UNIVERSITY of RWANDA

College of Medicine and Health Sciences

# MORPHOMETRIC ANALYSIS OF CERVICAL SPINE PEDICLES USING COMPUTED TOMOGRAPHY SCANS AND ITS SURGICAL IMPLICATION IN ADULT RWANDAN POPULATION

A dissertation submitted in partial fulfilment of the requirements for the award of the Degree of Master of Medicine in Orthopaedic Surgery of the University of Rwanda

By: **Dr Jean Baptiste MUVUNYI**

Supervisors: **Prof Alex BUTERA, MBCHB, FCS(ECSA), FC ORTH(SA),**
**Chief Consultant Orthopedic Surgeon**

**Dr Jean Claude BYIRINGIRO, MD, MMED-Surg, FCS-Orth(ECSA),**
**Consultant orthopedic surgeon**

Kigali, June, 30th, 2019

## DECLARATION

I declare that this study is original and has not been submitted for any other degree to any other institution of higher learning before. The views expressed herein are mine unless otherwise stated; acknowledgements or reference has been quoted.

**Dr Jean Baptiste MUVUNYI**

Date… **June 30th, 2019**..

This dissertation has been submitted for review and approval of the following supervisors:

**Prof Alex BUTERA, MBCHB, FCS(ECSA), FC ORTH(SA)**
**Chief Consultant Orthopedic Surgeon**

**Dr Jean Claude BYIRINGIRO, MD, MMED-Surg, FCS-Orth(ECSA),**

**Consultant Orthopedic Surgeon**

## DEDICATION

To my wife Jacqueline MUKANDUTIYE, your patience and support were very encouraging to do and finalise my work.

Late beloved father Naaman KAGWERA, you did everything you could for my education.

To my mother, parents-in-law, siblings and extended family; Thank you for your support and encouragement.

## ACKNOWLEGDEMENT

I am so glad to have been guided by my supervisors who put their effort for the accomplishment of this research; Prof Alex Butera and Dr Jean Claude Byiringiro.

Thanks to Dr Sabine Nyiraneza, Radiologist at CHUK. You gave me a good guidance and teaching on taking measurements since the beginning of this research.

Special thanks to Mr Niyoyita jean Claude and Dr Nkurikiyumukiza Laurent for biostatistical analysis of this work.

All Staff of the radiology department of Rwanda military hospital.

All staff of the department of orthopaedics for their inputs for the accomplishment of this work

My classmates: you are good friends and we had good collaboration for the long five years journey with you.

Finally glory be to the Almighty God.

Table of Contents

## LIST OF SYMBOLS AND ACRONYMS/ABREVIATIONS

C1: The first cervical spine vertebra

C2: The second cervical spine vertebra

C3: The third cervical spine vertebra

C4: The forth cervical spine vertebra

C5: The fifth cervical spine vertebra

C6: The sixth cervical spine vertebra

C7: The seventh cervical spine vertebra

C-spine: Cervical spine

CT-scan: Computed Tomography Scan

DICOM: Digital Imaging and Communications in Medicine

DVD: Digital Video Disks

EMG: Electromyogram

IRB: Institutional Review Board

PACS: Picture Archiving and Communication System

PAL: Pedicle Axis Length

PH: Pedicle Height

PL: Pedicle Length

PSA: Pedicle Sagittal Angle

PTA: Pedicle Transverse Angle

P-value: Probability value or Calculated Probability

PW: Pedicle Width

RMH: Rwanda Military Hospital

SD: Standard deviation

SPSS: Statistical Package for the Social Science

**LIST OF TABLES**

# LIST OF FIGURES AND GRAPHS

# ABSTRACT

**Background**: Studies on morphometric dimensions of cervical spine pedicles showed that differences are significant between races and gender. Among Rwandan population, there were no available data. Our study was aiming to describe the anatomical morphology of the cervical spine pedicles and give guidance to safe pedicle screws fixation.

**Method:** Retrospective cross-sectional study by using recorded Computed Tomography (CT) scans images of normal cervical spines. Images were selected from Radiology department electronic database of Rwanda Military Hospital. The total of 125 cervical CT-scans taken from January 2017 to June 2019 were analysed by RadiAnt DICOM software. Linear and angular measurements from the second to the seventh cervical spine were recorded and a total of 9000 measurements was analysed. Descriptive analysis, student t-test and p-values were done by using Microsoft Excel and SPSS.

**Results and discussion**: Pedicle Widths (PW) and Pedicle Heights (PH) were bigger on C2 (PW=6.38mm, PH=8.1mm) and C7 (PW=6.67mm, PH=7.99mm). Calculated percentage of safe pedicle fixation with a screw of 4.5mm was 96% on C2 and 98.4% on C7. Smaller values for PW and PH were on C3 and C4 with less percentage of pedicle fixation of 68% on C3 and 67.2% on C4. Pedicle lengths (PL) and Pedicle Axis lengths (PAL) were gradually increasing from C2-C7. In angular measurements, Pedicle Sagittal Angles were decreasing from C2-C7 (43.43˚ on C2 and 38.61˚ on C7). The Pedicle sagittal angles are more variable between persons and C2 angle was directing cephalic for some and caudal for others. There was no generalizable gender or side dominance.

**Conclusion:** Based on our findings, despite more variations in Rwandan population, safe pedicle fixation surgery can be done at the level of C2 and C7 and always the individual CT-scan analysis is important prior to surgery for proper anatomical analysis.

# CHAPTER ONE: INTRODUCTION

## 1.1. Introduction

The Cervical spine (C-spine) fixation is done worldwide by different ways depending on indications. It becomes more challenging and difficult when posterior elements are affected by tumor, infection or trauma, and requires a stable fixation. The morest stable fixation construct is done by pedicle screws compared to lateral mass screws. (Aydogan, et al., 2012), (2),(3)

Although the lateral mass fixation is preferred in sub-axial C-spine from C3 to C6, it was found to be less stable and the risks of nerve root injuries are higher compared to pedicle screws fixation. (1), (4). The pull-out strength of lateral mass screws compared to the pedicles screws fixation was shown to be less with low biomechanical stability. In a research done in Atlanta in 2011, Zenya et all and found that energy required for lateral masses screw pull-out was around 206 Newton compared to 643 Newton for pedicles screws. (5)

The C-spine anatomy that is made of bony structures, neural and vascular elements must be the most required prerequisites for a surgeon as any surgical step requires meticulous manupilation. In Japan, a series of 144 unstable c-spine cases of cervical pedicle screws placement from 1995 up to 2008 were reported. The total number of placed screws was 620. They found a pedicle perforation rate of 9.2%, one case the vertebral artery was injured, and one case of spinal cord injury with persistent radiculopathy. (6) In the same country, a multicentre study showed a malposition rate of 19.5% and complications related to the pedicle screws: five patients had complications related to pedicle screws including 3 with nerve root injury and 2 with vertebral artery injury. (6), (7)

The morphometry of pedicles has been found to be highly variable worldwide. A review of 12 articles included 5 Asian (3 Japanese, 1 Chinese, and 1 Malaysian) and 7 European/American populations (3 American, 2 German, 1 Turkish, and 1 England) found that the pedicle width (PW) ranged from 4.7 to 7.4mm. Apart C1 which doesn't have pedicle, C4 was found to have the smallest pedicle. Asian males have the smallest mean PW of 5.1mm and European/American female have the mean of 4.1mm. (8)

The largest mean PW in males and females was found at the level of C7. It was 7.7 mm in Asian males and 7.0mm in Asian female. The overall linear pedicle dimensions are higher in European/American than in Asian with a ratio of 91.4–98.8 %. (8)

Comparable results were found in a study done in Asia for Indians, Malay and Chinese people(9); they found that the smallest mean PW in males was at C4 with 5.4mm and at C3 in female with 4.75mm; they also found that the biggest mean PW is at C7 with 7.17mm, and that the incidence of having a very small pedicle <4mm of mean PW was 12.5% in Indians, 10% in Chinese the 8.3% in Malay.

