PREVALENCE OF AORTIC ARCH ANATOMICAL BRANCHING VARIANTS IN KENYAN POPULATION AS SHOWN ON CONTRAST ENHANCED CHEST MULTIDETECTOR COMPUTED TOMOGRAPHY (MDCT) A CROSS-SECTIONAL STUDY DONE AT THE RADIOLOGY DEPARTMENT OF KENYATTA NATIONAL HOSPITAL

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H58/67870/2013

A DISSERTATION SUBMITTED IN PARTIAL FULFILLMENT OF REQUIREMENT FOR THE DEGREE IN MASTERS OF MEDICINE IN DIAGNOSTIC RADIOLOGY AWARD

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SUPERVISOR’S APPROVAL

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ACKNOWLEDGEMENT

I am extremely grateful to my supervisor and chairman of the department of diagnostic imaging and radiation medicine of UoN Dr. Gladys Mwango for the expertise, guidance and encouragement she gave me throughout the duration of the study. My gratitude goes to the **Head of Department, Consultant Radiologists, Radiographers** and all staff of the Radiology Department of Kenyatta National Hospital for their support during the period of study. My special gratitude goes to **Dr Beatrice Mugi** (consultant radiologist KNH Radiology Department) who studied all the images obtained to confirm the AA configuration. Among the Radiographers I wish to point out **Mr. Eric Sunera** who was in charge of my Research assistants. My gratitude also goes to **Mr. Philip Ayieko** who offered statistical assistance especially in the analysis of the data. I thank my fellow resident doctors for their encouragement. My gratitude also goes to my brother **Zablon Nyandoya** who offered financial assistance for all my academic endeavors including this project. Lastly I am grateful to my entire family and friends for supporting me materially and socially hence enabling me to have ample time to carry out this study.
DEDICATION

This dissertation is dedicated to my spouse Rachael and my sons Washington and Ernest for being so understanding and giving me the needful support. I also dedicate it to my late parents who instilled a high level of discipline and integrity in me.
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ABBREVIATIONS

AA: Aortic arch
ARSCA: Aberrant right subclavian artery
BCT: Brachiocephalic trunk
CT: Computed Tomography
CTA: Computed tomography angiography
DSA: Digitally subtracted angiography
KNH: Kenyatta National Hospital
KNH-UoN-ERC: Kenyatta National Hospital-University of Nairobi Ethics and Research Committee
Kshs: Kenya shillings
LCCA: Left common carotid artery
LSCA: Left subclavian artery
LVA: Left vertebral artery
MDCT: Multidetector Computed Tomography
MPR: Multiplanar reconstruction
RCCA: Right common carotid artery
RECA: Right external carotid artery
RICA: Right internal carotid artery
RSCA: Right subclavian artery
RVA: Right vertebral artery
UoN: University of Nairobi
VRT: Volume rendering technique
ABSTRACT

Introduction
The classical or normal anatomical aortic arch (AA) is left-sided and the commonest branching pattern of the AA comprising of three vessels. These are the brachiocephalic trunk (BCT), the left common carotid artery (LCCA), and the left subclavian artery (LSCA) from right to left. The BCT branches into the right subclavian artery (RSCA) and right common carotid (RCCA). This branching pattern occurs in 64.9 – 94.3% of the population as reported in literature and is described as normal, conventional or classical. Anatomical branching variants of the AA include differences in the origins of different branches and the number of branches. The non-classical AA branching variants have been found to be associated with a higher occurrence of congenital cardiovascular malformations amongst these patients.

Objective
The objective of the study was to determine the aortic arch anatomical branching variants present in our Kenyan population as shown on contrast-enhanced multidetector CT chest.

Rationale
Knowledge of these branching patterns is important to interventional and diagnostic radiologists, anatomists, vascular, thoracic and neck surgeons. The mentioned specialists should recognize these patterns to avoid fatal outcomes during supra aortic thoracic, head and neck surgeries.

Study Setting
Kenyatta National Hospital (KNH) department of Radiology

Study Design
A prospective cross-sectional study

Sample Size
The number of subjects included in the study was 185

Methodology
A total of 185 subjects were recruited into the study. The gender distribution was 99 (53.5%) females and 86(46.5%) males. The study participants were recruited, following ethical approval by KNH-UoN ERC and informed consent from patients who presented themselves for contrast enhanced chest computed tomography for varied indications at the Department of Radiology KNH. Axial chest scans were obtained and the raw data was subjected to volume rendering technique (VRT) and multiplanar reconstruction (MPR) software to define the anatomy of the AA.
The type of the branching pattern was recorded in a designed data collection form and stored for data analysis. Pictures of the branching patterns were archived.

**Data Analysis**

Data analysis involved calculating the frequency distributions of the AA variations using Statistical Package for Social Sciences (SPSS) version 21 software.

**Study Duration**

The study was carried out in 6 months (between May and November 2016).

**Results**

The mean age of the participants was 50.7 years (SD ± 18.4). The mean age of female participants was 49.2 years (SD ± 19.4) and the mean age of male participants was 52 years (SD ± 17.9). The majority of participants 95 patients (51.3%) had classical AA Natsis type I. The remaining 90 participants (48.6%) had non-classical variant AA. Of these 83 participants (44.9%) had 2 branch pattern Natsis type II. Four patients (2.3%) had a four branch pattern AA where LVA originated directly from the AA (Natsis type III). The remaining 3 participants (1.6%) had a variant AA not classified under Natsis. These had AA with 3 branches i.e. BCT (giving off LCCA), LVA and LSCA (i.e. Natsis type II with an additional LVA.)

**Conclusion**

Variations in the branching pattern of AA are very common as shown in this study.
1.0 CHAPTER ONE: INTRODUCTION AND BACKGROUND

The aortic arch (AA) develops in a complex way and this intricacy predisposes it to various configurations. However, the conventional or classical AA is left-sided and the commonest branching pattern of the AA consisting of three vessels; first the brachiocephalic trunk (BCT), then the left common carotid artery (CCA), and finally the left subclavian artery (LSCA) from right to left. The BCT branches into the right subclavian artery (RSCA) and right common carotid (RCCA). This branching pattern occurs in 64.9 – 94.3% of the populations and is referred to as normal [1].

