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Aortic Knob Diameter in Chest Radiographs of Healthy Adults in Uganda

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Background: The burden of cardiovascular diseases, such as aortic and degenerative diseases, grows in the aging population. Chest radiograph still plays an important role in the diagnosis of cardiovascular diseases. Aortic knob diameter in chest radiographs can be used to evaluate early changes of the aortic structure and together with clinical and laboratory findings. This study was aimed at determining the mean values of aortic knob diameter among healthy adults in Uganda.

Methods: We conducted a descriptive cross-sectional study in three selected hospitals in Kampala Uganda. All participants had normal chest radiographs without radiological evidence of cardiovascular disease. Chest radiograph findings extracted included aortic knob diameter, aortic arch diameter, transverse heart diameter, and transverse thoracic diameter. All films were independently examined by two experienced radiologists.

Results: We analyzed chest radiograph findings of 294 participants, of which 204 (69.4%) were male. Aortic knob diameter increased with age ($p = 0.000$). The mean aortic knob diameter of males was higher than for females (3.14 ± 0.34 cm versus 2.77 ± 0.37 cm, $p = 0.000$). The mean aortic knob diameter on the digital screen was higher than plain films (3.03 ± 0.393 cm versus 2.96 ± 0.392 cm, $p = 0.000$). Aortic knob diameter positively correlated with age ($p = 0.000$) and aortic arch diameter ($p = 0.000$). Aortic knob diameter also correlated positively with a transverse thoracic diameter ($p = 0.05$), transverse heart diameter ($p = 0.05$), and cardiothoracic ratios ($p = 0.05$).

Conclusion: The aortic knob diameter was higher in males and there was a positive correlation with age, aortic arch diameter, transverse heart diameter, and transverse thoracic diameter. Aortic knob diameter measurements should be done on digital rather than printed x-ray films.

Keywords: aortic knob, diameter, chest radiograph, cardiovascular, Uganda

Background

Cardiovascular disease accounts for three-quarters of all global estimated deaths in low- and middle-income countries.¹ Chest radiograph remains an important tool for the investigation of cardiovascular conditions despite the advent of newer and more sophisticated imaging modalities such as echocardiography, computerized tomography (CT), and magnetic resonance imaging (MRI) in the world.² This is mainly due to the more readily available and comparatively cheaper costs of performing a chest radiograph and still provides valuable clues to the diagnosis of cardiovascular pathology.³ Moreover, the reproducibility of aortic and heart measurements on chest radiographs has been described in the literature.^{4,5}

The aorta is a major vascular supply of the human body and plays an important role in controlling systemic vascular resistance and heart rate. This control is done via pressure-responsive receptors located in the ascending aorta and aortic arch.⁶ An increase and decrease in aortic pressure results in a decrease in heart rate and systemic vascular resistance and an increase in heart rate and systemic vascular resistance, respectively.⁷

The Aortic knob is an important structure that refers to the hump-shaped contour of the aorta seen in a frontal chest radiograph on the left mediastinal silhouette.⁸ Abnormal aortic knuckle shape, enlargement, and aortic nipple may give cardiovascular disease the first clue.⁹ The aortic knob can be enlarged due to increased pressure or flow in the aorta,

increased volume, or changes in the elasticity of its wall. In adults, aortic knob enlargement can be seen in systemic hypertension, valvular insufficiency, aortic dissection, traumatic aortic injury, thoracic aortic aneurysm, and atherosclerosis.¹⁰

Aortic knob diameter (AKD) is a good predictor of target organ damage with a sensitivity ranging between 70% to 90% for hypertension-related cardiovascular conditions, even in early disease.¹¹ These include hypertensive heart disease, subclinical atherosclerosis, aneurysms, and aortic dissection.¹² Moreover, aortic knob width is positively correlated with both systolic and diastolic blood pressures.^{12–14}

Uganda is a low-income country and yet is experiencing a shift in major causes of death with coronary artery disease and other forms of heart failure on the rise.¹⁵ And the normal AKD in the literature was taken from studies done among Caucasians,¹⁶ Americans,¹² South Koreans, Indians, and West Africans. These studies showed that variations exist amongst different populations, age groups, and between sexes.¹⁷ In the current practice, more advanced imaging modalities are recommended to measure the AKD,¹⁸ however, this is not always feasible in low-income settings like Uganda due to the availability of the modalities and cost-effectiveness. In this study, therefore, we sought to determine the normal AKD amongst healthy adults in Uganda.