In Africa, the few available data about the morphometric values of pedicles are from Arab countries. In Egyptian people, the mean PW were found larger compared to Europeans and Asian; they ranged as follow: C3 has 6.2-6.8 mm, C4 has 6.2-6.9 mm, C5 has 6.5-7.5 mm, C6 has 6.2- 7.0 mm, and C7 has 6.1-6.9 mm. (2)

Despite the long history of pedicle screws fixation by Roy-Camille and Judet in 1963, then by American Harrington and Tullos in 1967, up to now, studies on different populations are still being done for the safe placement of pedicle screws. (3), (10), (11), (12), (13), (14)

They found that the morphometry of c-spine pedicles for Egyptians was promising for transpedicle fixation as the current small pedicle screws are 3.5mm.

The feasibility of pedicle screws fixation of c-spine, in our region and our country, is not known as there are no studies done yet on this topic. Surgeries are done on c-spine and the fixations are basing on prior imaging analysis for each individual but no available global view on the vertebra sizes of the population.

**1.2 Problem statement**

Cervical spine surgery is done with many precautions as it may result in serious complications including fatal ones. For this reason, since the introduction of pedicle screw fixation, changes are always made on the implants for the safety of patients. (10) The morphometric analysis of the spine by use of CT-scan was found to be the best way to predict the safety of pedicle screws fixation because of variety in population. (2), (9), (15)

The availability of data on morphological anatomy of cervical spine in our population is of great importance for the feasibility of posterior instrumentation surgery by using pedicle screws safely in our population. This type of data is largely missing in our population.

## 1.3 Study justification

Anatomical variations of cervical spine vertebra, in terms of size and orientation are significant from one population to another. They variations are also sex and age related. The pathology is a key factor to decide the treatment, but the morphologic variations pose a big challenge for surgeons during cervical spine surgery. The approach, type of fixation and implants to be chosen may differ depending on surgeon experience or special anatomy of the population.

To avoid surgery related complications, it is required to determine the appropriate vertebral morphology, then the size and orientation of screws or other implants to be used safely. Spine surgery in Rwanda is currently done in only one hospital, King Faisal. Up to now, no related study has been done to show if our population may have special anatomical patterns of the cervical spine vertebra.

This study will give much input in our daily academic and practical activities as it will show features and important considerations for safe cervical spine surgery in Rwandan population.

## 1.4 Research question

What is the anatomical morphometry of cervical spine in Rwandan adults?

## 1.5 Objectives

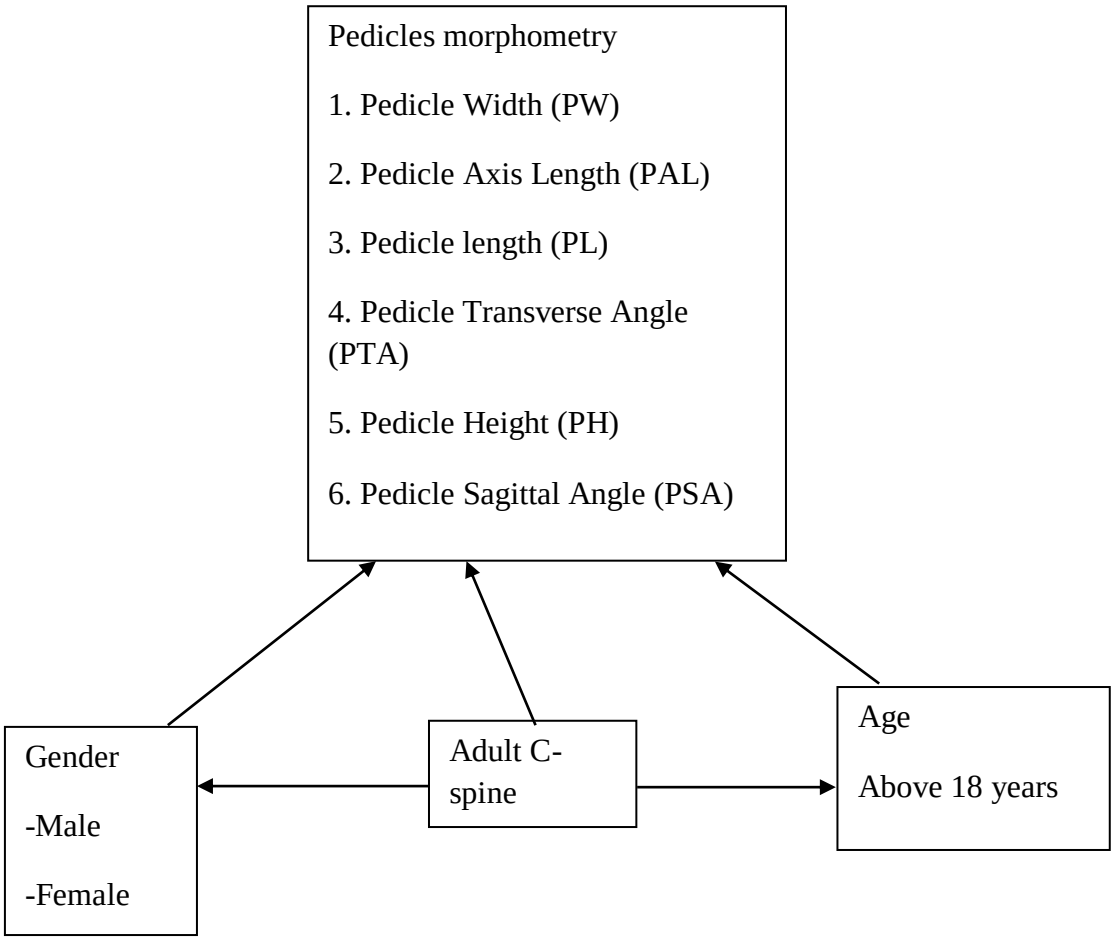
### 1.5.1 General objective

To describe the morphometry of cervical spine pedicles and to analyse the feasibility of cervical spine pedicle screws fixation in Rwandan adult population.

### 1.5.2 Specific objectives

- To describe the morphometry of cervical spine pedicles from C2 to C7 in our population.
- To describe the factors influencing the cervical spine pedicle morphometry in our population.
- To analyse the feasibility of cervical spine pedicle screws fixation in Rwandan adult population

## 1.6 Conceptual framework



# CHAPTER TWO: LITERATURE REVIEW

## 2.1 Introduction

The fixation of spine by pedicle screws was firstly described in 1963 by Roy-Camille and Judet and then the American Harrington and Tullos did the first fixation in 1967. In the beginning they were used in lumbar and, thoracic spine, but have now been extended to the cervical. Biomechanical studies have confirmed adaquate stability of this fixation and good clinical outcome and it is now widely used by spine surgeons (10).

Major advantages of transpedicle screws fixation on cervical spine are based on stable fixations which give a good a biomechanical construct especially when doing posterior decompression. In Germany, a biomechanical study done in 2004 on 8 cadaveric cervical spines from C2 to C7 showed a more stable construct when using pedicle screws compared to lateral mass screws fixation and there was a significant resistance on screws pullout (16). The same results were found in a study done in China (17)

Due to anatomical limitations of the c-spine, with risk of injury to the vertebral artery, spinal cord and nerve root; fixation by pedicle screws is still reserved on some cases of trauma and tumors. The placement of pedicle screws requires a proper knowledge of anatomy. This is why researchers are interested to know, through various populations and ethnic groups, the morphometric anatomy of the spine.