Variations in the branching pattern of the AA include differences in the origins of different branches and the number of branches. This has clinical and anatomical significance to diagnostic and interventional radiologists, cardiothoracic, vascular, head and neck surgeons. The non-classical AA branching variants have been found to be associated with a higher occurrence of congenital cardiovascular malformations amongst these patients [2].

Locally the anatomy of the aortic arch has only been studied by cadaver dissection [3]. In other regions of the world other methods including conventional angiography, digitally subtracted angiography (DSA), computed tomography angiography (CTA) and multidetector computed tomography (MDCT) have been used to study the anatomy of the AA. In this study the anatomy of the AA in a Kenyan population using the contrast-enhanced MDCT of the chest was used. From the literature review no such study has been reported in Kenya and Africa hence this is the first study using contrast enhanced MDCT in Kenya and Africa. It will form baseline radiological data for comparison with the cadaveric study and future studies in this topic.

1.1 Literature Review

1.1.1 Embryology of the Aortic Arch

Six paired arches develop by division of a common arterial trunk (truncus arteriosus) arising from the primitive heart. This occurs within the first weeks of fetal life [1, 4]. The 6 arteries fuse on both sides of the pharynx and form bilateral dorsal aortae. These aortae fuse into 1 descending aorta at the level of the body of the fourth thoracic vertebrae during the third week [1, 4]. Thereafter there is regression of 1st, 2nd and the 5th arches. The 3rd arches develop into the carotid arteries. The 4th arch on the right forms BCT and RSCA whilst on the left this forms the LSCA and the AA proper. The ascending aorta and pulmonary trunk
are formed by division of truncus arteriosus. The pulmonary arteries are formed by fusion of the pulmonary trunk fuses with the 6th arches [1, 4].

Thus non-classical variations of the AA occur when persistence of segments of the aortic arches that normally regress or regression of segments that persist during normal development or both [1, 4].

1.1.2 The AA anatomical variants:

The classification described by Natsis et al (2009) was used because it is radiological based and is the most recent in literature [5]. In this classification the anatomy of the AA vessels as seen on digital subtraction angiography was categorized into 8 types namely;

1. Type I. Refers to three branch normal or classical AA branching i.e. BCT, LCCA, LSCA
2. Type II. AA has two branches i.e. LSCA and BCT (with LCCA originating from BCT)
3. Type III. AA has four branches i.e. LVA directly leaves the AA between the LCCA and the LSCA
4. Type IV. Have three branches i.e. LCCA and RCCA arise from a common trunk arising between both RSCA and the LSCA.
5. Type V. Have three branches i.e. Common carotid arteries arising from a common trunk proximal to LSCA and ARSCA is present.
6. Type VI. Have two branches. Both Common carotid arteries and both subclavian arteries arise from 2 individual common trunks.
7. Type VII. Have four branches. BCT is absent and hence the RSCA, RCCA, LCCA, LSCA arise from the AA separately.
8. Type VIII. Have four branches. Thyroid ima artery arises from the AA.

The only locally available study on this subject was carried out on cadaveric dissection by Ogeng’o JA et al [3] and published in 2010. The researchers described the pattern of AA branching in the African Kenyan population using 113 cadaveric dissections at Department of Human Anatomy University of Nairobi where they found that 76 (67.3%) of the AA showed classical 3 branch pattern of BCT, LCCA and LSCA (Natsis type I). Six AA variants in this study were observed. The commonest variation was seen in 29 (25.7%) in which the AA had two branches namely the LSCA and a common trunk for the BCT and LCCA (Natsis type II).
The other variation seen was in 3 (2.7%) cadavers where the AA showed direct origin of LVA distal to LSCA, LCCA, and BCT which is not included in the Natsis classification. The other findings were Natsis type III 1 cadaver (0.9%), BCT giving rise to LCCA with LVA distal to the LSCA 2 cadavers (1.8%). The researchers concluded that over 30% of Kenyans may show variant branching pattern of the AA.

Jakanani G.C. and Adair W. of Leicester Royal Infirmary Hospitals Leicester United Kingdom carried out a retrospective study of 861 CT chest and thoracic aorta examinations in consecutive patients who underwent CT imaging during a 4-year period between January 2004 and January 2008 [4]. They found that 643 (74%) of the patients had the normal configuration while the rest 26% had variations. The most common variation was in 176 (20%) patients who had the two trunks pattern of BCT and LCCA originating from one trunk and the other trunk the RSCA (Natsis type II). In 53 (6%) of the patients the left vertebral artery arose directly from the AA. This group had further variations in that 32 (3.7%) cases 17 (1.9%) cases occurred with a BCT giving off LCCA, 4 (0.4%) cases occurred with both a BCT giving off LCCA and a retro-esophageal ARSCA. In the 4 (0.4%) cases with the ARSCA 2 of them had the RVA arising from the RCCA cranial to its origin. They also found 2 (0.2%) patients with a right-sided AA and 1 (0.1%) patient with aortic coarctation.

In a Serbian population Vucurevic G. et al investigated AA branching variants in 1266 patients [2] in their study published in January 2013. Of this 1265 had undergone angiographic and MDCT studies while 1 was a dissected specimen. They found out that (946) 74.72% of the patients had normal vascular pattern while (320) 25.28% had variations in the AA branches. Of these 2.84% had a BCT and common origin of the LCCA, and LSCA. Natsis type II was found in 15.56% patients and in 0.55% both the common carotids and subclavian arteries originated from the AA with the ARSCA having a retro-esophageal course. In 0.24% of the subjects the above variations were associated with a double or a right-sided AA. Other variations found were Natsis type III in 3.63% of the patients and Natsis type VIII in 2.22%. Of the subjects 0.24% had direct origin of RVA from the AA a variation without a Natsis classification.

