MORPHOMETRY OF FORAMEN TRANSVERSARIUM AND PREVALENCE OF ACCESSORY TRANSVERSE FORAMINA IN THE CERVICAL SPINE OF AN ADULT KENYAN POPULATION: AN OSTEOLOGICAL STUDY

DR. LEVIN ANYANGA WANYANGA

MS/ORT/4254/20

THESIS SUBMITTED IN PARTIAL FULFILLMENT AS A REQUIREMENT FOR AWARD OF MASTER OF MEDICINE IN ORTHOPAEDIC SURGERY IN MOI UNIVERSITY

DECLARATION

This proposal is my original work and has not been presented for a degree in any other university. No part of this thesis may be reproduced without prior written permission of the author and or Moi University.

Dr. Wanyanga Levin Anyanga

MS/ORT/4254/20

Signature:_____ Date:_____

Declaration by Supervisors:

This research proposal has been submitted for consideration with our approval as university supervisors.

Prof. Mohamed Galal Yahia El-Badawi

Professor of Human Anatomy

Department of Human Anatomy – Moi University

Signature _____ Date: 2/11/2023___

Dr. Elijah N. Muteti

Senior Lecturer and Consultant Orthopedic and Spine Surgeon

Department of Orthopedics and Rehabilitation - Moi University

Signature:_____ Date:_____

DEDICATION

First of all, this work is dedicated to God almighty for the gift of life, love and abundant blessings bestowed upon me.

Secondly, it is dedicated to my father, Mr. Wilson O. Wanyanga and my mother, Mrs. Florence K. Wanyanga for the love, care and endless support throughout my life.

Lastly, it is dedicated to my dear wife, Mrs. Estel Anyanga and my three kids, Allira K. Anyanga, Kian O. Anyanga and Tshazi N. Anyanga for the constant love, support and care for the years we've been together and for the strength to pursue my dreams.

ACKNOWLEDGEMENT

First and foremost, I'd like to thank God almighty for the opportunity, strength, knowledge, ability and resilience to undertake this research study and to complete it satisfactorily. Without Him, none of this would be possible.

Secondly, I wish to thank my supervisors for their constant support and guidance during the entire research period.

Finally, I wish to thank all of my lecturers and my fellow orthopaedic residents for their support and contributions.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF ABBREVIATIONS AND ACRONYMS

AFT	Accessory foramen transversaria
AP	Anteroposterior
APD	Anteroposterior diameter
C1	1st cervical vertebrae
C2	2nd cervical vertebrae
C3	3rd cervical vertebrae
C4	4th cervical vertebrae
C5	5th cervical vertebrae
C6	6th cervical vertebrae
C7	7th cervical vertebrae
FT	Foramen transversaria
IREC	Institutional Research and Ethics Committee
MTRH	Moi Teaching and Referral Hospital
T	Transverse
TD	Transverse diameter

OPERATIONAL DEFINITION OF TERMS

Bilateral: Appears on two/both sides.

Morphometry: Shape and Size

Shape: Irregular, Oval or Round.

Side: Left or right

Unilateral: Appears on one side

Variation: Difference in shape and size

ABSTRACT

Introduction: The foramen transversaria (FT) are unique to the transverse processes of the cervical vertebrae. They normally transmit the second part of the vertebral artery, the vertebral vein and sympathetic nerves with the exception of the seventh cervical vertebrae foramen transversarium that transmits the vertebral vein only. Published data indicate that the foramina transversaria exhibit several variations in their size, number, shape, and maybe present or absent. These variations could raise concerns about the integrity of the structures that traverse them and bring up the possibility of an extraosseous course of the vertebral artery. There is need for more information on foramen transversaria variations to improve surgical and patient outcomes.

Objective: To describe the morphometry of foramen transversaria and determine the prevalence of accessory foramen transversaria in intact dried cervical vertebrae of Kenyan population.

Methods: This was a descriptive, cross-sectional anatomical study done on 224 dried cervical vertebrae archived at the National Museums of Kenya. Dried intact adult skeletons that met the eligibility criteria were purposively sampled to saturation. Morphometric measurements (anteroposterior and transverse diameters) were obtained using a 150 mm steel ruler. Accessory foramen transversaria were noted, photographed and documented on a structured data collection sheet. Descriptive statistical analysis techniques of frequency (with corresponding proportions), mean (with corresponding standard deviation), median (with corresponding interquartile range) were used to describe the study participants and outcomes. A student t-test was conducted to compare the statistical difference in the means of the left and right transverse and anteroposterior diameters.

Results: This study reviewed 224 dried cervical vertebrae of which 47 had accessory foramen transversaria and 1 was missing foramen transversaria bilaterally. The prevalence of accessory foramen transversarium was 21% of the cervical vertebrae sampled and 55.3% (n=26) of these were unilateral while 44.7% (n=21) were bilateral. The overall mean anteroposterior (AP) diameter of foramen transversarium was 5.333 ± 1.218 mm while on the right it was 5.348 ± 1.273 mm and 5.365 ± 1.212 mm on the left. The overall mean transverse diameter was 5.703 ± 1.129 mm, while the mean right transverse diameter of foramen transversaria was 5.590 ± 1.195 mm and 5.868 ± 1.132 mm on the left. There was a statistically significant difference in the left and right mean transverse diameter of C3 (p=0.044) and C5 (p=0.043) as well as the mean anterior posterior diameter of C3 (p=0.015) and C6 (p=0.040). A single (0.5%) cervical vertebra (C7) exhibited bilateral absence of foramen transversaria. No unilateral absence of FT was noted. The most common shape of foramen transversarium was round (51.3%) followed by oval (43.3%) and irregular (4.9%).

Conclusions: The prevalence of accessory foramina is high. It indicates an anomalous course of the vertebral artery; that requires consideration by orthopedic and spine surgeons in the care of patients with cervical spine diseases.

CHAPTER ONE

1.0 INTRODUCTION

1.1 Background

The vertebral column in the human body is made up of alternating vertebrae and intervertebral discs which are held together by the spinal ligaments and muscles (Kusumi & Dunwoodie, 2010). These bony, cartilaginous, ligamentous, and muscular elements are needed for the structural integrity of the spine (Lalit et al., 2019). In humans , the vertebral column is made up of thirty three vertebrae that incudes seven cervical vertebrae which is the most cephalic portion of the spine then followed by twelve thoracic vertebrae which have attachments for the twelve ribs on each side followed by five lumbar vertebrae, five sacral vertebrae and finally four coccygeal vertebrae which are the most caudal vertebrae in the spine (DeSai et al., 2023). These vertebrae together with the cranium, ribs, sternum, make up the axial system of entire skeleton (DeSai et al., 2023). The spine is needed for three major functions, namely: protection of the spinal cord and spinal nerves, transmitting the weight of the body, and the provision of a flexible axis for movements of the head and the torso (Quiles-Guiñau et al., 2017). The vertebral column provides structural support and axis for movements, provides attachment s for the ribs in the thoracic region, provides attachment for various muscle groups and finally, through the effect of intervertebral discs, provides shock absorbing mechanisms during motion and while carrying loads (DeSai et al., 2023). This vertebral column is capable of extension, flexion, lateral flexion (side to side), and rotation. However, the degree to which the spine is capable of these movements varies by region. These regions, include the cervical, thoracic, lumbar, and the sacrococcygeal spine which form four major curvatures (Ulusoy, 2019).

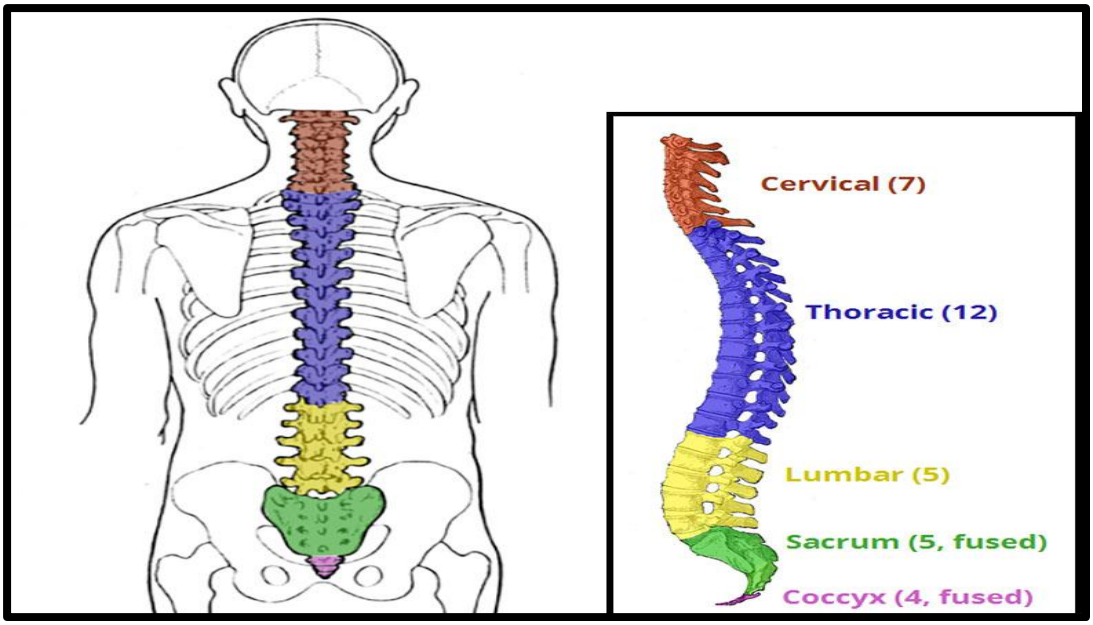


Figure 1: The human vertebrae (source: https://teachmeanatomy.info/)

The cervical vertebrae are divided into two major segments which are the craniocervical junction which is the proximal part and the subaxial spine which is the distal segment (Kaiser et al., 2023). The proximal part being the craniocervical junction includes the occiput and the first two cervical vertebrae namely the atlas and axis respectively while the subaxial part of the cervical vertebrae is composed of the third to the seventh cervical vertebrae (Kaiser et al., 2023). There are seven cervical vertebrae in the human body with the atypical ones being the first, second and seventh while the other four are known as typical vertebrae (Imre & Kocabiyik, 2016).

Atypical cervical vertebrae

There are three atypical cervical vertebrae which include: the atlas which is the first cervical vertebrae; the axis which is the second cervical vertebrae; and the vertebra prominens which is the seventh cervical vertebrae (Ambali & Jadhav, 2017).

The Atlas

The Atlas is the first cervical vertebrae and it is among the atypical vertebrae. It lies between the occipital condyles of the skull and the second vertebral vertebrae which is the axis (Pandey et al., 2020). It articulates superiorly with the occipital condyles found on each side of the foramen magnum and inferiorly with the second cervical vertebrae which is the axis. Its composed of an anterior and posterior arch, a lateral mass, a transverse process and a vertebral column (kenhub.com). The anterior arch contains the facet for articulating with the dens and the anterior tubercle whereas the posterior arch contains the groove and foramen for the vertebral artery and the posterior tubercle (kenhub.com). The lateral mass of the atlas contains a superior and inferior articular surface and a transverse ligament tubercle for the attachment of the transverse ligament. The atlas has two transverse processes on each side each containing an anterior and posterior root, a foramen transversarium and an apex of the transverse process (kenhub.com). The atlas participates in the formation of the atlanto-occipital joint, the median atlantoaxial joint, and the two lateral atlantoaxial joints. The atlas is ring shaped and encloses a space known as the spinal canal that transmits the spinal cord (kenhub.com). The atlas is unique from the rest of the cervical vertebrae in that it doesn't have a vertebral body and no spinous process (Pandey et al., 2020).

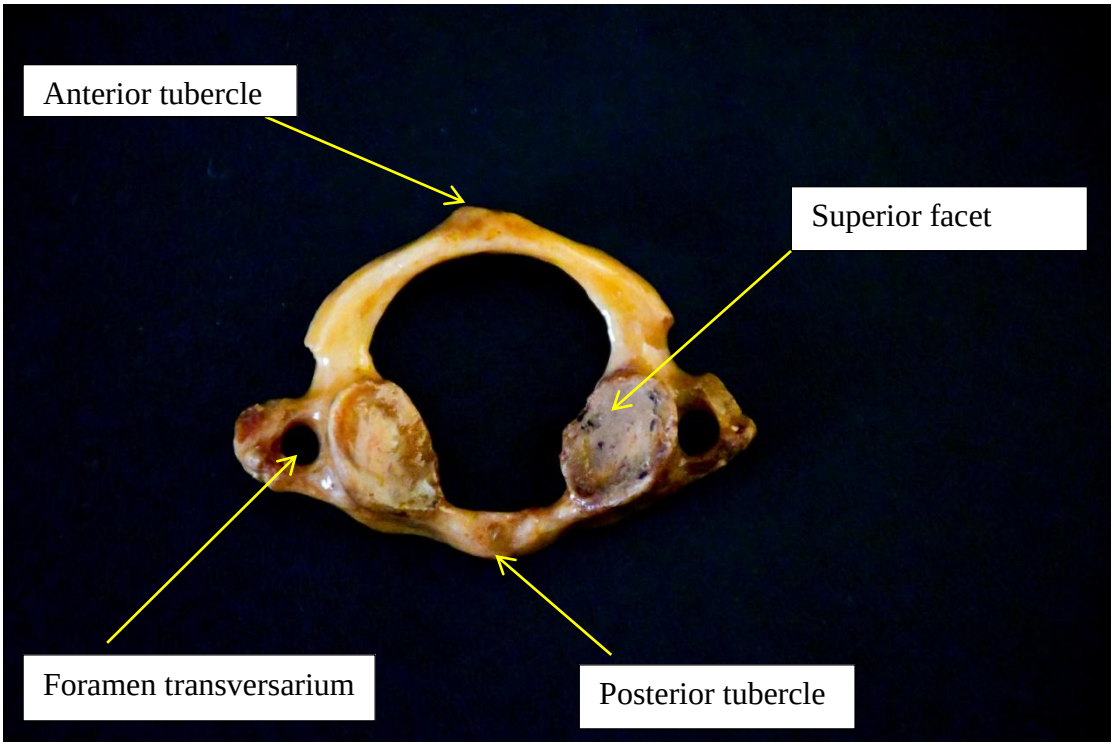


Figure 2: The atlas (source: Author's image taken at the Human Anatomy Laboratory of Moi University)

The Axis

The axis is the second vertebrae of the cervical spine articulating superiorly with the atlas and inferiorly with the third cervical vertebrae (Pandey et al., 2020). It consists anteriorly the dens or odontoid process and the vertebral body while posteriorly it consists of two pedicles, two transverse processes, two laminae and a spinous process (kenhub.com). The dens articulates with the atlas forming the median atlantoaxial joint, while the superior facets of the axis articulate with the atlas forming the lateral atlantoaxial joints(Sheik Abdul et al., 2018). The inferior facets of the axis articulate with the superior facets of the third cervical vertebrae forming the vertebroaxial joints (kenhub.com). The Axis is also among the atypical vertebrae in that it differs from the rest of the cervical vertebrae by the presence of a prominent odontoid process (Sheik Abdul et al., 2018).

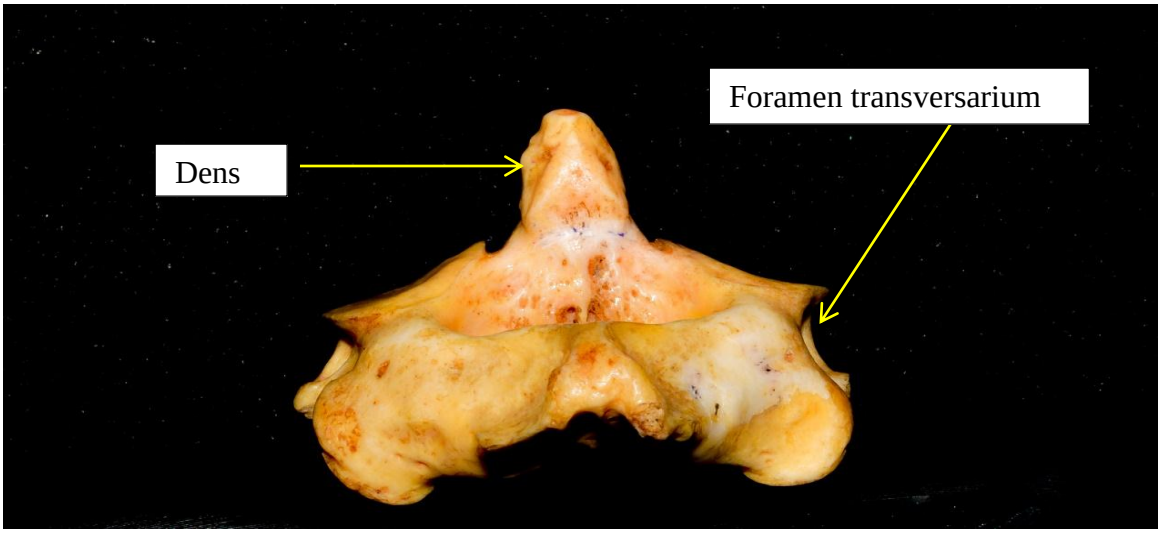


Figure 3: The axis Seventh cervical vertebrae -C7 (source: Author's image taken at the Human Anatomy Laboratory of Moi University)

Seventh cervical vertebrae (C7)

The vertebra prominens possesses the standard cervical vertebrae properties but differs from them by not having a bifid spinous process and having a smaller transverse foramen than the rest since it usually doesn't transmit the vertebral artery (Sheik Abdul et al., 2018).

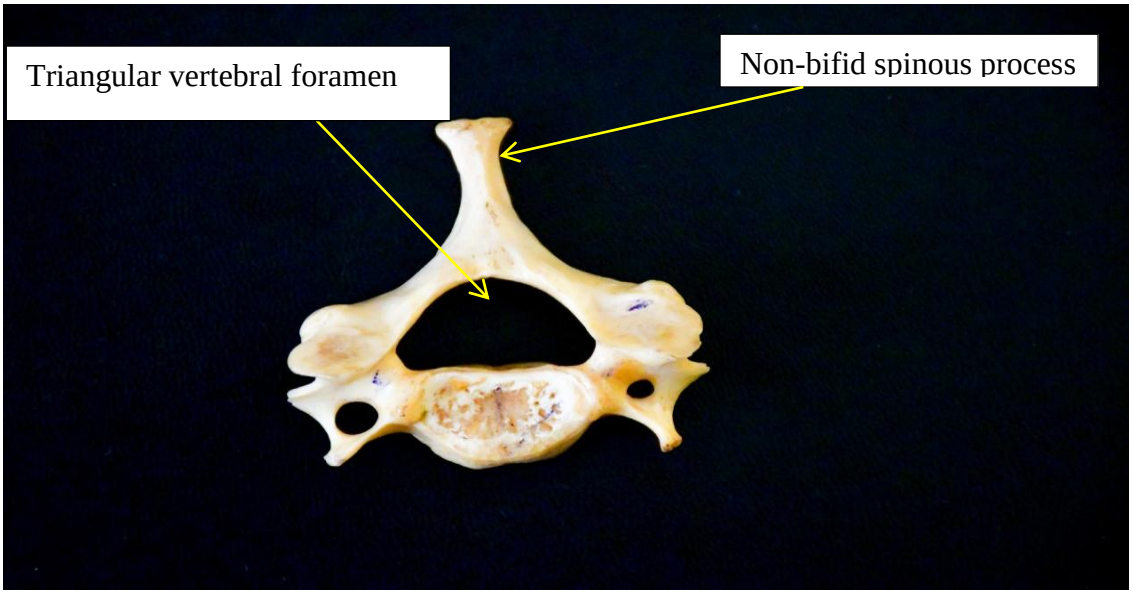


Figure 4: The seventh cervical vertebrae (source: Author's image taken at the Human Anatomy Laboratory of Moi University).

Typical cervical vertebrae

The typical cervical vertebrae are the third to the sixth cervical vertebrae (Sheik Abdul et al., 2018). The typical cervical vertebrae consist of spinous process, two laminae, superior and inferior articulating facets, two pedicles, two transverse processes each containing a foramen transversarium, vertebral body and spinal canal (Ji et al., 2015). The superior and inferior articulating facets of consecutive vertebrae form facet joints (Figure 5).

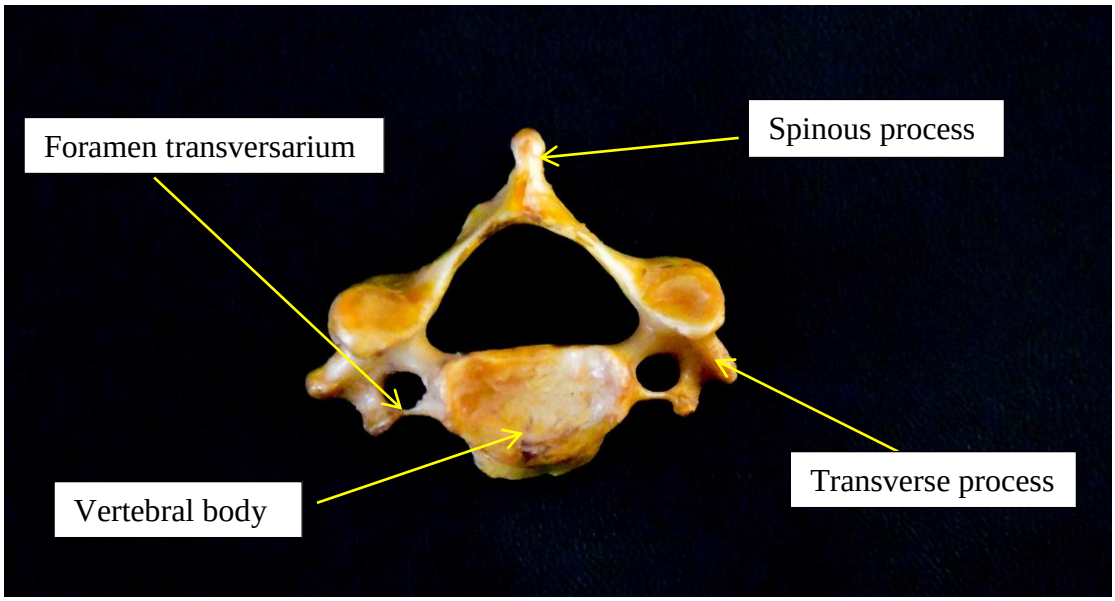


Figure 5: Typical cervical vertebrae (source: Author's image taken at the Human Anatomy Laboratory of Moi University)

The foramen transversarium (FT) is an anatomical structure in the transverse processes that uniquely discriminates the cervical vertebrae from the rest (Chaudhari et al., 2013). It transmits the vertebral artery, vertebral vein and sympathetic fibres; as the vertebral artery often enters the path of the foramen transversarium at the sixth cervical (C6) vertebra (Imre & Kocabiyik, 2016; Manjunath et al., 2018; Moreira Moreira & Herrero, 2020). However, the foramen transversarium on the seventh cervical vertebra only transmits the vertebral vein and its sometimes either small or absent (Moreira Moreira & Herrero, 2020).