The feasibility of transpedicle screws fixation in C-spine was proven by different researchers in America, Europe, and Asia. In 2014, Mohamed M Mohi Eldin demonstrated through Computerised Tomographic (CT) scan measurements that it's possible to do the fixation in Egyptian people by using pedicle screws of 3.5mm (2). In 2017, Al-Saeed found that Arabic population have the size of pedicles that allows fixation by pedicle screws but their sizes were smaller compaired to europeans and americans. (15)

The fixation with pedicle screws is now advised by safety on C2 and C7 because they have a big pedicle sizes that can accommodate a 3.5mm pedicle screw without screw cutout for causing injuries to other structures around. (18)

## 2.2 Types of cervical spine pedicles morphology analysis

The cervical spine anatomical analyses are done worldwide in different ways. With the development of imaging modalities, the commonest method uses CT-scan images where

different measurements can be taken. This system of analysis gives linear and angular aspects of the bones. (3), (19), (20), (21) Majority of studies were done retrospectively.

Other anatomical studies of cervical spine are done by using cadavers where bones are harvested and analysed as fresh or dry bones. This system is more experimental and used for analysing fixations technics, biomechanical studies and rate of screws cut-out. (16), (22), (23)

### 2.3 Methods of study

Measurements of the cervical spine are taken in different ways either from cadaver as fresh or dry bone or they are analysed from CT-scan images. The analyses can be done retrospectively or prospectively. Linear and angular measurements by CT-scan using a digital ruler/ Digital Vernier calliper were proven to be more accurate in predicting a good size and trajectory during surgery in order to avoid injuries. (11), (22), (24)

It requires appropriate tools to take these measurements. Standard metallic ruler and goniometer were used in Nepal to determine the morphometry of cervical spine (20). This analysis requires doing analysis on a print-out image.

Recent software which have proven to be more accurate with 0.01mm of precision are; Radiant DICOM software and MIMICS software (3), (21).

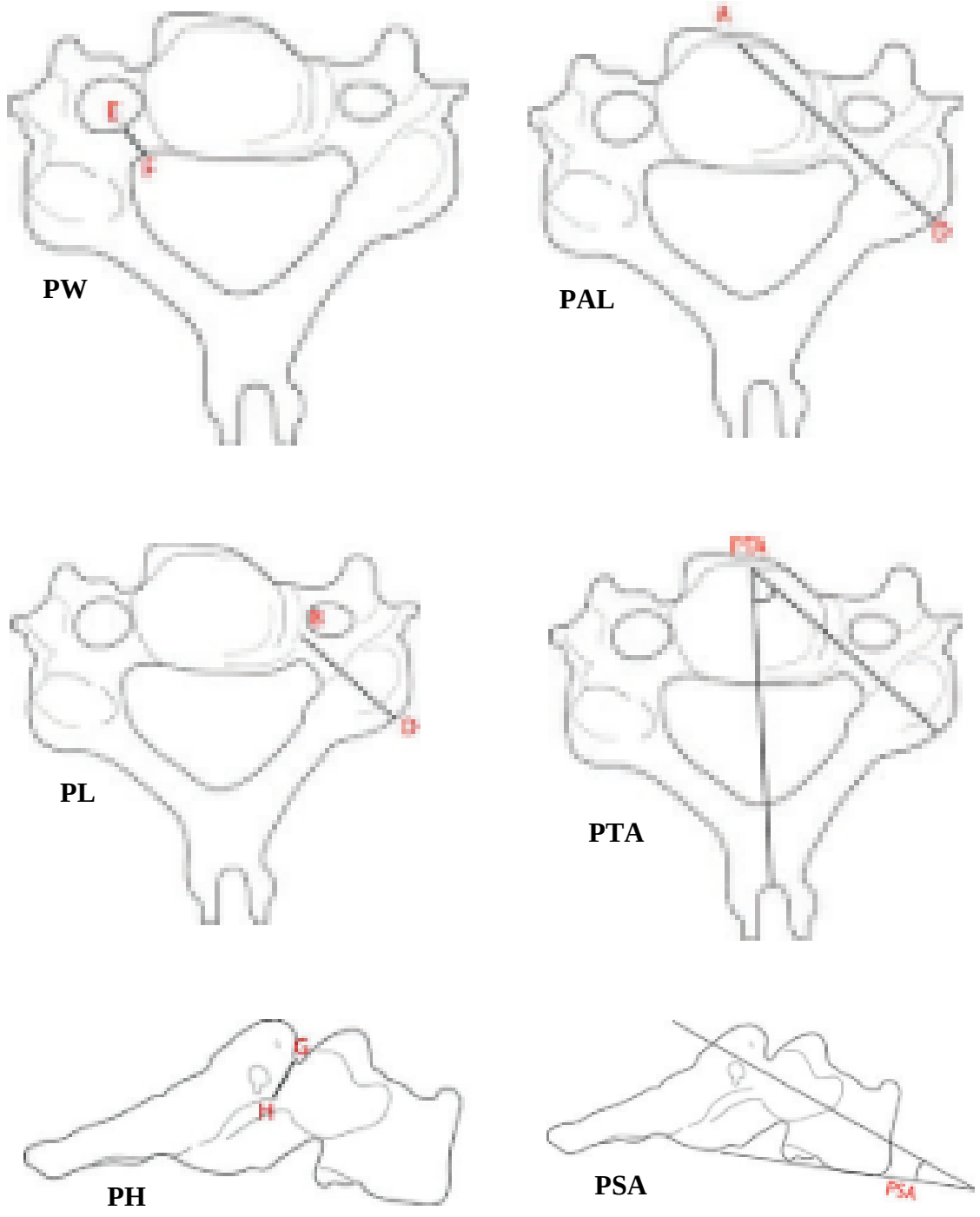
### 2.4 Description of measurements

The morphometric measurements of cervical spine by CT-scan images are of clinical relevance in c-spine surgery. They are taken from axial sagittal and coronal cuts of CT-scan. Linear measurements are expressed in millimetre and angular measurements in degree.

Different Authors have described different measurements, but the most important for consideration for surgical predictions are six: (11), (13), (14), (19)

- **Pedicle Longitudinal Axis (PLA) or Pedicle Axis Length (PAL):** is a line parallel to and in the middle of the lateral and medial border of the pedicle. The measurement is taken from its junction to the anterior part of the vertebral body and its junction to the posterior cortex of lateral mass.
- **Pedicle Length (PL)**: is a linear measurement of pedicle axis length from the junction of the pedicle and body, up to the posterior cortex of lateral mass.

- **Pedicle Width (PW):** linear measurement perpendicular to the pedicle longitudinal axis joining outer and inner cortex of pedicle. It defines the maximum pedicle screw diameter.
- **Pedicle Height (PH):** Linear measurement taken on sagittal CT-scan from outer superior cortex to outer inferior cortex.
- **Pedicle Transverse Angle (PTA):** Angular measurement made by pedicle longitudinal axis and median line joining the spinous process to the anterior and middle part of vertebra body.
- **Pedicle Sagittal Angle (PSA):** is an angular measurement taken on sagittal CT-scan image. It is made of the line parallel to the pedicle and the line parallel to the inferior end-plate.




Images of different measurements described by Kanthika (19)

## 2.5 Factors affecting cervical pedicles morphometry

### 2.5.1 Sex

According to the studies done in different countries, cervical spine vertebras have different sizes in males and females. In Thailand, females were found to have smaller pedicle height and width compared to males (19). The same results were found in Indian population. According to Banerjee, the means for all pedicle measurements had trends to be smaller in females with no statistical significance (3).

