junction	Referent Group	-	-
Age (Centered)	–	0.0156	0.0024	<.0001
Gender	Female	-0.1185	0.0295	<.0001
	Male	Referent Group	-	-
BSA (Mosteller method) (Centered)	–	0.4157	0.0631	<.0001
Hypertension	Yes	0.0540	0.0257	0.0360
	No	Referent Group	-	-
Diabetes	Yes	-0.0427	0.0387	0.2694
	No	Referent Group	-	-
Smoking status	Current smoker	-0.0181	0.0308	0.5580
	Former smoker	Referent Group	-	-
Smoking history (pack-year)	–	-0.0003	0.0007	0.6733
Interaction: Aortic level X Smoking status	Diaphragmatic Hiatus & Current smoker	0.0541	0.0298	0.0693
	Mid Descending & Current smoker	0.0462	0.0298	0.1210
	Transverse & Current smoker	0.0142	0.0298	0.6326
	Mid Ascend & Current smoking	0.0359	0.0298	0.2279
	Sinotubular junction & Current smoker	Referent Group	-	-
Interaction: Aortic level X Smoking history	Diaphragmatic Hiatus	0.0008	0.0007	0.2376
	Mid Descending	0.0000	0.0007	0.9867
	Transverse	-0.0003	0.0007	0.6743
	Mid Ascend	-0.0004	0.0007	0.5345
	Sinotubular junction	Referent Group	-	-

Table 5

Mean and upper limits of normal thoracic aortic diameters and aortic aneurysm thresholds in NLST participants, by sex and body surface area *. A thoracic aorta measuring between upper limit of normal and the threshold for aortic aneurysm should be described as dilated.

a) Men												
Age	Mean aortic diameter (cm)				Upper limit of normal (mean + 2 s.d.) (cm)				Aortic aneurysm threshold (1.5 × mean diameter) (cm)			
	55-59	60-64	65-69	70-74	55-59	60-64	65-69	70-74	55-59	60-64	65-69	70-74
Sinotubular junction												
Any BSA	3.32	3.44	3.44	3.46	4.09	4.08	4.24	4.31	4.98	5.15	5.15	5.19
BSA < 1.7 m2	3	3.4	NA**	NA	NA***	NA	NA	NA	4.5	5.1	NA	NA
1.70 – < 1.89 m2	3.16	3.27	3.15	3.45	3.9	3.75	NA	4.23	4.74	4.91	4.72	5.18
1.89– < 2.09 m2	3.33	3.38	3.42	3.35	4.11	4.06	4.07	4.11	5	5.06	5.14	5.03
>=2.09 m2	3.38	3.51	3.5	3.7	4.16	4.15	4.37	NA	5.07	5.26	5.25	5.55
Mid-ascending aorta												
Any BSA	3.37	3.5	3.64	3.57	4.1	4.22	4.31	4.14	5.06	5.25	5.46	5.35
BSA < 1.7 m2	3.2	3	NA	NA	NA	NA	NA	NA	4.8	4.5	NA	NA
1.70 – < 1.89 m2	3.23	3.25	3.4	3.57	4.15	3.83	NA	4.03	4.84	4.88	5.1	5.35
1.89– < 2.09 m2	3.34	3.47	3.56	3.5	3.98	4.26	4.06	4.12	5.01	5.21	5.34	5.25
>=2.09 m2	3.47	3.58	3.77	3.7	4.19	4.24	4.53	NA	5.21	5.37	5.66	5.55
Transverse aorta												
Any BSA	2.78	2.89	2.95	3	3.3	3.5	3.53	3.52	4.17	4.33	4.42	4.49
BSA < 1.7 m2	2.4	2.6	NA	NA	NA	NA	NA	NA	3.6	3.9	NA	NA
1.70 – < 1.89 m2	2.61	2.61	2.45	2.92	2.93	2.99	NA	3.41	3.92	3.92	3.68	4.38
1.89– < 2.09 m2	2.8	2.86	2.94	2.95	3.29	3.55	3.54	3.49	4.19	4.3	4.42	4.43
>=2.09 m2	2.85	2.98	3.03	3.18	3.38	3.52	3.47	NA	4.28	4.46	4.55	4.77
Mid-descending aorta												
Any BSA	2.59	2.7	2.81	2.86	3.16	3.17	3.41	3.35	3.89	4.05	4.21	4.29
BSA < 1.7 m2	2.2	2.7	NA	NA	NA	NA	NA	NA	3.3	4.05	NA	NA
1.70 – < 1.89 m2	2.43	2.51	2.5	2.78	2.83	3.03	NA	2.98	3.64	3.77	3.75	4.17
1.89– < 2.09 m2	2.58	2.75	2.78	2.83	3.02	3.28	3.3	3.27	3.87	4.13	4.17	4.25