The foramen transversaria may exhibit anatomical variations in terms of the shape, size, multiple or absent foramina (Metin Tellioglu et al., 2018). These anatomical variations could be developmental and may interfere with the course of the vertebral artery (Murlimanju et al., 2011; Quiles-Guiñau et al., 2017). An accessory transverse foramen could be posterior and often smaller than the primary foramen on the sixth cervical vertebra, with a low frequency on the adjacent vertebra (Molinet Guerra et al., 2017; Sheik Abdul et al., 2018). Although the prevalence of these accessory foramina varies across different demographic groups and regions, accessory foramina often interfere with the course of the vertebral artery (Murlimanju et al., 2011).

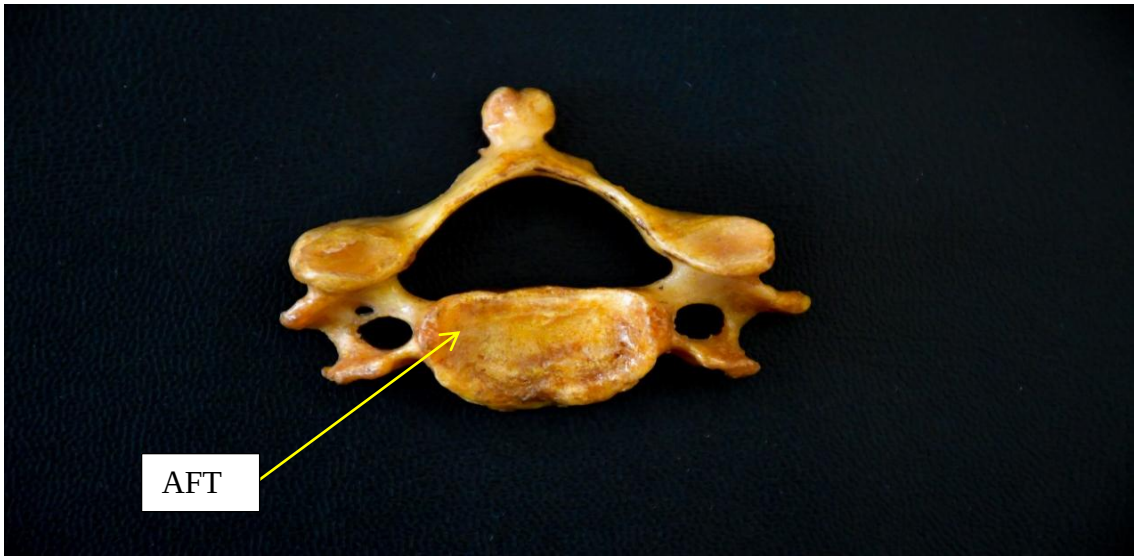


Figure 6: Accessory foramen transversaria -AFT (source: Author's image taken at the Human Anatomy Laboratory of Moi University)

Most patients with these anatomical variations in the number and size of the foramina transversaria will often complain of headaches, migraine and fainting as a result of vertebral artery compression a syndrome known as vertebrobasilar insufficiency thus necessitating the knowledge of variations of foramen transversaria to aid in the proper diagnosis and management of patients with cervical spine pathologies (Imre & Kocabiyik, 2016; Murlimanju et al., 2011).

The wider the antero-posterior diameter of the right and left foramen transversarium, the lesser the likelihood of vertebral artery compression that could arise from degenerative changes resulting in vertebral artery compression syndrome (Gul et al., 2017; Lalit et al., 2019). Previously published studies have reported that the mean diameter of the foramen transversarium vary across populations with wide asymmetries. In a study conducted among cadaveric specimens sourced from the Turkish population (Imre & Kocabiyik, 2016) the mean anterior-posterior (AP) diameter of the right and left foramen transversaria was 5.7mm and 5.5mm respectively. Furthermore, a wide asymmetry of 6mm to the right and 1mm to the left was seen in 1.2% of the study participants (Imre & Kocabiyik, 2016). In a different study conducted in Turkey (Metin Tellioglu et al., 2018) using a 3-dimensional multidetector computed tomography angiography (CTA), higher values of 7.09mm to the right and 4.56mm to the left were reported respectively. This implies a difference in morphometric measurements using cadaveric specimens and imaging techniques thus necessitating preoperative CT angiography to assess morphometric measurements of the foramen transversaria and vertebral artery size. In the Indian population, the average anteroposterior diameter of the right and left foramen transversarium were 5.21 (±1.15) mm and 5.26 (±1.12) mm respectively. However, wide morphometric asymmetries were noted on the right (1.91 mm to 8.65 mm) and left (2.12 mm to 8.47 mm) foramen transversarium (Gupta & Agarwal, 2019). In a study conducted at the Kwa Zulu Natal University among the South African population, the mean anteroposterior diameter of the right foramen transversarium was 4.12 (±1.97) mm and 4.44 (± 1.94) mm on the left (Sheik Abdul et al., 2018). Among cadaveric specimens obtained from the national museums of Kenya, the overall mean anteroposterior diameter of the atlas was 7.05 mm while among male

and female participants an average was 7.57mm and 6.73mm respectively (Karau et al., 2013).

The transverse diameter of the foramen transversarium is varied across different populations. The foramen transversarium was found to range between 3.79 mm to 7.38 mm in a study conducted in India (Yesender et al., 2017). Additionally, from more studies conducted in India, the average right transverse diameter was 5.78 (± 1.10) mm with a range of 2.44 mm to 8.76mm (Gupta & Agarwal, 2019) while the mean left transverse diameter was 5.84 (±1.03) mm with a range of 2.53 mm to 8.56 mm (Mehta & Mokhasi, 2021). In Turkey, the average right transverse diameter was 4.78 mm and 4.95 mm to the left (Polat et al., 2019). However, thesingle morphometric study conducted in Kenya reported the mean area of right transverse foramina at 36.30 mm^2 while the left transverse foramina at 37.20 mm^2 (Karau et al., 2013). This creates the need to find the average transverse diameter of the foramen transversarium in the local adult population in Kenya.

The foramen transversarium can either be small or totally absent on the seventh cervical (C_7) vertebrae (Godoy-Santos et al., 2017). Because the foramina in C7 are smaller than those in other cervical vertebrae; occasionally these foramina could be absent bilaterally or unilaterally, incomplete, small or double (Ambali & Jadhav, 2017). This small size could be because the vertebral artery enters its vertebral course almost always through the foramen transversarium of C_6. In a study conducted by researchers in India, the foramen transversaria was absent in C_1 and C_2, but present in C_4, C_5, C_6 and C_7 (Gupta & Agarwal, 2019). An absent foramen transversaria outside C_7 could imply that there is an absent vertebral artery or an extra osseous course of the vertebral artery which could be at risk of injury during cervical spine surgeries as a

result of lack of knowledge of possible variations of foramen transversaria (Yadav et al., 2014).

The foramen transversarium could be either oval, rounded, irregular or quadrangular in shape. Knowledge of different shapes of foramen transversaria is important in interpretation of medical images such as CT scan of the cervical spine and differentiation of normal foramen transversaria shapes from pathology involving the FT such as osteophytes, fractures (Aziz & Morgan, 2018). The anomalous variation of the foramen transversarium is important to the vascular and orthopaedic surgeons as well as neurosurgeons in determining the vascular variations of the entire cervical vertebra. Due to the increasing prevalence of head and neck syndromes and other injuries on the cervical spine, there is need to determine the morphology of the foramen transversarium to ensure safety and efficiency in the posterior surgical approaches to the cervical spine.

1.2 Problem statement

The cervical vertebra is an important anatomical feature in the human body as it provides both support to the head and neck while also providing a passage for the nerves and blood vessels (Oviya & Thenmozhi, 2016). Recent published statistics indicate that there is an increase in the number of road traffic accidents that lead to injuries on the cervical spine (Muguro et al., 2020). This creates an urgent need for surgical interventions for the unstable cervical spine injuries. However, there also exist variations in the morphology and dimensions of the components of the cervical spine such as the foramen transversarium which can interfere with both the interpretation of medical images as well as surgical manipulation of the cervical

vertebra (Aziz & Morgan, 2018; Karau & Odula, 2013). This necessitates a local study on the morphometric variation of the cervical spine and its components.

Furthermore, most of the documented studies on these variations have been conducted in homogenous Caucasian populations with very limited data being obtained from the heterogenous black populations (Mehta & Mokhasi, 2021; Metin Tellioglu et al., 2018; Molinet Guerra et al., 2017; Quiles-Guiñau et al., 2017). This interferes with both the standardization of surgical implants for the cervical spine and other specific intervention tools for this demographic group with varying morphology and morphometry of vascular and bony structures.

Inadequate local information and knowledge of these variations among both surgeons and radiologists may not only interfere with patient diagnosis and treatment planning, but further interfere with post-surgical outcomes among the affected patients (Das & Suri, 2005; El-Dwairi et al., 2020; Mitchell, 2009; Oviya & Thenmozhi, 2016). This study therefore aims to determine the morphometric differences in foramen transversarium (a hallmark of cervical vertebra) as well as the number of accessory foramens in an adult Kenyan population.

1.3 Justification

Anatomical variations in the shape, size, and number of foramina transversaria have been associated with the occurrence in syndromes and symptoms that include headaches, migraine, fainting blackouts attributed to blood pressure decrease in the vertebral artery, and vertebro-basilar insufficiency after certain neck movement maneuvers (Bulsara et al., 2006).

Knowledge on the morphological differences on the foramen transversarium will aid the surgeons understand the course of the vertebral artery, since an absent foramen

transversaria outside C_7 could imply that there is an absent vertebral artery or an extra osseous course of the vertebral artery which could be injured during cervical spine surgery due to lack of knowledge of FT variations leading to complications such as vertigo, stroke or even fatality (Yadav et al., 2014). Previous studies have shown that there are morphometric differences in the anteroposterior and transverse diameter of the foramen transversarium when using imaging modalities and cadaveric specimens. This study has therefore been designed to adopt cadaveric specimens to provide actual morphometric averages in the Kenyan population.

The findings of this study will be relevant to the vascular and orthopaedic surgeons as well as neurosurgeons and radiologists who often diagnose and intervene on injuries and pathologies of the cervical spine. Furthermore, the findings will inform manufacturers of cervical spine implants to produce personalized solutions based on the target population's averages and racial ancestry.

1.4 Research question

What are the morphometric findings or variations of the foramen transversarium of the cervical spine in the Kenyan population?

1.5 Objectives

1.5.1Main objective

To study the morphometric findings and variations of the foramen transversarium of the cervical spine in a Kenyan population.

1.5.2 Specific objectives

1. To determine the prevalence of accessory foramen transversaria in cervical spine specimens at the National Museums of Kenya.
2. To establish the prevalence of absent foramen transversaria in cervical spine specimens at the National Museums of Kenya.
3. To evaluate the antero-posterior diameter of the right and left foramen transversaria of the cervical spine specimens at the National Museums of Kenya.
4. To assess the transverse diameter of the right and left foramen transversaria of the cervical spine specimens at the National Museums of Kenya.
5. To identify the different types of shapes of foramen transversaria in the cervical spine specimens at the National Museums of Kenya.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Anatomy of the foramen transversarium

The cervical vertebrae are the first segment of the human spine. It has typical features which distinguish it from the rest of the human spine. Among the typical features of the cervical vertebrae, the presence of the foramen transversaria is a key feature (Polat et al., 2019). The foramen transversarium is a unique foramen which is located on the transverse processes of the cervical vertebrae. It's usually located on both the left and right transverse processes of the cervical vertebrae (Chaiyamoon et al., 2020). It transmits the vertebral artery (2^{nd} part), vertebral veins and sympathetic nerves from the cervicothoracic ganglion with the exception of the foramen transversaria of the seventh cervical vertebrae (Kalpana Ramachandran, 2014). Normally, the transverse foramina of the vertebra prominins (C7), transmits the vertebral vein and sympathetic nerves (Ambali & Jadhav, 2017).

The vertebral artery is a branch of the subclavian artery. From the subclavian artery, it usually proceeds into the neck by passing through the foramen transversaria of the sixth cervical vertebrae (Chaiyamoon et al., 2020). Various studies on the variations of the foramen transversaria show that the vertebral artery might also pass through the foramen transversaria of the seventh cervical vertebrae or even have an extra-osseous course(Molinet Guerra et al., 2017). The vertebral artery normally ascends from the foramen transversaria of the sixth cervical vertebrae through the foramen transversaria of the subsequent vertebrae to the first cervical vertebrae where it forms the basilar artery which proceeds into the skull through the foramen magnum (Chaiyamoon et al., 2021).

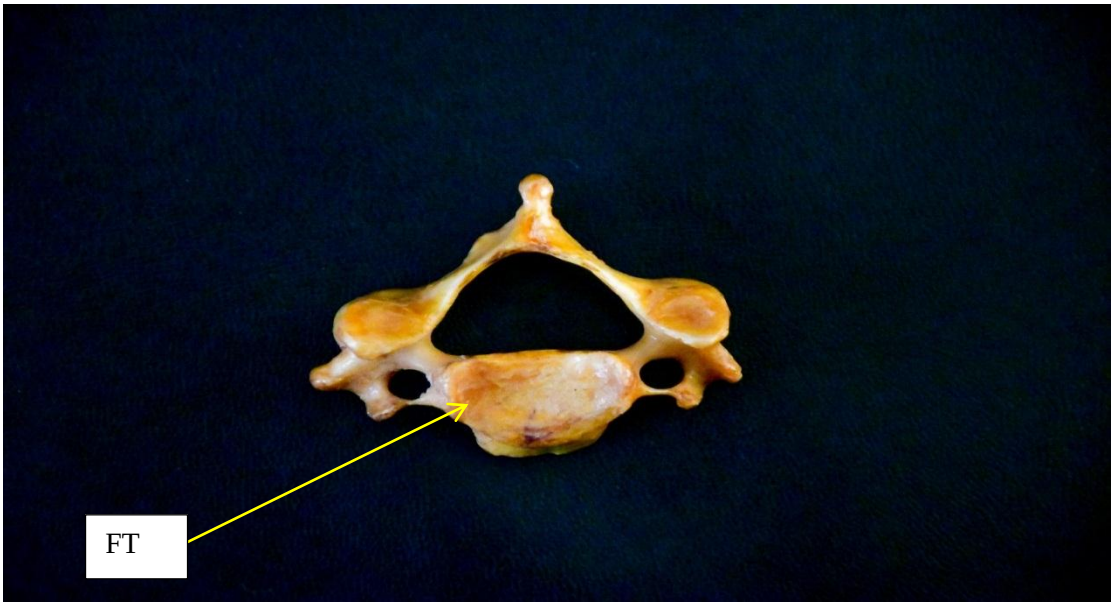


Figure 7: Foramen transversarium – FT (source: Author's image taken at the Human Anatomy Laboratory of Moi University)

Studies on the foramen transversarium show that it varies in number and size which may lead to significant clinical complications (Vikani et al., 2016). The variation in their number and size may be due to the variable course of the vertebral artery (Nayak et al., 2016). Embryologically, the foramen transversarium is formed by the union of the costal processes of the vertebral bodies and the true transverse process enclosing the vertebral artery, vertebral vein and sympathetic nerves with the exception of the seventh cervical vertebrae which normally transmits the vertebral vein only (Nayak et al., 2016).

The foramen transversaria is thus important in determining the course of the vertebral artery and thus variations in the foramen transversaria may indicate an altered course of the vertebral artery (Lalit et al., 2015). Abnormal course of the vertebral artery predisposes it to compression especially during head movements resulting in symptoms of vascular insufficiency such as headaches and syncope (Nayak et al., 2016).

An accessory foramen transversaria is the presence of another foramen in the transverse process of the cervical spine apart from the foramen transversaria. Accessory foramen transversaria may transmit variant vertebral vessels.

Variations in the foramen transversaria are present and documented (Aghera et al., 2020). The presence of double foramen transversaria, the presence of an accessory foramen transversaria, and the absence of foramen transversaria in various segments of the cervical vertebrae, have been identified (Ouies, 2018). The knowledge of the various variations in the number, size, shape, position, presence or absence of foramen transversaria; and the presence of accessory foramen transversaria is important for spine surgeons and radiologists in the management of patients with pathologies regarding the cervical spine (Aghera et al., 2020).

Anatomical variation of the transverse foramina is of significant importance to spine surgeons performing posterior cervical spine surgeries which involve instrumentation or internal fixation of the spine and also to radiologists for the proper interpretation of x-rays and CT-scans of the cervical spine (Nayak et al., 2016). The morphometry of the foramen transversaria in different populations varies and therefore, variations in the morphology of the foramen transversarium is clinically important when planning for cervical spine surgery especially in screw fixation procedures of the upper or lower Cervical vertebrae (Chaiyamoon et al., 2021).

2.2 Prevalence of accessory foramen transversaria

The accessory foramen transversaria is any foramen present in the transverse process of the cervical vertebrae together with foramen transversarium (Murlimanju et al., 2011). The accessory foramen transversarium may be unilateral or bilateral and are

normally smaller than the foramen transversarium (Sharma et al., 2010). There are various numbers of accessory foramen transversaria documented (Gul et al., 2017; Gupta et al., 2017; Pandey et al., 2020).

According to a study conducted in the Unit of Human Bone Warehouse for Research, Department of Anatomy, Faculty of Medicine, Khon Kaen University, Thailand; on one hundred and seven skeletons of specimens between the ages of thirty seven and ninety four years; presence of accessory foramen transversaria was noted. The authors categorized the accessory foramen transversaria into unilateral, bilateral and trilateral. The prevalence of unilateral accessory foramen transversaria was noted to be 8.41%. the prevalence of bilateral accessory foramen transversaria was noted to be 25.23% and that of trilateral accessory foramen transversaria was 1.87%. They concluded that the accessory foramen transversaria is a common variation in the vertebrae of the cervical region and recommended that preoperative imaging such as computed tomography angiograms should be done prior to cervical manipulation procedures or internal fixation using pedicle screws to avoid aberrant injury to the vertebral artery (Chaiyamoon et al., 2021).

A study conducted in the Department of Basic Biomedical Sciences of the University of Talca, Chile on one hundred and twenty-one dried osteological cervical vertebrae specimens; the authors studied the cervical vertebrae specimens on the basis of the anatomical variations of the foramen transversaria on the basis of presence of accessory foramen transversaria, presence of foramen transversaria, size and shape of the foramen transversaria. The authors identified presence of accessory foramen transversaria in 17.35% of the total cervical vertebrae studied. Out of all the cervical vertebrae that exhibited presence of accessory foramen transversaria, 66.6% exhibited

unilateral presence while 33.4% exhibited bilateral presence of accessory foramen transversaria. They concluded that presence of accessory foramen transversaria is common and that unilateral presence of accessory foramen transversaria is commoner than the presence of bilateral accessory foramen transversaria which was in agreement with similar studies in comparison from different geographical regions of the world. They recommended the importance of pre operative imaging of cervical spine disorders to identify variations of foramen transversaria and prevent intraoperative complications such as iatrogenic injury to an aberrant vertebral artery (Molinet Guerra et al., 2017).

A study conducted in the Department of Anatomy, Nelson Mandela School of Medicine, University of Kwa Zulu Natal, Durban, South Africa; one hundred and thirty dried human cervical osteological specimens were studied by the authors for variations of the foramen transversaria. The specimens were categorized into male and female specimens. Forty one female specimens out of the one hundred and thirty dried osteological cervical specimens studied had normal foramen transversaria (31.54%) whereas forty male specimens had normal foramen transversaria (30.77%). The total prevalence of normal foramen transversaria was 62.31%. Out of the one hundred and thirty dried osteological cervical specimens studied, twenty-two female specimens had accessory foramen transversaria (16.92%) while twenty six male specimens had accessory foramen transversaria (20%). The overall accessory transverse foramina prevalence being 36.92%. The authors concluded that the presence of accessory foramen transversaria is a quite common occurrence and that the knowledge of this variation is paramount in any clinician handling patients with cervical spine disorders (Zaw et al., 2021).

In a study conducted in the Department of Anatomy, Faculty of Medicine, Adnan Menderes University, Aydin, Turkey; the authors studied nine hundred and eighty-seven cervical spine specimens. Out of the nine hundred and eighty-seven cervical specimens, eighty eight cervical vertebrae exhibited presence of accessory foramen transversaria which was a prevalence of 8.91%. They concluded that presence of accessory foramen transversaria is a common occurrence and the knowledge of such variations is important for spine surgeons and radiologists in diagnosing and managing cervical vertebrae pathologies to avoid iatrogenic injury to an aberrant vertebral artery leading to devastating health effects and even possible fatality (Metin Tellioglu et al., 2018).

According to a study conducted in the Department of Anatomy, Gulhane Medical Faculty on eighty-two dried osteological cervical vertebrae specimens, the authors studied the cervical vertebrae specimens for anatomical and morphometric variations of the foramen transversaria on the basis of presence or absence of accessory foramen transversaria, absence of foramen transversaria, dimensions of the foramen transversaria and shapes of the foramen transversaria. Out of the eighty-two dried osteological cervical vertebrae specimens studied, eighteen cervical vertebrae exhibited the presence of accessory foramen transversaria which was a prevalence of 21.9%. Out of the eighteen cervical vertebrae with accessory foramen transversaria, six vertebrae exhibited unilateral presence of accessory foramen transversaria which was a prevalence of 7.3% while twelve cervical vertebrae exhibited bilateral presence of accessory foramen transversaria which was a prevalence of 14.6%. Of the six cervical vertebrae that exhibited unilateral presence of accessory foramen transversaria, one vertebrae exhibited the unilateral accessory foramen transversaria on the right side while five vertebrae exhibited accessory foramen transversaria on the

left side. They concluded that presence of accessory foramen transversaria is a common occurrence and that bilateral presence of accessory foramen transversaria is commoner than unilateral accessory foramen transversaria. They emphasized the importance of knowledge of morphometric and anatomical variations of the foramen transversaria in the management of patients with cervical spine pathologies. They recommended the co-relation of the findings of their study with those of cadaveric specimens and CT angiography to clearly ascertain if there exists differences in the morphometry of foramen transversaria among the dried cervical specimens, cadaveric specimens and CT angiography images (Imre & Kocabiyik, 2016).

