MORPHOMETRIC MEASUREMENTS OF SUB-AXIAL CERVICAL VERTEBRAE PEDICLES IN RELATION TO TRANSPEDICULAR SCREWS IN A KENYAN ADULT POPULATION

BY

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A THESIS SUBMITTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE AWARD OF MASTER OF MEDICINE IN ORTHOPAEDIC SURGERY

MOI UNIVERSITY

DECLARATION

Declaration by the student

This research thesis is the author's original work being submitted in partial fulfillment of the requirement for Master of Medicine in Orthopaedic Surgery of Moi University and has not been submitted for an award of any academic credit in research institutions or universities.

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DEDICATION

This thesis is dedicated to my family for the great support they have shown.

ACKNOWLEDGEMENT

I would like to thank my supervisors, Prof. M. G. Y, El-Badawi, and Dr. E. N, Muteti for their guidance, support, and contribution towards this thesis, Mr. Henry Mwangi for guiding me through the statistical aspects and my family and colleagues for their unyielding support throughout the duration of this thesis.

LIST OF ABBREVIATIONS AND ACRONYMS

C3	Third cervical vertebrae
C4	Fourth cervical vertebrae
C5	Fifth cervical vertebrae
C6	Sixth cervical vertebrae
C7	Seventh cervical vertebrae
IREC	Institutional Research and Ethics Committee
SD	Standard Deviation

DEFINITION OF TERMS

Angle of medial inclination	Angle between chord length and a line perpendicular to the anterior vertebral body
Cervical vertebrae	Are seven vertebrae designated C1 to C7 found in in the uppermost section of the spine between the skull and thoracic vertebrae
Chord length	Distance between the lateral mass and the vertebral body
Morphometry	The external shape and dimensions of a dry sub-axial cervical bone
Pedicle	A part of the bone in the vertebrae that is between the body of the vertebrae and the lamina bone
Pedicle width	Medial to the lateral diameter of the pedicle isthmus
Pedicle height	The superior-inferior width of the pedicle
Sub- axial cervical vertebrae	Section of the cervical vertebra from C3 to C7
Transpedicular screw	A pedicle screw that is inserted through the pedicle into the vertebral body in transpedicular screw surgery

ABSTRACT

Background: Morphometric measurements of sub-axial cervical vertebrae pedicles (C3-C7) are anatomical measurements that include pedicle width, height, chord length and angle of medial inclination. These measurements are used to define the right size of screw to use in transpedicular screw surgery. Transpedicular screws provide superior stability compared to other forms of fixation in sub-axial cervical spine surgery. For a spinal surgeon to perform transpedicular screw surgery he needs the anatomical measurements of the pedicle and the right size of screw. Different racial groups have been shown to have distinct anatomical measurements of the pedicle. Pedicle screws are currently based on anatomical measurements of European pedicles. Studies done on the Chinese and Indian populations have shown that they have smaller pedicle measurement and thus need smaller pedicle screw sizes. Because of lack of studies that define pedicle measurements in sub-Saharan Africa, this study will provide the anatomical measurements of sub-axial cervical vertebrae pedicles and define the right screw size for each pedicle to aid the Kenyan spine surgeon in transpedicular screw surgery.

Objective: To describe the morphometric measurements of the adult sub-axial cervical vertebrae pedicles in relation to transpedicular screws in the Kenyan adult population.

Methods: A descriptive cross-sectional anatomical study was conducted at the National Museum of Kenya in the month of August 2017. Ninety-seven dry bone specimens were selected for the study through purposive sampling. Measurements were collected using digital calipers and goniometer and recorded in data forms. The pedicle dimensions measured were width, height, chord length and angle of medial inclination. Data were analysed using STATA/ MP 13.0 and summarised using mean, standard deviation and presented in tables.

Results: The mean pedicle width was 4.45±0.65mm at C3, 4.64±0.76mm at C4, 5.24±0.78mm at C5, 5.46±0.82mm at C6, and 6.06±1.07mm at C7.The mean pedicle height was 6.36±0.81mm at C3, 6.67±0.89mm at C4, 6.62±1.04mm at C5, 6.53±0.90mm at C6, and 7.25±1.06mm at C7. The mean chord length was 30.81±2.50mm at C3, 31.47±2.63mm at C4, 31.83±2.89mm at C5, 32.17±3.31mm at C6, and 32.65±2.84mm at C7. The mean angle of medial inclination was 45.19±3.44 degrees at C3, 46.80±3.79 degrees at C4, 48.12±3.84 degrees at C5, 45.56±3.51 degrees at C6, and 42.13±3.22 degrees at C7.

Conclusion: Pedicle width and chord length increased caudally from C3 to C7. Pedicle height measurements were variable. The angle of medial inclination increased from C3 to C5 then decreased from C6 to C7.

Recommendations: Based on morphometric measurements of sub-axial cervical vertebrae pedicles from this study, the recommended screw diameter at C3 and C4 is 2.7mm while at C5, C6 and C7 is 3.5mm. The appropriate screw lengths at C3 is 22 mm while at C4, C5, C6 is 24 mm and at C7 is 26 mm. The recommended angle to advance a screw in transpedicular sub-axial cervical surgery is 45°.

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CHAPTER ONE: INTRODUCTION

1.1 Background information

The spine is composed of the spinal cord and its bony cage the vertebral bones. The spine is divided into sections cervical, thoracic, lumbar, sacrum, and coccyx (Waxenbaum & Futterman, 2019). The cervical spine has seven vertebral bones C1 to C7. The cervical vertebrae are subdivided into two groups one containing C1 and C2 which are highly specialized and another C3 to C7 also known as sub-axial cervical vertebrae which are typical vertebrae bones having a body, pedicle, lamina, spinous process, and facet joints (Waxenbaum & Futterman, 2019).

The cervical pedicle is part of the cervical vertebral bone that separates the transverse process and lamina from the body of the vertebral bone. The pedicle in sub-axial cervical vertebral bones has four surfaces. On the medial surface lies the spinal cord in the spinal canal, the lateral surface is related to the vertebral artery and vein in the foramen transversarium and the superior and inferior surfaces are closely related to the cervical nerves that radiate from the spinal cord (Standring & Gray, 2008). The pedicle is used for transpedicular screw surgery, where a screw is placed through the pedicle into the body of the cervical bone (Abumi, Itoh, Taneichi, & Kaneda, 1994). This surgery is used in cervical spine injuries to stabilise the cervical spine. The pedicle has a three-dimensional shape having a width, height, length, and angle making it easy for a screw size to be approximated from the measurements of the pedicle.

Transpedicular spinal surgery was started in 1984 by Roy Camille (Kabins & Weinstein, 1991) through fixing the lumbar spine while, Abumi, Itoh, Taneichi, & Kaneda (1994) were the first to introduce screws into the pedicles of the lower cervical spine in order to manage fractures and dislocations, followed by Jeanneret, Gebhard, & Magerl (1994). From then on it became a popular form of surgery with more neurosurgeons starting to embrace this surgical practice (Jo, Seo, Kim, Kim, & Lee, 2012).

Transpedicular spinal surgery has been shown to be superior to other forms of cervical spine surgery like anterior plating, lateral mass screw and plate fixation, and posterior wiring techniques. This is because the pedicles are strong structural elements of the vertebrae that offer the strongest point of attachment to the spine thus providing the greatest stability to the cervical spine, with reduced likelihood of hardware loosening (Abumi et al., 1994). In Kenya lateral mass screw and plating are used for sub-axial cervical spine surgery but this form of surgery has been shown to have an increased risk of hardware loosening. This is as a result of the small amount of bone a lateral mass screw purchases in the lateral mass during lateral mass screw and plate fixation (Jones, Heller, Silcox, & Hutton, 1997).

Transpedicular screw insertion is used for cervical stabilization in cases like cervical laminectomy, burst fracture, spinal tumour, degenerative conditions, and infective spondylitic processes of the cervical spine (Abumi et al., 1994; Cruz et al., 2011). Transpedicular screw insertion though superior to other forms of surgery is a very delicate surgery because of sensitive structures that surround it (Liu, Napolitano, & Ebraheim, 2010). A mismatch between the size of the screw and the pedicle size may lead to perforation through the pedicle cortex and cause injuries to structures that surround the pedicle (Tan, Teo, & Chua, 2004). Medially, cortical perforation may injure the spinal cord that may lead to paralysis, a lateral cortical perforation may injure the vertebral vessels that can lead to brain ischemia. A superior or inferior cortical perforation can injure cervical nerve roots that may lead to radiculopathies (Wasinpongwanich et al., 2014). These iatrogenic injuries are greatly reduced if the spinal surgeon has good anatomic knowledge on the measurements of the sub-axial cervical pedicle and the right size of transpedicular screw to use (Jo et al., 2012; Wasinpongwanich et al., 2014). Various racial groups have been shown to have different sub-axial cervical pedicle measurements and thus for each and every racial group a different kind of pedicle screw is prescribed (Li, Liu, Liu, Wu, & Zhu, 2015). Most sub-axial cervical pedicle measurements have been studied in European populations and so transpedicular screws are based on measurements from European populations (Tan et al., 2004). Research is being done on various populations to be able to provide measurements of their local populations. Research that was done on sub-axial cervical pedicles of the Chinese (Tan et al., 2004) and Indian (Mitra S R, Sah, & Mitra, 2015) population showed that they had smaller pedicles compared to European populations concluding that smaller transpedicular screws than the standard based screws needed to be provided to safely perform transpedicular screw surgery in their population.

For a sub-axial transpedicular screw to be placed safely a spinal surgeon needs to have good anatomical knowledge of the pedicle and the right size of screws (Jo et al., 2012; Wasinpongwanich et al., 2014). The anatomical knowledge that will be attained from research on the pedicle measurements width, height, chord length and angle of medial inclination will assist the Kenyan spine surgeon in estimating the size of screw that he needs to safely perform transpedicular screw surgery without causing damage to the delicate structures that surround it.

1.2 Problem statement

Spine surgeons in Moi Teaching and Referral Hospital use lateral mass screws for cervical stabilization. Inadequate purchase is observed in 1 in every 4 surgeries with 5 cases of hardware loosening reported per year. Transpedicular screws offer greater pull-out strength with reduced likelihood of hardware loosening when compared to lateral mass screws, but a lack of studies on sub-axial cervical pedicle anatomy and right screw size for the Sub–Saharan African population has prevented safe utilization of transpedicular screw fixation.

1.3 Justification

This study will provide the anatomical measurements of sub-axial cervical vertebrae pedicles and define the right screw size for each pedicle to aid the Kenyan spine surgeon to safely perform transpedicular screw surgery.

The pedicle width and height will provide anatomical knowledge of the pedicle and assist the spinal surgeon in defining the diameter of the pedicle screw to be used. This is to avoid perforating the pedicle cortex and causing damage to the vertebral artery laterally, spinal cord medially, or cervical nerve roots that are situated superiorly and inferiorly to the pedicle.

The pedicle chord length will provide the anatomical knowledge of the pedicle and help the spinal surgeon to select a screw of the appropriate length to avoid going beyond the vertebral body. This could damage the oesophagus or the pharynx that is situated on the anterior aspect of the vertebral bodies.

The pedicle angle will be used to provide information on the anatomical angle at which the screw is advanced to avoid damage to the vertebral artery or spinal cord at the side of the pedicle.

1.4 Research question

What are the morphometric measurements of sub-axial cervical vertebrae pedicles of dry cadaveric bone specimens in relation to transpedicular screws in Kenyan adults?

1.5 Objectives

1.5.1 Broad objective

To assess the morphometric measurements of sub-axial cervical vertebrae pedicles of dry cadaveric bone specimens in relation to transpedicular screws in Kenyan adults.

1.5.2 Specific objectives

1. To measure the linear parameters: width, height, and chord length of sub-axial cervical vertebrae pedicles of dry cadaveric bone specimens in Kenyan adults.
2. To determine the angle of medial inclination: pedicle angle of sub-axial cervical vertebrae pedicles of dry cadaveric bone specimens in Kenyan adults.