Another statistical difference in pedicle size for men compared to women was seen in multi-ethnic study in Singapore. Men were found to have bigger pedicles even in the same ethnic group. (9). Leonard Westerman did an analysis in Caucasians, on 100 CT-scans, he found a half of female and only a third of male had PW value less than 4.5mm from C3 to C7.(25) These differences were not statistically significant and had no great impact on c-spine surgery in terms of the size of used screw and its trajectory. (3), (26)

### 2.5.2 Age

Age related variations are reported by researchers to affect mainly the vertebral body, spinal canal and facet joints rather than pedicles. In adults the canal declines as the age increases, and this was due to osteophytes. (20), (27) More variations occur in paediatric population, where notable increase in size of vertebra and its pedicles is directly proportional to the age and stop growing in adulthood. (28)

In adults' people, no significant difference of pedicles was noted in previous researches. One detailed study was conducted in Mexico in 2018. On 170 dry c-spines vertebra, no significant changes noted on pedicles. Changes were noted on spinal canal which becomes small by the increase in age. (29)

### 2.5.3 Body mass index

Many researchers have put their effort in studying the association of body mass index and spine injuries and disc degeneration.

The linear dimensions of cervical spine pedicles are highly influenced by the body mass index (BMI)

In a study done in India, Smaller pedicle widths were found to be associated with low BMI. People with BMI>28 were found to have PW>4.5mm from C3-C7. (21)

### 2.5.4 Ethnic variations

The size of vertebra may show differences within the population of same country depending on their ethnic class, the race and geographical location. Smaller sizes of pedicles were reported in Indian population compared Caucasians, Europeans and Americans. (3) In the Eastern region of Nepal, the populations was found also to have almost the same size of pedicles as Indians but smaller than Europeans. (20)

North and South Indian population are having smaller pedicles than western Indians. (21). Saluja did a study in Indian population and compared his results with those found in other population and noted that Americans have average of PW of 5.91mm, Egyptians have 5.18mm and Mexicans have 4.76mm whereas PW in Indians was 4.56mm.(11)

A multi-ethnic study for Asian population was done in Singapore in 2010-1013, in three ethnic groups (Chinese, Malay and Indian). With statistically significant difference, Indian ethnics were found to have the smallest pedicle width and Malays had the largest.(9)

# CHAPTER THREE: METHODOLOGY

## 3.1 Study design

It is a retrospective cross-sectional study using available normal CT-scan images done for cervical spine in adult people.

## 3.2 Study site

Rwanda Military Hospital is a military referral hospital located in Kigali City, Kicukiro District. It has the capacity of 500 beds. Rwanda Military hospital has a new model CT-scan machine type GE Optima CT660- 128 slice CT scan that was installed in 2017.

## 3.3 Study population

Adult Rwandan patients who underwent the cervical spine CT-scan imaging between January 2017 and June 2019 and whose cervical spine CT images are available in the electronic database of Radiology departments of RMH since January 2017 up to June 2019.

## 3.4 Study duration

The study was done between April and June 2019.

## 3.5 Selection criteria

### 3.5.1 Inclusion criteria

-Cervical spine CT-scans done since January 2017 up to June 2019 in RMH

-Adults CT-scans (≥ 18 years old of age)

### 3.5.2 Exclusion criteria

-Pathologic bones of C-spine (tumors, fractures, infections, congenital abnormalities)

-Repeated exams for the same person.

-Previous C-spine surgeries

## 3.6 Sample size

This is a descriptive study and the sample size is determined by using Cochran formula

$$n = Z^2 \frac{p(1-p)}{e^2} \quad (30)$$

**N**: Sample size

**Z**: Confidence level. For a confidence level of 95%, Z value is **1.96**

**P**: Proportion of the population which has the problem. In our study we consider the population who underwent cervical CT-scan. Here data we have from local researches show a proportion of 3.7% of patients admitted for cervical spine injury in our referral hospitals. (31), (32). This proportion is smaller compared to the one in neighbouring countries where we have 8.8% in Mulago hospital Uganda. (33). We consider P=8.8%.

**e**: Level of precision or margin error. It is 5%

Sample size calculation is now

$$n = 1.96^2 \frac{(0.088)(1-0.088)}{(0.05)^2} = 123$$

The sample size estimate is 123, and 123 CT-scans had to be analysed. For each CT-scan, six vertebras, from C2-C7 were evaluated. Morphometric measurements were taken for two pedicles for each vertebra giving a total of 1476 pedicles to evaluate.

### 3.7 Sampling and measuring procedure

CT-scan images that fit for our criteria were picked and measured for the following:

- Pedicle width
- Pedicle length
- Pedicle axis length
- Pedicle transverse angle
- Pedicle height
- Pedicle sagittal angle

### 3.8 Analysis procedure

Collected measurements were entered in SPSS 16.0 (IBM Corporations 2015). Mean measurements and Linear regressions were calculated on all variables. We used *t-test* to analyse comparative variables and their statistical significance.

### 3.9 Data management

#### 3.9.1 Data collection and entry

Images collected from radiology electronic database of RMH were copied on Digital External Hard Disc, then analysed in the system of Digital Imaging and Communication in Medicine (RadiAnt DICOM 4.6.9) software by the main investigator. Linea and angular measurements were collected. Collected data were kept in Microsoft excel, Version 2016 spreadsheet.

#### 3.9.2 Data storage

Data were stored in the computer of the Principal Investigator with back-up on external hard disk.

### 3.10 Data analysis

Data analysis was done by using Microsoft SPSS, in which percentages and frequencies were computed for categorical variables. Standard deviations and means were calculated for continuous variables. The regression slop coefficient was used for the purpose of analysing changes along the age. Gender differences in pedicle sizes and age related morphometry were compared.

### 3.11 Quality control

The training of principal investigator and radiology technician was done prior to the data collection procedure. Images were magnified between 200-400 times the normal sizes for clear visualization and the double measuring done before recording the final values.

### 3.12 Ethical consideration

The study was focusing on cervical CT-scans done previously on patients and thus not harmful to them. Patients' identifiers were kept under strict confidentiality as they cannot appear in the report and the hard disk containing their images is kept in a locked box held only by the principle investigator.

Data collection was done after getting the approval from IRB of University of Rwanda and ethics committee of hospital at the RMH. The IRB reference umber: No300/CMHS IRB/2019.

# CHAPTER FOUR: RESULTS

## 4.1 Introduction

In our study, we analysed 125 cervical spines. The analysis was done on 6 vertebras from C2-C7, the totals of 750 vertebras were measured on both sides, right and left. On each side of vertebra, six measurements were taken on each pedicle giving a total of 72 measurements for one C-spine/patient, the total measurements taken were 9000.

## 4.2 Demographic description

For a total of 125 analysed CT-scans, males were 66 and 59 were females, representing respectively 53% and 47%. The median age of participants was 44.78 years which varied from 18 to 91 years. The mean age for males and females are 42.53 [SD=14.09] and 47.30 [SD=16.92].