According to a study conducted in Saveetha Medical college in Thandalam, India, the authors (Revathy et al., 2019) studied one hundred and twenty dried cervical spine specimens with emphasis on the presence and morphometry of the accessory foramen transversarium. Out of the one hundred and twenty cervical specimens studied, thirty-nine cervical vertebrae exhibited presence of accessory foramen transversaria which is a prevalence of 32.5%.

In an Italian study conducted in the Department of Anatomy and Human Embryology, University of Valencia; out of eighty-eight osteological specimens studied, a prevalence of accessory foramen transversaria was noted to be 15.5% with the prevalence of unilateral foramen transversaria being higher than that of bilateral. The presence of accessory foramen transversaria was also noted to be higher on the right than on the left (Quiles-Guiñau et al., 2017). In a different study conducted in the osteological department at the University of Kwa-Zulu Natal, South Africa; the authors studied one hundred and twenty-six dried osteological cervical specimens. They classified the vertebrae into atypical and typical vertebrae. The typical cervical

vertebrae exhibited accessory foramen transversaria prevalence of 23.2% while the atypical cervical vertebrae a prevalence of 25% (Sheik Abdul et al., 2018). They concluded that the presence of accessory foramen transversaria in the cervical spine is a common occurrence.

In an Egyptian study conducted in the Department of Anatomy, Cairo University, Egypt; the authors studied one hundred and thirty-five dried atlas vertebrae out of which, twenty three vertebrae exhibited accessory foramen transversarium. This was a prevalence of 17%. They concluded that the knowledge of the presence of accessory foramen transversarium is important because there could be a variant course of the vertebral artery if accessory foramen transversaria are present (Aziz & Morgan, 2018).

In a study conducted at the Department of Anatomy at the University of Thessaly in Greece, the authors (Zibis et al., 2016) found that ten out of seventeen skeletons with one hundred and two cervical vertebrae (C2-C7) had variations including extremely narrow or multiple foramina. From the same study (Zibis et al., 2016), hypoplastic, duplicate and triplicate foramen transversarium were identified. Prevalence of the duplicate foramina was at 13.72% and that of triplicate foramina was 0.98%.

According to a study conducted in Mangalore-India among one hundred and fourty cervical vertebrae, the authors (Rathnakar & Remya, 2013) noted variations in the number of the foramen transversaria unilaterally and bilaterally. Eight out of one hundred and fourty vertebrae presented accessory foramen transversaria which is a prevalence of 5.7%. Five vertebrae had unilateral accessory foramen transversaria (prevalence of 3.6%) and two vertebrae had bilateral double foramen transversaria

(prevalence of 1.42%). One of the vertebrae showed multiple foramen transversaria on the right side and incomplete accessory foramen transversaria on the left.

In a different study done in Chennai, India, the authors (Ramachandran, 2014) reviewed one hundred and twenty cervical vertebrae, nineteen vertebrae exhibited accessory foramen transversaria which is a prevalence of 15.8%. Ten out of the nineteen showed unilateral accessory foramen transversaria (8.3%) and nine out of the nineteen showed bilateral accessory foramen transversaria a prevalence of 7.5%. A morphological study of anatomical variation of foramen transversaria conducted in Rajasthan-India, the authors (Aghera et al., 2020) demonstrated variations in the number of foramen transversaria. Out of the one hundred and seventy-five cervical vertebrae studied, twenty-four vertebrae had duplicate foramen transversaria which is a prevalence of 13.7%. Out of the twenty-four vertebrae, twelve had bilateral duplicate foramen transversaria (6.8%) and the other twelve had unilateral duplicate foramen transversaria (6.8%). In a study conducted by authors (Gul et al., 2017) from Government Medical College Srinagar, India; one hundred adult cervical vertebrae were examined excluding deformed and damaged vertebrae and established that 9 (nine) vertebrae had accessory foramen transversaria which is a prevalence of 9%. Out of the nine, five accessory foramen transversaria were present unilaterally (5%) and four were present bilaterally (4%). From these findings, the authors concluded that unilateral accessory foramen transversaria, are more common than bilateral ones (Gul et al., 2017). In a different study conducted in India (Ambali & Jadhav, 2017) on the anatomical variations in foramen transversaria of typical cervical vertebrae in which one hundred and sixty-three typical cervical vertebrae were studied, twenty-four vertebrae had accessory foramen transversaria prevalence of 14.72%. Out of the twenty-four vertebrae, sixteen had bilateral accessory foramen transversaria (9.81%)

and eight vertebrae had unilateral accessory foramen transversaria (Ambali & Jadhav, 2017).

A local study conducted in Kenya on the foramen transversaria of one hundred and two Atlas vertebrae revealed four duplicate transverse foramina, one (1) on the left and three (3) on the right side (Karau & Odula, 2013). A study done at Turkey's Gulline University, the authors (Imre & Kocabiyik, 2016) demonstrated variations in the foramen transversaria. A total of eighty-two cervical vertebrae were studied.

According to the findings from a study conducted at the Department of Anatomy, Faculty of Medicine, Cairo University, Egypt; the authors (Aziz & Morgan, 2018) reviewed one hundred and thirty-five atlas vertebrae of which twenty-three (17%) had duplicate foramen transversaria, incomplete foramina in nine (6.7%), and incomplete accessory foramen transversaria in twelve (8.9%). In Bihar-India (Akhtar et al., 2015), of the one hundred and seventy-four cervical vertebrae studied, twenty-five vertebrae exhibited accessory foramen transversaria which is a prevalence of 14.3%. Out of the twenty-five vertebrae with accessory foramen transversaria, sixteen were typical vertebrae (9.19%) and nine were atypical vertebrae, representing 5.17% (Akhtar et al., 2015). In the sixteen typical cervical vertebrae, ten had accessory foramen transversaria on the right side (5.75%) while three typical vertebrae had accessory foramen transversaria on the left side (1.72%). The remaining three typical cervical vertebrae had bilateral accessory foramen transversaria (1.72%). Among the nine atypical cervical vertebrae, four vertebrae had accessory foramen transversaria on the right side (2.3%) while three had accessory foramen transversaria on the left side (1.72%). The remaining two atypical vertebrae had bilateral accessory foramen transversaria (1.15%). They concluded that, accessory foramen transversaria are

common in the right side than in the left side in both the atypical and typical cervical vertebrae.

A study conducted in the Department of Anatomy at IMS and SUM Hospital, Bhubaneswar, Odisha, India; the authors studied one hundred and thirty-three cervical vertebrae were studied on their morphometric basis. Out of the one hundred and thirty-three vertebrae studied, eight vertebrae exhibited accessory foramen transversaria (6%). Out of the eight vertebrae that exhibited accessory foramen transversaria, six exhibited unilateral presence of accessory foramen transversaria (4.5%) while two vertebrae exhibited bilateral presence of AFT(1.5%).The accessory foramen transversaria were noted to be of smaller size than the foramen transversaria (Nayak et al., 2016).

Another Indian study conducted in the Department of Anatomy, Rajendra Institute of Medical Sciences, Ranchi; seventy-two dried human cervical vertebrae were studied for the presence of accessory foramen transversaria. The authors noted that out of the seventy-two vertebrae studied, seven exhibited presence of accessory foramen transversaria either unilaterally or bilaterally. The prevalence was noted to be 9.72% (Patra et al., 2017).

A different study conducted in the Department of Anatomy, Weill Cornell Medical college, Cornell University, New York, USA; the authors studied seventy-one dried cervical vertebrae for variations. They found a prevalence of accessory foramen transversaria being 24%. They concluded that the prevalence of accessory foramen transversaria is high and that it suggests the possibility of duplications or fenestrations in the vertebral artery (Sangari et al., 2015).

A study conducted in the Department of Anatomy, Faculty of Medicine, Beykent University, Istanbul, Turkey on eighty-six dried osteological cervical vertebrae specimens on the basis of anatomical variations of the foramen transversaria; the authors identified fifteen cervical vertebrae with accessory foramen transversaria which was a prevalence of 17.4%. They further classified the accessory foramen transversaria into unilateral and bilateral presence. Unilateral accessory foramen transversaria were seen in 11.6% of the total cervical vertebrae with accessory foramen transversaria while bilateral accessory foramen transversaria were seen in 5.8% of the total cervical vertebrae with accessory foramen transversaria. They concluded that presence of accessory foramen transversaria is a common occurrence and that unilateral presence of accessory foramen transversaria was more common than bilateral presence of accessory transverse foramina. Out of the cervical vertebrae with presence of accessory foramen transversaria, the typical cervical vertebrae exhibited presence of accessory foramen transversaria in 10.5% while the atypical cervical vertebrae exhibited presence of accessory foramen transversaria in 15.1% of the cases. They recommended the use of pre-operative cervical spine imaging such as CT angiography and three dimensional CT scans of the cervical spine to identify presence of accessory foramen transversaria so as to prevent injury to the vertebral artery during cervical spine surgery (Ulusoy, 2019).

According to a study conducted in the Department of Medicine, University of Chieti-Pescara, Chieti, Italy; the authors studied four hundred and forty-six dried osteological cervical specimens assessing the anatomical variations of the transverse foramen of the cervical vertebrae on the basis of number, shape, and size of the transverse foramen. They identified presence of accessory foramen transversaria in 20.6% of the cervical vertebrae specimens studied. They concluded that the

occurrence of accessory foramen transversaria is common based on the results of their study and on the findings of similar studies in various geographical regions in comparison. They also concluded that further investigations on the variations of the foramen transversaria on the basis of number, shape and size is necessary to provide additional information on the variations of the foramen transversaria since the foramen transversaria is an important determinant in the proper embryological development of the vertebral artery (Viciano et al., 2021).

A study conducted in the anthropology section of the Department of Anatomy, Veer Surendra Sai institute of Medical sciences and Research, Buria, Odisha, India on three hundred and sixty seven dried osteological cervical specimens, the authors studied the cervical vertebrae specimens for morphological and morphometric variations of the foramen transversaria. Each of the dried cervical vertebrae was examined on the basis of size of foramen transversaria, shape of foramen transversaria and presence or absence of foramen transversaria. Out of the three hundred and sixty-seven cervical vertebrae studied, forty vertebrae exhibited presence of accessory foramen transversaria which was a prevalence of 10.9%. out of the forty cervical vertebrae that exhibited accessory foramen transversaria, eighteen exhibited bilateral presence of accessory foramen transversaria which was a prevalence of 4.9% while twenty-two exhibited unilateral presence of accessory foramen transversaria which was a prevalence of 6.0%. Two cervical vertebrae exhibited presence of more than one accessory foramen transversaria unilaterally which the authors termed as triplication of the foramen transversaria. The prevalence of the triplication of foramen transversaria was recorded as 0.54%. The authors concluded that accessory foramen transversaria is a common phenomenon which was similar conclusion to similar studies under comparison from different geographical regions. They recommended

the use of pre-operative imaging such as CT angiograms of the cervical spine to identify aberrant vertebral arteries and prevent iatrogenic injury to the arteries during cervical spine surgeries including posterior instrumentation and fusion. They concluded that the high number of cervical vertebrae that exhibited presence of accessory foramen transversaria suggested that vertebral artery variations would be featured in such cases. They emphasized on the importance of the knowledge of morphological and morphometric variations of the foramen transversaria to clinicians handling patients with cervical spine disorders most importantly to neurosurgeons, spine surgeons, radiologists and vascular surgeons, so as to properly diagnose and manage cervical spine related conditions preventing avoidable complications such as iatrogenic injury to an aberrant vertebral artery during cervical spine surgery (Behera et al., 2023).

According to a study conducted in the post graduate department of Anatomy at Government Medical College Karannagar Srinagar Kashmir, India on one hundred dried cervical vertebrae, the authors identified nine vertebrae with accessory foramen transversaria giving a prevalence of 9%. They also studied unilateral and bilateral presence of accessory foramen transversaria. Four out of the nine cervical vertebrae with accessory foramen transversaria exhibited bilateral presence of accessory foramen transversaria which was a prevalence of 4%. The other five cervical vertebrae with accessory foramen transversaria exhibited unilateral presence of accessory foramen transversaria which is a prevalence of 5%. They further studied the position of the accessory foramen transversaria in relation to the foramen transversaria. Seven out of eight foramen transversaria that were present bilaterally were present posterior to the foramen transversaria while one accessory foramen transversaria was anterior to the foramen transversaria. They concluded that unilateral

presence of accessory transverse foramina was commoner (5%) than bilateral accessory foramen transversaria (4%) and that the knowledge of presence of accessory foramen transversaria is important for spine surgeons and radiologists in the diagnosis and management of pathologies involving the cervical spine (Gul et al., 2017).

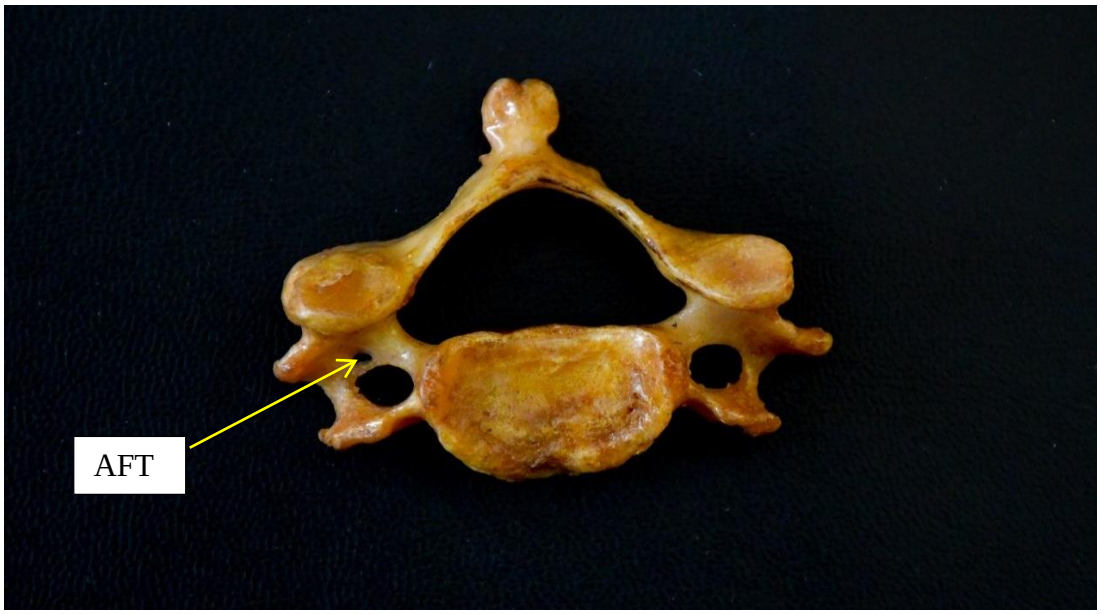


Figure 8: Accessory foramen transversarium – AFT (source: Author's image taken at the Human Anatomy Laboratory of Moi University)

Author	**Zibis**	**Rathnakar & Remya**	**Ramachandran**	**Gul**	**Karau & Odula**	**Imre**	**Aziz**	**Akhtar**
Year	**2016**	2013	2014	2017	2013	2016	2018	2015
Country	Greece	India - Mangalore	India - Chennai	India - Srinagar	Kenya	Turkey	Egypt	India - Bihar
Sample Size	102	140	120	100	102	82	135	174
Study Design	Cross-sectional	Cross-sectional	Cross-sectional	Cross-sectional	Cross-sectional	Cross-sectional	Cross-sectional	Cross-sectional
Prevalence (Accessory Foramen Transversarium)	13.72 %	5.7%	15.8%	9%	3.9%	23.95 % (n=18)	17%	14.3%
Bilateral	-	3.6%	8.3%	4%		14.63 %	-	1.72%
Unilateral	-	2.1%	7.5%	5%	3.9%	9.32%	-	12.58 %

2.3 Prevalence of absent FT in cervical spine

The foramen transversaria is a typical feature of the cervical spine, and it exhibits numerous variations in the shape, size and may be absent or present (Ramachandran, 2014). A study by Gupta & Agarwal, (2019) conducted on three hundred and nineteen foramen transversaria of one hundred and sixty-one dry cervical vertebrae revealed that three foramen transversaria (0.9%) were absent in two seventh cervical vertebrae. One seventh cervical vertebrae lacked a foramen transversaria bilaterally and one had a unilateral foramen transversaria (Gupta & Agarwal, 2019). This shows despite the fact that absent foramen transversaria are rare, there is still a chance of encountering cervical vertebrae without a foramen transversaria thus the varying course of the vertebral artery should always be in mind for spine surgeons and radiologists. According to a study by Ramachandran, 2014 among all the one hundred and twenty cervical vertebrae studied, none was missing a foramen transversaria.

According to a study conducted in the Department of Basic Biomedical Sciences of the University of Talca, Chile; the authors studied one hundred and twenty-one dried osteological cervical vertebrae specimens on the basis of the anatomical variations of the foramen transversaria for the presence of accessory foramen transversaria, presence of foramen transversaria, size and shape of the foramen transversaria. Out of the one hundred and twenty-one dried cervical specimens studied, none exhibited absence of foramen transversaria (0% prevalence). They concluded that absence of foramen transversaria is quite rare but still recommended pre operative imaging to assess possible absence of foramen transversaria since though it’s a rare occurrence, it’s absence has been documented in various studies across various geographical regions therefore the need to confirm the presence or absence of foramen transversaria

pre operatively to avoid intra operative complications such as vertebral artery injury since the foramen transversaria usually dictates the embryological development of the vertebral artery (Molinet Guerra et al., 2017).

In a study conducted in the Department of Anatomy, Faculty of Medicine, Adnan Menderes University, Aydin, Turkey; nine hundred and eighty-seven cervical vertebrae were studied. Out of the nine hundred and eighty-seven vertebrae studied, thirty-seven vertebrae exhibited absence of foramen transversaria either unilaterally or bilaterally which was a prevalence of 3.74%. With the findings noted, the authors concluded that the absence of foramen transversaria which was previously noted to be quite rare is actually common. They further recommended that pre operative cervical spine imaging such as CT angiography and three dimensional CT scan of the cervical vertebrae is necessary to assess the morphometry of the foramen transversaria and possible variations and also to assess the vertebral artery course in the neck to avoid injury to the vertebral artery during cervical spine surgeries as a result of lack of knowledge about variations of the foramen transversaria and consequent variable course of the vertebral artery (Metin Tellioglu et al., 2018).

A study conducted in the Department of Anatomy, Nelson Mandela School of Medicine, University of Kwa Zulu Natal, Durban, South Africa; the authors studied one hundred and thirty dried human cervical osteological specimens for variations of the foramen transversaria including presence or absence of foramen transversaria. The specimens were categorized into male and female specimens. Out of the one hundred and thirty specimens studied, forty-one female specimens had normal foramen transversaria (31.54%) whereas forty male specimens had normal foramen transversaria specimens (30.77%), the total prevalence of normal foramen

transversaria being 62.31%. Twenty-two female specimens had accessory foramen transversaria (16.92%) while twenty six male specimens had accessory foramen transversaria (20%). The total prevalence of accessory foramen transversaria being 36.92%. Only one male cervical specimen exhibited absence of foramen transversaria a prevalence of 0.77%. They concluded that absent transverse foramina is a rare occurrence yet a possibility that can prove catastrophic incase the spine surgeon handling cervical spine pathologies doesn't have the knowledge of possible variations of the foramen transversaria thus knowledge of possible absence of foramen transversaria and consequent extraosseous course of the vertebral artery is of great importance to neurosurgeons, spine surgeons and radiologists in the diagnosis and management of cervical pathologies (Zaw et al., 2021).

According to a study conducted in the Department of Medicine, University of Chieti-Pescara, Chieti, Italy on four hundred and forty-six dried osteological cervical specimens on the anatomical variations of the transverse foramen of the cervical vertebrae on the basis of number, shape, and size of the transverse foramen, the authors identified one cervical vertebrae with absent foramen transversaria giving a prevalence of 0.2%. They concluded that the absence of foramen transversaria either bilaterally or unilaterally is a very rare event backed up by evidence from similar studies in comparison from different geographical regions of the world. They also concluded that despite it being a rare occurrence, knowledge of this variation is crucial to neurosurgeons, spine surgeons and radiologists handling patients with cervical spine disorders since an absent foramen transversaria might indicate an extra osseous course of the vertebral artery thus putting it at risk of injury during cervical spine surgeries (Viciano et al., 2021).

According to a study conducted in the anthropology section of the Department of Anatomy, Veer Surendra Sai institute of Medical sciences and Research, Buria, Odisha, India on three hundred and sixty seven dried osteological cervical specimens, the authors studied the cervical vertebrae specimens for morphological and morphometric variations of the foramen transversaria. Each of the dried cervical vertebrae was examined on the basis of shape, size and presence or absence of foramen transversaria. Out of the three hundred and sixty-seven dried osteological cervical specimens studied, none showed absence of foramen transversaria. Their findings were similar to most of the similar studies under comparison in different geographical regions in that absence of foramen transversaria is a rare occurrence but contrasted with few similar studies which exhibited absence of foramen transversaria in several cervical vertebrae making it a rare yet possible phenomenon. They recommended pre-operative specialized imaging modalities such as CT scans of the cervical vertebrae to rule out the absence of foramen transversaria and CT angiograms to identify an extra osseous course of the vertebral artery. Knowledge of presence of an extraosseous vertebral artery is important to prevent injury to the vertebral artery during cervical spine surgery (Behera et al., 2023).