CHAPTER TWO: LITERATURE REVIEW

2.1 Anatomy of the vertebral column

The vertebral column is a curved bony structure formed from bones linked to each other. It is formed from 33 individual bones which include seven cervical, twelve thoracic, five lumbar, five sacral, and four coccygeal bones (Sinnatamby, 2013) (Figure 2.1.1). The bones that form the sub-axial cervical vertebral bones are C3 to C7. Every vertebral bone is composed of a body on its anterior aspect and a neural arch posteriorly. The spinal canal is formed from the neural arch when the vertebral bones are connected together to form the vertebral column. The spinal canal houses and protects the spinal cord (Sinnatamby, 2013). The neural arch forms the spinous process posteriorly and the transverse process laterally. The area of the neural arch between the spinous and transverse process is known as the laminae and between the vertebral body and transverse process is known as the pedicle (Sinnatamby, 2013). Each vertebral bone has a superior and an inferior articular facet that is formed at the point where the lamina and pedicle join (Sinnatamby, 2013). The pedicle of each vertebra has a groove at its superior and inferior aspects. The two grooves from each adjacent vertebrae together form a window called the intervertebral foramen that contains the spinal nerves (Sinnatamby, 2013).

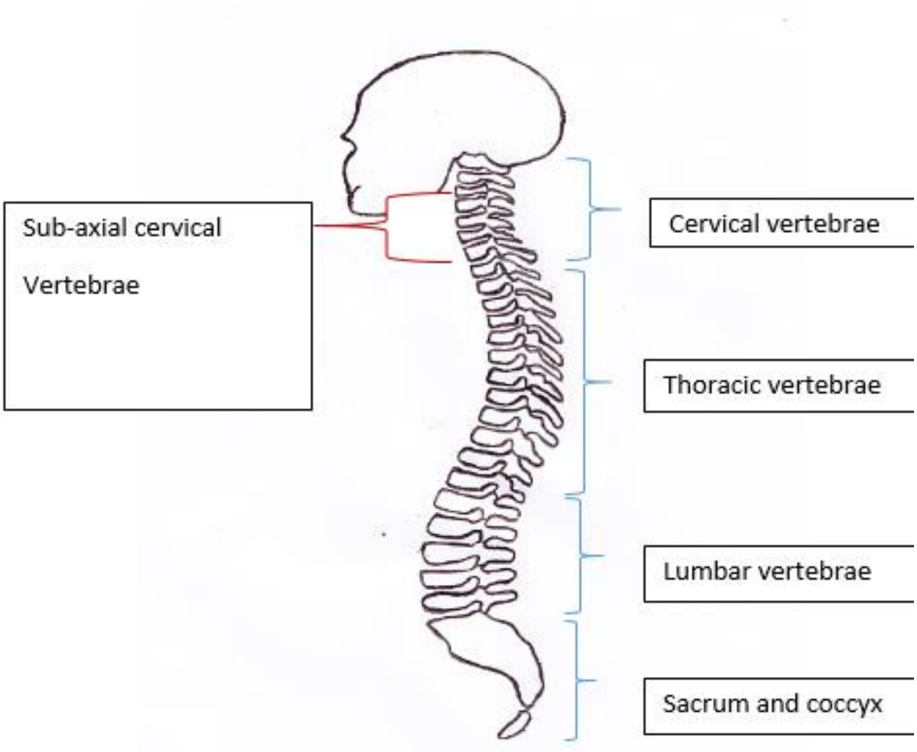

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Figure 2.1.1: Showing the vertebral column

2.2 Anatomy of the sub-axial cervical vertebrae (C3-C7)

The third to sixth cervical vertebrae

They have a small body with their measurement from side to side being larger than the dimensions from the superior to inferior surfaces. The body on its superior surface is concave and contains projections from its superior surface that are called the uncinate process which articulates with the inferior surface of the cervical vertebrae above which has a convex shape to form a synovial joint (Standring & Gray, 2008).

The transverse processes are directed laterally each has a foramen called the foramen transversarium. In the upper six vertebrae, the foramen transversarium transmits the vertebral artery, vein, and a plexus of sympathetic nerves. Each process consists of an anterior and posterior part. The anterior part arises from the side of the body and is directed laterally and anterior to the foramen it ends up as the anterior tubercle. The posterior part arises from the neural arch and is directed forwards and laterally ending as the posterior tubercle. These two parts are then joined together, outside the foramen, by a piece of bone that has a depression on its upper surface for the passage of the corresponding spinal nerve (Standring & Gray, 2008).

The pedicles are directed laterally and posteriorly and are attached to the body midway between its upper and lower borders.

The lamina are directed medially and posteriorly and together with the pedicles form the vertebral canal which houses the cervical part of the spinal cord (Sinnatamby, 2013). The spinous process is short and bifid, with two tubercles which are often unequal in size. The junction between lamina and pedicle bulges laterally between the superior and inferior articular processes to form when articulated, an articular pillar the lateral mass on each side (Standring & Gray, 2008).

The superior and inferior articular processes on either side are fused to form an articular pillar, which projects laterally from the junction of the pedicle and lamina. The articular facets are flat and oval: the superior look backwards, upward, and slightly medially while the inferior look forwards, downward, and slightly laterally (Standring & Gray, 2008) (Figure 2.2.1).

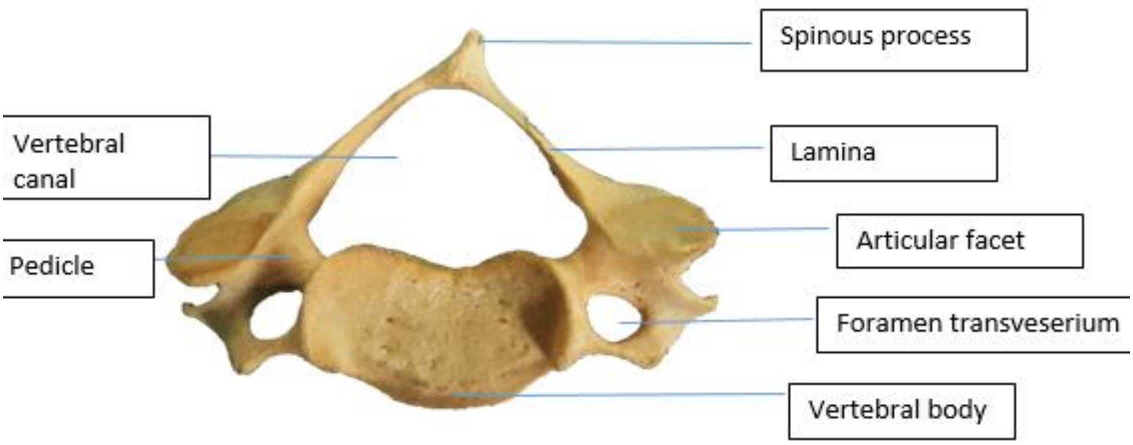

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Figure 2.2.1: Showing the anatomy of the cervical vertebral bone

The seventh cervical vertebrae

Has a long and prominent spinous process that is not bifurcated. The transverse processes are long and large and lack the anterior tubercles. The foramen transversarium is small and does not transmit the vertebral artery. It transmits only the accessory vertebral vein (Sinnatamby, 2013).

2.3 Morphometric measurements of the sub-axial cervical pedicle vertebrae in relation to transpedicular screws

The sub-axial cervical pedicle is said to be three dimensional, having a width, height, chord length, and an angle in which it projects from the vertebral body. The pedicle width and height aid in selecting the diameter of the screw. The pedicle chord length assists in coming up with the length of the screw while the angle of medial inclination aids the spine surgeon in advancing the screw.

There are two pedicles for every vertebra with studies showing no significant difference between the right and left pedicle measurements (Tomasino et al., 2010).

2.3.1 Pedicle Width

The pedicle width is the medial and lateral diameter of the pedicle isthmus, it is used to determine the diameter of the transpedicular screw. The width of a cervical pedicle is an important measurement in selecting the appropriate screw diameter with most pedicle wall breach resulting from trying to insert an inappropriate screw size into a pedicle causing injury to either the spinal cord on the medial aspect or the vertebral artery on the lateral aspect (Tan et al., 2004).

When performing transpedicular screw surgery it is of added value to knowing the anatomy of the structures that surround the pedicle. On the lateral aspect of the cervical pedicle, the vertebral artery and vein are present in the foramen transversarium (Figure 2.3.1.1). The vertebral artery and vein lie adjacent to the lateral wall with the vein being medial to the artery. The lateral wall which is adjacent to the vertebral artery is said to be the weakest and so the most perforated (Jeanneret, Gebhard, & Magerl, 1994). Though the lateral wall is the most breached, incidences of injury to the vertebral artery are low because it occupies only 35 percent of the foramen transversarium and the distance from the pedicle wall to the artery increases from C3 to C7 at 1.2 mm to 6.5mm (Tomasino et al., 2010). On the medial aspect, the spinal cord is present in the spinal canal (Figure 2.3.1.1). Tomasino et al., (2010) in their study noted that the dural sac was found on the medial wall of the pedicle at a distance of 2.4 to 3.1mm.

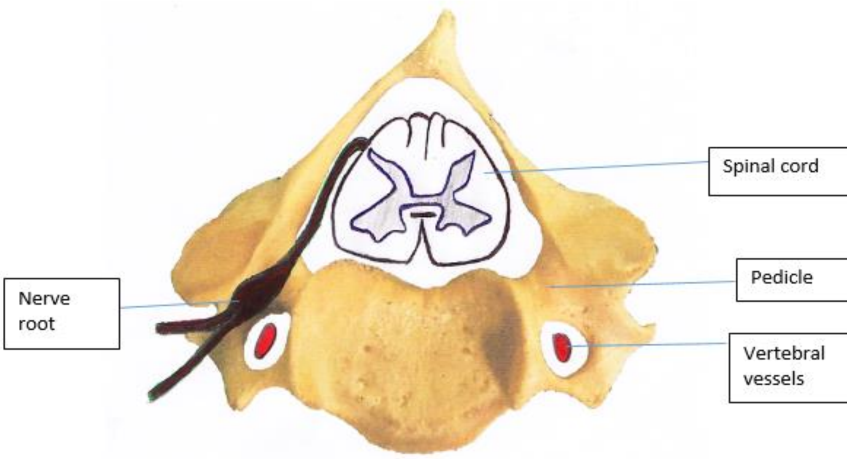

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Figure 2.3.1.1: Showing the anatomical relations of the cervical pedicles and structures that surround it

Different populations have been found to have varying pedicle width sizes thus pedicle diameter screw sizes are unique to each populace (Chanplakorn et al., 2014; Tan et al., 2004). There are various screw diameter sizes that are determined by the pedicle width of the different populations. The various screw size diameters include 2.7mm, 3.5mm, 4mm, 4.5mm, and 5.5 mm.

The width of a cervical pedicle is an important measurement in selecting the appropriate screw diameter with most pedicle wall breach resulting from trying to insert an inappropriate screw size into a pedicle causing injury to either the spinal cord on the medial aspect or vertebral artery on the lateral aspect (Tan et al., 2004) (Figure 2.3.1.2).

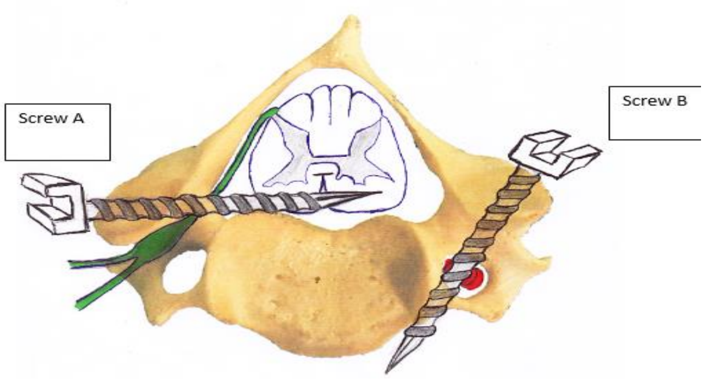

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Figure 2.3.1.2: Showing iatrogenic injuries as a result of misplaced screws. Pedicle screw A advancing into the spinal cord Pedicle screw B advancing into the vertebral vessels

The standard diameter of the screw that is used is 3.5 mm. This screw diameter size is based on Western countries as their pedicle widths are more than 5mm (Tan et al., 2004). A study by Ludwig et al., (2000) in America showed that using a screw of 3.5 mm on cervical pedicles of more than 5mm 79% of the screws were properly placed with no violations, 19% had non-critical violations and 2% had critical violations. The conclusion made from this study showed that for a 3.5 mm standard screw to be inserted into a pedicle, the pedicle has to be at least 5mm. This is to allow a gap of bone medially and laterally of 0.75mm from the vital structures that surround the pedicle (Patwardhan, Nemade, Bhosale, & Srivastava, 2012).

Western populations e.g. American (Onibokun, Khoo, Bistazzoni, Chen, & Sassi, 2009), German (Tomasino et al., 2010), and Austrian (Reinhold, Magerl, Rieger, & Blauth, 2007) have been shown to have larger pedicle widths and so can use a standard 3.5 mm pedicle screw (Table 2.3.1.1).