The majority of patients were aged 38 to 47 years with 24% (n=30). From the age of 58 years old to the oldest we had 21.6

**Figure 1: Gender distribution**

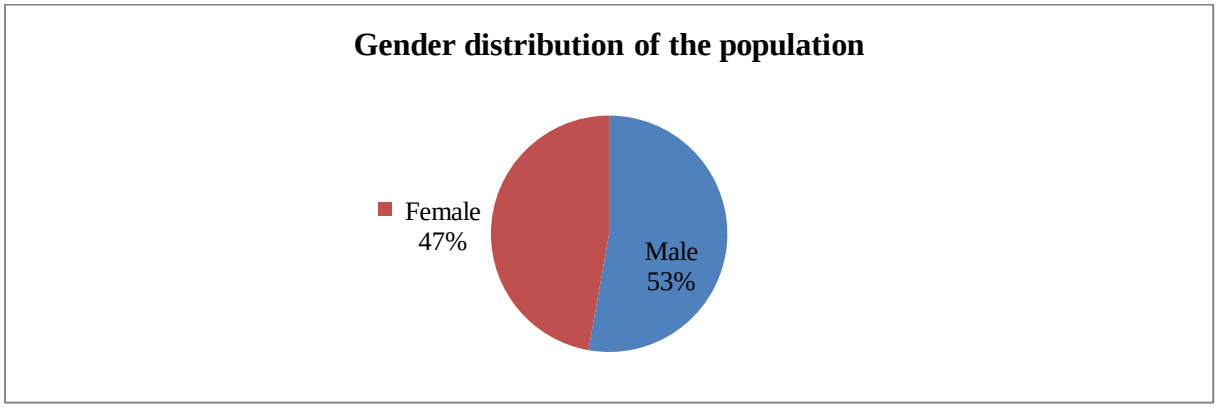
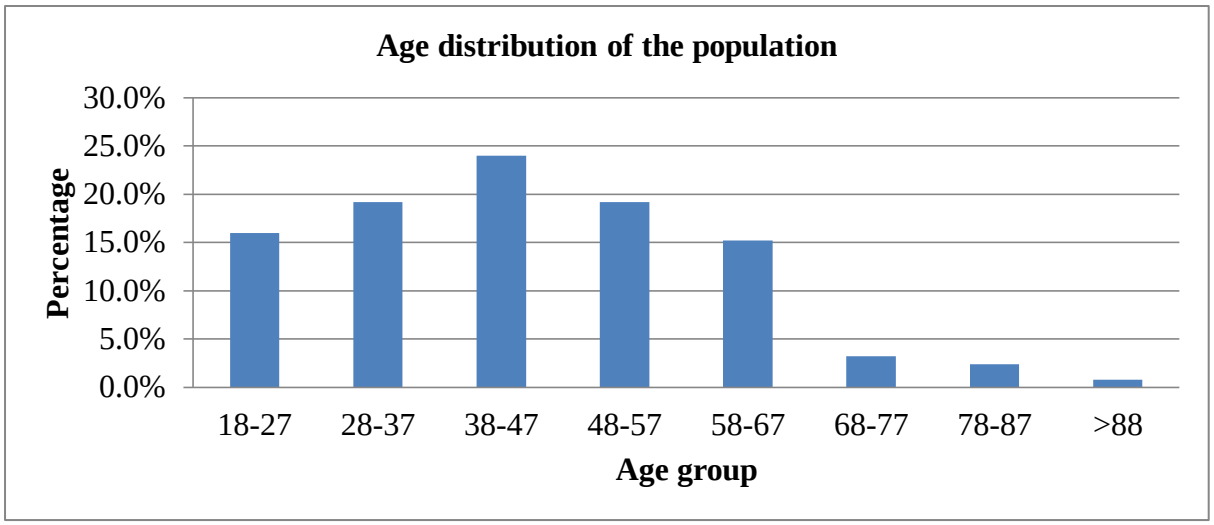


**Figure 2: Age distribution**




### 4.3 Comparison analysis of variables

#### 4.3.1 Means

Linear and angular measurements means for each vertebra were calculated from the database as the average of measurements of both sides (right and left) and for all participants at each vertebra. (Table 1) The mean for the Pedicle Width (PW) was 6.38mm at C2. It decreased at C3 with a mean of 5.03mm, and progressively increased from C4 to C7 with the mean of 5.22mm at C4, 5.57mm at C5, 5.71mm at C6 and 6.67mm at C7. The graph of PW, on Figure 3, is showing the progression curve from C2-C7. The mean PW in the whole population was 5.56mm.

Pedicle Axis Length (PAL) was shorter at C2 (27.99mm) and increased progressively with 31.03mm at C3, 31.43mm at C4, 32.98mm at C5, 34.18mm at C6 and 34.59mm at C7. The progression curve is shown on Figure 4.

The Pedicle length (PL) was shorter at C2 (11.64mm) and longest at C6 (15.19mm). A graphic design on the progression of PL is shown on Figure 5.

The Pedicle Height (PH) was biggest at C2 (8.10mm) followed by C7 (7.99mm).

The Pedicle Transverse angle (PTA) was biggest at C2 measuring 43.43degrees, it declines at C3 (41.57 Degrees) but increased again at C4 (42.41 Degrees) and then declined again till C7: C5 (42.22 Degrees); C6 had 41.62 Degrees and C7 had 38.61 Degrees.

The PSA was 12.29 Degrees at C2 and at this level the orientation was cephalic with the rest of angles at subaxial C-spine orienting caudally. It was 15.21 Degrees at C3 then became big at C4 and C5 with 17.44 Degrees and 17.12 Degrees. The PSA of C6 was 14.03 Degrees and C7 was 14.80 Degrees.