According to a study conducted in the post graduate department of Anatomy at Government Medical College Karannagar Srinagar Kashmir, India; the authors studied one hundred dried cervical vertebrae specimens. Out of the one hundred specimens studied, they did not identify any vertebrae that was missing a foramen transversaria. They concluded that absent foramen transversaria is rare since they didn’t find any vertebrae missing a foramen transversaria out of all the one hundred cervical vertebrae studied. They also noted that absent foramen transversaria is a possibility that should always be kept in mind despite them not identifying a cervical

vertebrae without an accessory foramen transversaria either unilaterally or bilaterally (Gul et al., 2017). They recommended the use of pre-operative imaging of the cervical spine to rule out an extra osseous course of the vertebral artery so as to avoid injury to an aberrant vertebral artery during cervical spine surgical procedures. A study by Karau et al., 2013 on the anatomical and morphometric observations in the transverse foramina of the atlas in which one hundred and two atlases were studied, no incidences of absent foramen transversaria were revealed. In an Indian study conducted in the Department of Anatomy, Krishna Institute of Medical Sciences; the authors studied one hundred and fifty-six dry seventh cervical vertebrae out of which, one exhibited unilateral absence of foramen transversarium. The prevalence of absent foramen transversaria being 0.01% (Ambali & Jadhav, 2020). Another Indian study conducted in the Department of Anatomy, PSG Institute of Medical Sciences and Research, Coimbatore; three hundred dried human cervical vertebrae were studied. Out of the three hundred specimens, one vertebrae exhibited unilateral absence of foramen transversarium giving a prevalence of 0.003% (A.K. et al., 2018). A study conducted in Israel from the Department of Anatomy and Anthropology, Sackler School of Medicine, Tel-Aviv University; the authors studied four hundred and eighty dried cervical human specimens. Out of the specimens studied, 3 fourth cervical vertebrae and 1 sixth cervical vertebrae exhibited bilateral absence of foramen transversaria. This gives a prevalence of 0.008% (Taitz et al., 1978). Numerous studies show that the prevalence of absent foramen transversaria in the cervical spine is rare and yet a possibility which should always be expected or anticipated by physicians, radiologists, spine and vascular surgeons to avoid inadvertent injury to an extra-osseous second part of the vertebral artery.

A study conducted in the Department of Anatomy, Gulhane Medical Faculty; the authors studied eighty-two dried osteological cervical vertebrae specimens for anatomical and morphometric variations of the foramen transversaria on the basis of presence or absence of accessory foramen transversaria, absence of foramen transversaria, dimensions of the foramen transversaria and shapes of the foramen transversaria. Out of the eighty-two dried osteological cervical vertebrae specimens studied, no vertebrae exhibited absence of foramen transversaria. They concluded that absent foramen transversaria is very rare but a possible occurrence which can be catastrophic during cervical spine surgery in case the spine surgeon isn't aware of the possibility of absent foramen transversaria and possible extra osseous course of the vertebral artery resulting in iatrogenic injury to the vertebral artery. Pre-operative cervical spine imaging was recommended to prevent iatrogenic injury to the aberrant vertebral artery (Imre & Kocabiyik, 2016).

Figure 10: Cervical spine with absent FT (Durge et al., 2017)

Author	Gupta & Agarwal	Ramachandran	Gul	Karau	Imre & Kocabiyik
Year	2019	2014	2017	2013	2016
Country	India	India	India	Kenya	Turkey
Sample Size	319	120	100	102	82
Study Design	Cross-sectional	Cross-sectional	Cross-sectional	Cross-sectional	Cross-sectional
Absent FT	n=3 (0.94%)	n=0	n=0	n=0	n=0

2.4 Dimensions of the foramen transversarium

The common dimensions used in the morphometry of the foramen transversaria are the measurements of the antero-posterior diameter and the transverse diameter.

2.4.1 Antero-posterior and transverse diameter of the foramen transversaria (right and left)

According to a study done locally by Karau et al., 2013 on one hundred and two atlas vertebrae, the mean anteroposterior diameter was 7.05mm whereas the mean transverse diameter was 6.50mm. There was no statistically significant bilateral asymmetry in this study (Karau & Odula, 2013). According to a study conducted in the Department of Anatomy, Gulhane Medical Faculty on eighty-two dried osteological cervical vertebrae specimens, the authors studied the cervical vertebrae specimens for anatomical and morphometric variations of the foramen transversaria on the basis of presence or absence of accessory foramen transversaria, absence of foramen transversaria, dimensions of the foramen transversaria and shapes of the foramen transversaria. Out of the eighty-two dried osteological cervical vertebrae specimens studied, the mean anteroposterior diameters of the right and left foramen transversaria were 5.7mm and 5.5mm respectively and the transverse diameters of the right and left foramen transversaria were 6.5mm and 6.6mm respectively. There was

no statistically significant difference in both diameters bilaterally (Imre & Kocabiyik, 2016).

According to a study conducted in the Unit of Human Bone Warehouse for Research, Department of Anatomy, Faculty of Medicine, Khon Kaen University, Thailand; on one hundred and seven skeletons of specimens between the ages of thirty seven and ninety four years; the authors studied the AP and transverse diameters of dried osteological specimens of males and females getting a mean AP diameter of 6.97mm for males and 6.81mm for females; mean transverse diameter of 5.57mm for males and 5.28mm for females. A statistical significant difference was gotten between the male and female transverse diameters of foramen transversaria with a p value of 0.003. The authors concluded that the variation between diameters of foramen transversaria of males and females is of clinical importance in that preoperative imaging such as CT angiography should be performed so as to assess the size of the foramen transversaria and use implants that are personalized per patient depending of the parameters of the foramen transversaria to avoid adverse effects during surgery (Chaiyamoon et al., 2021).

Another study on the morphometry of the cervical vertebrae done by Polat et al., 2019 showed that the mean of the anteroposterior diameter of the foramen transversaria was 4.23mm on the right and 4.28mm on the left. The study (Polat et al., 2019) also showed that the mean transverse diameter of the foramen transversaria was 4.78mm on the right and 4.95mm on the left. No statistically significant difference in the means of the diameters of the foramen transversaria was noted bilaterally.

A study by Mehta et al., 2021 on seven hundred and fifty cervical vertebrae revealed that the mean anteroposterior diameter of the foramen transversaria was 7.30mm on the left and 7.23mm on the right. It also showed that the mean transverse diameter of the foramen transversaria was 5.96mm on the left and 5.90mm on the right. There was no significant statistical difference between the means of the foramen transversaria diameters on both sides.

A study conducted in the Department of Anatomy, Weill Cornell Medical College, Cornell University, New York; conducted a study on seventy-one dried typical cervical vertebrae based on the dimensions of the foramen transversaria. The mean right and left anteroposterior diameters of the foramen transversaria ranged from 2.54mm to 7.79mm. The mean right and left transverse diameters of the foramen transversaria ranged from 2.65mm to 7.35mm. There was no statistical difference in the dimensions between the right and left sides (Sangari et al., 2015).

A study conducted in the anthropology section of the Department of Anatomy, Veer Surendra Sai institute of Medical sciences and Research, Buria, Odisha, India on three hundred and sixty seven dried osteological cervical specimens, the authors studied the cervical vertebrae specimens for morphological and morphometric variations of the foramen transversaria. Each of the dried cervical vertebrae was examined on the basis of shape, size and presence or absence of foramen transversaria. The size of the foramen transversaria was measured in terms of anteroposterior and transverse diameters. The mean anteroposterior diameter on the left side was 5.45mm while the mean anteroposterior diameter on the right side was 5.29mm. The mean transverse diameter on the right side was 5.23mm while on the left side was 5.42mm. The mean anteroposterior diameter and transverse diameters of the foramen transversaria on the

left side were larger than the diameters of foramen transversaria on the left. Their findings were similar to similar studies in comparison from different geographical regions. No statistically significant difference was noted between the mean anteroposterior diameter and transverse diameters of the foramen transversaria. They recommended pre-operative imaging modalities such as three dimensional CT scans of the cervical vertebrae to assess the sizes of the foramen transversaria to avail correct implant sizes for fixation of cervical spine pathologies (Behera et al., 2023).

A different study conducted in the Department of Anatomy, Sri Guru Das Institute of Medical Sciences and Research, Amristar, Punjab, India; the authors studied thirty atlases (C1) based on their morphometry. The mean anteroposterior diameter of the foramen transversaria was noted to be 6.72mm and 6.90mm on the right and left sides respectively. There was no statistically significant difference between the mean anteroposterior diameters of the foramen transversaria on the right and left sides. The mean transverse diameters of the foramen transversaria was noted to be 5.17mm and 5.40mm on the right and left sides with no statistical difference noted in the diameters of the foramen transversaria (Lalit et al., 2015).

A study conducted in India in the Department of Anatomy, Luxmi Bai Dental College and Hospital, Patiala, Punjab; the authors studied one hundred and seventy-six typical dried human cervical vertebrae based on their morphometry. The average anteroposterior diameter of the right and left foramen transversaria ranged from 5.39mm to 6.54mm. The average transverse diameter of the right and left foramen transversaria ranged from 5.27mm to 6.28mm. There was no statistically significant difference between the anteroposterior and transverse diameters of the foramen transversaria on the right and left sides (Aggarwal et al., 2020).

A different study conducted in the Department of Basic Biomedical Sciences of the Universidad de Talca, Chile; the authors studied one hundred and twenty-one cervical vertebrae. They measured the anteroposterior and transverse diameters of the foramen transversaria. The mean recorded anteroposterior diameter was 5.60mm on the right and 5.92mm on the left. The mean transverse diameter was 4.40mm on the right and 5.56mm on the left. A statistical significance was noted in the foramen transversaria diameters between dimensions on the right and left side (Molinet Guerra et al., 2017).

A study conducted in the Department of Anatomy, Nelson Mandela School of Medicine, University of Kwa Zulu Natal, Durban, South Africa on one hundred and thirty dried human cervical osteological specimens, morphometric dimensions of the foramen transversaria were taken of which AP and Transverse diameters were among the measurements taken. The measurements were categorized into male and female specimens. The average right male AP diameter of foramen transversaria was 6.16mm and the average right female AP diameter of the foramen transversaria was 5.93mm. There was no statistically significant difference between the mean right AP diameter of the foramen transversaria of the male and female specimens. The average left male AP diameter of foramen transversaria was 6.25mm and the average left female AP diameter of the foramen transversaria was 6.09mm. There was no statistically significant difference between the mean left AP diameter of the foramen transversaria of the male and female specimens. The average right male transverse diameter of foramen transversaria was 7.02mm and the average right female transverse diameter of the foramen transversaria was 6.77mm. There was no statistically significant difference between the mean right transverse diameter of the foramen transversaria of the male and female specimens. The average left male transverse diameter of foramen transversaria was 7.32mm and the average left female transverse diameter of the

foramen transversaria was 6.89mm. There was a statistically significant difference between the mean left transverse diameters of the foramen transversaria of the male and female specimens with a P value of 0.02. The AP diameters of both male and female specimens were higher on the left foramen transversaria. Similarly, Transverse diameters of both male and female specimens were higher on the left foramen transversaria. They concluded that knowledge of the variable foramen transversaria sizes was important for management of patients with cervical spine disorders and also important for implant manufacturing companies to provide cervical spine implants of variable sizes to cater for all patients with varied foramen transversaria sizes (Zaw et al., 2021).

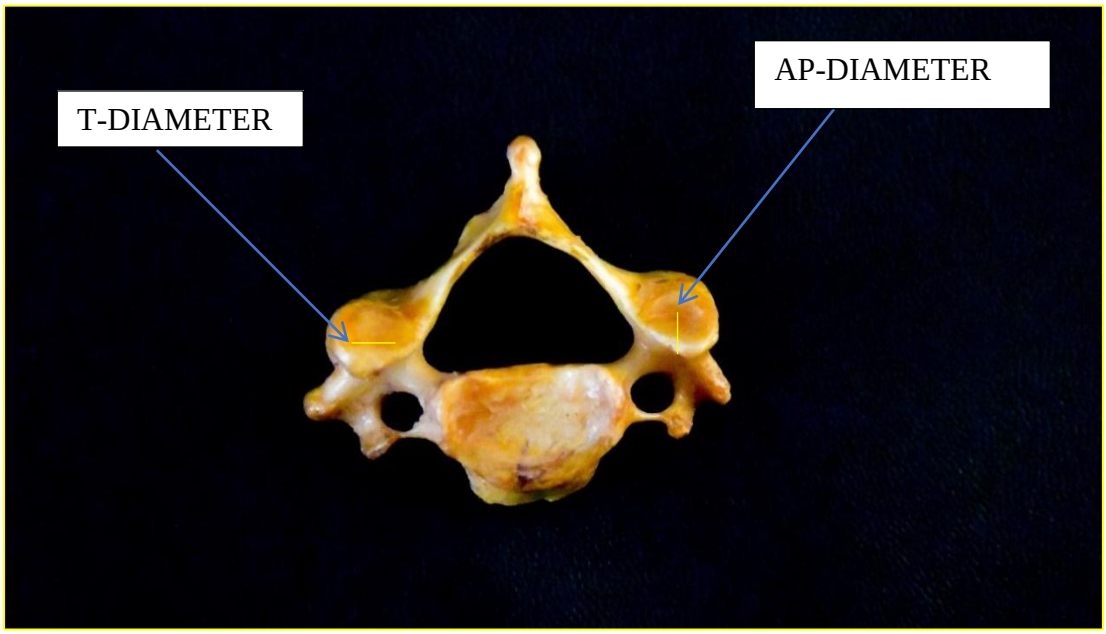


Figure 11: The anteroposterior (AP) and transverse (T) diameters of FT

	Karau & Odula,	Imre & Kocabiyik	Polat	Mehta
Year	2013	2016	2019	2021
Country	Kenya	Turkey	Turkey	India
Sample Size	102	82	96	750
Study Design	Cross-sectional	Cross-sectional	Cross-sectional	Cross-sectional
AP Diameter Overall Mean	7.05mm	-	-	-
AP Diameter RT _Mean	-	5.7mm	4.23mm	7.23mm
AP Diameter LT _Mean	-	5.5mm	4.28mm	7.30mm
Transverse Diameter RT _Mean	-	6.5mm	4.78mm	5.90mm
Transverse Diameter LT _Mean	-	6.6mm	4.95mm	5.96mm

2.5 Different types of shapes of foramen transversarium

There are numerous variations identified in the shapes of foramen transversaria. According to a study by Ramachandran, (2014) on one hundred and twenty cervical vertebrae, seventy-six had round shape which was 63.3% of the total number of the vertebrae studied. Forty-four vertebrae had elliptical shape with the axis of their main diameter facing different directions at 36.7% (Ramachandran, 2014) . A different study by Ambali & Jadhav, (2017) on one hundred and sixty-three typical cervical vertebrae, identified varying shapes of the foramen transversaria from round, elliptical, ‘D’ shapes to irregular shapes. The round and elliptical shapes were the majority (Ambali & Jadhav, 2017).

A study conducted in the Department of Anatomy, Nelson Mandela School of Medicine, University of Kwa Zulu Natal, Durban, South Africa on one hundred and thirty dried human cervical osteological specimens, the authors identified different

shapes of foramen transversaria and classified them into seven types. Type 1 was round shape, type 2 to type 5 was elliptical shapes in different directions, type 6 was irregular shape and type 7 was absent foramen transversaria. On the right side, type 1 foramen transversaria had a prevalence of 46.18%, type 2 had a prevalence of zero, type 3 had a prevalence of 20%, type 4 had a prevalence of 18.46%, type 5 had a prevalence of 2.31%, type 6 had a prevalence of 13.07% and type 7 had a prevalence of zero. On the left side, type 1 foramen transversaria had a prevalence of 43.85%, type 2 had a prevalence of 0.77%, type 3 had a prevalence of 23.06%, type 4 had a prevalence of 1.54%, type 5 had a prevalence of 16.92%, type 6 had a prevalence of 13.07% and type 7 had a prevalence of 0.77%. In both the right and left foramen transversaria, type 1 shape of foramen transversaria was the most prevalent. They concluded that knowledge of different shapes of foramen transversaria is important in differentiating normal foramen transversaria anatomy from pathologies involving the foramen transversaria such as fractures or degenerative changes especially on radiologic images of the cervical spine such as CT scans (Zaw et al., 2021).

According to a study conducted in the anthropology section of the Department of Anatomy, Veer Surendra Sai institute of Medical sciences and Research, Buria, Odisha, India on three hundred and sixty seven dried osteological cervical specimens, the authors studied the cervical vertebrae specimens for morphological and morphometric variations of the foramen transversaria. Each of the dried cervical vertebrae was examined on the basis of shape, size and presence or absence of foramen transversaria. The authors classified the shapes of the foramen transversaria into six types. Type one being round shape, type two to five being elliptical in different directional orientation and type six which was irregular shape. Type one was the commonest shape exhibited with a prevalence of 62.1% followed by type two

shape with a prevalence of 15.5% then type three shape with a prevalence of 7.1% then type six shape with a prevalence of 6.8% followed by type five shape with a prevalence of 5.2% and finally type four shape with the least prevalence of 3.3%. Their finding of the round shape being commonest shape of foramen transversaria was similar in most studies in comparison but contrasted with few other studies. The authors concluded that knowledge of different shapes of foramen transversaria is important in differentiating normal foramen transversaria shapes from pathologies involving the foramen transversaria such as fractures and degenerative features such as osteophytes. They recommended the use of three dimensional CT scans in patients with cervical pathologies to clearly differentiate pathology of foramen transversaria from normal foramen transversaria anatomy (Behera et al., 2023).

According to a study conducted in the Unit of Human Bone Warehouse for Research, Department of Anatomy, Faculty of Medicine, Khon Kaen University, Thailand; on one hundred and seven skeletons of specimens between the ages of thirty seven and ninety four years; the authors studied the various shapes of the foramen transversaria of the male and female dried osteological specimens available and classified them into five types; type one being rounded shape whereas types two to five were elliptical shapes with different directional orientation. The authors then developed prevalences of the various shapes identified and documented as follows: For the male specimens; Type 1 foramen transversaria shape had a prevalence of 23.6%, type 2 foramen transversaria shape had a prevalence of 69.8%, type 3 foramen transversaria shape had a prevalence of zero, type 4 foramen transversaria shape had a prevalence of 2.8%, and type 5 foramen transversaria shape had a prevalence of 3.7%. The female foramen transversaria shapes were documented as follows: Type 1 foramen transversaria shape had a prevalence of 20.4%, type 2 foramen transversaria shape

had a prevalence of 79.6%, type 3 foramen transversaria shape had a prevalence of zero, type 4 foramen transversaria shape had a prevalence of zero, and type 5 foramen transversaria shape had a prevalence of zero. They concluded that the type 2 foramen transversaria shape was commonest in both males and females and emphasized on the importance of the knowledge of different shapes of foramen transversaria in the interpretation of radiologic imaging of the cervical spine so as to be able to differentiate between normal foramen transversaria shapes and pathologies involving the foramen transversaria (Chaiyamoon et al., 2021).

A study in Kenya assessed the various shapes of the foramen transversaria of one hundred and two atlases. The shapes observed were round and elliptical shapes (Karau & Odula, 2013). Round shaped foramen transversaria were twenty-two (10 right and 12 left) and elliptical shaped foramen transversaria were one hundred and eighty-two (92 right and 90 left). The elliptical shapes were further classified using the direction of the axis of the main diameter of the foramen transversaria (Karau & Odula, 2013). Another study on eighty-two cervical vertebrae revealed that majority of the shapes of the foramen transversaria were rounded (Imre & Kocabiyik, 2016). According to a study by Aziz & Morgan, (2018) on one hundred and thirty-five atlas vertebrae, four shapes were noted: rounded, oval, irregular, and quadrangular. The rounded foramen transversaria dominated with an incidence of 54.1%, the oval was second at 29.6%, the irregularly shaped at 10.5%, and the quadrangular shape at 5.8% (Aziz & Morgan, 2018).

A study conducted by Taitz et al; 1978 on four hundred and eighty dried osteological cervical specimens of both males and females, the authors studied the cervical vertebrae specimens for anatomical variations of the foramen transversaria. They

assessed the foramen transversaria shapes and classified them into five types. Type one was round shape, type two was elliptical with main diameter anteroposterior, type three was elliptical with main diameter transverse, type four wads elliptical with main diameter oblique from right to left while type five was elliptical with main diameter oblique from left to right. The authors concluded that the commonest shape of the foramen transversaria was elliptical which contrasted with some of the similar studies conducted in different geographical regions. They emphasized on the importance of the knowledge of different types of shapes of foramen transversaria in the interpretation of cervical spine imaging and differentiating normal foramen transversaria anatomy from pathologies such as trauma, osteophytes (Taitz et al., 1978).

According to a study conducted in the Department of Anatomy, Nelson Mandela School of Medicine, South Africa; the authors studied one hundred and thirty dried human typical cervical vertebrae and the results showed two predominant shape types which were round and ellipsoid. The round shaped foramen transversaria predominated (43.85%) then ellipsoid (42.31%). Irregularly shaped foramen transversarium were also identified (13.07%). One vertebrae was missing foramen transversaria at 0.77% (Zaw et al., 2021).

According to a study conducted in the Department of Basic Biomedical Sciences of the University of Talca, Chile on one hundred and twenty-one dried osteological cervical vertebrae specimens; the authors studied the cervical vertebrae specimens on the basis of the anatomical variations of the foramen transversaria for the presence of accessory foramen transversaria, presence of foramen transversaria, size and shape of the foramen transversaria. The authors adopted the Taitz et al shape classification of foramen transversaria which classifies the various shapes of the foramen transversaria

into Types one to five, type one being round shape while type two to five being elliptical shapes with different directional orientations. The authors identified type one shape of foramen transversaria as the most predominant shape with a prevalence of 41.32%, followed by shape three with prevalence of 18.8% then shape four with a prevalence of 14.04%, followed by shape five with a prevalence of 12.39% and lastly shape two with a prevalence of 4.13%. They concluded that the knowledge on the different shapes of foramen transversaria is important to spine surgeons and radiologists in the diagnosis of pathologies involving the foramen transversaria and differentiating normal foramen transversaria shape from pathologies such as fractures and degenerative changes (Molinet Guerra et al., 2017).