Indian (Mitra S R et al., 2015), Malaysian (Yusof, Ming, & Abdullah, 2007), Chinese Singaporeans (Tan et al., 2004), and Turkish (Ugur et al., 2000) populations have been observed to have smaller pedicle width sizes with a 2.7 mm screw size being recommended for their populations (Table 2.3.1.1).

Most studies show that the male gender has a statistically significantly larger pedicle width than the female (Table 2.3.1.1). Most studies have shown that in both genders pedicle width increased from C3 to C7 (Table 2.3.1.1).

Table 2.3.1.1: Measurements of pedicle width in millimetres found in various populations

Cervical pedicles	(Onibokun et al., 2009) **American**		(Tomasino et al., 2010) **German**		(Ugur et al., 2000) **Turkish**	
	M	F	M	F	M	F
C3	5.2	4.2	5.7	4.3	5.1	4.5
C4	5.4	4.4	5.8	4.5	5.4	4.5
C5	5.9	5.0	6.2	4.9	5.5	4.4
C6	6.1	5.2	6.4	5.2	5.8	5.3
C7	6.9	5.9	7.1	5.8	6.1	5.7

Cervical pedicles	(Yusof et al., 2007) **Malaysian**		(Mitra S R et al., 2015) **Indian**		(Tan et al., 2004) **Chinese Singaporeans**	**(**Reinhold et al., 2007) **Austrian**
	M	F	M	F	M & F	M & F
C3	4	4.07	4.32	3.83	4.4	5.7
C4	4.58	3.81	4.44	3.51	4.5	5.6
C5	4.71	3.78	4.55	3.60	4.9	6.2
C6	4.76	3.99	5.16	4.81	5.4	6.7
C7	4.9	4.49	6.05	6.52	5.7	7.9

2.3.2 Pedicle Height

Pedicle height is the superior-inferior width of the pedicle, it aids in the selection of the appropriate screw diameter. The height of a cervical pedicle is an important measurement in selecting the appropriate screw diameter with most pedicle wall breaches resulting from trying to insert an inappropriate screw size into a pedicle causing injury to the cervical nerve roots on the superior and inferior aspect of the pedicle.

Cervical nerve roots are usually located on the superior and inferior aspect of the cervical pedicle exiting at 45 degrees on the sagittal plane and 10 degrees on the coronal plane from the neural foramina. Cervical nerves are said to occupy the inferior half of the neural foramina. On the superior aspect of the cervical pedicle, the nerves are thus said to be in close contact with the bone leaving no space between the bone and the nerve. On the inferior aspect of the cervical pedicle, there is some space (approximately 1.1 to 1.7 mm) between the nerve and the bone. This shows that a superiorly placed screw will have a higher chance of injury to the cervical nerve compared to one that is inferiorly placed (Tomasino et al., 2010).

The pedicle height in this study will aid in selecting a screw of appropriate diameter to reduce the chances of injury to cervical nerves that may lead to cervical radiculopathies. A 3.5 mm pedicle screw is the standard screw that is used for a pedicle height measurement of more than 5mm, while a 2.7 mm screw is used for a pedicle height measurement of less than 5mm (Ludwig et al., 2000).

Most studies show that the male gender has a statistically significantly larger pedicle height than the female (Table 2.3.2.1). Most studies have shown that in both genders pedicle height measurements had a variable pattern except in the American population where C3 had the smallest pedicle height which gradually enlarged to C7 with the largest pedicle height measurement (Table 2.3.2.1).

Table 2.3.2.1: Measurements of the pedicle height in millimeters found in various populations

Cervical pedicles	(Tan et al., 2004) **Chinese Singaporeans** M & F	(Panjabi, Duranceau, Goel, Oxland, & Takata, 1991) **American** M & F	(Chanplakorn et al., 2014) **Indian** M	 F
C3	6.8	7.2	6.05	5.4
C4	6.7	7.3	6.32	5.64
C5	5.9	7.3	6.02	5.51
C6	6.0	7.5	6.24	5.64
C7	6.1	7.5	7.05	6.4

Cervical pedicles	(Reinhold et al., 2007) **Austrian** M & F	(Wasinpongwanich et al., 2014) **Thai** M & F	(Ugur et al., 2000) **Turkish** M	 F
C3	7.5	6.37	6.5	5.7
C4	7.1	6.52	6.6	5.9
C5	6.8	6.96	6.7	5.6
C6	6.7	6.96	6.8	5.9
C7	7.2	7.47	7.2	6.1

2.3.3 Pedicle Chord Length

The pedicle chord length is measured from the most posterior aspect of the facet joint on the lateral mass to the anterior-most part of the vertebral body along the pedicle longitudinal axis line. When performing a transpedicular screw surgery the recommended entry point is the middle of the lateral mass, driving the screw from the lateral mass into the pedicle to the vertebral body. Various points of entry have been suggested but a point 3mm from the superior articular facet in the lateral mass is usually used (Kayalioglu, Erturk, Varol, & Cezayirli, 2007). Measurement of chord length assists in selecting the length of a transpedicular screw. When inserting a transpedicular screw, care should be taken not to use a screw length that is greater than the chord length measurement. Anterior to the vertebral bodies are the pharynx located above C4 and the oesophagus below C5 in the median portion. If screw insertion is too deep, the pharynx or oesophagus may be injured (Abumi et al., 1994). The length of the screw is determined from the chord length measurement of the pedicle, where the screw length is 75% of the chord length (Gangadhara, 2013).

Most studies show that the male gender has a statistically significantly larger pedicle chord length measurement than the female (Table 2.3.3.1). Most studies have shown that in both genders pedicle chord length increased from C3 to C7 (Table 2.3.3.1).

Table 2.3.3.1: Measurements of chord lengths in millimetres found in various populations

Cervical pedicles	(Onibokun et al., 2009) **American**		(Sakamoto, Neo, & Nakamura, 2004) **Japanese**		(Kayalioglu et al., 2007) **Turkish**	(Wasinpongwanich et al., 2014) **Thai**
	M	F	M	F	M & F	M & F
C3	31.2	28.4	30.6	29.5	30.56	29.10
C4	31.1	28.5	30.3	29.5	32.12	30.48
C5	32.1	29.7	31.2	30.2	32.66	32.05
C6	32.7	30.5	33.2	30.5	32.55	33.40
C7	34.2	31.4	31.7	27.7		34.36

2.3.4 Pedicle Angle of Medial inclination

This measurement will involve an angle between the pedicular axis line and a line perpendicular to the anterior vertebral body. The angle of medial inclination determines the direction of the transpedicular screw. In a cervical pedicle, transpedicular screws are inserted at an angle of 25 to 45 degrees (Omeis, DeMattia, Hillard, Murali, & Das, 2004) at a point 3mm from the superior articular facet in the lateral mass (Kayalioglu et al., 2007). If the angle of insertion is incorrect a spinal surgeon can injure the vertebral artery on the lateral aspect of the cervical pedicle or spinal cord on the medial aspect of the cervical pedicle.

Most studies have observed a pattern in the angle of medial inclination measurements e.g. in the Thai population (Wasinpongwanich et al., 2014) the angle of medial inclination increases from C3 to C5 then reduces to C7 where the largest measurement is C5 and the smallest is C7, while in Mexican (Vargas-Mena et al., 2011) and Austrian (Reinhold et al., 2007) populations the angle of medial inclination increases from C3 to C4 and then drops gradually to C7 where C4 had the largest angle of medial inclination while C3 had the smallest angle of medial inclination (Table 2.3.4.1).

Studies have shown a difference in gender when it comes to sub-axial cervical pedicle angle of medial inclination, American (Onibokun et al., 2009) and Indian (Chanplakorn et al., 2014) population studies observed that females had a larger angle of medial inclination compared to their male counterparts while in the Japanese (Sakamoto et al., 2004) population males had a larger angle of medial inclination compared to the females (Table 2.3.4.1).

Table 2.3.4.1: Measurements of the angle of medial inclination found in various populations

Cervical pedicles	(Onibokun et al., 2009) **American** M	F	(Sakamoto et al., 2004) **Japanese** M	F	(Reinhold et al., 2007) **Austrian** M & F
C3	42.5°	44.2°	51.1°	48.6°	47.6°
C4	44.5°	46.0°	53.2°	50.7°	50.3°
C5	44.6°	46.1°	52.1°	49.0°	49.3°
C6	41.9°	42.7°	46.1°	43.7°	44.0°
C7	37.2°	38.2°	35.6°	33.9°	39.1°

Cervical pedicles	(Wasinpongwanich et al., 2014) **Thai** M & F	(Chanplakorn et al., 2014) **Indian** M	F	(Vargas-Mena et al., 2011) **Mexican** M & F
C3	46.36°	42.02°	42.91°	42.11°
C4	48.52°	43.48°	44.49°	44.79°
C5	48.89°	42.86°	44.59°	44.77°
C6	44.30°	41.35°	42.51°	42.40°
C7	38.79°	38.27°	39.13°	38.02°

2.4 Ossification of the cervical vertebrae bone

Measurements of sub-axial cervical vertebrae pedicle parameters were conducted only on adult cervical vertebrae bones and in order to meet this criterion, bones that were fully ossified were identified and used for the study.

Ossification of the sub-axial cervical vertebrae is from three primary centres, one in each half vertebral arch and one in the centrum. Centres in arches appear at the roots of the transverse processes, and ossification spreads backward into laminae and spines, forwards into pedicles and posterolateral parts of the body, laterally into transverse processes and upwards and downwards into articular processes. Primary ossification centres in vertebral arches appear in the 10th week (Standring & Gray, 2008).

The upper and lower surfaces of bodies and apices of transverse and spinous processes are cartilaginous until puberty, at which time five secondary centres appear, one in the apex of each transverse and spinous process and two annular epiphyses for the circumferential parts of the upper and lower surfaces of the body. Costal articular facets are extensions of these anular epiphyses. They fuse with the rest of the bone at about 25 years. Full ossification of the cervical vertebrae occurs at twenty-five years of age (Standring & Gray, 2008).

2.5 Bones in the study of orthopaedics

Bones have been used in research to be able to come up with implants for orthopaedics. In transpedicular screw surgery a number of studies have been done to show the significance of bones in the study, a study on the Egyptian population (Mohi Eldin, 2014) compared measurements done on 22 dry bones on computer tomography (CT) scan and direct measurements of dry bones and he found out that there was a high correlation between the two modes of measurements. Karaikovic, Daubs, Madsen, and Gaines (1997) in America collected fifty-three dry bone specimens from the years 1893 to 1938 and conducted manual and CT scan measurements and the results had a high correlation with studies that were currently done on the American population cervical pedicle. In his comment he added that there have not been any changes to the anatomic proportion of human skeletons in the last several hundred years, meaning that bones studied even one hundred years ago are still relevant and can be used to make conclusions on current research. A study by Liu et al., (2010) reported that there was no statistical difference in cervical pedicle measurements between direct measurements and CT scans. The study also reported differences in cervical measurements between the various races and gender. These variations should be considered in the choice of a transpedicular screw (Liu et al., 2010).

The modern human also called Homo sapiens evolved three hundred thousand years ago. Variations among the modern population are as a result of evolutionary trends and migration. The genetic differences in body size between various populations are a result of climatic adaptation in the different geographical areas. This is further affected by the nutritional status which impacts on growth (Ruff, 2002).

There are two ways that you can estimate the size of a screw from a dry bone pedicle. The first is to place a screw into a dry bone cervical pedicle and using computer tomography to come up with a screw for each pedicle, this was done in a study by Ludwig et al., (2000) in America. The second way is by measuring the anatomic measurements of each pedicle and then estimating the screw size for each pedicle from its anatomic measurement as was done in studies on Indian (Mitra S R et al., 2015) and Chinese Singaporean (Tan et al., 2004) populations. This study will use the second option of estimating the size of a screw from the anatomic measurements of each sub-axial cervical pedicle.

2.6 Transpedicular screw insertion

Transpedicular screw surgery is a form of spine surgery where a screw is placed through the pedicle into the body of the cervical bone (Abumi et al., 1994) (Figure 2.6.1).

Source: Author

Figure 2.6.1: Transpedicular screw fixation

Transpedicular screw insertion is performed in various ways which include the freehand technique, freehand technique with assistance from fluoroscopy, intraoperative computer tomography, or computer navigation system (Avila & Baaj, 2016). In Kenya transpedicular screw surgeries of the lumbar and thoracic spines are usually performed by freehand technique, the use of freehand technique necessitates a spinal surgeon to have good anatomical knowledge of the pedicle so that through vision and palpation he can be able to insert a transpedicular screw safely.