In Sanliurfa Turkey Nurefsan B. et al at the Harran University Medical Faculty, Departments of Radiology and Cardiovascular Surgery Departments carried out a study by analyzing the frequency of AA and its branching [6]. This was done retrospectively on routine contrast-
enhanced chest MDCT images of 1170 patients acquired between January 2012 and January 2013. They found that overall 1046 (89.4%) of the patients had Natsis type I. The most common variant was Natsis type III 53 (4.5%) cases followed by Natsis type II in 30 (2.6%) cases. ARSCA was found in 26 (2.2%) cases. Two (0.2%) cases had right sided AA. Six patients (0.5%) had dextrocardia.

In Ankara Turkey Pasaoglu L. et al of the Department of Radiology of Ankara Numune Training and Research Hospital studied variations in branching patterns of the AA as detected by CTA on 881 patients between 2010 and 2013 [1]. In this study 87.4% had normal branching pattern of the AA. The remaining 12.6% had variations. Of these the majority i.e. 7.2% had Natsis type II and 2.8% of the patients had a Natsis type III of LVA arising directly from the AA between the origin of the LCCA and LSCA while 1.9% of the patients had ARSCA and 0.3% had a right AA. Of the subjects 2 patients had right AA with aberrant LSCA.

Another study in Ankara Turkey by Ergun O. et al of Diskapi Yildirim Beyazit Training and Research Hospital, Department of Radiology carried a retrospective analysis of AA branching of 270 patients who had undergone DSA from September 2011 to November 2013 [7]. They found 198 (73.3%) of the patients had Natsis type I. Natsis type II was found in 58 (21.5%) of the patients. Natsis type III was found in 7 (2.6%) of the cases. Natsis type II with an additional LVA originating from the AA was found in 3 (1.1%) cases. Natsis type V was found in 3 (1.1%) of the patients. Natsis type VI was found in 1 patient (0.4%).

The 3 foregoing studies in Turkish population differ in their findings. The classical AA branching patterns in the populations is within the range reported in most literature of 64.9 – 94.3%. However, the non-classical AA branching variants vary significantly. Among the population in Ankara the DSA study on 270 subjects carried by Ergun O. et al revealed 4 AA branching variants i.e. Natsis types II, III, V, and VI. In the same location the CTA study by Pasaoglu L. et al on 881 subjects (i.e. with more than 3 times the number of subjects in the Ergun study) showed only 2 AA branching variants i.e. Natsis types II and III. Natsis types V and VI were not observed. The difference in the 2 studies could be mainly due to sampling. The MDCT study at Sanliurfa by Nurefsan on 1170 subjects showed 2 AA variants of Natsis types II and III. And in this study, patients with Natsis type III were more than those with Natsis type II which is the reverse of that demonstrated by the Ankara studies. This difference
could be due to environmental influence since Sanliurfa is found about 350 km south of Ankara near the Mediterranean Sea.

Makhanya N.Z. et al of the Department of Diagnostic Radiology Medical university of Southern African carried out an angiographic study on 60 randomly selected patients in 2004 [8]. They found that 65% of the patients had a normal AA. The rest had variations i.e. 28.3% had Natsis type II AA. The Natsis type II with LVA, and LVA originating from AA distal to the LSCA were present in 1.7% each. The remaining 3.3% had an ARSCA as the last branch.

G.L. Faggioli et al in Bologna Italy carried out a research between December 2004 and July 2006 to find out whether non-classical AA branching variants were associated with increased technical difficulties and risk of neurological events in carotid artery stent procedures [9]. In their study among 214 patients, they found that 88.3% of the patients had a Natsis type I AA. The remaining 11.7% had AA variants. Of these 10.2 % had Natsis type II while 0.9% had separate origin of RSCA and RCCA (Natsis type VII). LCCA agenesis with separate origin of left internal and left external carotids from AA directly was present in 0.5 % of the patients. In this study technical difficulties and neurological events were found to be common in patients with Natsis type II as compared to the rest of the AA variants.

In Central India Virendra, Budhiraja et al did a cadaveric study on Anatomical variations in the branching pattern of AA [10] published in August 2013. They found out that 63.5% of cadavers had the classical branching Natsis type I while 36.5% had variations in the branching pattern.

In this study 19.2% of the cadavers had a Natsis type II while 15.3% had BCT, LCCA, LVA and LSCA (Natsis type III). The remaining 1.9% had Natsis type II with an additional LVA.
### Table 1: Frequency Of AA Variants (Natsis Types) in The Other Studies

<table>
<thead>
<tr>
<th>Study researchers</th>
<th>Study population (N)</th>
<th>Type I %</th>
<th>Type II %</th>
<th>Type III %</th>
<th>Type IV %</th>
<th>Type V %</th>
<th>Type VI %</th>
<th>Type VII %</th>
<th>Type VIII %</th>
<th>Non Natsis %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vucurevic et al</td>
<td>1266</td>
<td>74.7</td>
<td>15.5</td>
<td>3.6</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>2.2</td>
<td>3.0</td>
</tr>
<tr>
<td>Nurefsan et al</td>
<td>1170</td>
<td>89.4</td>
<td>2.6</td>
<td>4.5</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>5.5</td>
</tr>
<tr>
<td>Pasaoglu et al</td>
<td>881</td>
<td>87.4</td>
<td>7.2</td>
<td>2.8</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>2.4</td>
</tr>
<tr>
<td>Ergun et al</td>
<td>270</td>
<td>73.3</td>
<td>21.5</td>
<td>2.6</td>
<td>-</td>
<td>1.1</td>
<td>0.4</td>
<td>-</td>
<td>-</td>
<td>1.1</td>
</tr>
<tr>
<td>Makhanya et al</td>
<td>60</td>
<td>65</td>
<td>28.3</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>5.0</td>
</tr>
<tr>
<td>Ogeng’o JA et al</td>
<td>113</td>
<td>67.3</td>
<td>25.7</td>
<td>0.9</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>2.7</td>
</tr>
<tr>
<td>Jakanani, Adair</td>
<td>861</td>
<td>74</td>
<td>20</td>
<td>3.7</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>2.7</td>
</tr>
<tr>
<td>Faggioli et al</td>
<td>214</td>
<td>88.3</td>
<td>10.2</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>0.9</td>
<td>-</td>
<td>0.5</td>
</tr>
<tr>
<td>Virendra et al</td>
<td>52</td>
<td>63.5</td>
<td>19.2</td>
<td>15.3</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>1.9</td>
</tr>
</tbody>
</table>