Methods

Study Design and Setting

This was a descriptive cross-sectional study conducted in three selected tertiary hospitals in Kampala, Uganda from January 2020 to June 2020. Hospital A is a private tertiary referral hospital with a capacity of 361 beds and approximately 450 chest radiographs were performed per month. Hospital B is also a tertiary public hospital where chest radiographs were performed as part of ongoing recruitment in government agencies like police, the army, and local governments. Hospital C is a private, tertiary hospital and around 100 chest radiographs were performed per month.

Study Population

Study participants included asymptomatic participants referred for chest radiograph examination for pre-employment and pre-travel medical check-ups and were recruited in this study. Participants with a normal chest radiograph (Posterior anterior view, erect), and age between 18–90 years, with no thoracic skeletal deformity, no known cardiovascular disease, and normal blood pressure for age (blood pressure chart) were included in the study. Participants whose chest radiographs had significant rotation (>0.5cm) or artifacts were excluded from the study.

Sample Size

A sample size of 294 participants was used using the formula proposed by Rosner B. 2015¹⁹ as summarized below.

$$N = (Z_{\alpha/2} + Z_{\beta})^2 * 2 * \sigma^2 / d^2$$

Where N = sample size required. $Z_{\alpha/2}$ = is the critical value of the Normal distribution at $\alpha/2$ (eg for a confidence level of 95%, α is 0.05 and the critical value is 1.96), Z_{β} = is the critical value of the Normal distribution at β (eg for a power of 80%, β is 0.2 and the critical value is 0.84), σ^2 = is the population variance, d = desired level of precision/marginal error.¹ Based on a cross-sectional study done by Ray et al 2014 in the Indian population²⁰ where the mean and standard deviation of the aortic diameter was 3.04±4.1 among the male and female population, population variance was taken as 4.1.

$$N = (1.96 + 0.84)^2 * 2 * (4.1)^2 / (1)^2 = 264. \text{ Non-response of 10\% was 30. Hence the sample size was 294.}$$

Study Procedure

Study participants who gave their consent were physically examined and enrolled in the study. A total of 294 participants' posteroanterior (PA) chest radiographs were obtained. The PA chest radiograph of all the candidates was taken in the erect position with a film focus distance of 1.8m. The exposures were made at normal arrested inspiration. Participants' names, sex, age, height, and medical history were recorded. A normal chest radiograph was confirmed by two independent radiologists. Parameters such as AKD, transverse thoracic diameter (TTD), and transverse heart

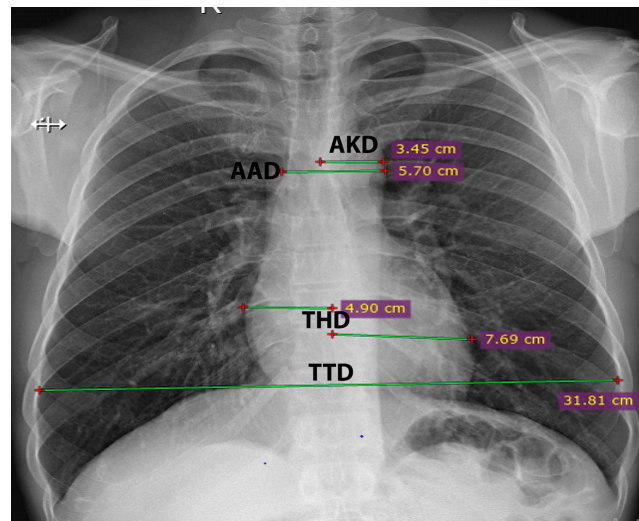


Figure 1 Chest x-ray measurements, aortic knob diameter denoted AKD, aortic arch diameter denoted by AAD, transverse heart diameter denoted by THD (summation of the upper and the lower measurements), and transverse thoracic diameter denoted by TTD.