In freehand technique, the patient is put in a prone position where a posterior midline incision is made, the paravertebral muscles are then exposed and dissected laterally to expose the lateral margins of the compromised facet joints. The entry site is then decorticated using a high-speed drill to penetrate the cortex of the pedicle. A pedicle probe is then used to develop a path for the screw through the cancellous bone of the pedicle into the vertebral body. When advancing the probe make sure it is smooth and consistent. After cannulation, the pedicle sounding probe is placed into the pedicle and then the pedicle is palpated from within to make sure there is not a medial, lateral, rostral or caudal disruption in the cortex of the pedicles. The Sound probe should also be used to determine that there is bone at the bottom of the pilot hole verifying that penetration of the ventral cortex of the vertebral body has not occurred.

After pedicles have been probed, Steinman pins or K-wires are placed bilaterally or unilaterally into the pedicles to confirm the trajectory and entry site. This is followed by tapping the pedicle screw path if non-self-tapping screws are used; then placement of the permanent screws with the larger diameter that will not fracture the pedicle (Kumar, 2010). The length of the screw can be determined by measuring the length of the Steinman pin/ K-wire/pedicle probe from the pedicle entry site to a depth of 40-80% of the vertebral body.

After pedicle screw placement, the transverse process and the lateral aspects of the facet joints are decorticated. Screws are then connected to a longitudinal construct, usually a rod (can be a plate). This may need to be bent to conform to the proper curvature of the spine; screws are secured (top-loading or side-loading); and a bone graft is then placed on the previously fused bed (Kumar, 2010).

CHAPTER THREE: STUDY METHODOLOGY

3.1 Study site

The study was conducted at the National Museum of Kenya in Nairobi County. The National Museum is a state corporation. 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. Its main goal has been to conduct an ongoing critical scientific examination of the natural attributes of the East African habitat. The museum houses collections of temporary and permanent exhibits. The dry bone specimens are located in the osteology section of the zoology department. A workshop is present in the department that was used for the study.

3.2 Study design

This was a descriptive cross-sectional anatomical study design.

3.3 Target population

Four hundred dry human spine specimens were available from the National Museum of Kenya.

3.4 Study population

Ninety-seven carefully preserved dry cervical spines containing all C3-C7 vertebral bone specimens were selected from the target population for research.

3.5 Sample technique and Sample size

Purposive sampling was used to select ninety-seven spine specimens that contained all C3-C7 vertebral bones that met the inclusion criteria from a target population of four hundred dry bone specimens.

3.6 Eligibility criteria

3.6.1 Inclusion

Fully ossified modern human dry bone specimens of African descent were used

3.6.2 Exclusion

Grossly malformed and damaged bones either through disease or environment were not used in the research.

3.7 Materials and methods

A literature search was conducted by the researcher on the measurements on a pedicle that would aid a spinal surgeon to perform transpedicular screw surgery.

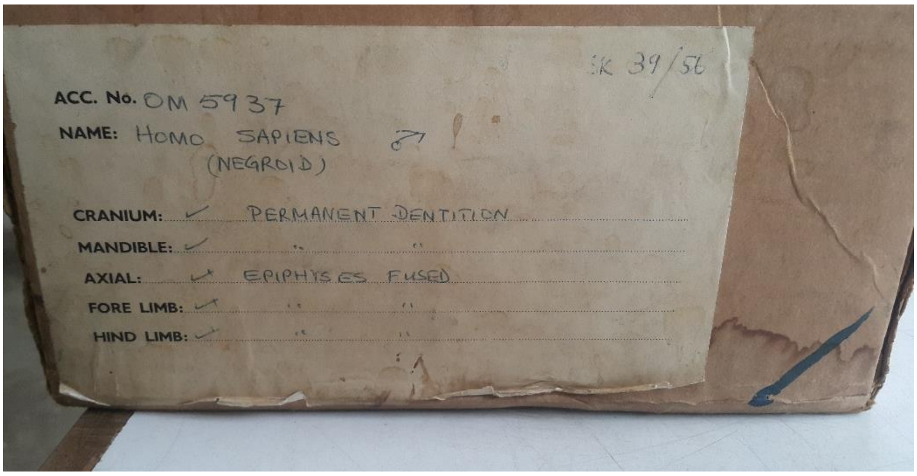
The cervical pedicle morphometric measurements (width, height, chord length, and angle of medial inclination) were identified from the literature as the most important in guiding a spinal surgeon in safely performing transpedicular screw surgery.
Once the measurements were identified the specific anatomic points and how to measure were identified from the literature (Kayalioglu et al., 2007; Onibokun et al., 2009) and discussed together with two supervisors- a professor in anatomy and a spinal surgeon.

A pilot study was then conducted at Moi University School of Medicine Human Anatomy Laboratory under supervision, where the appropriate anatomic site for each parameter was visualized and the accuracy of each measurement tested.

Once the supervisors deemed the researcher was competent in taking measurements as per literature the researcher proceeded to the National Museum of Kenya for his research.

Ninety-seven dry human cervical spines containing all C3 – C7 vertebral bones (a total of four hundred and eighty-five cervical vertebrae pedicles) from the National Museum of Kenya amassed between 1950 to present-day from all over Kenya were used for this project [in the literature available there have not been any significant changes in the anatomic proportions of the human skeleton for the last several hundred years have been reported (Karaikovic, Daubs, Madsen, & Gaines, 1997)].

The specimens were stored in four hundred boxes where each box had the bony remains of one human being. Each box was labelled: the serial number, homo sapiens (modern human), gender, race, and the bones that had been recovered and whether epiphysis had fused or not (Figure 3.7.1). Ninety-seven sets of dry cervical spines that had all the sub-axial cervical vertebrae (C3-C7) that met the inclusion criteria were chosen for this study. Each set of cervical spine had five vertebrae bones (C3-C7) (Figure 3.7.2) and so for the ninety-seven sets, four hundred and eighty-five cervical vertebrae were studied.



Source: National Museum of Kenya

Figure 3.7.1: Picture showing one of the boxes used to store the specimens

Source: National Museum of Kenya

Figure 3.7.2: One set of the dry sub-axial cervical spine containing the five cervical vertebrae

All measurements of the pedicle were performed by hand, the linear measurements were measured using digital calipers with 0.01 mm accuracy while the pedicle angle was determined by a goniometer measured to the 1/10th of a degree. The various specimens and measurements were taken and recorded using a digital camera and data collection forms.

Bones used for the study had been collected within the boundaries of Kenya, from the 1950s to the present day. The bones are usually excavated from construction sites, road works, or found in the various areas. They are then differentiated between males and females from the shape of the pelvis. The race of the bones is identified through measurements of the midface. The age of the bones is identified through the stage of epiphysis fusion. The bones are then handed over to the police for investigation and through a court order are sent to the Kenya national museum where they are sorted and treated and stored in boxes as in Figure 3.7.1.

3.7.1 Linear parameters

For purposes of comparison, the definitions of all parameters are similar to those by Kayalioglu et al., (2007) and Onibokun et al., (2009). Before the commencement of data collection, digital calipers were calibrated following established procedures recommended by the manufacturer. The various linear measurements included:

Pedicle width which is the medio-lateral diameter of the pedicle isthmus (Figure 3.7.2.1).

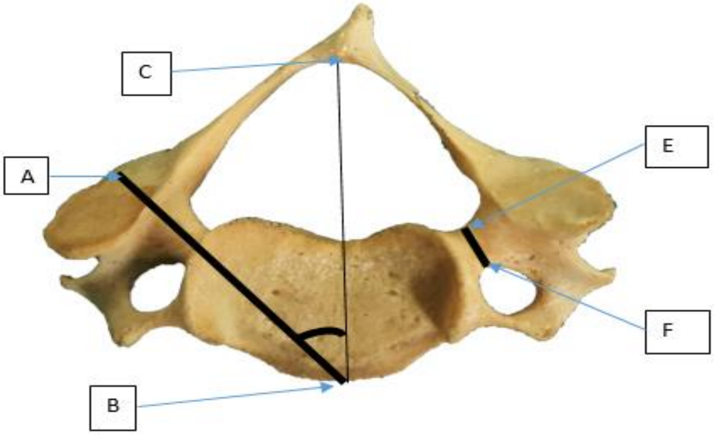
Pedicle height which is the supero-inferior diameter of the pedicle isthmus (Figure 3.7.2.2).

Chord length (distance between the lateral mass and the vertebral body) a line drawn from a point on the most posterior aspect of the facet on the lateral mass, along with the pedicle axis line to a point on the most anterior aspect of the vertebral body (Figure 3.7.2.1).

3.7.2 Angle of medial inclination of the pedicles.

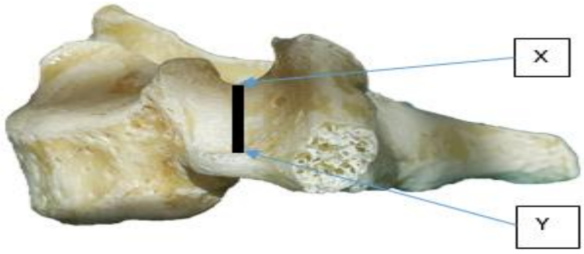
For the purpose of comparison, the definition of this measurement is similar to Onibokun et al., (2009). Before collecting angular measurements the goniometer was calibrated following established procedures recommended by the manufacturer. The goniometer is a direct contact instrument that is placed on the vertebrae to measure the medial inclination angle.

The angle of medial inclination was measured as follows, in a horizontal plane, the angle between the chord length and a line perpendicular to the vertebral body cortex will be measured (Figure 3.7.2.1).



Source: Author

Figure 3.7.2.1: Cervical vertebrae bone showing the different measurements of the pedicle where AB is the chord length ABC is the angle of medial inclination and EF is the measurement of pedicle width



Source: Author

Figure 3.7.2.2: Cervical pedicle showing the pedicle height measurement XY

3.8 Data management, analysis, and presentation

Data was collected using a structured form. The collected data were entered into an electronic database for analysis. Data was encrypted for security and confidentiality. A backup of the same database using memory drives was done to cushion against loss of data.

Data analysis was done using software for statistical computing and analysis STATA/ MP 13.0. Continuous variables such as chord length, width, height, and angle of the projections of the cervical were assessed if they follow normal distribution using the

Shapiro Wilk test. T-test was used for comparing means between males and females. Results were summarized using mean and standard deviation then presented in graphs and tables. The morphometric measurement results of the sub-axial cervical pedicles were then used to infer on the right size of a transpedicular screw to use.

3.9 Ethical considerations

Ethical approval was sought from the Moi Teaching and Referral Hospital / Moi University Institution Research and Ethics Committee (IREC) and the National Museum of Kenya before the commencement of research (*Appendix 2 and Appendix 4).* The study was conducted in accordance with The Anatomy Act Chapter 243-9 (REVISED EDITION OF 2012) of The Laws of Kenya, which entitles a person registered as a student in an approved school of anatomy or medicine to examine and conduct anatomical research on human cadavers as long as the requirements stipulated in the Act are strictly adhered to (Laws of Kenya, 1968).

Data confidentiality was strictly maintained and this included the use of passwords in the database. The reports of analysed results will be disseminated through an oral defense of this thesis and thereafter presented at relevant conferences/seminars, publication in a peer-reviewed scientific journal and a printed thesis.

3.10 Study limitations

The angle of medial inclination measurement could be altered during measurement because of the morphology of the cervical bone. This was mitigated by mapping out the points of measurement on the specimen and drawing the lines of the angle of medial inclination before proceeding to measure the angle.

CHAPTER FOUR: RESULTS

4.1 Introduction

The results presented here are based on ninety-seven sets of dry cervical spine specimens from the National Museum of Kenya. For each specimen, five spine levels (C3, C4, C5, C6, and C7) were included and four measurements (width, height, chord length and angle of medial inclination) were taken. In total, one thousand nine hundred and forty pedicle measurements were taken from ninety-seven sets of dry sub-axial cervical spine bone specimens. The only demographic information available for each specimen was gender. The male to female ratio was 1.49:1, that is, fifty-eight (59.8%) male dry sub-axial cervical spine bone specimens and thirty-nine (40.2 %) female dry bone specimens of the total specimens sampled.