A different study conducted in India at the Department of Anatomy, Shivamogga Institute of Medical Sciences, Shimoga; the authors studied one hundred and fifty-three atlas vertebrae for the presence of different shapes of the foramen transversaria. They noted two shapes which were round and ellipsoid. The predominant shape was ellipsoid (92.74%) then round (7.26%) (Rekha & Neginhal, 2014). Another Indian study conducted in the Department of Anatomy, Sri Guru Ram Das Institute of Medical Sciences and Research, Amristar, Punjab; the authors studied sixty foramen transversaria from thirty dried human atlases for the different shapes of foramen transversaria. They predominantly identified ellipsoid shapes (86.7%) then round shapes (13.3%) (Lalit et al., 2015).

A study conducted in the Department of Anatomy, Gulhane Medical Faculty on eighty-two dried osteological cervical vertebrae specimens, the authors studied the cervical vertebrae specimens for anatomical and morphometric variations of the foramen transversaria on the basis of presence or absence of accessory foramen

transversaria, absence of foramen transversaria, dimensions of the foramen transversaria and shapes of the foramen transversaria. The authors studied different shapes of foramen transversaria and classified them into five types. Type one was round shape, typed two to five were elliptical shapes with different directional orientation. They further categorized the foramen transversaria shapes based on the sides either right or left. They found that Type one foramen transversaria shape had prevalence of 59.72% on the right side and 61.42% on the left. Type two foramen transversaria shape had prevalence of 4.11% on the right side and 1.4% on the left side. Type three foramen transversaria shape had a prevalence of 19.4% on the right side and 22.85% on the left side. Type four foramen transversaria shape had a prevalence of 9.7% on the right side and 4.28% on the left side. Type five foramen transversaria shape had a prevalence of 6.94% on the right side and 10% on the left side. They concluded that type one foramen transversaria shapes exhibited the most common shape on both the right and left sides. They highlighted the importance of knowing the various shapes of foramen transversaria that exist so as to be able to differentiate between normal foramen transversaria and pathologies involving foramen transversaria such as fractures and degenerative changes (Imre & Kocabiyik, 2016).

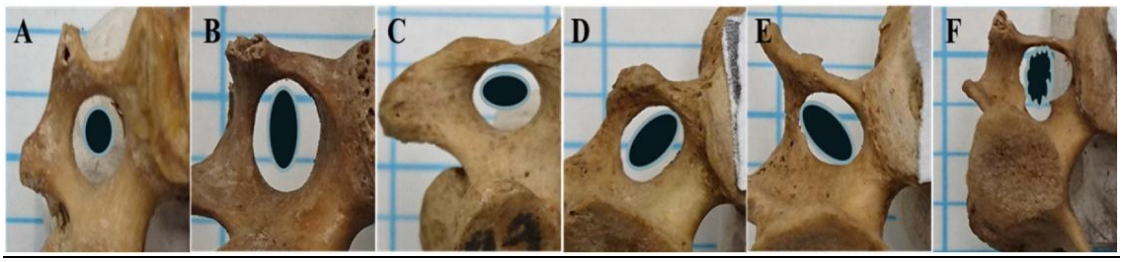


Figure 12: Different shapes of FT (Zaw et al., 2021)

Legend: *A – type 1 (round), B – type 2 (elliptical anteroposterior), C – type 3 (elliptical transverse), D - type 4 (elliptical oblique right to left), E - type 5 (elliptical oblique left to right), and F – type 6 (irregular).*

Author	Ramachandran	Ambali & Jadhav	Karau	Imre & Kocabiyik,	Aziz & Morgan
Year	2014	2017	2013	2016	2018
Country	India	India	Kenya	Turkey	Egypt
Sample Size	120	163	102	82	135
Oval (%)	36.7%	56.4%	78.4%	-	29.6%
Round (%)	63.3%	21.5%	21.6%	>50%	54.1%
Irregular (%)	-	4.6%	-	-	10.5%
Quadrangular (%)	-	-	-	-	5.8%
Triangular (%)	-	-	-	-	-
Semi Circle (%)	-	14.8%	-	-	-

2.6 Summary of Literature Review

The foramen transversaria is a foramen located on the transverse processes of the cervical vertebrae. It normally transmits the vertebral artery and sympathetic nerves with the exception of the foramen transversaria of the seventh cervical vertebrae which transmits the vertebral vein. Normally there exists a single foramen transversaria bilaterally. Variations of the foramen transversaria including presence of accessory foramen transversaria, varying dimensions of the foramen transversaria, different shapes of the foramen transversaria and the absence of foramen transversaria have been documented in various studies done across the globe. Prevalence of accessory foramen transversaria ranged from 3.9-32.5% among the literature reviewed in this study. The prevalence of absent foramen transversaria ranged from 0.0-0.94%. The mean right AP diameters ranged from 4.2- 7.2mm and mean left AP diameters 4.2-7.3mm. The mean right transverse diameters ranged from 4.7-6.5mm whereas the mean left transverse diameters range from 4.9-6.6mm.

The various studies reviewed indicate that the prevalence of accessory foramen transversaria is high while the prevalence of absent foramen transversaria is low. Statistically significant differences were reported in the AP and transverse dimensions of the foramen transversaria in some studies reviewed. There were different shapes noted among the various studies that were reviewed. The most commonly reported shapes being round and oval. Therefore, the knowledge of these variations is important to clinicians for proper diagnosis and management of cervical spine related disorders.

CHAPTER THREE

3.0 METHODOLOGY

3.1 Study site

This study was conducted in the osteology department of the National Museum of Kenya (NMK) between 2nd January 2022 and 1st July 2022. The museum was established in 1929 and is a state-owned corporation in Kenya. It carries out heritage research and has expertise in subjects ranging from paleontology, ethnography, biodiversity research and conservation. It is located on Museum Hill near Uhuru highway between the Central Business District and Westlands in Nairobi. It houses celebrated collections of Kenya's history, nature, culture, and human vertebrae. It has a cultural, natural, and biological collection that spans a period of over 100 years and are utilized by researchers in diverse fields.

3.2 Study design

The study adopted a descriptive, cross-sectional anatomical study design.

3.3 Study population

The study included all dried adult skeletons each containing all seven cervical vertebrae within the osteology department of the National Museum of Kenya. The National Museum of Kenya has been archiving dried human skeletons for anthropological and medical studies since 1929. These specimens have been sourced from various parts of Kenya and kept under ideal conditions as celebrated collections of Kenya's history, nature, culture, and contemporary art.

3.4 Eligibility criteria

3.4.1 Inclusion criteria

i. Dried, adult, cervical vertebrae from C_1-C_7.

3.4.2 Exclusion criteria

i. Damaged cervical vertebrae

ii. Cervical vertebrae with degenerative changes

3.5 Study procedure

This study was conducted at the osteology department of the National Museums of Kenya. A census was conducted on all the cervical vertebrae that met the eligibility criteria. These cervical vertebrae obtained from individuals were sampled purposively as either typical (C_3 to C_6) or atypical (C_1, C_2, C_7) to saturation, without gender differentiation.

The individual specimens were examined from C_1 to C_7 for the presence or absence of foramen transversarium. In the presence of foramen transversarium, anteroposterior and transverse diameters were measured from C_1 to C_7. The researcher then documented the shapes of the foramen transversarium and classified them as oval, rounded, irregular or quadrangular. Cervical vertebrae with accessory foramen transversarium and those without an accessory foramen were documented into a structured data collection tool (Appendix I). The anteroposterior and transverse diameters of the foramen transversarium were measured using a 150 mm steel ruler. All diameters were measured on both the left and right sides of the foramen transversarium. Each measurement was rechecked twice to reduce the chances of inter-observer variability and increase accuracy.

The 150 mm steel ruler was pre-tested on the cervical vertebrae archived at the Human Anatomy Department of Moi University school of Medicine prior to the commencement of the study.

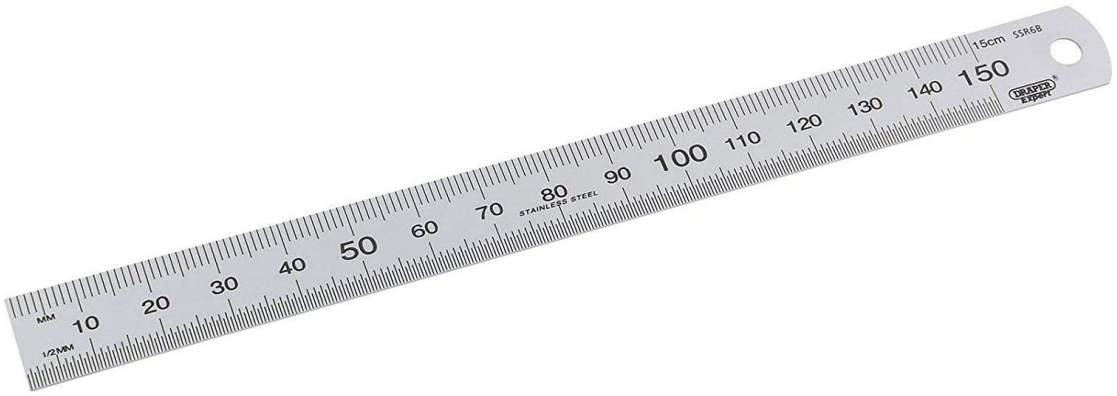


Figure 9: 150 mm steel ruler

3.6 Data Management and Analysis

The data on the forms was entered into a Microsoft Access database using a double data entry technique to mitigate for data entry errors and ensure validity of the study results. The data collection forms were stored in a safe and private cupboard which is always under lock and key. The data was backed up in different storage devices such as flash disks, external hard drives and kept in safe and private locations to avoid data loss or damage. The data entered was exported to Statistical Package for Social Sciences (SPSS) version 26 and analyzed descriptively and inferentially.

Descriptively, the study computed the frequency and corresponding proportions of accessory and absent foramen transversarium by level of the cervical spine (C_1 to C_7). Furthermore, the frequency and corresponding proportion of varying shapes of the foramen transversarium were tabulated. The mean and corresponding standard deviation of the right and left anteroposterior and transverse diameters of the foramen transversarium were computed. A student t-test was conducted to compare the

statistical difference in the means of the left and right Transverse and AP diameters; with p-values <0.05 considered statistically significant.

3.7 Ethical considerations

Ethical approval to conduct the study and informed consent waiver was obtained from the Institutional Research and Ethics Committee (IREC). Approval from the Director of the National Museums of Kenya was sought prior to conducting the study.

The study was conducted in accordance with the Anatomy Act (Chapter 249), 2012 of The Laws of Kenya. Data privacy and confidentiality was maintained through deidentification and using password-protected databases.

The findings of this study will be published in peer-reviewed scientific journals and disseminated through professional scientific conferences.

CHAPTER FOUR

RESULTS

4.0 Summary of Results

This study included all dried adult skeletons each containing all seven cervical vertebrae within the osteology department of the National Museum of Kenya. At the time the study was conducted, there were two hundred and eighty cervical spine specimens archived at the National Museums of Kenya of which two hundred and twenty-four cervical specimens met the eligibility criteria. Fifty-six cervical specimens were rejected. When the foramen transversarium was examined on the osteological cervical specimens, one hundred and seventy six (78.5%) of them had normal foramen transversaria, one (0.5%) vertebra did not have foramen transversaria bilaterally while forty seven (21%) had accessory foramen transversaria (Figure 4.1).

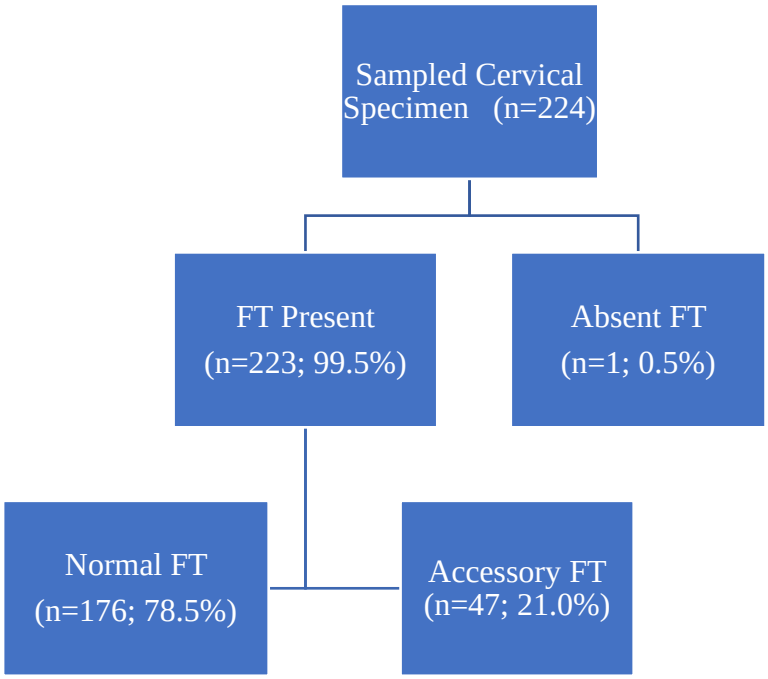


Figure 4. 1: Distribution of Normal, Absent and Accessory Foramen Transversaria

Of the two hundred and twenty-four cervical vertebrae osteological specimens sampled, C1 to C3 had thirty-one specimens each, there were thirty-two C4 specimens and thirty three cervical specimens each for C5 to C7 (Table 4.1).

Table 4. 1: Summary Distribution of Normal, Absent and Accessory Foramen Transversaria by level

Level	Foramen Transversaria			TOTAL
	Present	Absent	Accessory	
C1	31 (100%)	-	-	31
C2	31 (100%)	-	-	31
C3	29 (93.5%)	-	2 (6.5%)	31
C4	29 (90.6%)	-	3 (9.4%)	32
C5	19 (57.6%)	-	14 (42.4%)	33
C6	18 (54.5%)	-	15 (45.5%)	33
C7	19 (57.6%)	1 (3.0%)	13 (39.4)	33
Total	176 (78.5%)	1 (0.5%)	47 (21.0%)	224 (100%)

4.1Prevalence of accessory foramen transversaria in cervical spine specimens at the National Museums of Kenya

The prevalence of Accessory Foramen Transversaria in this study was 21% (Figure 4.2)

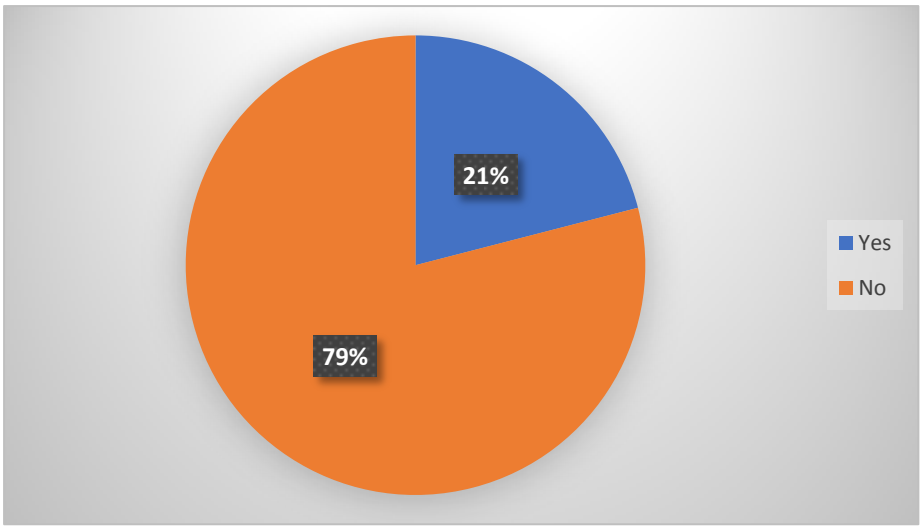


Figure 4. 2: Prevalence of Accessory Foramen Transversaria

Of the forty seven specimens found to have accessory foramen transversaria, twenty six (55.3%) had one (unilateral) accessory foramen transversaria while twenty one (44.7%) had bilateral accessory foramen transversaria.

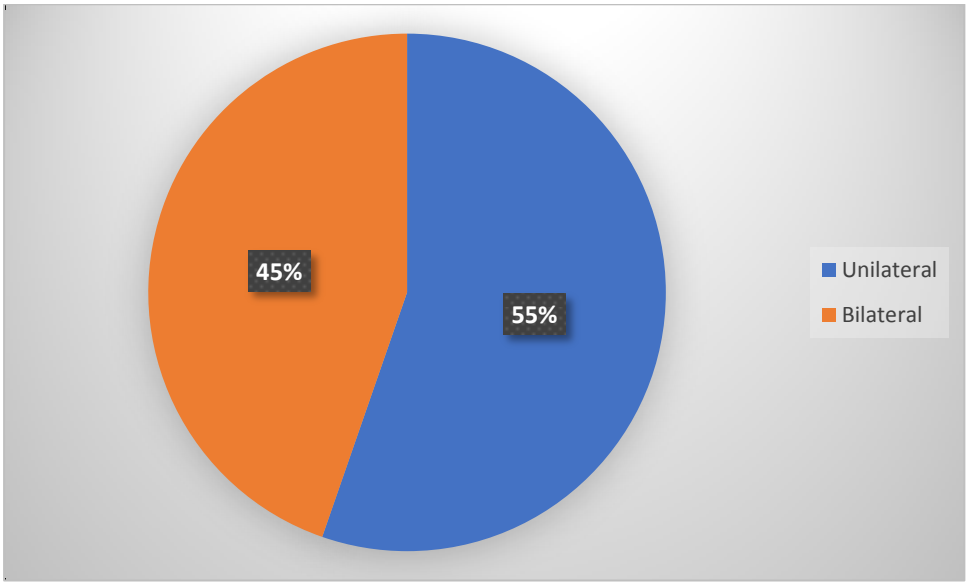


Figure 4.3: Accessory Foramen Transversaria Distribution

Figure 4. 3: Unilateral Accessory Foramen Transversarium

Figure 4. 4: Bilateral Accessory Foramen Transversarium

4.2 Prevalence of absent FT in cervical spine specimens at the National Museum of Kenya.

This study reports absent foramen transversarium were noted bilaterally at the c7 level of a single cervical vertebra. This gave an absent foramen transversarium prevalence of 0.5% (Figure 4.6a)

Figure 4. 5a: Absent Foramen Transversarium on C7

Figure 4.6b: Foramen Transversarium on C7

4.3 Antero-posterior diameter of the right and left foramen transversarium in the cervical spine specimens at the National Museums of Kenya.

The mean anteroposterior diameter of foramen transversarium was 5.348 ± 1.2731 mm (range: 2.0-8.5 mm) on the right and 5.365 ± 1.2117 mm (range: 1.5-8.0 mm) on the left (Table 4.2).

Table 4.2: Antero-posterior diameter of the right and left foramen transversarium.

		Anteroposterior diameter of right foramen transversarium (mm)	Anteroposterior diameter of left foramen transversarium (mm)
N	FT Present	223	223
	Absent FT	1	1
Mean		5.348	5.365
Range		2.0-8.5	1.5-8.0
Median		5.000	5.500
Std. Deviation		1.2731	1.2117
Percentiles	25	4.500	5.000
	50	5.000	5.500
	75	6.000	6.000

4.4 Transverse diameter of the right and left FT in the cervical spine specimens at the National Museums of Kenya.

The mean transverse diameter of foramen transversarium was 5.590 ± 1.1953 mm on the right (range: 2.0 - 8.5 mm) and 5.868 ± 1.1317 mm (range: 2.0 - 8.0 mm) on the left (Table 4.3).

Table 4. 3: Transverse diameter of the right and left FT of the cervical spine specimens

		Transverse diameter of right foramen transversarium (mm)	Transverse diameter of left foramen transversarium (mm)
N	FT Present	223	223
	Absent FT	1	1
Mean		5.590	5.868
Median		6.000	6.000
Std. Deviation		1.1953	1.1317
Percentiles	25	5.000	5.000
	50	6.000	6.000
	75	6.500	6.500

Inferentially, a student t-test of association was conducted to compare whether there is a statistically significant difference in the anteroposterior and transverse diameters on both the left and right sides. A statistically significant difference was noted on AP and transverse diameters of c3, transverse diameters of c5 and AP diameters of c6 as shown on Table 4.4.

Table 4. 4: Summary mean AP and Transverse FT diameters

	AP		**p-value**	**Transverse**		**p-value**
	Right	**Left**		**Right**	**Left**	
C1	7.177 (±0.7588)	7.000 (±0.7792)	0.698	6.367 (±1.0601)	6.167 (±1.0635)	0.252
C2	5.429 (±0.9376)	5.393 (±0.8589)	0.295	6.143 (±0.8644)	6.393 (±0.8589)	0.085
C3	4.964 (±0.664)	5.000 (±0.6504)	**0.015**	5.786 (±0.4258)	6.429 (±0.9579)	**0.044**
C4	5.156 (±0.4732)	5.281 (±0.6575)	0.070	5.969 (±0.6183)	6.000 (±0.7746)	0.138
C5	4.857 (±0.6022)	5.143 (±0.4569)	0.345	5.571 (±0.8516)	5.714 (±0.4688)	**0.043**
C6	5.071 (±1.4657)	5.536 (±1.0825)	**0.040**	5.250 (±1.2519)	5.964 (±0.6924)	0.654
C7	4.167 (±1.5275)	3.917 (±1.6492)	0.597	4.125 (±1.3336)	4.792 (±1.9005)	0.459

4.5 Different types of shapes of FT in the cervical spine specimens at the National Museums of Kenya.

The most prevalent shape of foramen transversarium in this study was round in more than half (51.3%) of the osteological specimen sampled, followed by oval (43.3%) with the least being irregular shape at 4.9% (Table 4.5).