diameter (THD) were evaluated for each patient (Figure 1). The AKD was measured as the maximum transverse diameter from the lateral border of the air in the trachea to the lateral border of the aortic knob.¹⁶ The measurements were done on both the printed films and screens independently for all study participants. The Aortic arch diameter (AAD) was measured as the most lateral extension to the right and left of the midline at the level of the aortic knob. TTD was measured as the maximum horizontal distance between the internal margins of the chest wall at the level of the right hemidiaphragm.^{21,22} THD was measured as the sum of the maximum projection to the right and left heart borders from the midline.^{21,22} The measurements were done using a standard metric ruler of 30 cm long for the measurements that were taken from printed films and a DICOM viewer inbuilt measurement ruler for the measurements that were taken from screens.

Data Analysis

A structured data collection tool was used to collect bio-demographics and relevant history (Appendix 1). Data were analyzed using STATA version 16. Descriptive statistics for continuous variables were presented as mean and standard deviation. Spearman rank correlation was used to test for the correlation between the aortic diameter measurements with continuous independent variables. In addition, a Student's *t*-test was performed to test for the mean difference of AKD between groups. A $p < 0.05$ was considered statistically significant.

Results

A total of 294 participants, of whom 204 (69.4%) were male and the age range between 18–89 years were recruited in the study. Overall, 196 (66.7%) participants were attending the hospital for a pre-employment medical exam, 92 (31.3%) came for annual medical checkup exams, and 6 (2%) pre-travel exams. The mean age of the participants was 35.3 ± 10.5 . Sex distribution in the different age ranges is shown in Table 1.

Male participants had significantly higher mean AKD compared to their female counterparts (3.14 ± 0.34 cm versus 2.77 ± 0.37 cm, $p = 0.000$). Those in the age group of 50–59 years had significantly higher means than younger people in the age group of 18–29 years (Table 2). Females aged 18–29 years have lower mean AKD compared to men in the same age groups. Overall, male patients had higher AKD when compared with females of all age categories (Figure 2).

Multivariate regression analysis among different age groups demonstrated increased AKD in older participants compared to the younger participant ($p < 0.001$). Moreover, males had larger AKD than their female counterparts ($p < 0.001$). But no difference among the different hospitals was seen (Table 3).

Table 1 Age Distribution of the Participants

Age Category	Female (N, %)	Male (N, %)	Total (N, %)
18–29 years	40 (39.6)	61 (60.4)	101 (34.4)
30–39 years	27 (29.4)	65 (70.6)	92 (31.3)
40–49 years	15 (20.6)	58 (79.4)	73 (24.8)
50–59 years	7 (28.0)	18 (72.0)	25 (8.5)
≥60 years	1 (33.3)	2 (66.7)	3 (1.0)
Total	90 (30.6)	204 (69.4)	294 (100)

Table 2 The Mean Aortic Knob Diameter of 294 Participants

Variables	Frequency N=294	Mean ± SD /cm	P-value
Gender			
Male	204	3.14±0.34	< 0.001
Female	90	2.77±0.37	
Age category			
18–29 years	101	2.76±0.34	< 0.001
30–39 years	92	3.01±0.30	
40–49 years	73	3.26±0.33	
50–59 years	25	3.43±0.30	
≥60 years	3	3.34±0.56	

The average AKD of the sample population was 3.03±0.39cm, the smallest was 2.2cm and the largest was 4.1 cm. The mean AAD of the study population was 5.63±0.64cm and the average cardiothoracic ratio is 0.446±0.037 with the highest being 0.522cm and the lowest 0.366cm (Table 4).