4.2 Pedicle Width

The pedicle width is measured from the medial to the lateral cortex of the pedicle isthmus (Figure 4.2.1)

Source: Author

Figure 4.2.1: Cervical vertebrae showing the measurement of pedicle width EF

Table 4.2.1: Width distribution in millimetres

Cervical pedicles	N	Mean (SD)(mm)	Minimum(mm)	Maximum(mm)
C3	97	4.45 (0.65)	2.97	6.22
C4	97	4.64 (0.76)	2.60	6.26
C5	97	5.24 (0.78)	3.22	7.59
C6	97	5.46 (0.82)	3.02	7.27
C7	97	6.06 (1.07)	4.06	9.70

The combined male and female width measurement increased gradually from an average of 4.45 mm at C3 to a maximum of 6.06 mm at C7 (Table 4.2.1).

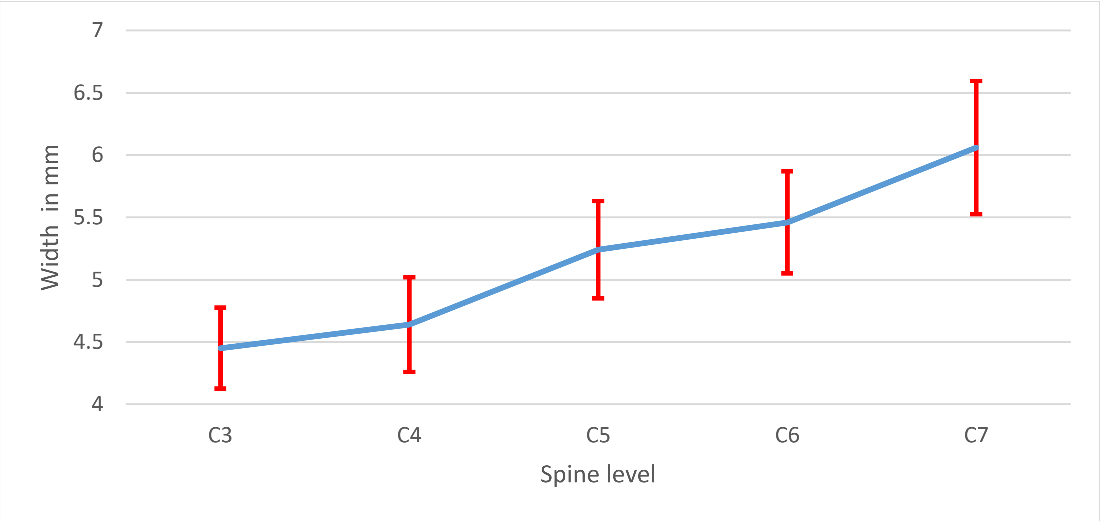


Figure 4.2.2: Width distribution

The combined male and female distribution of width with standard deviations as error bars are as shown in Figure 4.2.2. The measurement variations seem to increase with an increase in average width measurement.

Table 4.2.2: Comparing the width between male and female

Cervical pedicles	Female N= 39 Mean(SD)(mm)	Male N= 58 Mean(SD)(mm)	Absolute mean difference	p-value
C3	4.16 (0.65)	4.63 (0.59)	0.47	<0.001
C4	4.33 (0.80)	4.83 (0.67)	0.51	<0.001
C5	4.81 (0.65)	5.52 (0.73)	0.72	<0.001
C6	5.06 (0.73)	5.72 (0.77)	0.66	<0.001
C7	5.60 (0.81)	6.35 (1.12)	0.75	<0.001

The mean male pedicle width increased gradually from C3 to C7, where C3 had the lowest measurement at 4.63 mm while C7 had the highest measurement at 6.35 mm (Table 4.2.2).

The mean female pedicle width increased gradually from C3 to C7, where C3 had the lowest measurement at 4.16 mm and C7 had the highest measurement at 5.60 mm (Table 4.2.2).

The male gender had a statistically larger pedicle width measurement when compared to females in all the sub-axial cervical pedicles ($p<0.001$) (Table 4.2.2).

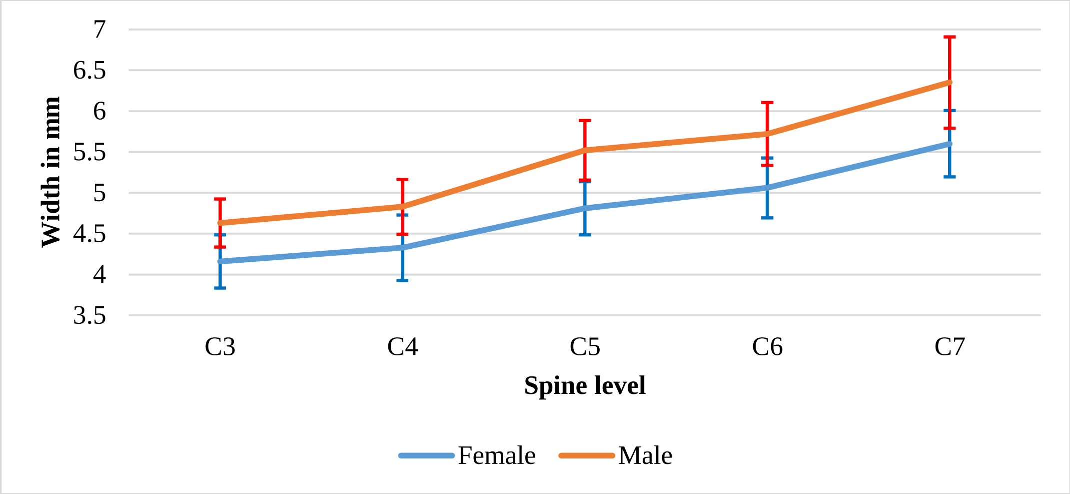
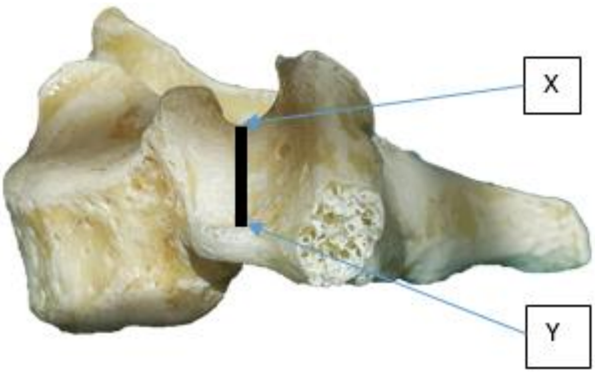


Figure 4.2.3: Width difference between male and female

Males' mean width measurements were larger compared to that of females in all the levels. The mean width and standard deviation for males increased with an increase in width measurement from C3 to C7 however, females did not show the same trend (Figure 4.2.3).

4.3 Pedicle Height

Pedicle height is measured from the superior to the inferior cortex of the pedicle isthmus (Figure 4.3.1).



Source: Author

Figure 4.3.1: Cervical vertebrae showing pedicle height XY

Table 4.3.1: Height distribution in millimetres

Cervical pedicles	N	Mean (SD) (mm)	Minimum (mm)	Maximum (mm)
C3	97	6.36 (0.81)	4.79	8.31
C4	97	6.67 (0.89)	3.75	9.06
C5	97	6.62 (1.04)	3.82	10.17
C6	97	6.53 (0.90)	4.10	8.71
C7	97	7.25 (1.06)	4.78	10.68

The combined male and female pedicle mean height measurements were variable, where C3 had the lowest measurement at 6.36 mm while C7 had the largest measurement at 7.25 mm (Table 4.3.1).

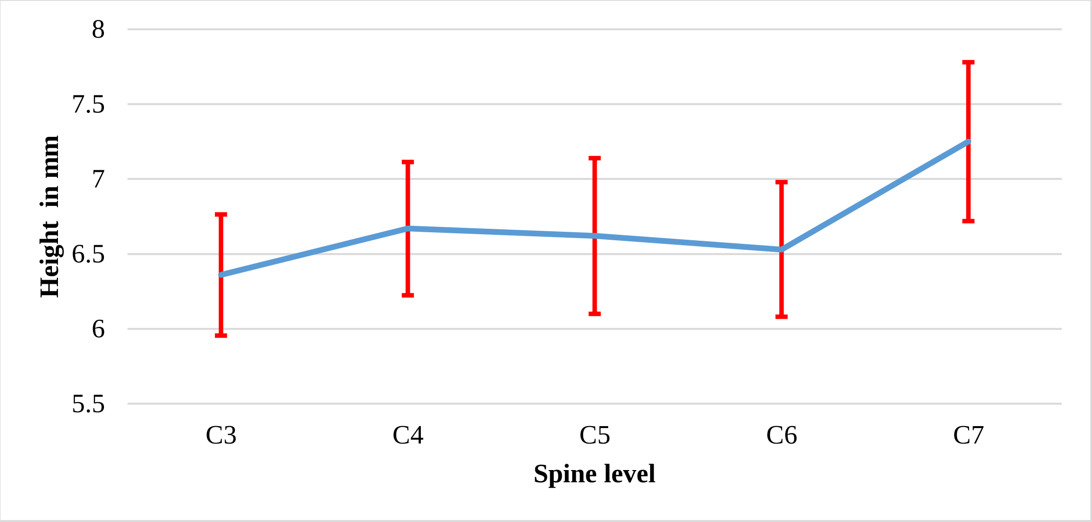


Figure 4.3.2: Height distribution

The combined male and female mean pedicle height distribution with standard deviations as error bars are shown in Figure 4.3.2 where the measurement variations were high at C5 and smallest at C3.

Table 4.3.2: Comparing height between male and female

Cervical pedicles	Female N= 39 Mean(SD)(mm)	Male N= 58 Mean(SD)(mm)	Absolute mean difference	p-value
C3	6.11 (0.76)	6.53 (0.80)	0.42	0.011
C4	6.35 (0.95)	6.87 (0.80)	0.52	0.004
C5	6.34 (0.97)	6.80 (1.06)	0.46	0.032
C6	6.15 (0.84)	6.78 (0.85)	0.63	<0.001
C7	6.84 (1.05)	7.52 (0.99)	0.68	0.002

The male mean pedicle height measurements were variable, where C3 had the smallest measurement at 6.53 mm while C7 had the largest measurement at 7.52 mm (Table 4.3.2).

The female mean pedicle width measurements were variable where C3 had the smallest measurement at 6.11 mm while C7 had the largest measurement at 6.84 mm (Table 4.3.2).

The male mean pedicle height measurement was statistically larger compared to the females in all sub-axial cervical pedicles ($p<0.05$) (Table 4.3.2).

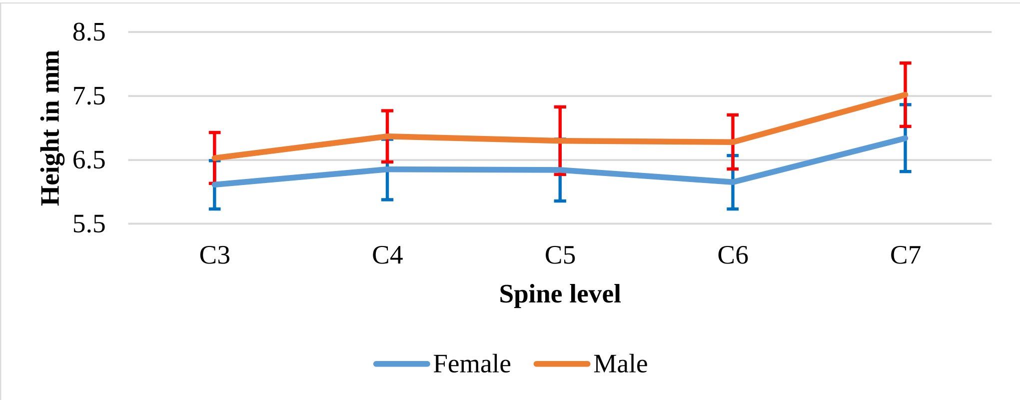
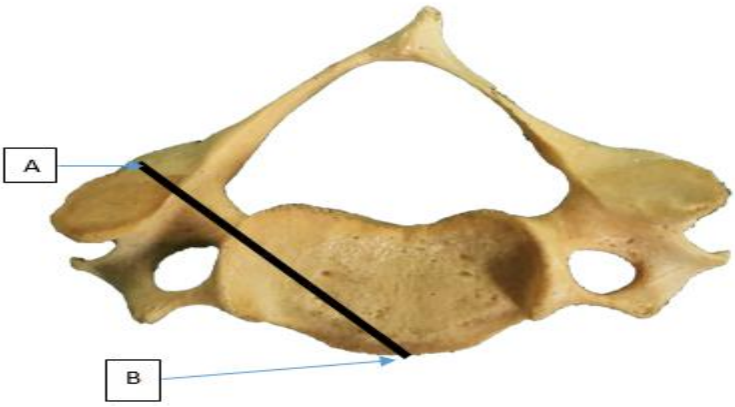


Figure 4.3.3: Height difference between male and female

The combined male and female distribution of pedicle height with standard deviations as error bars are as shown in Figure 4.3.3. The mean male pedicle height had a slightly larger measurement when compared to females in all the levels.