Table 4. 5: Summary of Types of Foramina Transversarium Shapes in Kenyan cervical specimens (N=224)

Level	**Oval (n/%)**	**Round (n/%)**	**Irregular (n/%)**	**Absent**	**Total**
C1	22 (9.8)	9 (4.0)	-	-	31
C2	15 (6.7)	16 (7.1)	-	-	31
C3	12 (5.4)	18 (8.0)	1 (0.5)	-	31
C4	8 (3.6)	19 (8.5)	5 (2.2)	-	32
C5	11 (4.9)	22 (9.8)	-	-	33
C6	16 (7.1)	17 (7.6)	-	-	33
C7	13 (5.8)	14 (6.3)	5 (2.2)	1 (0.5)	33
Total (**n/%)**	**97 (43.3)**	**115 (51.3)**	**11 (4.9)**	**1 (0.5)**	224 (100%)

Figure 4. 6: C1 FT shape- round

Figure 4. 7: C2 FT shape- oval

Figure 4. 8: C3 FT shape- oval

Figure 4.9: C4 FT shape- round

Figure 4. 10: C5 FT shape- oval

Figure 4. 11: C6 FT shape –round

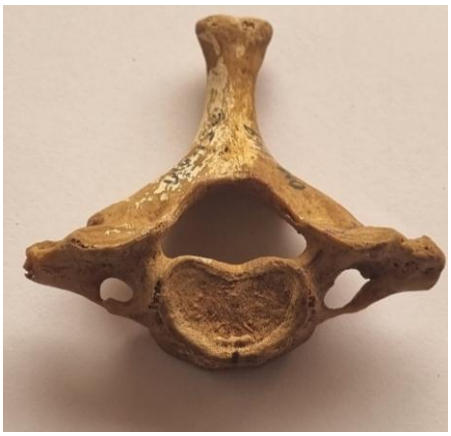


Figure 4. 12: C7 FT shape-irregular

Figure 4. 13: Summary of different shapes of FT observed in Kenyan specimens

CHAPTER FIVE

DISCUSSION

5.1 Prevalence of accessory foramen transversaria in cervical spine specimens at the National Museums of Kenya.

This study collected data from two hundred and twenty-four cervical spine specimens obtained from archived human skeletons preserved in thirty-three cassettes at the National Museum of Kenya. Of these forty-seven (21%) had an accessory foramen transversarium. This finding matches that reported in a study conducted at Turkey's Gulline University (Imre & Kocabiyik, 2016) where the prevalence of accessory foramen transversaria stood at 21.9%. Although the Turkish study (Imre & Kocabiyik, 2016) had a lower sample size (n=82) than the current study, the prevalence in both studies were similar. This could be attributed to the fact that both studies were conducted using a similar study design and targeted a cross-section of their respective nationals. In India, the authors (Patra et al., 2022) of an osteological study assessing the variations in the foramen transversarium of the cervical spine and their surgical importance, noted that the prevalence of accessory foramen transversarium was 20%. These two studies adopted a nearly similar sample size of n=200 in India (Patra et al., 2022) and n=224 (in the current study). Furthermore, the findings were published the same year this current study's data was collected, signifying temporal similarity. However, a higher prevalence of accessory foramen at 27.3% (Vikani et al., 2016) was reported in Gujarat, India among the one hundred and fifty osteological specimens of cervical spine collected.

Lower prevalence than the current study was reported in South Africa's Kwa Zulu Natal region (Zaw et al., 2021) at 9.23% and 5.7% in Mangalore – India (Rathnakar & K., 2013). In the preliminary study on foramen transversarium of typical cervical

vertebrae in KwaZulu-Natal population, the authors enrolled one hundred and thirty dried human typical cervical vertebrae (C3-C6) while the current study enrolled both atypical (C1, C2 and C7) and typical specimens. This could explain the proportionate difference. In Mangalore – India, the authors (Rathnakar & K., 2013) collected the one hundred and forty samples from the Nitte University's Department of Anatomy while the current study sampled a nationally diverse population.

When the accessory foramen transversaria were stratified by the cervical vertebrae, none was identified on C1 and C2 cervical vertebra. Majority of the accessory foramina were on C6 (31.9%), followed by C5 (29.8%), C7 (27.6%), C4 (6.4%) and C3 (4.3%). This high prevalence of accessory foramen transversarium on C6 was also noted in Valencia, Spain at 26.1% (Quiles-Guiñau et al., 2017). The study conducted in the rural Spanish rural population targeted eighty-eight complete adult skeletons from the late 17th and 18th centuries. This could explain the slight proportional difference. Furthermore, in Patiala-India; the proportion of accessory foramen transversaria on C6 almost matched the current study at 27.5% (Patra et al., 2022). However, the authors (Patra et al., 2022) noted a higher prevalence on C7 at 35% compared to the current study.

There were nearly equal proportions of bilateral (n=22; 46.8%) and unilateral (n=25; 53.2%) accessory foramina identified in this study. In Kwa Zulu Natal (Zaw et al., 2021), there were equal proportions of bilateral and unilateral accessory foramen transversaria. A contrasting proportion of bilateral (34.2%) and unilateral (65.8%) accessory foramen transversaria was reported in study conducted in Gujarat, India (Vikani et al., 2016); a finding that could be explained by racial and demographic differences.

From the findings of this study on accessory foramen transversarium, it is important for spine surgeons to know and understand these anatomical variations to inform their cervical approach during spine surgery and prevent injuring the adjacent vascular structures (Aghera et al., 2020). This is because anatomical variations may induce an extra-osseous position of the vertebral artery (A. Zibis et al., 2018). Lack of knowledge of this may have catastrophic consequences on the patient during a surgery in the cervical spine. In the event the surgeon is not aware that there is an extra-osseous position of the vertebra artery, by analyzing preoperative medical images to identify the variations, he/she may accidentally damage the artery during positioning of muscular retractors or surgical maneuvers (Pruthi et al., 2014). These abnormalities could require the use of lateral mass screws combined with pedicle screws (Pruthi et al., 2014) or newer techniques that adopt anterior transarticular crossing screw in place of classic posterior or anterior fixation techniques (Ji et al., 2015). Furthermore, small lesions of the vertebral arteries risk causing significant hemorrhages (Barbagallo et al., 2014). If the contralateral vertebral artery is hypoplastic, the patient might die or have significant neurological deficits due to insufficient blood supply to the brain (Ji et al., 2015). Patients with an accessory foramen transversarium have an increased risk of thrombus formation on the vertebral artery resulting in a stroke (Viciano et al., 2021). With this backdrop, it is necessary for the spine surgeon to request for preoperative imaging and carefully examine them before choosing the most appropriate technique to avoid possible complications.

Table 5. 1: Prevalence of accessory foramen transversaria in cervical spine specimens

Author	Current study	Laura	Zaw	Gul	Rathnakar	Vikani	Imre	Patra
Year	2022	2017	2021	2017	2013	2016	2016	2022
Country	Kenya	Spain -Valencia	Soth Africa (kwazulu-Natal)		Mangalore - India	Gujarat, India	Turkey	Patiala, India
Sample Size	224 (n=33)	88 (complete adult skeletons)	130	100 (vertebrae)	140	150	82	200
Study Design	Cross-sectional	Cross-sectional		Cross-sectional	Cross-sectional			
Prevalence (Accessory Foramen)	21%	-	9.23% (Average)	9%	5.70%	27.3% (41)	21.9% (18)	20% (n=40)
C1	0	-	-	-	-	-	-	-
C2	0	-	-	-	-	-	-	-
C3	4.3	-	-	-	-	-	-	7.50%
C4	6.4	6.8	-	-	-	-	-	12.50%
C5	29.8	20.4	-	-	-	-	-	17.50%
C6	31.9	26.1	-	-	-	-	-	27.50%
C7	27.6	7.9	-	-	-	-	-	35%
Bilateral	46.8% (n=22)	-	24 (50%)	4 (44.4%)	-	14 (34.2%)	-	22 (55%)
Unilateral	53.2% (n=25)	-	24 (50%)	5 (55.6%)	-	27 (65.8%)	-	18 (45%)

5.2 Prevalence of absent FT in cervical spine specimens at the National Museums of Kenya.

This study reports absent foramen transversarium on both sides of a single (0.45%) dried C7 cervical spine specimen obtained at the National Museum of Kenya. Although most studies reviewed did not find absent foramen transversarium, a low prevalence of absent foramen transversarium in the cervical spine was also reported in a study conducted in Kwa Zulu Natal, South Africa (Zaw et al., 2021) on the left side of single C7 specimen (0.77%). In India (Gupta & Agarwal, 2019), absent Foramen Transversarium of the cervical spine was reported in 2 (1.24%) specimens and they were all noted on C7. The authors (Gupta & Agarwal, 2019) of the study conducted in India noted that one C7 vertebrae showed bilateral absence of foramen transversarium while another C7 showed unilateral absence.

Absent foramen transversarium implies that the vertebral artery has an extra-osseous course (Zibis et al., 2018). Lack of knowledge of this absence may endanger the vertebral artery during surgery.

Table 5. 2: Comparison of Prevalence of absent FT in cervical spine specimens

Author	**Current study**	**Gupta**	**Zaw**
Year	2022	2019	**2021**
Country	Kenya	India	**South Africa (Kwa Zulu Natal)**
Sample Size	224	161	**130**
Study Design	Cross-sectional		
Absent FT	1 (c7) 0.5%	3 (c7) 0.9%	**1 (0.77%)**

5.3 Antero-posterior diameter of the right and left foramen transversarium of the cervical spine specimens at the National Museums of Kenya.

The mean anteroposterior (AP) diameter of foramen transversarium was 5.348 ± 1.2731 mm on the right and 5.365 ± 1.2117 mm on the left. These mean AP diameters match that reported in New York -USA (Sangari et al., 2015), New Delhi- India (Gupta & Agarwal, 2019) and Mangalore-India (Rathnakar & K., 2013). In New York (Sangari et al., 2015), the mean right AP diameter was 5.17 ± 0.89 mm and 5.13 ± 0.79 mm to the left. This is despite them using 71 dried complete typical cervical vertebrae (C3-C6) while this study collected samples from 33 cassettes that included both typical and atypical cervical vertebra. In New Delhi (M. Gupta & Agarwal, 2019) the right AP diameter was 5.21±1.15 mm and 5.26±1.12 mm to the left while in Mangalore-India (Rathnakar & K., 2013) it was 5.55 ± 0.87mm and 5.48 ± 0.77 mm to the right and left respectively.

However, the findings contrast those reported in Bathinda-India (Patra et al., 2022) at 4.96 ± 1.08 mm to the right and 5.07 ± 1.12 mm to the left. In another anatomical study conducted at the Kenya National Museum on the atlas only (C1), the mean right AP diameter was 7.05 mm (Karau et al., 2013). This focus on the atlas could explain the reason for morphometric variation to the current study.

The AP diameter ranged between 2.0-8.5 mm to the right and 1.5-8.0 mm to the left. This finding matched that reported in a study conducted in New York-USA (Sangari., 2015) where the mean AP diameter ranged between 2.19-7.21 mm to the right and 2.5-6.81 mm to the left. Both studies used similar data collection and methodological approaches which could explain the similarity. Furthermore, in a cross-sectional study conducted in Delhi-India (Gupta, 2019), the left AP diameter 2.12 mm-8.47 mm.

However, the right AP diameter ranged between 1.91 mm to 8.65 mm, a margin larger than that reported in the current study. Another contrasting study was that conducted at the University Museum of Chieti, Italy where the AP diameter to the right ranged between 3.33 mm to 6.30 mm which is a narrower range than the current study (Viciano et al., 2021). This difference could be attributed to the target population as the researchers in Italy targeted 143 osteological specimens from victims of Vesuvius Volcano in the ancient beach of Herculaneum (Italy) in 79 CE (Viciano et al., 2021). Of these 143 victim samples, only 83 met the eligibility criteria. Because of evolutionary changes over time, the anthropometric averages of osteological specimens have changed, and this could explain the variance. Furthermore, in this study most of the osteological specimens reviewed in this study were recently archived within the National Museums of Kenya.

This study went further to determine the average AP diameter of each of the cervical vertebrae. The average C1 AP diameter was 7.177 (SD±0.7588) mm to the right and 7.000 (SD±0.7792) mm to the left, with no statistically significant variation on both sides (p=0.698). This finding and the standard deviation were similar to majority of the studies under comparison. In India (Gupta & Agarwal, 2019), the average C1 AP diameter was 6.74±1.05mm to the right and 6.56±1.00mm to the left among the 161 samples collected. However, the authors did not report any statistically significant difference on either side. Similarly, in a larger study conducted in Turkey across 987 specimens (Metin Tellioglu et al., 2018), the average C1 AP diameter was 6.73±1.16mm to the right and 6.70±1.18mm to the left with no statistically significant association reported. The same finding was reported in Italy (Viciano et al., 2021) where the average AP diameter was 6.15±0.81mm to the right and 6.30±0.72mm to the left, with no statistically significant difference reported.

The mean C2 AP diameter reported was 5.429 (±0.9376) mm to the right and 5.393 (±0.8589) mm to the left with no statistically significant association noted (p=0.295). This finding matched all studies under comparison where the mean AP diameter for C2 was 5.58±0.80mm to the right and 5.79±0.57mm to the left in Italy (Viciano et al., 2021); 5.28±0.84mm to the right and 5.46±0.69mm to the left in India (Gupta & Agarwal, 2019); and 5.37±1.21mm to the right and 5.58±1.16mm to the left in Turkey (Metin Tellioglu et al., 2018). None of the studies under comparison reported any statistically significant association between the difference of the mean right and left AP diameter for C2.

This study reports a statistically significant difference (p=0.015) in the mean C3 AP diameter on the right (4.964 ±0.664 mm) and the left (5.000±0.6504 mm). The other studies under comparison did not report any statistically significant difference on the right and left C3 AP diameters and their mean values did not match those of the current study. In Italy, the average AP diameter of C3 was 5.21±0.55mm to the right and 5.31±0.53mm to the left, which is higher than the current study. In India (Gupta & Agarwal, 2019), the right AP diameter of C3 was higher (5.03±0.58 mm) on the right and lower on the left (4.72±0.49mm), which contrasts the findings of this current study. Lower mean C3 AP diameter was reported in Turkey (Metin Tellioglu et al., 2018) with the averages on the right being 4.50±0.64 mm and 4.64±0.77mm to the left.

The mean C4 AP diameter to the right was 5.156 ±0.473 mm to the right and 5.281±0.6575 mm to the left, a difference that was not statistically significant (p=0.070). This finding was close to that reported in Italy (Viciano et al., 2021), where the mean C4 AP diameter was 5.05±0.87mm to the right and 5.44±0.57 mm to the left. Contrasting findings were reported in both India and Turkey. In India (Gupta

& Agarwal, 2019) it was 4.88±0.88mm to the right and 5.03±0.84mm to the left, with no statistically significant difference reported. Similarly, In Turkey, lower mean C4 AP diameter was reported at 4.58±0.85mm and 4.74±0.79mm to the right and left respectively.

The mean C5 AP diameter to the right (4.857±0.6022 mm) and left (5.143 ±0.4569 mm) reported in this study were lower than all studies under comparison with no statistically significant difference (p= 0.345) noted. In Italy (Viciano et al., 2021), the mean values were 5.63±0.58mm to the right and 5.82±0.30mm to the left, while in India (Gupta & Agarwal, 2019) it was 5.01±0.91mm to the right and 5.28±0.98 to the left. The lowest mean value for C5 AP diameter among the studies under comparison was reported in Turkey (Metin Tellioglu et al., 2018) at 4.90±1.05mm and 5.05±1.00mm to the right and left respectively.

This study further notes a statistically significant difference (p=0.040) between the right (5.071±1.4657 mm) and left (5.536 ±1.0825 mm) C6 AP diameter. This finding matches most of the studies under comparison where it was 5.67±1.10mm and 5.75±1.06mm to the right and left respectively in Italy (Viciano et al., 2021); in India (Gupta & Agarwal, 2019), it was 5.28±1.01mm to the right and 5.20±1.27 mm to the left. In Turkey two studies reported contrasting values. In the first study (Metin Tellioglu et al., 2018) the mean C6 AP diameter was 5.18±1.25 mm to the right and 5.28±1.27mm to the left, while in the second study (Patra et al., 2022) it was 4.97±1.12mm to the right and 5.10±1.70mm to the left. The second study focused on 200 osteological specimens obtained from South–Central Asian cadavers, of which 160 were typical cervical vertebrae (C3, C4, C5, and C6) while 40 were atypical cervical vertebra (C7).

Lastly, the mean C7 AP diameter was 4.167±1.5275 mm to the right and 3.917 ±1.6492 mm to the left with no statistically significant association noted (p=0.597). This finding is close to that reported in India (Gupta & Agarwal, 2019) where the mean right C7 AP diameter was 4.04±1.42mm and 4.12±1.77mm to the left. Lower right C7 AP diameter was reported in the first study conducted in Turkey (Metin Tellioglu et al., 2018) at 3.94±1.57mm and 3.80±1.24 mm to the left; while higher values were reported in a second (Patra et al., 2022)Turkish study at 4.5±1.91mm to the right and 4.63±1.90mm to the left. The least C7 AP diameter was reported in Italy (Viciano et al., 2021) at 3.36±1.02 mm to the right and 3.52±0.88 mm to the left.

Table 5. 3: Antero-posterior diameter of the right and left foramen transversarium of the cervical spine pecimens

Study	**Current**		**Viciano**		**Gupta**		**Metin**		**PATRA**	
Year	**2022**		2021		2019		2018		2022	
Country	Kenya		Italy	Italy	India	India	Turkey	Turkey	Turkey	Turkey
Sample Size	224 (n=33)		83	83	161	161	987	987	200	200
Study Design	Cross-sectional		Cross-sectional	Cross-sectional	Cross-sectional	Cross-sectional	Cross-sectional	Cross-sectional	Cross-sectional	Cross-sectional
	AP		**AP**		**AP**		**AP**		**AP**	
	Right	**Left**	**Right**	**Left**	**Right**	**Left**	**Right**	**Left**	**Right**	**Left**
C1	7.177 (±0.7588)	7.000 (±0.7792)	6.15±0.81	6.30±0.72	6.74±1.05	6.56±1.00	6.73±1.16	6.70±1.18		
C2	5.429 (±0.9376)	5.393 (±0.8589)	5.58±0.80	5.79±0.57	5.28±0.84	5.46±0.69	5.37±1.21	5.58±1.16		
C3	4.964 (±0.664)	5.000 (±0.6504)	5.21±0.55	5.31±0.53	5.03±0.58	4.72±0.49	4.50±0.64	4.64±0.77	5.14±0.63	5.23±0.53
C4	5.156 (±0.4732)	5.281 (±0.6575)	5.05±0.87	5.44±0.57	4.88±0.88	5.03±0.84	4.58±0.85	4.74±0.79	5.10±0.73	5.17±0.60
C5	4.857 (±0.6022)	5.143 (±0.4569)	5.63±0.58	5.82±0.30	5.01±0.91	5.28±0.98	4.90±1.05	5.05±1.00	5.11±0.88	5.23±0.90
C6	5.071 (±1.4657)	5.536 (±1.0825)	5.67±1.10	5.75±1.06	5.28±1.01	5.20±1.27	5.18±1.25	5.28±1.27	4.97±1.12	5.10±1.70
C7	4.167 (±1.5275)	3.917 (±1.6492)	3.36±1.02	3.52±0.88	4.04±1.42	4.12±1.77	3.94±1.57	3.80±1.24	4.5±1.91	4.63±1.90

5.4 Transverse diameter of the right and left FT of the cervical spine specimens at the National Museums of Kenya.

This study reports a mean right transverse diameter of foramen transversaria noted on the dry cervical spine specimens archived at the osteology department of the National Museums of Kenya was 5.590 ± 1.1953 mm. This finding compares to that reported in New York City -United States of America where the mean right transverse diameter was 5.69 ± 1.04 (Sangari et al., 2015). Despite the similarity, the authors (Sangari et al., 2015) focused on typical cervical vertebrae (C3-C6) on the seventy-one complete dried cervical vertebrae obtained from the Program in Anatomy and Body Visualization, Department of Radiology, Weill Cornell Medical College, New York. This is opposed to the current study that collected both atypical (C1, C2, C7) and typical cervical vertebrae. Secondly, in a cross-sectional study conducted at the Department of Anatomy at Lady Hardinge Medical College, Delhi, India (Gupta & Agarwal, 2019), the mean right transverse diameter was reported to be 5.78±1.10 mm which matches that reported in the current. However, a local study conducted at the same Osteology department of the National Museums of Kenya (Karau et al., 2013) found a mean transverse right diameter of 6.50mm. This difference could be attributed to the fact that the author (Karau et al., 2013) focused on the Atlas (C1) as opposed to the current study that conducted morphometric measurements on the entire cervical vertebrae. Additionally, the study (Karau et al., 2013) did not distinguish the mean transverse diameter as either on the left or right. The right transverse diameter of the foramen transversaria identified in this study ranged between 2.0 - 8.5 mm, a finding which was comparable to that reported in New York and New Delhi at 2.54mm to 7.79mm (Sangari et al., 2015) and 2.44 mm to 8.76 mm (Gupta & Agarwal, 2019) respectively.

The mean left transverse diameter in this study was 5.868 ± 1.1317 mm, a finding comparable to the two main studies under comparison at 5.87 ± 0.89 (Sangari et al., 2015) and 5.84±1.03 mm(Gupta & Agarwal, 2019) . This left transverse diameter ranged between 2.0 - 8.0 mm in the current study with a range of 2.65mm to 7.35mm reported in the USA (Sangari et al., 2015) and 2.53 mm to 8.56 mm in India (Gupta & Agarwal, 2019).

This study further reports the mean transverse diameter of all the cervical spine vertebrae. For C1, the mean transverse diameter was 6.367 (±1.0601) mm to the right and 6.167 (±1.0635) mm to the left, with no statistically significant difference (p=0.252) on either side. This finding is comparable to that reported in Turkey (Metin Tellioglu et al., 2018) where the right C1 transverse diameter was 6.56±1.02 mm and 6.62±0.96 mm to the left. The average transverse diameter reported in this study is lower than that reported in the first comparative study conducted in Italy (Viciano et al., 2021) but higher than that reported in India (Gupta & Agarwal, 2019) and a second comparative study conducted in Italy (Travan et al., 2015). In the first comparative study conducted in Italy, the authors (Viciano et al., 2021) reported a mean right C1 transverse diameter of 7.27±0.50mm and 7.26±0.74mm to the left with no statistically significant difference noted. In the second study conducted in Italy, the authors (Travan et al., 2015) measured osteological specimens obtained from one hundred and eighty individuals excavated from different archaeological sites in Friuli Venezia Giulia, a district in North-eastern Italy. From the one hundred and twenty-nine adults (71 males, 51 females, seven indeterminates) and fifty-one young subjects included in the study, the mean C1 transverse diameter was 5.5±1.2mm to the right and 5.6±1.3 mm to the left with no statistically significant difference on either side

(p=0. 331). In India (Gupta & Agarwal, 2019), the average C1 transverse diameter was 5.85±0.83 mm to the right and 5.87±1.03mm to the left.