**Figure 3: Graph of Pedicle width means**

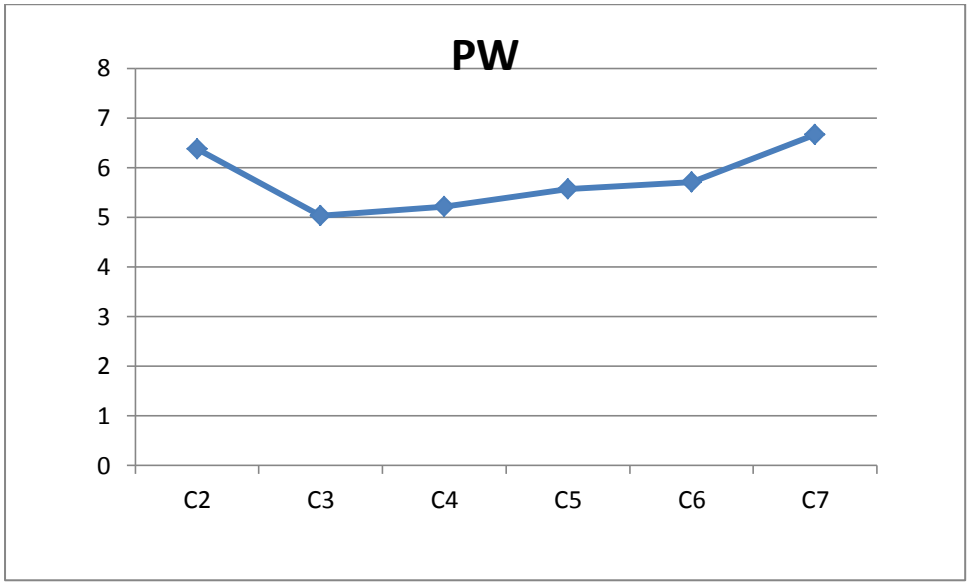



**Figure 4: Graph of Pedicle Axis length means**

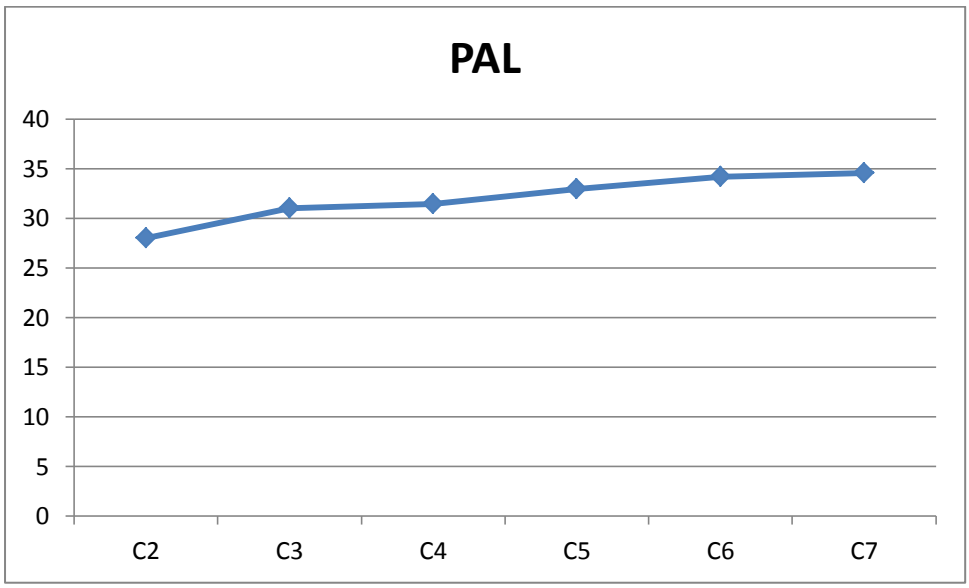


**Figure 5: Graph of Pedicle length means**

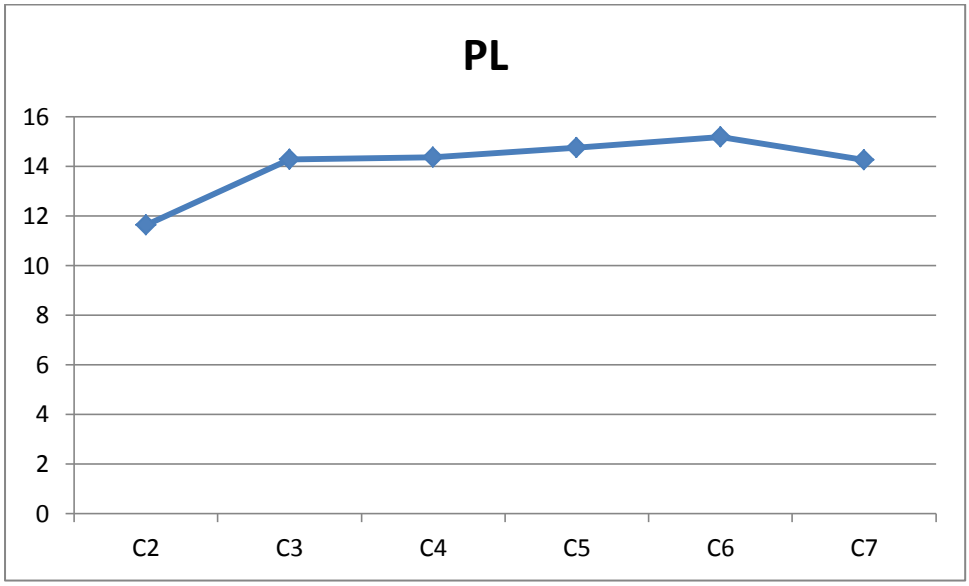



**Figure 6: Graph of Pedicle Transverse Angle**

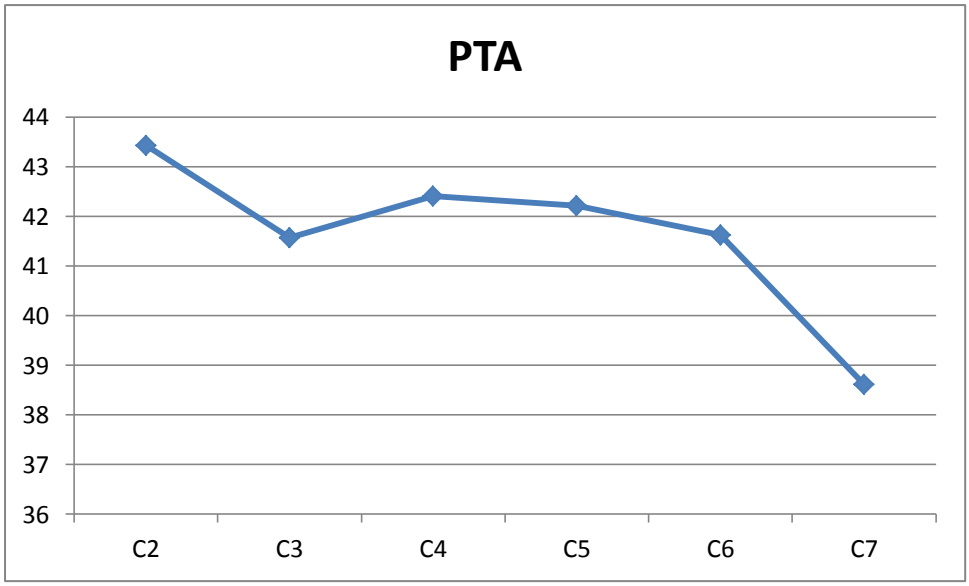


**Figure 7: Graph of Pedicle Height means**

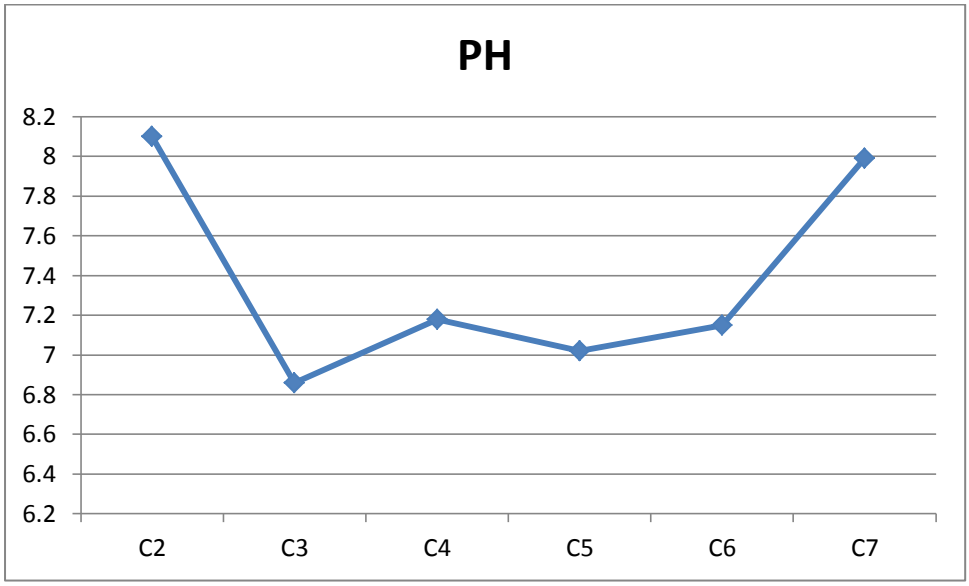
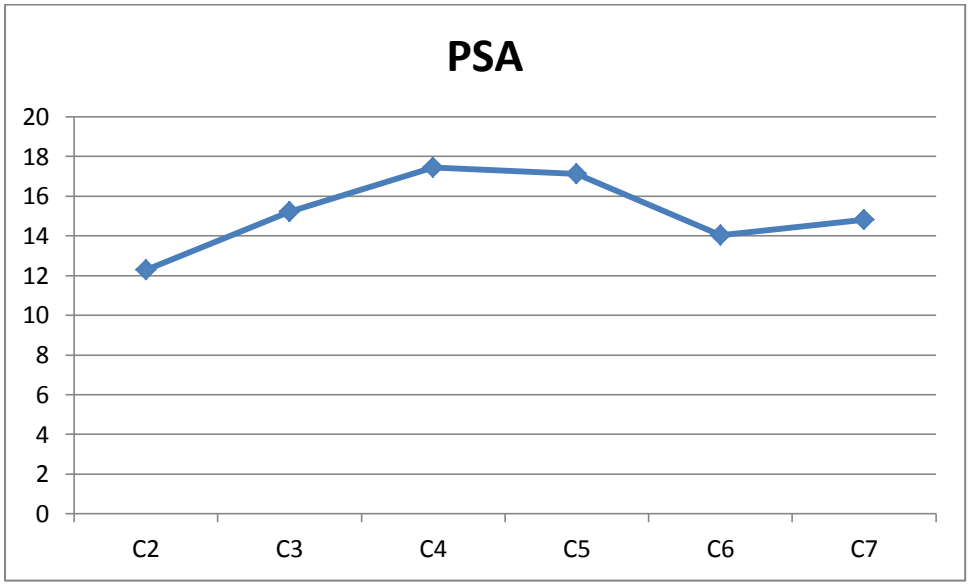