4.4 Pedicle Chord Length

Chord length is measured from the most posterior aspect of the facet joint on the lateral mass to the anterior-most part of the vertebral body along the pedicle longitudinal axis line (Figure 4.4.1)



Source: Author

Figure 4.4.1: Cervical vertebrae showing the measurement of chord length AB

Table 4.4.1: Chord length distribution in millimetres

Cervical pedicles	N	Mean(SD)(mm)	Minimum(mm)	Maximum(mm)
C3	97	30.81 (2.50)	24.79	37.50
C4	97	31.46 (2.63)	25.86	39.80
C5	97	31.82 (2.89)	25.39	41.21
C6	97	32.17 (3.31)	27.08	40.86
C7	97	32.64 (2.84)	26.05	41.00

The combined male and female mean chord length increased gradually from C3 to C7 where C3 had the smallest measurement at 30.81 mm, while C7 had the largest measurement at 32.64 mm (Table 4.4.1).

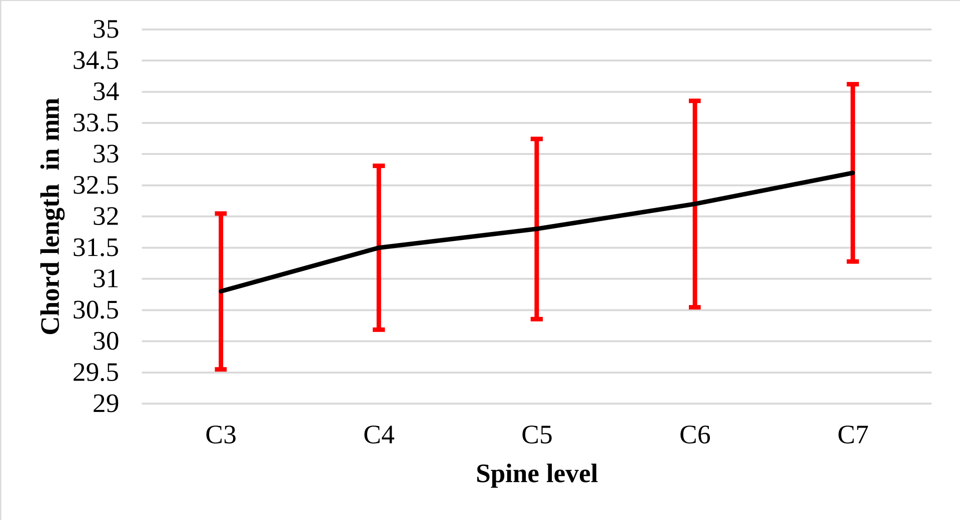


Figure 4.4.2: Average chord length distribution

Figure 4.4.2 shows the combined male and female chord length mean measurement with standard deviations as error bars. The sixth cervical vertebral pedicle has the highest measurement variations compared to the rest.

Table 4.4.2: Comparing chord length between male and female

Cervical pedicles	Female (N=39) Mean(SD)(mm)	Male (N=58) Mean(SD)(mm)	Absolute mean difference	p-value
C3	30.07 (2.41)	31.29 (2.46)	1.21	0.017
C4	30.58 (2.47)	32.03 (2.59)	1.45	0.006
C5	30.90 (2.31)	32.41 (3.08)	1.51	0.010
C6	31.21 (3.25)	32.81 (3.23)	1.60	0.018
C7	32.06 (2.42)	33.03 (3.04)	0.97	0.105

The male chord length mean measurement increased gradually from C3 to C7, where C3 had the smallest measurement at 31.29 mm while C7 had the largest measurement at 33.03 mm (Table 4.42).

The female chord length measurement increased gradually from C3 to C7, where C3 had the smallest measurement at 30.07 mm while C7 had the largest measurement at 32.06 mm (Table 4.42).

The male pedicle mean chord length measurements were significantly larger when compared to the females in all sub-axial cervical pedicles except C7 where the difference was not statistically significant ($p<0.05$) (Table 4.42).

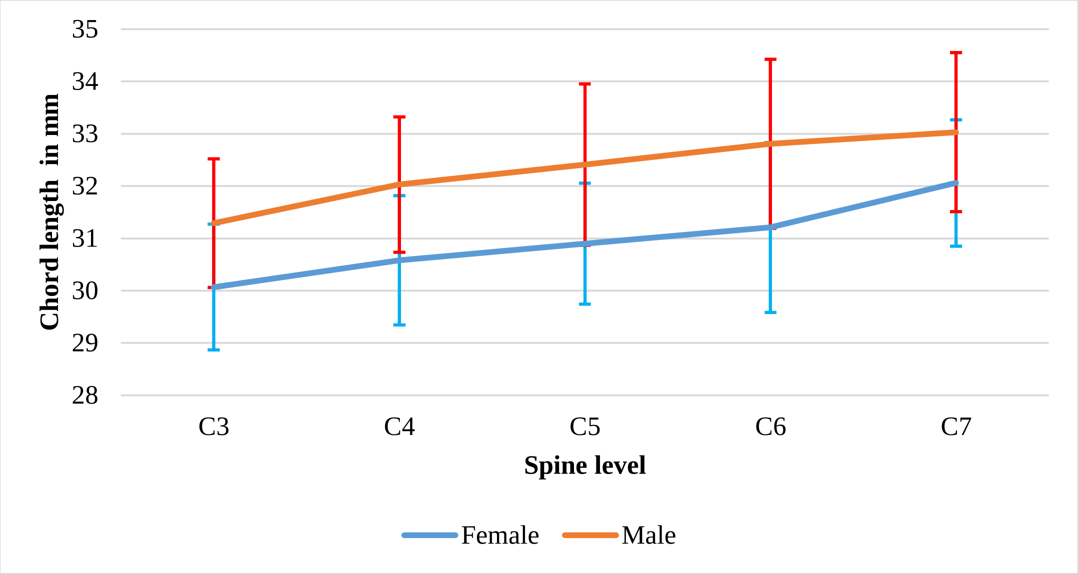
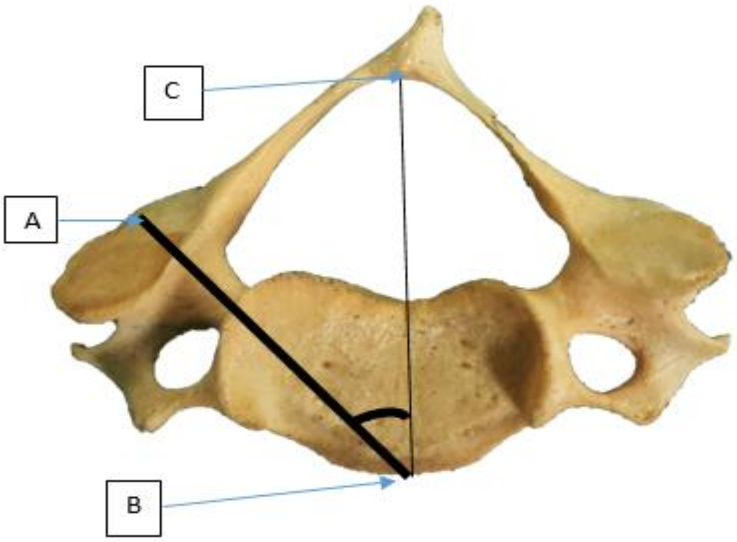


Figure 4.4.3: Average chord length difference between male and female

The absolute mean difference for chord length gradually increased from C3 to C6 and then reduced drastically at C7. Male chord lengths had a wider standard deviation when compared to the female (Figure 4.4.3).

4.5 Pedicle Angle of Medial Inclination

The angle of medial inclination is measured between the pedicular axis line and a line perpendicular to the anterior vertebral body (Figure 4.5.1).



Source: Author

Figure 4.5.1: Cervical vertebrae showing the medial inclination measurement ABC

Table 4.5.1: Angle of medial inclination distribution in degrees

Cervical pedicles	N	Mean(SD) (degrees)	Minimum(degrees)	Maximum(degrees)
C3	97	45.19 (3.44)	33.7	56.5
C4	97	46.80 (3.79)	35.0	61.7
C5	97	48.12 (3.84)	37.7	59.4
C6	97	45.56 (3.51)	35.7	52.3
C7	97	42.13 (3.22)	33.1	48.7

The combined male and female angle of medial inclination measurement increased from an average of 45.19 degrees at C3 to a maximum of 48.12 degrees at C5 and then reduced gradually to a minimum of 42.13 degrees at C7 (Table 4.5.1).

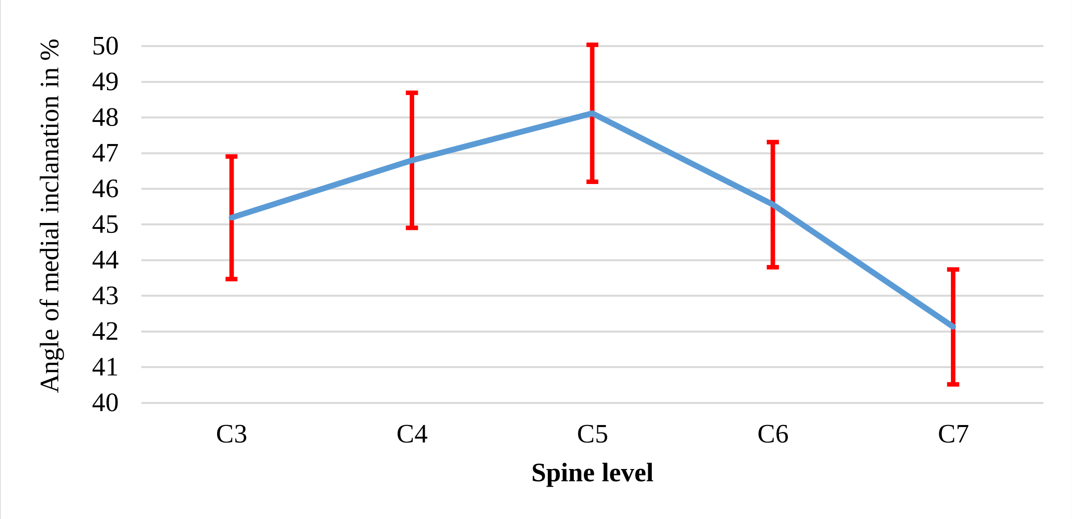


Figure 4.5.2: Angle of medial inclination distribution

The combined male and female mean angle of medial inclination distribution with standard deviations as error bars are shown in Figure 4.5.2. The measurement variations seem to increase with an increase in the average angle of medial inclination measurement.

Table 4.5.2: Comparing the angle of medial inclination between male and female

Cervical pedicles	Female N=39 Mean(SD)(degrees)	Male N= 58 Mean(SD)(degrees)	Absolute mean Difference	p-value
C3	45.65 (3.21)	44.89 (3.57)	0.77	0.279
C4	47.65 (3.93)	46.26 (3.62)	1.40	0.070
C5	48.40 (4.14)	47.94 (3.66)	0.45	0.569
C6	45.57 (3.48)	45.55 (3.56)	0.02	0.973
C7	41.92 (2.84)	42.27 (3.47)	0.34	0.619

The male angle of medial inclination mean increased from C3 at 44.89 degrees to C5 at 47.94 degrees then reduced to C7 at 42.27 degrees (Table 4.5.2).

The female angle of medial inclination mean increased from C3 at 45.65 degrees to C5 at 48.40 degrees then reduced to C7 at 41.92 degrees (Table 4.5.2).

The female angle of medial inclination mean was larger than the male but this was not statistically significant in all the sub-axial pedicle measurements ($p>0.05$) (Table 4.5.2).