From these studies we can hypothesize that Natsis type II is the commonest non classical AA variant in most world populations except in the Nurefsan study in Southern of Turkey where Natsis type III is higher. The sample size did not seem to have any impact interestingly.

The other notable finding was that there were other AA anatomic variants among the world population which were not classified under Natsis classification. These variations need to be studied and an all-inclusive classification established.

### 1.2 Clinical Importance of These Studies

As emphasized by the authors of the above studies, there is need to establish the prevalence of the AA variants in the population, so that diagnostic radiologists can look for and report these variants during routine reporting of contrast enhanced MDCT of the Chest. This is clinically important because of the following reasons:

1. Some of these variants e.g. the Natsis type II AA are known to be associated with a higher incidence of congenital cardiovascular diseases [8]. It is also associated with risk of retrograde aortic dissection during or after thoracic endovascular aortic repair (TEVAR). The occurrence rates ranges from 1% to 3% [8].
2. Although AA anatomic variants are largely asymptomatic some e.g. ARSCA may cause compression to the trachea and esophagus and lead to respiratory disturbances (dyspnoea) and dysphagia (dysphagia lusoria) [3.10]. ARSCA can be fatal in symptomatic infants and their timely diagnosis could be lifesaving. If the ARSCA courses anterior to the trachea it may cause great danger in a patient who requires a tracheostomy.

3. Other variants can lead to intermittent claudication, misinterpretation of radiological examination and complications during neck and thoracic surgery [3.10].

4. As shown by Faggioli et al in their study AA anatomical variants are associated with a higher risk of neurological complications in carotid stent procedures and technical failure was more in the same group of patients [9].
2.0 CHAPTER TWO : METHODOLOGY

2.1 Research Question
What is the prevalence of AA anatomical branching variants in the Kenyan population as depicted by contrast enhanced chest MDCT?

2.2 Study Justification
There is need to carry out scientific studies to add and expand the body of knowledge and create our own local database. Therefore, this study aimed at creating a database on the local prevalence of AA anatomical variants among the Kenyan population as depicted by enhanced chest MDCT and correlate it with the only locally documented cadaveric study and other studies reported in literature worldwide.

The study findings are important for head and neck surgeons, cardiothoracic surgeons and vascular surgeons and interventional radiologists to recognize and anticipate the possibility of encountering AA anatomical variants during their procedures [11, 12]. MDCT could be used in order to identify these variants prior to the procedures to avoid catastrophic outcomes during operations and instrumentations since prior knowledge of these variants would be important when planning for these procedures. MDCT is a better tool to evaluate the AA because it is relatively available, less invasive and fast.

As mentioned earlier from the literature review this is the first study carried out in Kenya and in Africa using contrast enhanced MDCT of the chest.

2.3 Study Objectives
2.3.1 Broad Objective
The aim of this study was to investigate the prevalence of AA anatomical branching variations in patients who undergo contrast enhanced chest MDCT scans for various reasons at KNH department of Radiology.

2.3.2 Specific Objectives
i. To determine the prevalence of aortic arch branching variants as depicted by chest enhanced MDCT scans.
ii. To describe the patterns of aortic arch branching variations depicted by chest enhanced MDCT scans
iii. To determine gender distribution of these variants in the Kenyan population

2.4 Study Design
The study design was a prospective cross-sectional study
2.5 Study Area
The study took place at the KNH department of Radiology

2.6 Inclusion Criteria

a) Consecutive patients who underwent contrast enhanced MDCT of the chest for any reason at the KNH department of Radiology within the period of study and who gave informed consent were recruited into the study.

b) Pediatric subjects, minors and those patients who were unable to give individual consent were included as long as their guardians gave informed consent.

2.7 Exclusion Criteria

1. Patients who underwent unenhanced chest MDCT examination.
2. Patients who declined consent.
3. Pediatric or minors or relatives who had no consent from their parents, caretakers or relatives.
4. Patients whose AA could not be elucidated due to motion artifacts or poor contrast distribution.
3.0 CHAPTER THREE: MATERIALS

Chest CT scan images were acquired by the “Siemens SOMATOM Definition AS+ 128 slice Multidetector Row CT scanner (Siemens AG, Munich, Germany)”. For adults the following protocol was used ; 120 kV, up to 200 effective (mAS), 128x0.6mm collimation pitch 0.9, 3 mm section slices, reconstruction interval = 0.8mm, tube rotation period = 0.5 seconds. The field of view was adjusted to the size of the patient. Topogram length of 512 mm was used. This was from the apices of the lungs extending to the lowest hemidiaphragm. Scans in full inspiration were obtained. Intravenous contrast consisting of a volume of 60-70ml of iodine based, non-ionic contrast material (300mg I/ml) injected through an antecubital vein by an injector pump at a rate of 2.5ml/s. 5 seconds delay time was allowed. Scan time was 5.91 seconds.

For pediatric patients a low dose radiation CT protocol was used which included 110 kV, 35 mAS, 128x0.6mm collimation, pitch 0.7, slice thickness of 0.6 mm, delay time of 2 seconds, a topogram length of 256 mm, and the contrast medium calculated at a rate of 1ml/kg body weight of the patient. The contrast medium was injected at a rate of 1ml/s. Scan time was 4.1 seconds. Raw and reformatted data MDCT scans of every patient were examined and subjected to the MPR and VRT software by a consultant radiologist and the principal investigator to confirm the AA branching pattern.