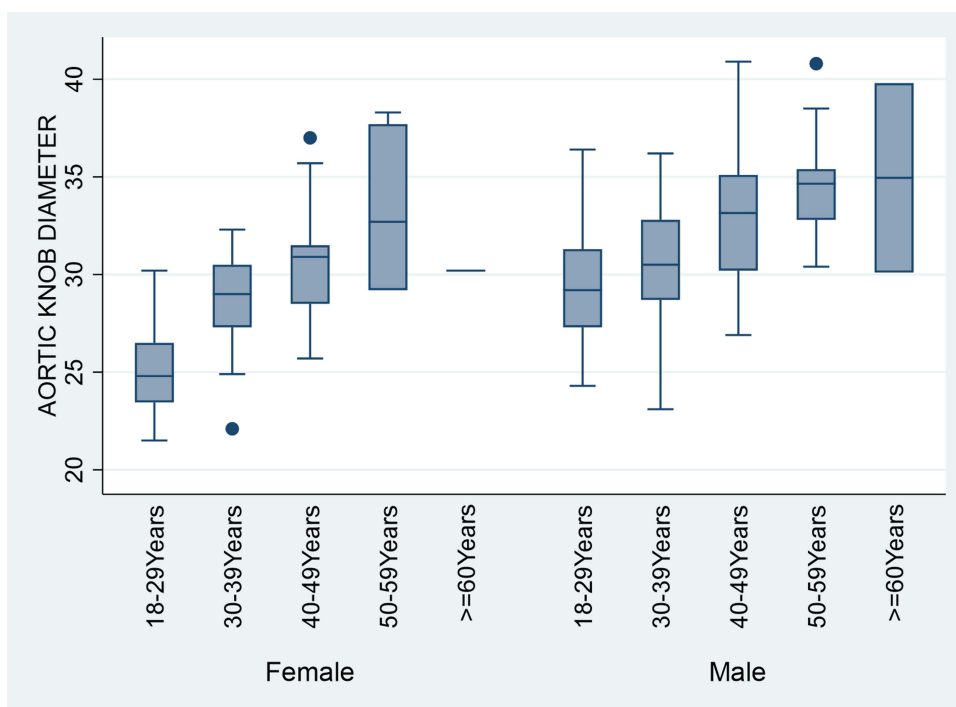


Figure 2 Box and whisker plot showing participants' age-group and gender-specific aortic knob diameters.

Table 3 Multivariate Regression Analysis for the Association Between the Aortic Knob Diameters and Other Parameters

Variables	Adjusted Coefficient and 95% CI	Standard Error	P-value
Age category			
18–29 years	1.00		
30–39 years	2.19 (1.35,3.03)	0.42	<0.001
40–49 years	4.42 (3.47,5.37)	0.48	<0.001
50–59 years	6.30 (4.94,7.66)	0.69	<0.001
≥60 years	5.54 (0.95,10.13)	2.33	<0.001
Sex			
Female	1.00		
Male	3.11 (2.38–3.85)	8.33	<0.001
Hospital of recruitment			
Hospital C	1.00		
Hospital B	–0.01 (–1.17,1.16)	–0.1	0.993
Hospital A	–0.19 (–0.99,0.61)	–0.638	0.638

Table 4 Other Cardiovascular Parameters on Chest X-Ray for 294 Participants

Variables (Unit Measures)	N	Mean ± SD	Minimum	Maximum
Aortic knob diameter (cm)	294	3.03±0.39	2.2	4.1
Aortic arch diameter (cm)	294	5.63±0.64	4.11	7.63
Transverse heart diameter (cm)	294	12.97±1.26	10.03	16.43
Transverse thoracic diameter (cm)	294	29.07±2.78	27.4	36.89
Cardiothoracic ratio	294	0.446±0.037	0.366	0.522

Weight and height were weakly correlated though positively associated with the aortic knob diameter across both genders. However, it was all higher among the female counterpart and the relationships were not statistically significant at a 95% confidence level (Table 5).