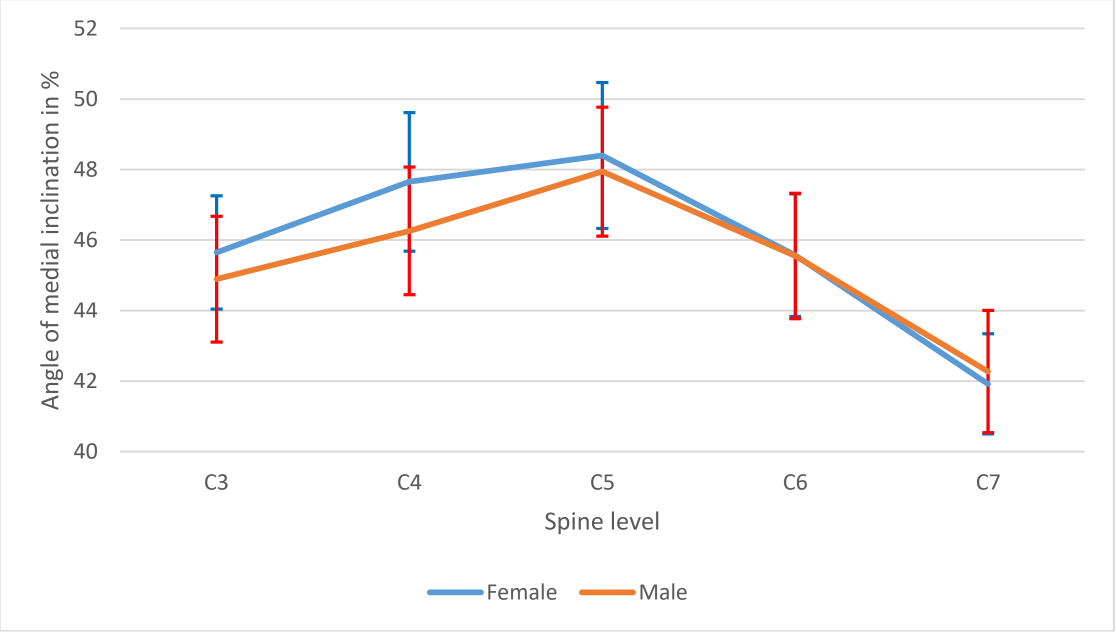


Figure 4.5.3: Angle of medial inclination difference between male and female

The female angle of medial inclination is wider than that of the male for C3, C4, C5, and C6 but less for C7 (Figure 4.5.3).

CHAPTER FIVE: DISCUSSION

5.1 Pedicle Width

Table 5.1.1: Pedicle width mean measurements of the various populations compared to the Kenyan population mean in millimetres.

Cervical pedicles	(Onibokun et al., 2009) **American**		(Tomasino et al., 2010) **German**		(Ugur et al., 2000) **Turkish**		(Reinhold et al., 2007) **Austrian**
	M	F	M	F	M	F	M & F
C3	5.2	4.2	5.7	4.3	5.1	4.5	5.7
C4	5.4	4.4	5.8	4.5	5.4	4.5	5.6
C5	5.9	5.0	6.2	4.9	5.5	4.4	6.2
C6	6.1	5.2	6.4	5.2	5.8	5.3	6.7
C7	6.9	5.9	7.1	5.8	6.1	5.7	7.9

Cervical pedicles	(Yusof et al., 2007) **Malaysian**		(Mitra S R et al., 2015) **Indian**		(Tan et al., 2004) **Chinese Singaporeans**	**Kenyan**		
	M	F	M	F	M & F	M	F	M & F
C3	4.0	4.07	4.32	3.83	4.4	4.63	4.16	4.45
C4	4.58	3.81	4.44	3.51	4.5	4.83	4.33	4.64
C5	4.71	3.78	4.55	3.60	4.9	5.52	4.81	5.24
C6	4.76	3.99	5.16	4.81	5.4	5.72	5.06	5.46
C7	4.9	4.49	6.05	6.52	5.7	6.35	5.60	6.06

The combined overall mean of males and females showed an increase of the mean pedicle width from C3 to C7 with C3 having the smallest width at 4.45 mm and C7 having the largest width at 6.06 mm this concurred with studies done on Austrian (Reinhold et al., 2007) and Chinese Singaporean (Tan et al., 2004) populations (Table 5.1.1).

The results from this research suggest that Kenyan pedicles are much smaller than the European pedicles e.g. the Austrian population (Reinhold et al., 2007), Germans (Tomasino et al., 2010), and Americans (Onibokun et al., 2009) but larger than the Asian pedicles e.g. Indian (Mitra S R et al., 2015), Chinese Singaporeans (Tan et al., 2004) and Malaysian (Yusof et al., 2007) (Table 5.1.1).

The pedicle width of the male gender increased from C3 to C7 with C3 having the smallest pedicle at 4.63 mm and C7 having the largest pedicle at 6.35 mm. This concurs with studies that were done on populations in America (Onibokun et al., 2009), Malaysia (Yusof et al., 2007), Germany (Tomasino et al., 2010), Turkey (Ugur et al., 2000) and India (Mitra S R et al., 2015) (Table 5.1.1).

The female pedicle width increased caudally from C3 to C7 with C3 being the smallest at 4.16 mm and C7 being the largest at 5.60 mm these concur with studies done in America (Onibokun et al., 2009) and Germany (Tomasino et al., 2010). This contrasts with studies that were done in India (Mitra S R et al., 2015) where C4 was the smallest pedicle and Turkish (Ugur et al., 2000) and Malaysian (Yusof et al., 2007) populations where C5 had the smallest pedicle measurement (Table 5.1.1).

The differences in measurements were observed in both males and females with the males having larger pedicles at all levels when compared to females. This difference in size was found to be statistically significant. These findings concur with studies done on the American (Onibokun et al., 2009), Turkish (Ugur et al., 2000), Indian (Mitra S R et al., 2015) and German (Tomasino et al., 2010) populations (Table 5.1.1).

5.2 Pedicle Height

Table 5.2.1: Pedicle height mean measurements of the various populations compared to the Kenyan population mean in millimeters.

Cervical pedicles	(Tan et al., 2004) **Chinese Singaporeans** M & F	(Panjabi et al., 1991) **American** M & F	(Ugur et al., 2000) **Turkish** M	F	(Chanplakorn et al., 2014) **Indian** M	F
C3	6.8	7.2	6.5	5.7	6.05	5.4
C4	6.7	7.3	6.6	5.9	6.32	5.64
C5	5.9	7.3	6.7	5.6	6.02	5.51
C6	6.0	7.5	6.8	5.9	6.24	5.64
C7	6.1	7.5	7.2	6.1	7.05	6.4

Cervical pedicles	(Reinhold et al., 2007) **Austrian** M & F	(Wasinpongwanich et al., 2014) **Thai** M & F	**Kenyan** M	F	M&F
C3	7.5	6.37	6.53	6.11	6.36
C4	7.1	6.52	6.87	6.35	6.67
C5	6.8	6.96	6.80	6.34	6.62
C6	6.7	6.96	6.78	6.15	6.53
C7	7.2	7.47	7.52	6.84	7.25

The overall mean a combination of both males and females, C3 had the smallest pedicle height at 6.36 mm while C7 had the largest pedicle height at 7.25 mm. This concurs with studies on populations in America (Onibokun et al., 2009) but contrasts studies done on Chinese Singaporeans (Tan et al., 2004) where their smallest pedicle height was C7 and largest was C3 (Table 5.2.1).

In males, the largest pedicle height measurement was C7 at 7.52 mm and the smallest pedicle height measurement was at C3 at 6.53 mm. This concurs with a study done on the Turkish population (Ugur et al., 2000) but contrasts studies done on the Indian population (Chanplakorn et al., 2014) where the smallest pedicle height measurement was C5 and the largest at C7 (Table 5.2.1).

In females, the largest pedicle height measurement was C7 at 6.84 mm while the smallest pedicle height measurement was C3 at 6.11mm. This concurs with studies done in India (Chanplakorn et al., 2014) and contrasts one done in Turkey (Ugur et al., 2000) where the smallest was at C5 and the largest height measurement was at C7 (Table 5.2.1).

Males had larger pedicle heights statistically when compared to females. This concurs with studies on populations in Turkey (Ugur et al., 2000) and India (Chanplakorn et al., 2014).

5.3 Pedicle Chord Length

Table 5.3.1: Pedicle chord length mean measurements of the various populations compared to the Kenyan population mean in millimeters.

Cervical pedicles	(Onibokun et al., 2009) **American**		(Sakamoto et al., 2004) **Japanese**		(Kayalioglu et al., 2007) **Turkish**	(Wasinpongwanich et al., 2014) **Thai**	**Kenyan**		
	M	F	M	F	M & F	M & F	M	F	M & F
C3	31.2	28.4	30.6	29.5	30.56	29.10	31.29	30.07	30.81
C4	31.1	28.5	30.3	29.5	32.12	30.48	32.03	30.58	31.46
C5	32.1	29.7	31.2	30.2	32.66	32.05	32.41	30.90	31.82
C6	32.7	30.5	33.2	30.5	32.55	33.40	32.81	31.21	32.17
C7	34.2	31.4	31.7	27.7		34.36	33.03	32.06	32.64

From the overall mean a combination of both male and female means, there was a progressive increase in the chord length mean measurement from C3 to C7 with C3 having the smallest chord length measurement at 30.81 mm and C7 having the largest at 32.64 mm this was in agreement with studies done in Thailand (Wasinpongwanich et al., 2014) but was in contrast to a study that was done in Turkey (Kayalioglu et al., 2007) where C5 had the largest chord length measurement (Table 5.3.1).

Males were observed to have a gradual increase in the mean chord length measurement from C3 to C7 where C3 was the smallest at 31.29 mm and C7 was the largest at 33.03 mm. This contrasts populations in Japan (Sakamoto et al., 2004) where the largest pedicle chord length measurement was at C6 and the smallest was at C4 and was also in disagreement with a study in America (Onibokun et al., 2009) where C4 was the smallest and C7 was the largest pedicle chord length measurement (Table 5.3.1).

Females were observed to have a progressive increase in the mean chord length measurement from C3 to C7 where C3 had the smallest chord length at 30.07 mm and C7 had the largest chord length at 32.06 mm. This concurs with a study carried out in America (Onibokun et al., 2009) but contrasts from a study conducted in Japan (Sakamoto et al., 2004) where the smallest chord length was at C7 and the largest was at C6 (Table 5.3.1).

Males were observed to have statistically significantly larger chord lengths than females in all cervical spine levels. This difference in gender was also observed in studies on populations in America (Onibokun et al., 2009) and Japan (Sakamoto et al., 2004) (Table 5.3.1).

5.4 Pedicle Angle of Medial Inclination

Table 5.4.1: The angle of medial inclination of the various populations compared to the Kenyan population in degrees

Cervical pedicles	(Chanplakorn et al., 2014) **Indian**		(Sakamoto et al., 2004) **Japanese**		(Vargas-Mena et al., 2011) **Mexican**	(Reinhold et al., 2007) **Austrian**
	M	F	M	F	M & F	M & F
C3	42.02°	42.91°	51.1°	48.6°	42.11°	47.6°
C4	43.48°	44.49°	53.2°	50.7°	44.79°	50.3°
C5	42.86°	44.59°	52.1°	49.0°	44.77°	49.3°
C6	41.35°	42.51°	46.1°	43.7°	42.40°	44.0°
C7	38.27°	39.13°	35.6°	33.9°	38.02°	39.1°

Cervical pedicles	(Onibokun et al., 2009) **American**		(Wasinpongwanich et al., 2014) **Thai**	**Kenyan**		
	M	F	M & F	M	F	M & F
C3	42.5°	44.2°	46.36°	44.89°	45.65°	45.19°
C4	44.5°	46.0°	48.52°	46.26°	47.65°	46.80°
C5	44.6°	46.1°	48.89°	47.94°	48.40°	48.12°
C6	41.9°	42.7°	44.30°	45.55°	45.57°	45.56°
C7	37.2°	38.2°	38.79°	42.27°	41.92°	42.13°

In the overall combined mean for both males and females there seem to be a gradual increase from C3 up to C5 then a decrease in C6 and C7 where C5 had the largest angle of medial inclination at 48.12 degrees while C7 had the smallest angle of medial inclination at 42.13 degrees. This concurred with a study done on the Thai population (Wasinpongwanich et al., 2014) but was in contrast to studies done on Austrian (Reinhold et al., 2007) and Mexican (Vargas-Mena et al., 2011) populations where there was a gradual increase in the angle of medial inclination from C3 up to C4 then a decrease in C5 to C7 where C4 had the largest angle of medial inclination while C7 had the smallest (Table 5.4.1).

In males, the largest angle of medial inclination was C5 at 47.94 degrees the smallest angle was C7 at 42.27 degrees. This concurs with a study done on the American population (Onibokun et al., 2009) but contrasts Indian (Chanplakorn et al., 2014) and Japanese (Sakamoto et al., 2004) populations where C4 had the largest angle of medial inclination (Table 5.4.1).