3.1 Personnel
These included 4 trained data clerks among CT radiographers from KNH department of Radiology that worked together with the principal researcher in recruitment of participants and a consultant radiologist who examined the images to confirm the branching pattern.

3.2 Data Collection and Analysis:
Biodata was collected by the principal researcher and the trained data clerks recruited among the radiographers stationed at the Siemens CT room where chest MDCT examinations are performed. Patients who gave informed consent were recruited into the study according to the inclusion criteria stated above. There after the acquired images were reviewed, processed, reformatted and analyzed by principal researcher together with a consultant radiologist. The raw data for patients with non-classical variant AA were stored on DVD discs. shown in the appendix A.
Data analysis involved calculating the number and frequencies of different aortic arch configurations related to the whole group of participants as well as among the participants with different anatomical aortic arch variations as well as in relation to gender. The Statistical Package for Social Sciences (SPSS) version 21 software was used for data analysis.

3.3 Sample Size

The sample size was determined by Cochran formula (1963) [13]

\[
\text{Sample size } n = \frac{NZ^2 P (1-P)}{d^2 (N-1) + Z^2 P (1-P)}
\]

\(N\) is the target population and is the estimated number of contrast enhanced chest MDCT done in KNH department of Radiology in 6 months. 
\(n\) is the sample size for target population < 10000. 
\(Z^2\) is the abscissa of the normal curve that cuts off an area at the tails (1-\(\alpha\) equals the desired confidence level e.g. 95% it is 1.96). 
\(d\) is the desired level of precision. 
\(p\) is the estimated proportion of an attribute that is present in the target population. 

The study will desire a 95% confidence level and + 5% precision. 

From the local cadaveric study done the \(p=30\%\). 

The sample size becomes 
\[
\text{Sample size } n = \frac{420 \times (1.96)^2 \times 0.3 \times (1-0.3)}{(0.05)^2 \times (420-1) + (1.96)^2 \times 0.3 \times (1-0.3)}
\]

Therefore, a minimum of 181 patients were to be included in the study. However, 185 patients were recruited into the study.

3.4 Ethical Consideration

3.4.1 Study approval

Before embarking on the study and collection of data approval was obtained from Kenyatta National Hospital-University of Nairobi Ethics and Research Committee (KNH-UoN ERC). This was granted on 18th May 2016. The reference number for this approval was KNH-ERC/A/167.
3.4.2 Consent
Informed consent to use images for this study was obtained from the participants after a full explanation. For those patients who were not able to consent i.e. children and very ill patients consent was obtained from guardians. The patient was then prepared for the chest MDCT image acquisition as per the protocol above.

3.4.3 Radiation protection
All the studies were justified and the set study protocols as per requested investigation were followed strictly to ensure only minimum optimum radiation dose was given to the subjects to ensure radiation safety. There was no repetition of any chest MDCT examinations where the vascular structures were not adequately demonstrated either due to motion artifacts or poor conduction or mixing of contrast agent. This ensured that no patient was exposed to additional and unnecessary radiation and also avoided re-exposure to contrast agent.

3.4.4 Confidentiality
Confidentiality was strictly observed. Patient’s names were not quoted anywhere in the write up or in any discussion of the images and study findings.

3.5 Study Period
Study period was 6 months extending between the months of May and November 2016.
4.0 CHAPTER FOUR: RESULTS

The study was performed among 185 participants who included pediatric and adult patients undergoing contrast enhanced chest MDCT at KNH department of Radiology. Of these participants 86 (46.5%) were males and 99 (53.5%) were females giving a male-to-female ratio of approximately 1:1.

The mean age of the participants was 50.7 years (SD ± 18.4). (range 3 years to 93 years). The mean age of female participants was 49.2 years (SD ± 19.4) and the mean age of male participants was 52 years (SD ± 17.9).

4.1 Prevalence of AA Branching Variants among Study Participants

The majority of the participants 51.3% (95/185) had the classical vascular branching pattern Natsis type I of three branches consisting of BCT, LCCA and LSCA. This is as shown in table 2 below.

Table 2: NATSI Classification Of Variant AA Branching Visualized Using MDCT In Study Participants

<table>
<thead>
<tr>
<th>Natsis type</th>
<th>No of patients</th>
<th>Frequency (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>95</td>
<td>51.3</td>
</tr>
<tr>
<td>II</td>
<td>83</td>
<td>44.9</td>
</tr>
<tr>
<td>III</td>
<td>4</td>
<td>2.2</td>
</tr>
<tr>
<td>Non Natsis types</td>
<td>3</td>
<td>1.6</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>185</strong></td>
<td><strong>100</strong></td>
</tr>
</tbody>
</table>

The overall prevalence of non-classical vascular pattern of AA branching was 48.7% (90/185). The prevalence of Natsis type II was highest at 44.9% (83/185). This is as shown in table 3 below.

Table 3: NATSI Classification of Non-Classical AA Branching Variants Visualized Using MDCT in Study Participants

<table>
<thead>
<tr>
<th>Natsis type</th>
<th>No of patients</th>
<th>Frequency (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>II</td>
<td>83</td>
<td>44.9</td>
</tr>
<tr>
<td>III</td>
<td>4</td>
<td>2.2</td>
</tr>
<tr>
<td>Non Natsis types</td>
<td>3</td>
<td>1.6</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>90</strong></td>
<td><strong>48.7</strong></td>
</tr>
</tbody>
</table>
4.2 Gender Distribution of AA Branching Variants

Classical Natsis type I variant was found in 46 male participants (53.3%) and 49 of female participants (49.5%). Non-classical variants were found in 40 males (46.7%) and 50 female participants (50.3%). This is as shown in table 4 below.