The mean C2 transverse diameter in this study was 6.143 (±0.8644) mm to the right and 6.393 (±0.8589) mm to the left, a difference that was not statistically significant (p= 0.085). This study was lower than that reported in two studies (Metin Tellioglu et al., 2018; Viciano et al., 2021) under comparison but higher than that in another two studies (Gupta & Agarwal, 2019; Travan et al., 2015). The average C2 transverse diameter reported in the first Italian study (Viciano et al., 2021) was 6.83±0.89 mm to the right and 7.12±1.19 mm; a finding that is way higher than that in this study and could be attributed to the time of collection of target osteological specimens. This study targeted a mix of recently archived and non-dated osteological specimens while in Italy, the authors (Viciano et al., 2021) used specimens collected during the Vesuvius Volcanic eruption that occurred in 79 CE. This temporal difference which could be associated with evolutionary changes in morphometric averages could explain the differences in the mean transverse diameters reported in both studies. In Turkey (Metin Tellioglu et al., 2018), the mean transverse diameter was 6.85±1.32 mm to the right and 6.80±1.50 mm to the left, a difference that was found to be statistically significant (p<0.001). In a second Italian study (Travan et al., 2015), the mean C2 transverse diameter was reported to be 4.1±0.9 mm to the right and 4.2±0.9 mm to the left, however, the authors did not find any statistically significant difference (p=0.812). In India (Gupta & Agarwal, 2019), the average C2 transverse diameter was 5.07±0.82 mm to the right and 5.31±0.83 to the left.

A similar trend was noted across all the other cervical vertebrae. However, of note, this study reports a statistically significant difference on the average transverse

diameter on the left and right sides of C3 and C5. The mean transverse diameter of C3 reported in this study was 5.786 (±0.4258) mm to the right and 6.429 (±0.9579) mm to the left, a difference that was found to be statistically significant (p= 0.044). This statistically significant difference was also noted in a study conducted in Turkey (Metin Tellioglu et al., 2018) where the mean transverse diameter of C3 was 5.86±1.01mm to the right and 5.93±1.00mm to the left (p<0.001). This similarity could be attributed to the study design and data collection techniques as both studies were cross-sectional, collected data from National Museums, and included an inferential statistical analysis component to the anthropometric findings. However, the second study conducted in Italy (Travan et al., 2015) did not find any statistically significant difference (p=0.301) between the right (4.7±0.7 mm) and left (4.7±0.6 mm) mean transverse diameter of the third cervical vertebra. Higher mean values for the C3 transverse diameter were reported in the first Italian study (Viciano et al., 2021) under comparison with 6.22±0.67mm being noted on the right and 6.60±0.68 mm to the left. In Belgium, the authors (Cagnie et al., 2005) found an average C3 transverse diameter of 5.6±0.7 mm (without specifying the side). Similar C3 transverse diameter averages were reported in India (Gupta & Agarwal, 2019) at 6.22±0.93 mm to the right and 6.36±0.54 mm to the left. A second cross-sectional study conducted in Turkey (Patra et al., 2022) reported a mean C3 transverse diameter of 5.88±0.73 mm to the right and 5.93±0.54 to the left. The authors (Patra et al., 2022) focused on 160 typical cervical vertebrae (C3, C4, C5, and C6), and 40 atypical cervical vertebrae (C7) as opposed to this study which assessed the entire cervical spine.

This study reports a mean C4 transverse diameter of 5.969 (±0.6183) mm to the right and 6.000 (±0.7746) mm to the left, with no statistically significant association (p=

0.138). This finding was close to that reported in Italy (Viciano et al., 2021) at 6.16±0.53 mm to the right and 6.45±0.71 mm to the left. Other comparative findings were in Belgium (Cagnie et al., 2005) at an average of 5.8±0.6 mm, India (Gupta & Agarwal, 2019) at 6.10±0.92 mm to the right and 5.94±0.84 mm to the left and Turkey (Patra et al., 2022) at 5.86±0.88 mm to the right and 5.92±0.60 mm to the left. Lower C4 transverse diameter averages were reported in a second cross-sectional study conducted in Turkey (Metin Tellioglu et al., 2018) at 5.59±0.94 mm to the right and 5.67±0.79 mm to the left; and a second Italian study (Travan et al., 2015) at 4.6±0.7 mm to the right and 4.7±0.6 mm to the left with no statistically significant difference noted (p= 0.634).

The mean C5 transverse diameter in this study was 5.571 (±0.8516) mm to the right and 5.714 (±0.4688) mm to the left, a difference that was statistically significant (p=0.043). The findings of this study were similar to that reported in Italy (Viciano et al., 2021) where the right mean transverse diameter of C5 was 5.86±0.62mm, while the left was lower at 6.56±0.62 mm. Another study conducted in Italy (Travan et al., 2015)reported a much lower C5 transverse diameter of 4.7±1.0 mm to the right and 5±0.9 mm to the left, a difference that was not statistically significant (p= 0.135). In Belgium (Cagnie et al., 2005), the average C5 transverse diameter in the one hundred and eleven osteological specimens assessed was 5.8±0.6 mm however, the authors did not get specific averages for the left and right sides. The C5 transverse diameter findings of this study are similar to those reported in India at 6.00±1.17 mm to the right and 5.96±1.00 mm to the left. The same was reported in a Turkish (Metin Tellioglu et al., 2018) study where the mean to the right was 5.50±0.94 mm and 5.40±0.97 mm to the left, a difference that was found to be statistically significant (p <0.001). However, higher mean values were reported in a second study conducted in

Turkey where the authors noted 6.02±0.90 mm to the right and 6.12±1.10 mm to the left.

The mean right C6 transverse diameter was 5.250 (±1.2519) mm and 5.964 (±0.6924) mm to the left. This finding matched that reported in India (Gupta & Agarwal, 2019)at 5.67±1.10 mm to the right and 5.74±1.33 mm to the left and Turkey (Metin Tellioglu et al., 2018) at 5.37±1.23 mm to the right and 5.49±1.20 mm to the left. Wider variance in the mean were noted in the two Italian studies under review. In the first study conducted in Italy (Viciano et al., 2021), the right mean C6 transverse diameter matched that in the current study at 5.45±2.42 mm (although with a wider standard deviation) while on the left, a higher mean C6 transverse diameter was reported at 7.04±0.81 mm. In the second study conducted in Italy (Travan et al., 2015), lower averages were reported at 5.0±1.1 mm to the right and 5.1±1.1 mm to the left, with no statistically significant difference noted (p=0.662). It is worth noting that both Italian studies utilized osteological samples that were collected hundreds of years prior to the morphometric measurements reported in these studies. In Belgium, the overall C6 transverse diameter average (irrespective of the side) was 6.1±0.5 mm (Cagnie et al., 2005).

For C7, the mean transverse diameter was 4.125 (±1.3336) mm to the right and 4.792 (±1.9005) mm to the left, with no statistically significant difference in means (p=0.459) noted in this study. The finding contrasts all transverse C7 averages reported in studies under comparison. In Italy (Viciano et al., 2021), the first study reported an average of 5.19±1.75 mm to the right and 5.19±1.57 mm to the left, while in the second study conducted in Italy (Travan et al., 2015) found averages of 3.6±1.3 mm to the right and 3.5±1.2 mm to the left, with no statistically significant difference noted. In Belgium (Cagnie et al., 2005), the overall C7 average was 4.7±0.8 mm

irrespective of the side while in India, the authors (Gupta & Agarwal, 2019) reported 5.27±1.85 mm to the right and 5.18±2.05 mm to the left. In Turkey (Patra et al., 2022), the mean C7 transverse diameter for the two hundred osteological specimens sampled was 5.10±2.30 mm to the right and 5.24±2.10 mm to the left.

Much lower C7 transverse diameter averages were reported in the second study conducted in Turkey (Metin Tellioglu et al., 2018) at 3.58±1.25 mm to the right and 3.60±1.32 mm to the left, with the authors using a combination of morphometric and CT scan approaches. Knowledge of both anteroposterior and transverse diameters of foramen transversarium is important to the orthopedic and spine surgeons because a narrow foramen results in the compression of the vertebral artery and sympathetic nerves surrounding it which could lead to vertebrobasilar insufficiency syndrome that is characterized by syncope, problems with muscular coordination, double vision, hearing disturbances, vertigo, and transient ischemic attacks. In addition to this, the anatomical knowledge of the variations in the diameter of the foramen transversarium of cervical vertebra can be relevant to both vascular surgeons and neurosurgeons operating in the cervical region, as well as physicians and radiologists for proper interpretation of X-rays and CT scans (Chanda et al., 2017). The knowledge of these diameter variations will help the clinicians to diagnose vertebrobasilar insufficiency syndrome and manage it surgically using a procedure known as decompressive foraminotomy. Lastly, narrow or stenosed foramen transversarium resulting either from embryological development or as a sequelae of degenerative spine disorders such as osteophytes, results in compression of the vertebral artery which causes turbulent blood flow that increases the risk of thrombus formation and embolization to the brain (Ranjan et al., 2022).

Table 5. 4: Comparison of Transverse diameter of the right and left FT of the cervical spine specimens

	Current study (2022)		**Viciano (2021)**		**Travan (2015)**		**Cagnie (2015)**	**Gupta (2019)**		**Metin (2018)**		**PATRA (2022)**		**Sangari (2015)**	
Country	Kenya		Italy		Italy		Belgium	India		Turkey		Turkey		**New York - USA**	
Sample Size	224		83		180		111	161		987		200		**71**	
Study Design	Cross-sectional		Cross-sectional		Cross-sectional		Cross-sectional	Cross-sectional		Cross-sectional		Cross-sectional		**Cross-sectional**	
Diameter (mm)	**Transverse**		**Transverse**		**Transverse**		**Transverse**	**Transverse**		**Transverse**		**Transverse**		**Transverse**	
	Right	**Left**	**Right**	**Left**	**Right**	**Left**	**Average (both)**	**Right**	**Left**	**Right**	**Left**	**Right**	**Left**	**Right**	**Left**
Overall Mean (mm)	5.590 ± 1.1953	5.868 ±1.1317	-	-	-	-	-	5.78±1.10	5.87 ± 0.89	-	-	-	-	5.69 ± 1.04	**5.87 ± 0.89**
Overall Range (mm)	2.0 - 8.5	2.0 - 8.0	4.74-7.84		-	-	-	-	-	-	-	-	-	2.54-7.79	**2.65 - 7.35**
C1 (mm)	6.367 ±1.0601	6.167 (±1.0635)	7.27±0.50	7.26±0.74	5.5±1.2	5.6±1.3	-	5.85±0.83	5.87±1.03	6.56±1.02	6.62±0.96	-	-	-	-
C2 (mm)	6.143 (±0.8644)	6.393 (±0.8589)	6.83±0.89	7.12±1.19	4.1±0.9	4.2±0.9	-	5.07±0.82	5.31±0.83	6.85±1.32	6.80±1.50	-	-	-	-
C3 (mm)	5.786 (±0.4258)	6.429 (±0.9579)	6.22±0.67	6.60±0.68	4.7±0.7	4.7±0.6	5.6±0.7	6.22±0.93	6.36±0.54	5.86±1.01	5.93±1.00	5.88±0.73	5.93±0.54	-	-
C4 (mm)	5.969 (±0.6183)	6.000 (±0.7746)	6.16±0.53	6.45±0.71	4.6±0.7	4.7±0.6	5.8±0.6	6.10±0.92	5.94±0.84	5.59±0.94	5.67±0.79	5.86±0.88	5.92±0.60	-	-
C5 (mm)	5.571 (±0.8516)	5.714 (±0.4688)	5.86±0.62	6.56±0.62	4.7±1.0	5±0.9	5.8±0.6	6.00±1.17	5.96±1.00	5.50±0.94	5.40±0.97	6.02±0.90	6.12±1.10	-	-
C6 (mm)	5.250 (±1.2519)	5.964 (±0.6924)	5.45±2.42	7.04±0.81	5.0±1.1	5.1±1.1	6.1±0.5	5.67±1.10	5.74±1.33	5.37±1.23	5.49±1.20	5.55±1.23	5.60±1.93	-	-
C7 (mm)	4.125 (±1.3336)	4.792 (±1.9005)	5.19±1.75	5.19±1.57	3.6±1.3	3.5±1.2	4.7±0.8	5.27±1.85	5.18±2.05	3.58±1.25	3.60±1.32	5.10±2.30	5.24±2.10	-	-

5.5 Different types of shapes of FT in the cervical spine specimens at the National Museums of Kenya

This study reports that the most prevalent shape of foramen transversarium was round in more than half (51.3%) of all the osteological specimens sampled. This finding is comparable to that reported in Chile where 60.1% of the osteological specimens from the cervical spine sampled were round in shape (Molinet Guerra et al., 2017). Although the highest proportion of foramen transversarium identified in a study conducted at KwaZulu-Natal in South Africa (Zaw et al., 2021) were round, the proportion (43.85%) was lower than the current study. The authors (Zaw et al., 2021) sampled one hundred and thirty specimens from the KwaZulu-Natal population of South Africa that included sixty-seven males and sixty-three females archived at the Nelson Mandela School of Medicine. This sample size was lower than that adopted in the current study (n=224), furthermore, the authors restricted themselves to a regional sampling as opposed to the current study which opted for representation from multiple regions. These difference in study procedures and implementation could explain the proportionate difference in both studies.

Lower proportions (26.19%) of round foramen transversarium were reported in a second study conducted in the osteological bank of the same university in South Africa where the authors (Sheik Abdul et al., 2018) classified the one hundred and twenty-six osteological samples into 82 typical and 44 atypical. This proportionate difference could be attributed to methodological differences in both studies under comparison. Closer proportion of round foramen transversarium of 23.35% were reported in Turkey (Patra et al., 2022) and Kenya at 21.6% (Karau & Odula, 2013), with the lowest proportions being reported in two studies conducted in India at 11.7% (Lalit et al., 2019) and 7.26% (Rekha & Neginhal, 2014) respectively. In Turkey

(Patra et al., 2022), the authors adopted the Taitz classification criteria which uses the shape and direction of the main diameter and classifies foramina transversaria into five types namely type 1 round, type 2 elliptical with main diameter (length) anteroposterior, type 3 elliptical with main diameter transversal (breadth), type 4 elliptical with main diameter oblique, from right to left and type 5 elliptical with main diameter oblique, from left to right. The Taitz classification was also adopted by authors of studies published with data collected from India (Lalit et al., 2019; Rekha & Neginhal, 2014), Turkey (Patra et al., 2022) and Kenya (Karau & Odula, 2013). However, the current study was more objective and reported the shapes as they were seen (round, oval and irregular), without restricting itself to the five Taitz classification types which are basically round (type 1) and oval shapes (type 2-5). This is in line with a number of studies under comparison such as those published with data collected from South Africa (Sheik Abdul et al., 2018; Zaw et al., 2021) and Chile (Molinet Guerra et al., 2017).

The second most common shape of foramen transversarium reported in this study was oval in 43.3% of all osteological specimens sampled. This finding is close to that reported in two studies conducted in South Africa at 42.31% (Zaw et al., 2021) and 38.09% (Sheik Abdul et al., 2018) respectively. However, higher proportions were reported in India at 92.74% (Rekha & Neginhal, 2014) and 88.3% (Lalit et al., 2019), Turkey at 76.65% (Patra et al., 2022) and 78.4% in Kenya (Karau & Odula, 2013).

Irregularly shaped foramen transversarium was noted in 4.9% of osteological specimens sampled in this study. This is lower than the 13.07% (Zaw et al., 2021) and 19.04% (Sheik Abdul et al., 2018) reported in South Africa and 14% reported in Chile (Molinet Guerra et al., 2017). Other studies under comparison did not report

irregularly shaped foramen transversarium due to the Taitz classification criteria adopted (Taitz et al., 1978).

Although this study did not identify additional shapes of the foramen transversarium, a study conducted in South Africa (Sheik Abdul et al., 2018) reported Quadrangular (3.97%), Triangular (9.52%) and Semi-circle shapes (2.38%). Absent foramen transversarium was noted bilaterally in a single (0.5%) osteological specimen in this study while in South Africa (Zaw et al., 2021) it was unilaterally absent on the left in a single (0.77%) osteological specimen studied. Knowledge of shapes of the foramen transversaria has a direct effect on the intraoperative surgical approaches and instrumentation which directly impacts surgical outcomes (Ambali & Jadhav, 2017). Knowledge of the different shapes of the foramen transversarium will inform radiologists how to interpret the medical images and distinguish variant anatomy from pathologies on the cervical spine (Molinet Guerra et al., 2017).

Table 5. 5: Comparison of Different types of shapes of FT in the cervical spine specimens at the National Museums of Kenya

Author	Current study	Zaw	Abdul	Rekha	Molinet	Lalit	Patra	Karau
Year	2022	**2021**	2018	2014	**2017**	2015	**2022**	**2013**
Country	Kenya	**South Africa**	South Africa	India	**Chile**	India	**Turkey**	**Kenya**
Sample Size	224	**130**	126	153	**121**	30	**400**	**102**
Study Design	Cross-sectional	**Cross-sectional**	Cross-sectional	Cross-sectional	**Cross-sectional**		**Cross-sectional**	
Oval (n/%)	97 (43.3)	42.31	38.09	92.74	16.4	88.3	76.65	**78.4**
Round (n/%)	115 (51.3)	43.85	26.19	7.26	60.1	11.7	23.35	**21.6**
Irregular (n/%)	11 (4.9)	13.07	19.04	0	14	0	0	**0**
Quadrangular	**0**	**0**	3.97	0	0	0	0	**0**
Triangular	**0**	**0**	9.52	0	0	0	0	**0**
Semi-Circle	**0**	**0**	2.38	0	0	0	0	**0**

CHAPTER SIX

CONCLUSIONS, RECOMMENDATIONS AND STUDY LIMITATIONS

6.0 Summary

In the present study of two hundred and twenty-four cervical vertebrae, accessory foramen transversaria were observed in one-fifth of all the osteological specimens of cervical vertebrae sampled at the National Museums of Kenya. More than half (55.3%) of these accessory foramen transversarium were exhibited unilaterally with the rest bilaterally. However, the atlas and axis vertebrae didn't exhibit presence of accessory foramen transversarium, with the majority (31.9%) being noted on the sixth cervical vertebrae. The mean anteroposterior (AP) diameter of foramen transversarium was 5.348 ± 1.2731 mm on the right and 5.365 ± 1.2117 mm on the left, while the mean right transverse diameter of foramen transversaria was 5.590 ± 1.1953 mm and 5.868 ± 1.1317 mm on the left. This study notes that a single cervical vertebra (C7) exhibited bilateral absence of foramen transversarium. The most common shape of foramen transversarium was round followed by oval and irregular, with nearly equal proportions of round and oval foramen transversaria.

6.1 Conclusions

The findings of this study demonstrate a high prevalence of accessory foramen transversarium which implies associated alteration in the anatomy of the vertebral artery. There was a statistically significant difference in the left and right mean transverse diameters of C3 and C5 as well as in the mean anterior posterior diameters of C3 and C6. The sound knowledge on the morphometry of foramen transversarium and its variations is important for neurosurgeons, spine surgeons, vascular surgeons, and radiologists in the interpretation of medical images of the cervical spine for

proper diagnosis and management of conditions associated with foramen transversarium variations. Iatrogenic injury to the vertebral artery during spine surgery due to lack of knowledge on the variations of the foramen transversarium could be catastrophic since minor lesions to the vertebral artery could lead to significant haemorrhage and subsequent neurologic deficits or even fatality.

6.2 Recommendations

With the findings of this study showing how common accessory foramen transversarium are and possibility of abnormal anatomy of the vertebral artery, there is need to perform a CT-angiogram of the neck in addition to plain radiographs and computerized tomography (CT) of the cervical spine as a pre-operative test to prevent accidental injury to aberrant vertebral artery during surgery of the cervical spine.

Furthermore, it is not clear whether the accessory foramen transversarium contains the vertebral artery or veins or both. Therefore, further investigations on the subject should be co-related with the findings of cadaveric dissected specimens and CT-angiograms of the neck so as to clarify the contents of the accessory foramen transversarium.

REFERENCES

Aghera, B. R., Ahmed, S., Parmar, A., Agarwal, G. C., & Singel, T. C. (2020). Morphological study of anatomical variation of foramen transversarium in cervical vertebrae and its clinical implication. *Indian Journal of Clinical Anatomy and Physiology*, *5*(2), 170–172.

Akhtar, M., Madhukar, P., Rahman, S., & Kashyap, N. (2015). A morphometric study of foramen transversarium of dried cervical vertebrae. *International Journal of Research in Medical Sciences*, *3*(4), 912.

Ambali, M. P., & Jadhav, S. D. (2017). Anatomical Variations in Foramen Transversarium of Typical Cervical Vertebrae and Its Clinical Significance. *International Journal of Anatomy and Research*, *5*(1.1), 3426–3429.

Aziz, J. N., & Morgan, M. (2018). Morphological study of the foramen transversarium of the atlas vertebra among Egyptian population and its clinical significance. *Anatomy Physiology & Biochemistry*, *4*(4), 1–5.

Barbagallo, G., Certo, F., Albanese, V., & Visocchi, M. (2014). The impact of complications following cervical spine surgery: A systematic review. *Journal of Neurosurgical Sciences*, *58*, 55–64.

Bulsara, K. R., Velez, D. A., & Villavicencio, A. (2006). Rotational vertebral artery insufficiency resulting from cervical spondylosis: case report and review of the literature. *Surgical Neurology*, *65*(6), 625–627.

Cagnie, B., Barbaix, E., Vinck, E., D'Herde, K., & Cambier, D. (2005). Extrinsic risk factors for compromised blood flow in the vertebral artery: Anatomical observations of the transverse foramina from C3 to C7. *Surgical and Radiologic Anatomy*, *27*(4), 312–316. https://doi.org/10.1007/s00276-005-0006-7

Chanda, C., Patra, S., Kumar, A., Ms, D., & Ms, R. P. (2017). *Accessory Foramen Transversarium in Cervical Vertebrae*. *05*(02), 17437–17439.