In females, the largest angle of medial inclination was C5 at 48.40 degrees and the smallest was C7 at 41.92 degrees. This trend concurs with studies done on American (Onibokun et al., 2009) and Indian (Chanplakorn et al., 2014) but was in contrast to a study done on the Japanese population (Sakamoto et al., 2004) where C4 had the largest angle of medial inclination (Table 5.4.1).

The difference between the male and female angle of medial inclination measurements was not statistically significant. This was in contrast to studies done in America (Onibokun et al., 2009) and India (Chanplakorn et al., 2014) where females had a larger angle of medial inclination, and in Japan (Sakamoto et al., 2004) where the males had a larger angle of medial inclination (Table 5.4.1).

5.5 Clinical significance of sub-axial cervical pedicle measurements

The anatomical measurements of the sub-axial cervical pedicles are important clinically in defining a pedicle screw for the Kenyan population.

The pedicle width and height were used to estimate the pedicle screw diameter while the chord length measurement was used to approximate the length of the screw.

The angle of medial inclination measurement was used to define the angle with which a spine surgeon will advance the transpedicular screw into the sub-axial cervical pedicle.

5.5.1 Sub-axial cervical pedicle screw diameter

The pedicle screw diameter size is approximated from the pedicle width and height measurements. A pedicle screw diameter that is larger than the pedicle width can cause cortical perforation and injury to the spinal cord medial to the pedicle or the vertebral vessels on the lateral aspect of the pedicle. A pedicle screw diameter that is larger than the pedicle height might injure the cervical nerve roots that pass on the superior and inferior aspect of the pedicle. A spinal surgeon, therefore, needs the right screw diameter for the right pedicle width and height to avoid iatrogenic injuries when inserting a transpedicular screw (Tan et al., 2004).

The standard pedicle screw diameter is a 3.5 mm diameter screw which is based on research done on European populations (Mitra S R et al., 2015). From the literature, if a sub-axial cervical pedicle width or height has a measurement of more than 5 mm then it can accommodate a 3.5 mm diameter screw, but if the width or height pedicle measurement is less than 5 mm then a 2.7 mm diameter screw has to be used (Ludwig et al., 2000).

From the combined male and female findings of pedicle width (Table 5.1.1) and pedicle height (Table5.2.1), the pedicle height measurements seem to be larger than the pedicle width measurement. This observation has led to the conclusion that the pedicle width is the limiting measurement in defining the diameter of a pedicle screw, and so to come up with the pedicle diameter screw sizes the pedicle width measurement was used. From the combined male and female pedicle width measurements as per Table 5.1.1, the optimal screw diameters for use at C3 and C4 levels are 2.7 mm, while at C5, C6 and C7 are 3.5 mm.

5.5.2 Sub-axial cervical pedicle screw length

The screw length measurement is determined from the chord length; if the length of the screw is more than the chord length then the oesophagus or pharynx could be injured. The length of the screw should be 75 % of the chord length measurement of the pedicle (Gangadhara, 2013). From the chord length measurements of the combined mean of both males and females in Table 5.3.1, the following are the recommended screw lengths: 22 mm at C3, 24 mm at C4, C5 and C6; and 26 mm at C7.

5.5.3 Angle to advance the sub-axial cervical pedicle screw

In order to insert a transpedicular screw, a Kenyan spinal surgeon needs to know the angle of entry; if the angle is too acute one might injure the vertebral vessels if the angle is too large one can cause a spinal cord injury. To come up with the proposed screw angle the mean and standard deviation were used for each cervical pedicle level, the mean is the average measurement and the standard deviation identifies where a majority of people lie near the average measurement. For ease of recall by a spine surgeon, the study proposes that from the sum of the mean and standard deviation a median figure is selected to come up with the proposed angle of entry (Table5.5.1). In the combined mean of male and females angle of medial inclination as per Table 5.4.1, the following are the angles to use while inserting a pedicle screw into the sub-axial cervical pedicles at C3 (46°), at C4 (47°), at C5 (48°) at C6 (46°) at C7 (42°) (Table 5.5.1). For practicability, during surgery, an angle of 45° is recommended to spinal surgeons in advancing a transpedicular screw through sub-axial cervical pedicles.

Table 5.5.1: Male and female angle of medial inclination their standard deviation (SD) and the proposed angle of entry in degrees

Cervical pedicles	**M & F Angle of medial inclination**	**SD**	**Mean +/- SD**	**The proposed angle of entry**
C3	45.19°	3.44°	42-49°	46°
C4	46.80°	3.79°	43-51°	47°
C5	48.12°	3.84°	44-52°	48°
C6	45.56°	3.51°	42-49°	46°
C7	42.13°	3.22°	39-45°	42°

CHAPTER SIX: CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions.

1. Pedicle width measurement increased caudally from C3 to C7; C3 had the smallest measurement at 4.45 mm while C7 had the largest measurement at 6.06 mm.
2. Pedicle height measurement was smallest at C3 with a measurement of 6.36 mm while C7 had the largest measurement of 7.25 mm.
3. Chord length measurement of the pedicles increased caudally from C3 to C7 with C3 having the smallest measurement at 30.81 mm, while C7 had the largest measurement at 32.64 mm.
4. The Angle of medial inclination was largest at C5 with a measurement of 48.12 degrees and the smallest measurement was at C7 with a measurement of 42.13 degrees.
5. The linear measurements (width, chord length, and height) in males were larger than females.
6. There was no difference in the angles of medial inclination between males and females.

6.2 Recommendations.

From the various morphometric measurements of the sub-axial cervical vertebrae pedicle, the following screw sizes are recommended for the Kenyan population in transpedicular screw surgery of the sub-axial cervical spine:

a) The optimal pedicle screw diameter for use at C3 and C4 is 2.7 mm while a 3.5 mm screw is suitable for C5, C6, and C7.
b) Appropriate screw lengths would be 22 mm for C3, 24 mm for C4 and C5 and C6; and 26 mm screw for C7.
c) The recommended angle to advance a screw in sub-axial cervical transpedicular spine surgery is 45°.

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APPENDICES

Appendix 1: Formal approval from IREC to conduct the Study

INSTITUTIONAL RESEARCH AND ETHICS COMMITTEE (IREC)

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Reference: IREC/2016/102
Approval Number: 0001696

28th July, 2016

Dr. Muthoga Owen Kiboi,
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INSTITUTIONAL RESEARCH & ETHICS COMMITTEE
28 JUN 2016
APPROVED
P. O. Box 4606-30100 ELDORET

Dear Dr. Muthoga,

RE: FORMAL APPROVAL

The Institutional Research and Ethics Committee has reviewed your research proposal titled:-

"Morphometric Measurements of Subaxial Cervical Vertebrae Pedicles in a Kenyan Adult Population".

Your proposal has been granted a Formal Approval Number: ***FAN: IREC 1696*** on 28th July, 2016. You are therefore permitted to begin your investigations.

Note that this approval is for 1 year; it will thus expire on 27th July, 2017. If it is necessary to continue with this research beyond the expiry date, a request for continuation should be made in writing to IREC Secretariat two months prior to the expiry date.

You are required to submit progress report(s) regularly as dictated by your proposal. Furthermore, you must notify the Committee of any proposal change (s) or amendment (s), serious or unexpected outcomes related to the conduct of the study, or study termination for any reason. The Committee expects to receive a final report at the end of the study.

Sincerely,

PROF. E. WERE
CHAIRMAN
INSTITUTIONAL RESEARCH AND ETHICS COMMITTEE

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

Appendix 2: IREC extension approval

INSTITUTIONAL RESEARCH AND ETHICS COMMITTEE (IREC)

MOI TEACHING AND REFERRAL HOSPITAL
P.O. BOX 3
ELDORET
Tel: 33471/2/3

MOI UNIVERSITY
SCHOOL OF MEDICINE
P.O. BOX 4606
ELDORET
Tel: 33471/2/3

Reference: IREC/2016/102
Approval Number: 0001696

28th July, 2017

Dr. Muthoga Owen Kiboi,
Moi University,
School of Medicine,
P.O. Box 4606-30100,
ELDORET-KENYA.

INSTITUTIONAL RESEARCH & ETHICS COMMITTEE
28 JUL 2017
APPROVED
P.O. Box 4606-30100 ELDORET

Dear Dr. Muthoga,

RE: CONTINUING APPROVAL

The Institutional Research and Ethics Committee has reviewed your request for continuing approval to your study titled:-

"Morphometric Measurements of Subaxial Cervical Vertebrae Pedicles in a Kenyan Adult Population".

Your proposal has been granted a Continuing Approval with effect from 28th July, 2017. You are therefore permitted to continue with your study.

Note that this approval is for 1 year; it will thus expire on 27th July, 2018. If it is necessary to continue with this research beyond the expiry date, a request for continuation should be made in writing to IREC Secretariat two months prior to the expiry date.

You are required to submit progress report(s) regularly as dictated by your proposal. Furthermore, you must notify the Committee of any proposal change (s) or amendment (s), serious or unexpected outcomes related to the conduct of the study, or study termination for any reason. The Committee expects to receive a final report at the end of the study.

Sincerely,

DR. S. NYABERA
DEPUTY-CHAIRMAN
INSTITUTIONAL RESEARCH AND ETHICS COMMITTEE

cc:	CEO	-	MTRH	Dean	-	SOD
	Principal	-	CHS	Dean	-	SPH
	Dean	-	SOM	Dean	-	SON

Appendix 3: Work plan

Activity	**Duration**	**Date**	**Participant**
Selection of topic	1 month	0ctober 2015	Researcher and supervisor
Literature Review	2 months	November – December 2015	Researcher and supervisor
Proposal writing and presentation to the department	3months	January –March 2016	Researcher and supervisor
Proposal submission to IREC	1 month	April –May 2016	Researcher
Approval by IREC	1 month	June 2016	Reviewers
Data collection	1 month	August 2017	Researcher
Data analysis	10 months	September–June 2018	Researcher
Thesis writing	6 months	June 2018- Jan 2019	Researcher and supervisor
Thesis submission	1 month	September 2019	Researcher

Appendix 4: Budget

	Kshs
Four rims of plain paper	2,000
Pencils, pens, rubber	200
Vernier calipers	9,000
Folders	1,000
Computer	14,000
Flash Disc	4,000
Printing and binding services (proposal and thesis)	8,000
I.R.E.C fee	1,000
Data handling	14,000
Payment of clerks and secretaries	10,000
Transport and accommodation in Nairobi	40,000
Total	**104,700**

Note: All the budget costs were financed by the researcher

Appendix 5: Formal letter from Kenya National Museum confirming that the research was conducted at the facility.

NATIONAL MUSEUMS OF KENYA

WHERE HERITAGE LIVES ON

8th June, 2018

Institution Research and Ethics Committee,

Moi University School of Medicine

Dear sir/madam,

RE: CONFIRMATION OF OWEN KIBOI MUTHOGA DATA COLLCTION ON CERVICAL DRY BONE SPECIMENS IN OSTEOLOGY SECTION NATIONAL MUSEUMS OF KENYA

This is to confirm that **Owen Kiboi Muthoga**; an Orthopaedics registrar from Moi University School of Medicine studied our human skeleton collection in August, 2017. He collected data on dry cervical bones specimens to answer his research question on morphometric variation of cervical vertebrae pedicle in a Kenyan adult population. This data collection was approved as per the National Museums of Kenya research collection access procedures. This collection is always accessible to researchers and collaboration between Moi University School of Medicine and National Museums of Kenya on research in understanding the Kenyan population skeletal variation is most welcome.

Yours Sincerely,

Dr. Ogeto Mwebi,

Head Osteology Section, Zoology Department

Appendix 6: Data collection sheet/form

DATE…………………………………..

IDENTIFICATION CODE……………..

MEASUREMENT OF PEDICLE HEIGHT

C3…………………………….

C4…………………………….

C5…………………………….

C6…………………………….

C7……………………………..

MEASUREMENT OF PEDICLE WIDTH

C3……………………………..

C4……………………………..

C5……………………………..

C6……………………………..

C7……………………………...

MEASUREMENT OF THE CHORD LENGTH

C3………………………………

C4………………………………

C5………………………………

C6………………………………

C7………………………………

MEASUREMENT OF MEDIAL INCLINATION

C3…………………………….

C4…………………………….

C5…………………………….

C6…………………………….

C7…………………………….

Appendix 7: Equipment and instruments

1. Measuring instruments: Vernier calipers and goniometer.
2. Digital camera

Figure 1: Showing digital Vernier calipers that that was used to measure the linear measurements of the cervical pedicle

Figure 2: Goniometer that was used to measure the pedicle angle

Figure 3: Digital camera that was used to record the dry specimens being measured