Overall, there was no statistically significant association between AA branching variants and gender ($\chi^2 = 1.98$, $p = 0.576$)

Table 4: Showing AA Branching Variants According to Gender of Participants

<table>
<thead>
<tr>
<th>Types of variants</th>
<th>Males</th>
<th>Females</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Participants(n)</td>
<td>Frequency (%)</td>
</tr>
<tr>
<td>I</td>
<td>46</td>
<td>53.3</td>
</tr>
<tr>
<td>II</td>
<td>36</td>
<td>41.9</td>
</tr>
<tr>
<td>III</td>
<td>3</td>
<td>3.5</td>
</tr>
<tr>
<td>Non Natsis type</td>
<td>1</td>
<td>1.2</td>
</tr>
<tr>
<td>Total</td>
<td>86</td>
<td>100</td>
</tr>
</tbody>
</table>

4.3 Aortic Arch (AA) Branching Patterns as Depicted by MDCT

The AA branching patterns demonstrated in the study are represented below by volume-rendered MDCT image of 4 patients (participants).

Figure 1 : NATSIS TYPE I. Anterior coronal 3D volume-rendered MDCT image.
The classical AA vascular branching pattern with 3 branches i.e. BCT, LCCA and LSCA.

Figure 2: NATSIS TYPE II. Anterior coronal 3D volume-rendered MDCT image.

This pattern consists of two branches BCT and LCSA. The LCCA originates from BCT instead of directly from the AA.

Figure 3: TYPE III. Anterior coronal 3D volume-rendered MDCT image.

The AA has four branches, BCT, LCCA, LVA, LSCA where LVA originates directly from the AA between the LCCA and LSCA.
The AA has three branches BCT, LVA and LSCA. The BCT gives rise to LCCA while the LVA originates directly from the AA between the BCT and LSCA.
CHAPTER FIVE: DISCUSSION

In this study the classical or conventional or normal three branch pattern Natsis type I was observed in 51.3% of the cases. This falls below the incidence found in most studies worldwide of between 64.9-94.3% according to literature [1]. However, this falls within 2 studies cited by Nurefsan in his literature review which reported that the incidence of Natsis type I varied between 49.7 and 51.7% in African Americans [6]. The remaining 48.7% of the participants had non-classical variants. This is a higher incidence when compared to that found in most literature of 5.7-35.1% but still coincides with the above studies reported by Nizankowski C and Williams GD [6] and the other reports by McDonald and Anson that deviation from classical AA branching is more common in African populations [1].

The most common non-classical variant of the AA was Natsis type II with two branches ([BCT sharing one AA origin with LCCA] and LSCA) is found with an incidence of 44.9%. This is within the range reported in studies which report varying prevalence rates ranging between 0.9 and 45.6%. The highest reported rate was by a study on American Africans and American Caucasians by Williams and Henry of 45.6% [6]. Two Turkish studies reported prevalence of 2.6% and 7.2% [1, 6] with much larger sample sizes of 1170 and 881 patients respectively. This difference may also be attributed to genetic differences in study populations.

Natsis type III was observed in 2.2% of my study population which compares well to the prevalence reported in literature of between 2.4-8.0% [1,2,4,6,8]. However, the frequency is higher than that reported by Ogeng’o et al [3] in the earlier local cadaver dissection study (0.9%) from a similar population. The reasons for this difference remains unclear. However, in both Kenyan studies, there was agreement in the absence of Natsis IV–VII. These later types have been reported in European and Asian subcontinents [2,8,10,11,12].

The non-Natsis variants were seen in 1.6% of study participants. Comparable prevalence was reported in the South African population by Makhanya et al of 1.7% The racial structure is not mentioned in this study [9]. This prevalence also compares closely to that reported in a Central Indian population by Budhiraja et al [10]. Similar variants in Turkish population have been reported with a frequency of 1.1% [6] and in British population with a frequency of 0.2% [4]. It is postulated that the non-Natsis branching pattern and the Natsis type II have a higher incidence in the African study populations. [8]
In this study there were no cases of Natsis type IV, V, VI, VII and VIII. This study did not demonstrate any significant gender difference amongst the participants a finding that is found in most study populations around the world.

5.1 Study Limitation
Lack of a Picture Archiving and Communication System (PACS) at the KNH department of Radiology for storing patient information including images prevented retrospective data collection. Storage of patients’ data in a PACS would have yielded larger samples of participants as seen with similar studies elsewhere in the world.

5.2 Conclusion
Variations in the branching pattern of AA are very common in Kenya with the most common being Natsis type II. This prevalence is higher as compared to the local study by Ogeng’o et al carried by cadaver dissection. This difference could be due to sampling technique.

Knowledge of these variations is important for cardiothoracic, head and neck surgeons and interventional radiologists to be aware so as ensure safer and more accurate endovascular and surgical planning

5.3 Recommendation
A prospective study should be undertaken to investigate the incidence of congenital cardiac anomalies in the Kenyan population considering the relative higher prevalence of AA variants at 48.7 % depicted by this study.

A prospective study should be undertaken to investigate the pathologies and/or perfusion abnormalities if any that could be associated with these variants in the Kenyan population.

Installation of a picture archiving and communications system (PACS) for storage and archiving of patient data and images should be installed at Kenyatta National Hospital as a matter of priority as it would facilitate patient follow-up and research.
REFERENCES


APPENDICES

Appendix A: Data Collection Form

Biodata of Participant

Date of Examination.................................................................
CT Number..................................................................................
Telephone number......................................................................
Patient's unique number.........................................................
Date of Birth............................................................................
Age.......................................................................................
Gender...................................................................................
County of birth......................................................................

Aortic Arch Radiological Anatomy

Number of branches
..........................................................................................................................

Relative positions of the branches
..........................................................................................................................
..........................................................................................................................
..........................................................................................................................
..........................................................................................................................
..........................................................................................................................
..........................................................................................................................
..........................................................................................................................
..........................................................................................................................
..........................................................................................................................
Type of AA Branching pattern

(i) Natsis classification
..........................................................................................................................