a) Men									
	Mean aortic diameter (cm)			Upper limit of normal (mean + 2 s.d.) (cm)			Aortic aneurysm threshold (1.5 × mean diameter) (cm)		
	55-59	60-64	65-69	70-74	55-59	60-64	65-69	70-74	70-74
Age									
>=2.09 m2	2.68	2.71	2.89	3	3.35	3.12	3.58	NA	4.5
Diaphragmatic hiatus									
Any BSA	2.53	2.63	2.76	2.81	3.04	3.08	3.22	3.32	4.21
BSA < 1.7 m2	2	2.5	NA	NA	NA	NA	NA	NA	NA
1.70 – < 1.89 m2	2.38	2.56	2.7	2.85	2.69	3.04	NA	3.22	4.28
1.89 – < 2.09 m2	2.54	2.68	2.74	2.72	3	3.18	3.17	3.04	4.08
>=2.09 m2	2.59	2.63	2.79	2.94	3.15	3.05	3.27	NA	4.41
b) Women									
	Mean aortic diameter (cm)			Upper limit of normal (mean + 2 s.d.) (cm)			Aortic aneurysm threshold (1.5 × mean diameter) (cm)		
	55-59	60-64	65-69	70-74	55-59	60-64	65-69	70-74	70-74
Age									
Sinotubular junction									
Any BSA	3.12	3.17	3.11	3.29	3.83	3.82	3.86	3.81	4.94
BSA < 1.7 m2	2.99	3.12	3.05	3.25	3.61	3.98	3.98	3.7	4.88
1.70 – < 1.89 m2	3.09	3.15	3.09	3.23	3.66	3.76	3.79	NA	4.84
1.89 – < 2.09 m2	3.22	3.22	3.19	3.25	4.18	3.58	3.82	NA	4.88
>=2.09 m2	3.26	3.38	3.25	3.9	NA	NA	NA	NA	5.85
Mid-ascending aorta									
Any BSA	3.19	3.27	3.35	3.44	3.97	3.97	3.95	4.12	5.16
BSA < 1.7 m2	3.07	3.22	3.25	3.42	3.85	3.86	3.88	3.86	5.12
1.70 – < 1.89 m2	3.18	3.19	3.34	3.3	3.98	3.99	3.79	NA	4.95
1.89 – < 2.09 m2	3.23	3.33	3.41	3.3	3.95	3.73	4.05	NA	4.95
>=2.09 m2	3.48	3.62	3.6	4.4	NA	NA	NA	NA	6.6
Transverse aorta									
Any BSA	2.66	2.71	2.63	2.78	3.14	3.15	3.15	3.2	4.17
BSA < 1.7 m2	2.6	2.66	2.59	2.82	2.99	3.13	2.88	3.01	4.22
1.70 – < 1.89 m2	2.63	2.66	2.63	2.8	3.16	3.1	3.29	NA	4.2
1.89 – < 2.09 m2	2.71	2.82	2.62	2.5	3.2	3.11	3.33	NA	3.75

a) Men											
	Mean aortic diameter (cm)				Upper limit of normal (mean + 2 s.d.) (cm)				Aortic aneurysm threshold (1.5 × mean diameter) (cm)		
	55-59	60-64	65-69	70-74	55-59	60-64	65-69	70-74	55-59	60-64	65-69
Age											
>=2.09 m2	2.78	2.9	2.8	3	NA	NA	NA	NA	4.17	4.35	4.2
Mid-descending aorta											
Any BSA	2.4	2.46	2.53	2.63	2.83	2.96	3.08	3.01	3.6	3.68	3.79
BSA < 1.7 m2	2.26	2.37	2.38	2.57	2.63	2.97	2.72	2.81	3.4	3.55	3.57
1.70 – < 1.89 m2	2.35	2.41	2.56	2.65	2.71	2.81	3.33	NA	3.53	3.62	3.84
1.89 – < 2.09 m2	2.51	2.6	2.62	2.75	2.9	3.04	3.11	NA	3.77	3.9	3.94
>=2.09 m2	2.64	2.73	2.75	2.7	NA	NA	NA	NA	3.96	4.09	4.12
Diaphragmatic hiatus											
Any BSA	2.35	2.4	2.44	2.52	2.81	2.91	3.04	2.98	3.53	3.59	3.66
BSA < 1.7 m2	2.23	2.3	2.23	2.47	2.56	2.93	2.48	2.77	3.34	3.45	3.34
1.70 – < 1.89 m2	2.32	2.39	2.59	2.48	2.63	2.8	3.34	NA	3.48	3.59	3.88
1.89 – < 2.09 m2	2.41	2.5	2.5	2.75	2.91	3.05	3.08	NA	3.62	3.75	3.75
>=2.09 m2	2.66	2.58	2.7	2.5	NA	NA	NA	NA	3.99	3.86	4.05

* as measured on axial CT images, using Mosteller Body surface area (BSA) calculation

** NA values were caused by missing observations in that category.

*** Where there were fewer than 6 observations in a category, SD was not calculated and the upper limit was reported as “NA” (Wolak et al 2008).