AKD was strongly and more positively correlated with age among the females than in males, the coefficient was higher among the females and the relationship was statistically significant at 95% confidence level $r=0.7411$ p-value <0.001 for females vs $r=0.5191$ p-value <0.001 for males. A strong positive correlation was also observed between the AKD and AAD for both males and females. However, AKD was weakly correlated with THD, TTD, and cardiothoracic ratio respectively (Table 5).

The mean AKD was higher when the measurement was done on a digital screen than on the chest radiograph film (3.03±0.393 cm versus 2.96±0.392cm, $p = 0.000$). However, the males still had significantly higher AKD compared to females and a unit increase in age would also increase the AKD (Table 6).

Discussion

The best way to measure aortic knob diameter is using cross-sectional imaging.¹⁸ However, the easy accessibility and comparatively cheaper cost of acquiring chest radiography and higher cost, and lack of easy access to cross-sectional imaging in our setting make it harder to use the latter. Therefore, this study sought to determine the aortic knob diameter in chest radiographs of healthy adults in Uganda. The results of our study showed that AKD increases with age in both sexes. This can be explained by geometric and functional alterations seen with aging.^{23,24} Studies in India, Nigeria, Zambia, the United States, and South Korea also showed similar results.^{12,13,20,25,26}

Table 5 Correlation of the Aortic Knob Diameter with Aortic Arch Diameter, the Transverse Diameter of the Chest, and Heart Diameter for Male and Female Population (Spearman Correlation and Pearson's Correlation)

Variables (Unit Measures)	Age (Years) (R)	AAD (cm) (r)	THD (cm) (r)	TTD (cm) (r)	Cardiothoracic Ratio (cm) (r)	Height	Weight
Male AKD (cm)	0.5191*	0.6451*	0.4671*	0.2245*	0.3019*	0.0228	0.0620
Female AKD (cm)	0.7411*	0.7001*	0.5058*	0.3840*	0.261*	0.1499	0.1585

Notes: Pearson's correlation coefficients (r), Spearman correlation (R), * correlation is significant at the 0.05 level.

Table 6 The Aortic Knob Diameter Measurement on Digital Screen and X-Ray by Gender and Age Groups of 294 Participants

Variables	n=294	AKD in Digital Screen Mean ± SD /mm	P-value	AKD in X-Ray Film Mean ± SD /mm	P-value
AKD	294	3.03±0.393		2.96±0.392	< 0.001
Gender					
Male	204	3.14±0.34	0.000	3.08±0.37	< 0.001
Female	90	2.77±0.37		2.70±0.37	
Age category					
18–29 years	101	2.76±0.34	0.000	2.71±0.24	< 0.001
30–39 years	92	3.01±0.30		2.92±0.27	
40–49 years	73	3.26±0.33		3.20±0.37	
50–59 years	25	3.43±0.30		3.39±0.47	
≥60 years	3	3.34±0.56		3.67±0.58	

AKD was higher in males than in females. Among males, the mean average diameter of the aortic knob was 3.14 ±0.34 cm. A population-based large cohort study in the Netherlands showed that men had higher mean thoracic aorta diameter than women but provided no explanation as to why.²⁷ Mean AKD findings in the Indian population²⁰ and South Korean population¹³ were comparable with our findings (3.10 cm±0.334 cm and 3.42±0.478 respectively). The mean aortic knob diameter among females was 2.77±0.37. This value was smaller in comparison to the value obtained in the Indian²⁰ study of 3.076 cm±0.39 cm and the south Korean¹³ study of 3.00±0.498 (Table 7).