(ii) Other configuration
..........................................................................................................................
Appendix B: Consent Form

1. Title of study:
Prevalence of Aortic Arch Anatomical Branching Variants in Kenyan Population as shown on Chest contrast enhanced MDCT

2. Name of researcher;
Dr Amakabane Daniel Mikalo MBChB (UoN)
Postgraduate Radiology Resident
Department of Diagnostic Imaging and Radiation
University of Nairobi
P.O. Box 19676-00202,
Nairobi.

3. NAME OF AND CONTACTS THE LEAD SUPERVISOR:
Dr. Gladys Mwango
Consultant Radiologist and Senior Lecturer and Chairman,
Department of Diagnostic Imaging and Radiation Medicine,
P.O. Box 19676-00202,
Nairobi.

4. Kenyatta National Hospital-University of Nairobi Ethics and Research Committee
Secretariat
P.O. Box 19676 code 00202,
Nairobi
Telephone (254-020)2726300 Ext 44355

5. I hereby confirm that the doctor has explained to me about the above study and I understand fully. I have been given the opportunity to ask questions which have been adequately answered.

6. I understand that my participation is voluntary and that I have not been forced to participate. I understand that I can decline without any explanation or my medical care or legal rights being violated.

7. I understand that I will not receive any compensation either financial or otherwise, and will not receive any preferential treatment, gift or reward, for participating in the above study.

8. My personal information will be kept confidential, but any relevant medical information regarding the results of my scans and the data collected will be accessible to the researcher, and may be looked at by his supervisors where relevant to the study. I give them permission to have access to this information.
I hereby consent to take part in the above study

Name of participant.................................................................

Date ........................................ Signature ................................................

Mobile number.................................................................

Name of parent/guardian/caregiver providing consent for the minor

Date ........................................ Signature .................................

Name ........................................ Signature .................................

Name of witness........................................................................

Date ........................................ Signature .................................
Appendix C: Fomu ya Idhini ili Kushiriki Katika Utafiti

1. **Kichwa cha utafiti:**
Kuchunguza viwango vya Matawi Mbadala ya Aortic Arch kwenye Jamii ya Wakenya tukitumia mbinu ya MDCT scan ya kifu

2. **Jina na anwani ya mtafiti:**
Dakt. Amakabane Daniel Mikalo, MBChB (UoN)
Mwanafunzi wa shahada ya uzamili katika fani ya radiologia
Idara ya Radiologia.
Chuo kikuu cha Nairobi,
Sanduku la posta 19676-0020
Nairobi.

3. **Jina la Msimamizi**
Dakt Gladys Mwango
Daktari mshauri wa radiologia Mhadhiri mkuu na Mwenyekiti
Idara ya Radiologia
Chuo kikuu cha Nairobi
Sanduku la posta 19676-0020

4. Nairobi. Kenyatta National Hospital-University of Nairobi Ethics and Research Committee Secretariat
Sanduku la posta 19676 code 00202

5. Mimi ninatoa dhibitisho kuwa daktari amenieleza vilivyo kuhusu utafiti ambao kichwa chake kimetajwa hapo juu. Ninakiri pia nimepewa fursa ya kuuliza maswali kuhusu utafiti huu na nimeridhika.


7. Ninaelew a sitapokea fidia yoyote iwe fedha au vinginevyo wala sitapokea matibabu yoyote au mapendeleo, zawadi au tuzo kwa ajili ya kushiriki katika utafiti huu.

8. Naelew a kuwa taarifa yangu binafsi itakuwa siri. Hata hivyo habari kuhusu matookeo ya uchunguzi zitakazokusanywa wakati wa utafiti zitaangaliwa na kuchambuliwa na mtafiti mkuu na hata wasimamizi wake pindi itakavyohitajika.
Ninatoa idhini yangu kushiriki katika utafiti huu.

Jina la Mshiriki..........................................................
Tarehe.................................Sahihi......................................................

Nambari ya simu...............................................................

Jina la mzazi /mlezi anayetoa idhini kwa niaba ya mshirika wa umri mdogo
Tarehe..................Sahihi..........................

ina la shahidi……………………………………………………..…..
Tarehe……………………Sahihi……………………………………


Appendix D: Assent Document (For Study Participants Who Are Minors)

1. **Title of Study:**
To find out the proportion of Aortic Arch Anatomical Branching Variants in Kenyan Population as shown on Chest contrast enhanced MDCT

2. **Name and Contacts of Researcher:**
Dr Amakabane Daniel Mikalo MBChB (UoN)
Postgraduate Radiology Resident
Department of Diagnostic Imaging and Radiation Medicine,
University of Nairobi
P.O. Box 19676-00202,
Nairobi.

3. **Name Of And Contacts The Lead Supervisor:**
Dr. Gladys Mwango
Consultant Radiologist, Senior Lecturer and Chairman,
Department of Diagnostic Imaging and Radiation Medicine,
P.O. Box 19676-00202, Nairobi.

4. **Kenyatta National Hospital-University of Nairobi Ethics and Research Committee Secretariat**
P.O. Box 19676 code 00202,
Telephone (254-020)2726300 Ext 44355

5. I hereby confirm that the doctor has explained to me about the above study and I understand fully. I have been given the opportunity to ask questions which have been adequately answered.

6. I understand that my participation is voluntary and that I have not been forced to participate. I understand that I can decline without explanation, or my medical care or legal rights being violated.

7. I will not receive any compensation either financial or otherwise, and will not receive any preferential treatment, gift or reward, for participating in the above study.

8. My personal information will be kept confidential, but that any relevant medical information regarding the results of my scans and the data collected will be accessible to the researcher, and may be looked at by his supervisors where relevant to the study. I give them permission to have access to this information.

I hereby consent to take part in the above study

Name of participant…………………………………………………………………………………………………………………………
Date ................................. Signature ...................................................