**Figure 8: Graph of Pedicle Sagittal Angle means**




### 4.3.2 Minima and Maxima

The means for linear measurements on different C-spine vertebra and on both sides were measured; smaller numbers are found to be on C3 for PW with 3.01mm, C2 for PAL, PL and PH with 22.1mm, 8.2mm and 5.01mm respectively

Larger measurements were found on C2 for PW with 9.43mm, C3 for PAL with 47.6mm, C6 for PL with 22.0mm and C7 on PH with 12.1mm. Table 1.

Angular measurements showed smaller PTA at C4 of 24.8 degrees and smaller PSA at C3 of 2.9 Degrees. Bigger PTA is at C5 with 56.4 Degrees and bigger PSA at C4 with 17.44 Degrees. Table 1.

**Table 1: Means, minima and maxima of variables**

| | | | C2 | C3 | C4 | C5 | C6 | C7 |
|---|---|---|---|---|---|---|---|---|
| **PW** | **Minima** | **Right** | **4.05** | **3.01** | **3.20** | **3.71** | **3.49** | **4.16** |
| | | **Left** | **4.14** | **3.41** | **3.06** | **3.62** | **3.39** | **4.47** |
| | **Maxima** | **Right** | **9.31** | **8.16** | **7.55** | **7.95** | **7.91** | **9.00** |
| | | **Left** | **9.43** | **7.27** | **8.33** | **7.55** | **7.92** | **8.98** |
| | **Mean** | | **6.38** | **5.03** | **5.22** | **5.57** | **5.71** | **6.67** |
| **PAL** | **Minima** | **Right** | **22.1** | **24.2** | **26.9** | **25.5** | **27.0** | **24.8** |
| | | **Left** | **26.6** | **25.2** | **27.0** | **26.2** | **27.7** | **29.8** |
| | **Maxima** | **Right** | **34.2** | **36.9** | **38.7** | **40.0** | **42.2** | **44.7** |
| | | **Left** | **34.5** | **47.6** | **38.2** | **44.2** | **43.7** | **44.1** |
| | **Mean** | | **27.99** | **31.03** | **31.43** | **32.98** | **34.18** | **34.59** |
| **PL** | **Minima** | **Right** | **8.2** | **8.89** | **10.3** | **10.6** | **11.1** | **10.9** |
| | | **Left** | **7.52** | **9.96** | **10.1** | **11.0** | **11.6** | **12.3** |
| | **Maxima** | **Right** | **16.8** | **21.2** | **18.2** | **19.2** | **20.7** | **21** |
| | | **Left** | **16.7** | **19.0** | **17.6** | **19.4** | **22.0** | **20.3** |
| | **Mean** | | **11.64** | **14.28** | **14.36** | **14.76** | **15.19** | **14.26** |
| **PTA** | **Minima** | **Right** | **31.5** | **31.8** | **24.8** | **34.0** | **34.7** | **31.6** |
| | | **Left** | **35.6** | **32.1** | **30.0** | **30.6** | **25.6** | **30.9** |
| | **Maxima** | **Right** | **53.6** | **50.3** | **51.8** | **54.8** | **50.3** | **49.2** |
| | | **Left** | **51.6** | **52.4** | **50.2** | **56.4** | **51.6** | **49.3** |
| | **Mean** | | **43.43** | **41.67** | **42.41** | **42.22** | **41.62** | **38.61** |
| **PH** | **Minima** | **Right** | **5.01** | **3.36** | **3.96** | **3.77** | **4.03** | **5.4** |
| | | **Left** | **5.0** | **3.42** | **3.79** | **4.0** | **4.17** | **4.49** |
| | **Maxima** | **Right** | **11.2** | **9.44** | **9.8** | **9.58** | **10.0** | **12.1** |
| | | **Left** | **11.3** | **9.64** | **10.1** | **9.6** | **9.74** | **10.3** |
| | **Mean** | | **8.10** | **6.86** | **7.18** | **7.02** | **7.15** | **7.99** |
| **PSA** | **Minima** | **Right** | **4.8** | **2.9** | **7.0** | **6.0** | **4.5** | **6.8** |
| | | **Left** | **4.8** | **2.9** | **7.0** | **6.0** | **4.5** | **6.5** |
| | **Maxima** | **Right** | **29.0** | **29.2** | **35.6** | **32.6** | **27.5** | **31.9** |
| | | **Left** | **29.0** | **29.2** | **35.6** | **32.1** | **27.5** | **31.9** |
| | **Mean** | | **12.29** | **15.21** | **17.44** | **17.12** | **14.03** | **14.80** |

### 4.3.3 Variations with age

The calculation of regression slop from C2 to C7 for all linear and angular measurements gives clear statistical explanation about possible variations with age. As seen on Table 2 below, the variations were significant for some measured variables. The statistical significance for our measurements is defined as the deviation from 0mm/year or 0degree/year. Considering the variables trends along years, the linear measurements increase and angular measurements decrease.

For C2, the PW increases by 0.001666 mm every year. This mean that when considering an 18year old person and a 90 years old, the age difference is 72 years but PW difference is not above 0.12mm [0.001666x72]. The difference was still around **zero** then considered not significant.

The biggest variation was seen on PTA of C5 where the slop was -0.1070 degrees per year, and we expected the decrease of 7.704 degrees of transverse angle deviation between 18 years old person compared to a 90 years old. It was statistically significant as p-value is <0.0001.

**Table 2: Regression slop of C-spine measurements for age**

| Variables | | **PW mm/year** | **PAL mm/year** | **PL mm/year** | **PTA degree/year** | **PH mm/year** | **PSA degree/year** |
|---|---|---|---|---|---|---|---|
| C2 | value | 0.001666 | 0.04081 | 0.01019 | -0.03608 | -0.002084 | -0.03795 |
| | p-value | 0.7730 | **0.0021** | 0.2082 | 0.0363 | 0.7565 | 0.2000 |
| C3 | value | 0.006058 | 0.03445 | -0.003750 | 0.006058 | -0.07422 | -0.07375 |
| | p-value | 0.1538 | **0.0149** | 0.6592 | 0.1538 | **<0.0001** | **0.0241** |
| C4 | value | 0.01128 | 0.04762 | 0.009029 | -0.05894 | -0.003446 | -0.08536 |
| | p-value | **0.0210** | **0.0002** | 0.2716 | **0.0048** | 0.5761 | **0.0104** |
| C5 | value | 0.008783 | 0.06991 | 0.01010 | -0.1070 | -0.002076 | -0.07831 |
| | p-value | 0.0783 | **<0.0001** | 0.2533 | **<0.0001** | 0.7226 | **0.0212** |
| C6 | value | 0.01386 | 0.09314 | 0.02479 | -0.07407 | -0.001625 | -0.05501 |
| | p-value | **0.0080** | **<0.0001** | **0.0104** | **<0.0001** | 0.8013 | **0.0447** |
| C7 | value | 0.01138 | 0.06757 | 0.01896 | -0.07494 | 0.01778 | -0.08515 |
| | p-value | **0.0218** | **<0.0001** | **0.0467** | **<0.0001** | **0.0041** | **0.0008** |

### 4.3.4 Comparison of sides and gender

Gender and sides differences on linear and angular variables on c-spine from C2-C7 were reported on tables 3, and 4.