Chaudhari, M., Maheria, P., & Bachuwar, S. (2013). Double foramen transversarium in cervical vertebra: morphology and clinical importance. *Indian Journal of Basic and Applied Medical Research*, *2*(8), 1084–1088.

Das, S., & Suri, R. (2005). *Double foramen transversaria: An osteological study with clinical implications*.

https://www.researchgate.net/publication/289474145_Double_foramen_transversaria_An_osteological_study_with_clinical_implications

Durge, S. V, Durge, N. W., & Gosavi, S. R. (2017). Study on variations of Foramen Transversarium in 7th cervical vertebrae in the region of Andhra Pradesh – A clinical approach. *Indian Journal of Anatomy and Surgery of Head, Neck and Brain*, *3*(1), 21–23.

El-Dwairi, Q. A., Ghaida, J. H. A., Isa, H. M., Al-Mousa, A. A., Marashdeh, W., & Al-Muqbel, K. M. (2020). Morphometric study of foramina transversaria in Jordanian population using cross-sectional computed tomography. *Anatomical Science International*, *0123456789*.

Godoy-Santos, A. L., Rammelt, S., & Zoboli, A. C. (2017). Clinical anatomy. In *Foot and Ankle Sports Orthopaedics*. https://doi.org/10.1007/978-3-319-15735-1_1

Gul, S., Itoo, M. S., Bhat, G. H. M., Kamal, Y., & Akhter, F. (2017). *Accessory Foramen Transversarium an Osteological Study and Its Clinical Correlation*. *4*(1), 31–33.

Gupta, M., & Agarwal, S. (2019). Morphometric Study of Foramina Transversaria and the Incidence of Accessory Foramina in Cervical Spine of Indian Population. *Journal of Clinical and Diagnostic Research*.

Gupta, S., Patel, Z., & Gautam, R. S. (2017). Morphological Study of Accessory Foramen Transversarium in Dried Cervical Vertebrae in Human Being. *International Journal of Anatomy and Research*, *5*(2.2), 3791–3795.

Imre, N. E., & Kocabiyik, N. (2016). Anatomical and morphometric evaluation of the foramen transversarium of cervical vertebrae. *Gulhane Medical Journal*, *58*(3), 282–285. https://doi.org/10.5455/Gülhane.182803

Ji, W., Zheng, M., Tong, J., Huang, Z., Chen, J., Qu, D., & Zhu, Q. (2015). Feasibility and trajectory study of anterior transarticular crossing screw placement for atlantoaxial joint instability: a cadaveric study and description of a novel technique. *European Spine Journal 2015 24:12*, *24*(12), 2954–2960.

Kalpana Ramachandran, P. (2014). A Study on the Foramen Transversarium in Cervical Vertebrae. -. *International Journal of Health Sciences and Research (IJHSR)*, *4*(12), 178–183.

Karau, P. B., & Odula, P. (2013). Some anatomical and morphometric observations in the transverse foramina of the atlas among Kenyans. *Anatomy Journal of Africa*, *2*(1), 61-66–66.

Anatomy Act (Chapter 249), (2012). www.kenyalaw.org

Kusumi, K., & Dunwoodie, S. L. (2010). The genetics and development of scoliosis. In *The Genetics and Development of Scoliosis* (Issue January).

Lalit, M., Mahajan, A., Piplani, S., & Kullar, J. S. (2019). An Anatomical Study of the Morphometric Differences between Complete Arcuate Foramina and Ipsilateral Foramina Transversaria in Human Atlas Vertebrae: Could these Be Responsible for Vaso-occlusive Symptoms? *National Journal of Clinical Anatomy*, *08*(03),

Manjunath, M., Kavitarati, D., & Sugathan, K. (2018). A study of presence of accessory foramina transversaria in dry human cervical vertebrae of South Indian origin. *International Journal of Medical Science and Public Health*, *7*(11), 934.

Mehta, G., & Mokhasi, V. (2021). *Morphometric Study of Foramina Transversaria in Cervical Vertebrae and its Clinical Significance*. *May 2020*, 1–5. https://doi.org/10.7860/IJARS/2021/45726

Metin Tellioglu, A., Durum, Y., Gok, M., Polat, A. G., Karaman, C. Z., & Karakas, S. (2018). Evaluation of morphologic and morphometric characteristic of foramen transversarium on 3-dimensional multidetector computed tomography angiography. *Turkish Neurosurgery*, *28*(4), 557–562.

Mitchell, J. (2009). Vertebral artery blood flow velocity changes associated with cervical spine rotation: A meta-analysis of the evidence with implications for professional practice. *Journal of Manual and Manipulative Therapy*, *17*(1), 46–57.

Molinet Guerra, M., Robles Fuentes, P., & Roa, I. (2017). Anatomical Variations of the Foramen Transversarium in Cervical Vertebrae. *International Journal of Morphology*, *35*(2), 719–722.

Moreira Moreira, J. J., & Herrero, C. F. P. S. (2020). Anatomical Variations and Morphometric Features of the Foramen Transversarium in the Cervical Vertebrae of a Latin American Population: A Brazilian Study. *World Neurosurgery*, *137*, e18–e26. https://doi.org/10.1016/j.wneu.2019.11.040

Muguro, J. K., Sasaki, M., Matsushita, K., & Njeri, W. (2020). Trend analysis and fatality causes in Kenyan roads: A review of road traffic accident data between 2015 and 2020. *Cogent Engineering*, *7*(1).

Murlimanju, B. V., Prabhu, L. V., Shilpa, K., Rai, R., Dhananjaya, K. V. N., & Jiji, P. J. (2011). Accessory transverse foramina in the cervical spine: Incidence, embryological basis, morphology and surgical importance. *Turkish Neurosurgery*, *21*(3), 384–387. https://doi.org/10.5137/1019-5149.JTN.4047-10.0

Nayak, G., Mohanty, B. B., Baisakh, P., Das, S. R., Panda, S. K., & Chinara, P. K. (2016). Study of accessory foramina transversaria in cervical vertebrae and their surgical and morphological importance. *Research Journal of Pharmaceutical, Biological and Chemical Sciences, 7*(3), 1370–1373.

Ouies, S. M. (2018). A Morphologic and Morphometric Study of the Foramen Transversarium of the Cervical Vertebrae: An Osteological Study in Upper Egypt. *Photosynthetica, 2*(1), 1–13.

Oviya, V. J., & Thenmozhi, M. S. (2016). Accessory foramen transversarium and its incidence in South Indians dried cervical vertebrae. *Journal of Pharmaceutical Sciences and Research, 8*(10), 1204–1205.

Pandey, R., Tabassum, S., Noida, G., & Pradesh, U. (2020). *Anatomical Study of Morphometric Patterns of Accessory Foramen Transversarium in Dried Atlas Vertebrae*. *7*(11), 2718–2724.

Patra, A., Chaudhary, P., & Kaur, H. (2022). Variations in the Foramen Transversarium of Cervical Spine and Their Surgical Importance: An Osteological Study in Dried Cervical Vertebrae of North Indian Origin. *Turkish Neurosurgery*, *32*(1), 36–42. https://doi.org/10.5137/1019-5149.JTN.32701-20.3

Polat, S., Göker, P., Yücel, A. H., & Bozkir, M. G. (2019). Morphometric Study of Dried Cervical Vertebrae. *International Journal of Morphology, 37*(3), 845–851.

Pruthi, N., Dawn, R., Ravindranath, Y., Maiti, T. K., Ravindranath, R., & Philip, M. (2014). Computed tomography-based classification of axis vertebra: choice of screw placement. *European Spine Journal 2014 23:5*, *23*(5), 1084–1091.

Quiles-Guiñau, L., Gómez-Cabrero, A., Miquel-Feucht, M., & Sanchis-Gimeno, J. A. (2017). Double transverse foramen in cervical vertebrae in a Spanish rural population of the late 17th and 18th centuries. *Italian Journal of Anatomy and Embryology*, *122*(1), 27–38.

Rakesh Ranjan, Md. Zahid Hussain, Soni Kumari, Vijay Kumar Singh, & Rashmi Prasad. (2022). The morphology and incidence of the accessory foramen transversarium in human dried cervical vertebrae as well as their clinical significance in the Eastern Indian population. *Asian Journal of Medical Sciences*, *13*(8), 47–53. https://doi.org/10.3126/ajms.v13i8.43777

Rathnakar, P., & K., R. (2013). Study of Accessory Foramen Transversaria in Cervical Vertebrae. *Journal of Health and Allied Sciences NU*, *03*(04), 097–099.

Rekha, B. S., & Neginhal, D. D. (2014). Variations in foramen transversarium of atlas vertebra : An osteological study in South Indians. *Int J Res Health Sci*, *2*(1), 224–228.

Sangari, S. K., Dossous, P.-M., Heineman, T., & Mtui, E. P. (2015). Dimensions and Anatomical Variants of the Foramen Transversarium of Typical Cervical Vertebrae. *Anatomy Research International*, *2015*, 1–5.

Sheik Abdul, R., Lazarus, L., Rennie, C., & Satyapal, K. S. (2018). The foramen transversarium of typical and atypical cervical vertebrae: Morphology and morphometry. *International Journal of Morphology*, *36*(4), 1439–1446.

Taitz, C., Nathan, H., & Arensburg, B. (1978). Anatomical observations of the foramina transversaria. *Journal of Neurology Neurosurgery and Psychiatry*, *41*(2), 170–176. https://doi.org/10.1136/jnnp.41.2.170

Travan, L., Saccheri, P., Gregoraci, G., Mardegan, C., & Crivellato, E. (2015). Normal anatomy and anatomic variants of vascular foramens in the cervical vertebrae: a paleo-osteological study and review of the literature. *Anatomical Science International*, *90*(4), 308–323. https://doi.org/10.1007/s12565-014-0270-x

Ulusoy, M. (2019). Anatomical Variations in Foramen Transversarium. *Eurasian Journal of Medical Investigation*, *4*(3), 312–314.

Viciano, J., Remigio, M., D'Anastasio, R., & Capasso, L. (2021). Anatomical variations of the foramen transversarium of cervical vertebrae from the ancient population of Herculaneum (79 CE; Naples, Italy). *Homo : Internationale Zeitschrift Fur Die Vergleichende Forschung Am Menschen*, *72*(1), 61–85.

Vikani, S., Patel, S., Suthar, K., & Maheria, P. (2016). Morphological Study of Accessory Foramen Transversarium in Dry Cervical Vertebra and Its Clinical Importance. *International Journal of Anatomy and Research*, *4*(3.3), 2847–2849.

Yadav, Y., Goswami, P., & Bharihoke, V. (2014). an Osteological Study of Foramen Trasversarium: Variations and Clinical Aspects. *Journal of Evolution of Medical and Dental Sciences*, *3*(68), 14562–14566.

Yesender, M., Devadas, P., Saritha, S., & Vinila, B. H. S. (2017). Study on the Anatomical Variations and Morphometry of Foramen Transversaria of the Subaxial Cervical Vertebrae. *International Journal of Anatomy and Research*, *5*(2.1), 3708–3712. https://doi.org/10.16965/ijar.2017.151

Zaw, A. K., Olojede, S. O., Lawal, S. K., Offor, U., Naidu, E. C. S., Rennie, C. O., & Azu, O. O. (2021). Preliminary study on foramen transversarium of typical cervical vertebrae in KwaZulu-Natal population: Age and gender related changes. *Translational Research in Anatomy*, *22*, 100099.

Zibis, A. H., Mitrousias, V., Baxevanidou, K., Hantes, M., Karachalios, T., & Arvanitis, D. (2016). Anatomical variations of the foramen transversarium in cervical vertebrae: findings, review of the literature, and clinical significance during cervical spine surgery. *European Spine Journal*, *25*(12), 4132–4139.

Zibis, A., Mitrousias, V., Galanakis, N., Chalampalaki, N., Arvanitis, D., & Karantanas, A. (2018). Variations of transverse foramina in cervical vertebrae: what happens to the vertebral artery? *European Spine Journal*, *27*(6), 1278–

APPENDICES

Appendix 1: Data Collection Form

Participant Number_____

1. Presence of an accessory foramen Yes___ No___
    a. If yes, specify Level _____ and Number _____
2. Absent Foramen Transversarium Yes___No___
3. Anteroposterior diameter of right foramen transversarium _____mm
4. Anteroposterior diameter of left foramen transversarium _____mm
5. Transverse diameter of right foramen transversarium _____mm
6. Transverse diameter of left foramen transversarium _____mm
7. Shape of foramen transversarium
    a. Oval Yes___No___
    b. Rounded Yes___No___
    c. Irregular Yes___No___
    d. Quadrangular Yes___No___

Summary of length and shape

Vertebra	Right		Left		Shape
	AP	Transverse	AP	Transverse	
C1					
C2					
C3					
C4					
C5					
C6					
C7					

Appendix II: Proposed budget

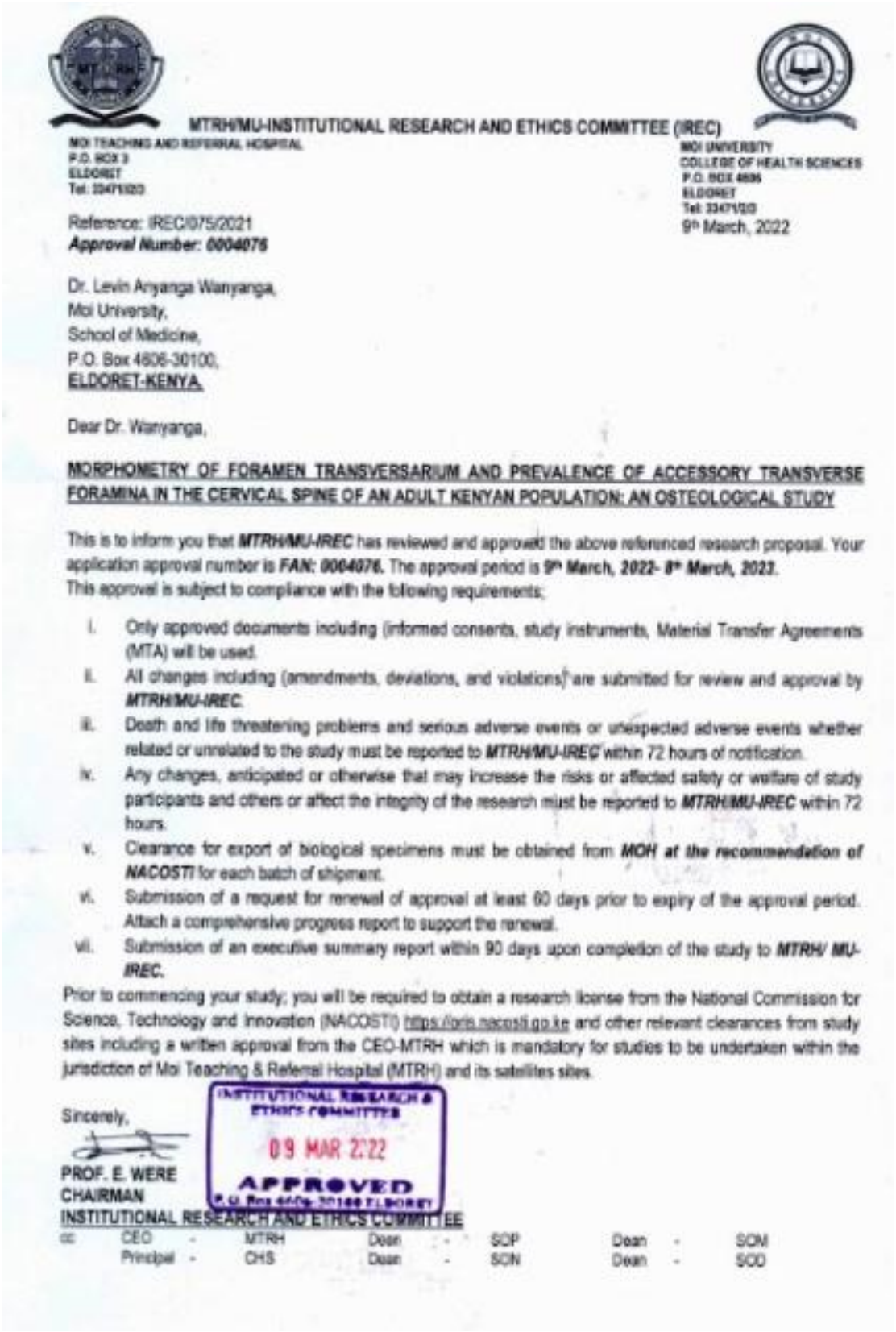
ITEM	**COST (KSHS)**
STATIONERY	1,000
FLASH DISKS (2)	2,000
RESEARCH PROPOSAL PRINTING	2,000
IREC SUBMISSION FEE	2,000
RESEARCH ASSISTANT FEE	10,000
BIOSTATISTICIAN FEES	30,000
PRINTING & BINDING THESIS	5,000
TOTAL	52,000

Appendix III: Work Plan

ACTIVITY	START	END
Concept paper development	JANUARY 2021	FEBRUARY 2021
Proposal writing	MARCH 2021	AUGUST 2021
Submission to IREC	SEPTEMBER 2021	NOVEMBER 2021
Data collection	2nd JANUARY 2022	31st JANUARY 2022
Data analysis	1st FEBRUARY 2022	MAY 2022
Thesis writing	1st JUNE 2022	SEPTEMBER 2022

Appendix IV: IREC APPROVAL

N



MTRH/MU-INSTITUTIONAL RESEARCH AND ETHICS COMMITTEE (IREC)

MOI TEACHING AND REFERRAL HOSPITAL
P.O. BOX 3
ELDORET
Tel: 33471020

MOI UNIVERSITY
COLLEGE OF HEALTH SCIENCES
P.O. BOX 4606
ELDORET
Tel: 33471020

Reference: IREC/075/2021
Approval Number: 0004076

9th March, 2022

Dr. Levin Anyanga Wanyanga,
Moi University,
School of Medicine,
P.O. Box 4606-30100,
ELDORET-KENYA.

Dear Dr. Wanyanga,

MORPHOMETRY OF FORAMEN TRANSVERSARIUM AND PREVALENCE OF ACCESSORY TRANSVERSE FORAMINA IN THE CERVICAL SPINE OF AN ADULT KENYAN POPULATION: AN OSTEOLOGICAL STUDY

This is to inform you that ***MTRH/MU-IREC*** has reviewed and approved the above referenced research proposal. Your application approval number is ***FAN: 0004076.*** The approval period is ***9th March, 2022- 8th March, 2023.***
This approval is subject to compliance with the following requirements;

i. Only approved documents including (informed consents, study instruments, Material Transfer Agreements (MTA) will be used.
ii. All changes including (amendments, deviations, and violations) are submitted for review and approval by ***MTRH/MU-IREC.***
iii. Death and life threatening problems and serious adverse events or unexpected adverse events whether related or unrelated to the study must be reported to ***MTRH/MU-IREC*** within 72 hours of notification.
iv. Any changes, anticipated or otherwise that may increase the risks or affected safety or welfare of study participants and others or affect the integrity of the research must be reported to ***MTRH/MU-IREC*** within 72 hours.
v. Clearance for export of biological specimens must be obtained from ***MOH at the recommendation of NACOSTI*** for each batch of shipment.
vi. 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.
vii. Submission of an executive summary report within 90 days upon completion of the study to ***MTRH/ MU-IREC.***

Prior to commencing your study; you will be required to obtain a research license from the National Commission for Science, Technology and Innovation (NACOSTI) https://oris.nacosti.go.ke and other relevant clearances from study sites including a written approval from the CEO-MTRH which is mandatory for studies to be undertaken within the jurisdiction of Moi Teaching & Referral Hospital (MTRH) and its satellites sites.

Sincerely,

INSTITUTIONAL RESEARCH & ETHICS COMMITTEE
09 MAR 2022
APPROVED
P.O. Box 4606-30100 ELDORET

PROF. E. WERE
CHAIRMAN
INSTITUTIONAL RESEARCH AND ETHICS COMMITTEE

cc CEO - MTRH Dean - SOP Dean - SOM
Principal - CHS Dean - SON Dean - SOD

Appendix V: NACOSTI Approval

REPUBLIC OF KENYA

NATIONAL COMMISSION FOR SCIENCE,TECHNOLOGY & INNOVATION

Ref No: **214392**

Date of Issue: **18/March/2022**

RESEARCH LICENSE

This is to Certify that Dr.. Levin Anyanga Wanyanga of Moi University, has been licensed to conduct research in Nairobi on the topic: MORPHOMETRY OF FORAMEN TRANSVERSARIUM AND PREVALENCE OF ACCESSORY TRANSVERSE FORAMINA IN THE CERVICAL SPINE OF AN ADULT KENYAN POPULATION: AN OSTEOLOGICAL STUDY for the period ending : 18/March/2023.

License No: **NACOSTI/P/22/16412**

214392

Applicant Identification Number

Director General
NATIONAL COMMISSION FOR SCIENCE,TECHNOLOGY & INNOVATION

Verification QR Code

NOTE: This is a computer generated License. To verify the authenticity of this document, Scan the QR Code using QR scanner application.

Appendix VI: Approval from NMK

NATIONAL MUSEUMS OF KENYA

WHERE HERITAGE LIVES ON

Ref: NMK/HRD/ADM/4397

21st March, 2022

Dr. Levin Anyanga Wanyanga

Dear Dr. Wanyanga,

RE: REQUEST FOR PERMISSION TO CARRY OUT RESEARCH

We refer to the letter on the aforementioned subject.

This is to inform you that you have been granted permission to conduct research on **Morphometry of Foramen Transversarium and Prevalence of Accessory Transverse Foramina in the Cervical Spine of an adult Kenyan population: An Osteological Study** at National Museums of Kenya (NMK). In this respect, you have been allowed to access Osteology Section for purposes of data collection.

Please note that while conducting the research you will be expected to observe all organizational policies relating to information management and also share your findings with NMK.

Yours sincerely.

Stanvas Ongalo.

Acting Director General.

Address P.O. Box 40658 00100 GPO Nairobi Telephone +254 20 4448930/3. +254 20 3742161/4. +254 20 3742131/4. Fax +254 20 3741424. Website www.museums.or.ke