Mobile number ..............................................................................................

Name of parent/guardian/caregiver providing consent for the minor
.........................................................................................................................

Date................................. Signature .................................

Name ................................. of

witness ...........................................................................................................

Date ................................. Signature .................................
Appendix E: Fomu ya Idhini ili Kushiriki Katika Utafiti (Kwa Washiriki Wenye Umri Chini ya Miaka Kumi Na Minane)

1. **Kichwa cha utafiti:**
   Kuchunguza Viwango vya Matawi Mbadala ya Mshipa ule mkubwa mwilini kwenye Jamii ya Wakenya tukitumia mbinu ya CT scan ya kifua

2. **Jina la mtafiti:**
   Dakt. Amakabane Daniel Mikalo, MBChB (UoN)
   Mwanafunzi wa shahada ya uzamili katika fani ya radiologya Idara ya Radiologia, Chuo kikuu cha Nairobi,
   Sanduku la Posta 19676-00202,
   Nairobi.

3. **Jina la Msimamizi**
   Dakt Gladys Mwango
   Daktari mshauri wa radiologya, Mhadhiri mkuu na Mwenyekiti,
   Idara ya Radiologia, Chuo kikuu cha Nairobi
   Sanduku la posta 19676-00202
   Nairobi

4. Kenyatta National Hospital-University of Nairobi Ethics and Research Committee Secretariat,
   Sanduku la posta 19676 code 00202, Nambari ya simu (254-020)2726300 Ext 44355

5. Mimi ninatoa dhibitisho kuwa daktari amenieleza vilivyovyo kuhusu utafiti ambao kichwa chake kimetajwa hapo juu. Ninakiri pia namepewa fursa ya kuuliza maswali kuhusu utafiti huu na nimeridhika.


7. Ninaelewa sitapokea fidia yoyote iwe fedha au vinginevyo wala sitapokea matibabu yoyote au mapendeleo, zawadi au tuzo kwa ajili ya kushiriki katika utafiti huu.

8. Naelewa kuwa taarifa yangu binafsi itakuwa siri. Hata hivyo habari kuhusu matokoe ya uchunguzi zitakazokusanywa wakati wa utafiti zitaangaliwa na kuchambuliwa na mtafiti mkuu na hata wasimamizi wake pindi itakavyohitajika.
Ninatoa Idhini Yangu Kushiriki Katika Utafiti Huu.

Jina la Mshiriki…………………………………………………………

Tarehe………………………….Sahihi………………………………………..

Nambari ya simu…………………………………………………………………………

Jina la mzazi /mlezi anayetoa idhini kwa niaba ya mshirika wa umri mdogo

Tarehe………………………….Sahihi………………………………………..

Jina la shahidi…………………………………………………………………………

Tarehe………………………….Sahihi………………………………………..
Appendix F: KNH/UON-ERC Letter of Approval

UNIVERSITY OF NAIROBI
COLLEGE OF HEALTH SCIENCES
P O BOX 15675 Code 00202
Telegrams: varcity
Tel: (254-020) 2726300 Ext 44355

KENYATTA NATIONAL HOSPITAL
P O BOX 20723 Code 00202
Tel: 788389-0
Fax: 725072
Telegrams: MEDIUP, Nairobi

KNUH- ERC
Email: uonhknr_erc@uoni.ac.ke
Website: http://www.erc.uoni.ac.ke
Facebook: https://www.facebook.com/uonihknr
twitter: @UONKNH_ERC https://twitter.com/UONKNH_ERC

Ref: KNH-ERC/A/167

Dr. Amakabane Daniel Mikalo
Reg. No. H58/67870/2013
Dept. of Diagnostic Imaging and Rad. Medicine
School of Medicine
College of Health Sciences
University of Nairobi

Dear Dr. Mikalo

REVISED RESEARCH PROPOSAL: PREVALENCE OF AORTIC ARCH ANATOMICAL BRANCHING VARIANTS IN KENYAN POPULATION AS SHOWN ON CONTRAST ENHANCED CHEST MULTIDETECTOR COMPUTED TOMOGRAPHY (MDCT) (P237/03/2016)

This is to inform you that the KNH-UoN Ethics & Research Committee (KNH-UoN ERC) has reviewed and approved your above proposal. The approval period is from 18th May 2016 – 17th May 2017.

This approval is subject to compliance with the following requirements:

   a) Only approved documents (informed consents, study instruments, advertising materials etc) will be used.
   b) All changes (amendments, deviations, violations etc) are submitted for review and approval by KNH-UoN ERC before implementation.
   c) Death and life threatening problems and serious adverse events (SAEs) or unexpected adverse events whether related or unrelated to the study must be reported to the KNH-UoN ERC within 72 hours of notification.
   d) Any changes, anticipated or otherwise that may increase the risks or affect safety or welfare of study participants and others or affect the integrity of the research must be reported to KNH-UoN ERC within 72 hours.
   e) Submission of a request for renewal of approval at least 60 days prior to expiry of the approval period. (Attach a comprehensive progress report to support the renewal).
   f) Clearance for export of biological specimens must be obtained from KNH-UoN ERC for each batch of shipment.
   g) Submission of an executive summary report within 90 days upon completion of the study. This information will form part of the data base that will be consulted in future when processing related research studies so as to minimize chances of study duplication and/or plagiarism.

For more details consult the KNH-UoN ERC website http://www.erc.uoni.ac.ke

Protect to discover
Yours sincerely,

PROF M. CHINDIA
SECRETARY, KNH-UoN ERC

c.c. The Principal, College of Health Sciences, UoN
     The Deputy Director, CS, KNH
     The Assistant Director, Health Information, KNH
     The Chair, KNH-UoN ERC
     The Dean, School of Medicine, UoN
     The Chair, Dept. of Diagnostic Imaging and Rad. Medicine, UoN
     Supervisor: Dr. Gladys Mwango