The mean aortic knob and arch diameters were higher in males than females which is consistent with the findings of Ikeme et al²⁸ and Ray et al.²⁰ On the contrary, a study done in Jamaica reported a higher aortic arch size in females than males.²⁹ These findings were attributed to the higher blood pressures in females than males.²⁹

Kim and Choi observed that an aortic knob diameter (AKD) width of more than 4 cm occurred more frequently in patients with the thoracic aortic disorder as compared to normal subjects.³⁰ In this study, there was no female with an AKD > 4cm but there were 2 males whose AKD was slightly above 4cm measured on the digital screen. These were healthy males with no cardiovascular disease and normal blood pressure for age.

The AAD is another measurement for evaluation of the size of the aorta on chest radiograph.³¹ In this study, the mean of the AAD was 5.6 ±0.64cm. This value is comparable to other values in different studies by Yousef and colleagues in Sudan³² 5.3±0.6, and 5.3 by Umerah in Zambia.²⁶ Anyanwu and Agwuna measured the width of the aortic shadow as the sum of the maximum extension of the aortic shadow to the right and left of the midline and found the mean of AAD varied between 4.7±0.5 cm in the Nigerian population.³³

The mean THD and mean TTD were 12.9±12.6 cm and 29.07±2.78cm respectively. This was comparable to 11.9 ± 9 cm of mean THD and 27.8± 7cm of mean TTD in the Sudanese population.³² This means, our study population had a higher mean of transverse heart and thoracic diameters. In Sudanese and Nigerian studies, aortic knob diameter correlated positively with chest and heart diameters.^{25,32}

In this study, we found that there was a slightly higher mean AKD when measurements were done on a digital screen than on the x-ray films and the difference was statistically significant. This can be explained by the fact that digital measurements on screens are correct to the nearest millimeter, which may be difficult to achieve on plain films due to

Table 7 Comparison of Aortic Knob Diameters in Different Populations

Authors	Country	Mean AKD/cm
Ray et al, 2014	India	Overall- 3.04 cm±0.41 Male - 3.10 cm±0.334 Female - 3.076±0.39 cm
Felson, 1973	United States of America	3.0 cm
Lee et al, 2018	South Korea	Mean overall –3.30±0.334 Males- 3.42±0.478 cm Females –3.00±0.498 cm
Rayner et al, 2004	United States of America	Normotensives –3.28 cm Hypertensives –3.69 cm
Magera et al, 2020	Uganda	Overall- 3.03±0.39 cm Male- 3.14±0.34 cm Female- 2.77±0.37 cm.

approximation. Hence, in practice, measurements should be done on a digital screen rather than x-ray films. This study also demonstrated that weight and height did not significantly affect the size of the aortic knob.

The strengths of our study include being a prospective study with a relatively large sample size and its multi-centric nature. The limitation of the study was that it was a hospital-based study which could introduce selection bias. Moreover, the number of female participants was much smaller than the number of male counterparts.

Conclusions and Recommendations

The aortic knob diameter was higher in males and there was a positive correlation with age, aortic arch diameter, transverse heart diameter, and transverse thoracic diameter. We recommend aortic knob diameter measurements should be done on a digital screen than printed x-ray films and sex-specific aortic knob diameters should be utilized in clinical practice.

Abbreviations

AAD, aortic arch diameter; AKD, aortic knob diameter; THD, transverse heart diameter; PA, postero-anterior; TTD, transverse thoracic diameter.

Data Sharing Statement

The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

Ethics Approval and Consent to Participate

Written informed consent was obtained from all participants to participate in the study. Ethical approval was obtained from the Makerere University School of Medicine Research and Ethics committee and administrative clearance was sought from the three hospitals. The study complies with the Declaration of Helsinki.

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Author Contributions

All authors made a significant contribution to the study by participating in its conception, study design, execution, acquisition of data, analysis, and interpretation of the study results. The further all participated in the drafting, revising,

and critically reviewing the article; gave final approval of the version to be published; have agreed on the journal to which the article has been submitted; and agreed to be accountable for all aspects of the work.

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Disclosure

The authors declare that they have no competing interests in this work.

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