For C2, results were showing statistically significant difference on Pedicle Height on both sides and gender. The left side of C2 was longer compared to the right with 8.069mm against 8.441mm [p-value<0001] and there was male predominance with 8.460mm against females with 8.026mm of PH [p-value<0.05].

For C3, the differences were seen on PAL where the left side is bigger with 31.4008 mm compared to 30.6552 mm of right [p-value<0.05]. For the same vertebra (C3), the right side was bigger at PL with 14.458mm against 14.252mm of left side [p-value<0.05]. At this variable of at C3, males were having long pedicles with 14.50mm whereas females have 14.19mm [p-value=0.05].

For C4, left sides were dominant on PAL and PTA and male predominance at PAL with 31.66mm and 30.95mm of females [p-value=0.023]. The same left side predominance was found on C5 PAL with 31.546 mm against 31.16 mm of right [p-value=0.0003]. No gender differences on C5.

The side difference on C6 was seen at PH where the left side was 14.822mm and right side was 14.004mm [p-value<0.001]. The gender difference was the male predominance at PL with 15.223mm on 15.15mm of females [p-value=0.0311]. No differences on gender and side for C7.

**Table 3: Comparative analysis of linear measurements**

| | | PW | | | PAL | | | PL | | | PH | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | **Mean** | **SD** | **P-value** | **Mean** | **SD** | **P-value** | **Mean** | **SD** | **P-value** | **Mean** | **SD** | **P-value** |
| **C2** | **R** | 6.38 | 1.09 | 0.72 | 28.02 | 2.44 | 0.89 | 11.59 | 1.63 | 0.14 | 8.069 | 1.30 | **0.01** |
| | **L** | 6.36 | 1.12 | | 27.97 | 2.41 | | 11.69 | 1.43 | | 8.441 | 3.81 | |
| | **M** | 6.49 | 0.93 | 0.33 | 28.15 | 2.27 | 0.61 | 11.56 | 1.44 | 0.68 | 8.460 | 2.74 | **0.01** |
| | **F** | 6.23 | 1.06 | | 27.83 | 2.42 | | 11.73 | 1.37 | | 8.026 | 1.12 | |
| **C3** | **R** | 5.07 | 0.80 | 0.68 | 30.65 | 2.48 | **0.01** | 14.45 | 2.90 | **0.01** | 6.848 | 1.09 | 0.39 |
| | **L** | 4.98 | 0.78 | | 31.40 | 3.09 | | 14.25 | 1.16 | | 6.867 | 1.01 | |
| | **M** | 5.09 | 0.75 | 0.73 | 31.06 | 2.26 | 0.15 | 14.50 | 2.23 | **0.01** | 7.013 | 1.00 | 0.62 |
| | **F** | 4.95 | 0.72 | | 30.99 | 2.72 | | 14.19 | 1.36 | | 6.684 | 0.94 | |
| **C4** | **R** | 5.20 | 0.96 | 0.25 | 31.11 | 3.47 | **0.03** | 14.38 | 1.58 | 0.89 | 7.09 | 1.18 | 0.34 |
| | **L** | 5.23 | 0.86 | | 31.54 | 2.49 | | 14.33 | 1.53 | | 7.26 | 1.09 | |
| | **M** | 5.19 | 0.90 | 0.33 | 31.66 | 2.30 | **0.02** | 14.35 | 1.45 | 0.77 | 7.29 | 1.05 | 0.85 |
| | **F** | 5.25 | 0.79 | | 30.95 | 3.08 | | 14.37 | 1.39 | | 7.04 | 1.07 | |
| **C5** | **R** | 5.20 | 0.96 | 0.25 | 31.11 | 3.47 | **0.03** | 14.38 | 1.58 | 0.74 | 6.99 | 1.06 | 0.89 |
| | **L** | 5.23 | 0.86 | | 31.54 | 2.49 | | 14.33 | 1.53 | | 7.03 | 1.08 | |
| | **M** | 5.57 | 0.91 | 0.37 | 33.02 | 2.64 | 0.94 | 14.62 | 1.52 | 0.96 | 7.08 | 1.07 | 0.31 |
| | **F** | 5.56 | 0.81 | | 32.93 | 2.62 | | 14.90 | 1.53 | | 6.94 | 0.94 | |
| **C6** | **R** | 5.72 | 0.91 | 0.28 | 33.72 | 3.96 | 0.08 | 15.17 | 1.78 | 0.13 | 7.12 | 1.15 | 0.67 |
| | **L** | 5.69 | 1.01 | | 34.35 | 3.40 | | 15.19 | 2.04 | | 7.06 | 1.17 | |
| | **M** | 5.70 | 0.97 | 0.27 | 34.12 | 3.10 | 0.78 | 15.22 | 1.90 | 0.03 | 7.29 | 1.15 | 0.48 |
| | **F** | 5.71 | 0.84 | | 33.95 | 2.99 | | 15.15 | 1.43 | | 6.98 | 1.05 | |
| **C7** | **R** | 6.72 | 0.94 | 0.39 | 34.41 | 3.05 | 0.72 | 14.31 | 1.90 | 0.35 | 38.62 | 3.43 | 0.53 |
| | **L** | 6.61 | 0.87 | | 34.77 | 2.96 | | 14.20 | 1.75 | | 38.60 | 3.63 | |
| | **M** | 6.64 | 0.78 | 0.13 | 35.01 | 2.49 | 0.10 | 14.36 | 1.55 | 0.28 | 38.86 | 3.61 | 0.16 |
| | **F** | 6.70 | 0.95 | | 34.12 | 3.07 | | 14.14 | 1.77 | | 38.33 | 3.02 | |

**Table 4: Comparative analysis of angular measurements**

| | | PTA | | | PSA | | |
|---|---|---|---|---|---|---|---|
| | | Mean | SD | P-value | Mean | SD | P-value |
| C2 | R | 43.21 | 3.38 | 0.64 | 12.23 | 5.19 | 0.89 |
| | L | 43.65 | 3.24 | | 12.35 | 5.13 | |
| | M | 43.49 | 3.09 | 0.68 | 12.32 | 5.15 | 1 |
| | F | 43.36 | 2.93 | | 12.26 | 5.15 | |
| C3 | R | 41.65 | 3.53 | 0.37 | 15.19 | 5.74 | 0.95 |
| | L | 41.47 | 3.82 | | 15.22 | 5.72 | |
| | M | 41.81 | 3.46 | 0.54 | 16.04 | 5.99 | 0.32 |
| | F | 41.29 | 3.20 | | 14.28 | 5.27 | |
| C4 | R | 42.14 | 4.44 | **0.01** | 17.40 | 5.93 | 0.82 |
| | L | 42.67 | 3.56 | | 17.48 | 5.81 | |
| | M | 42.51 | 3.64 | 0.85 | 17.97 | 6.37 | 0.10 |
| | F | 42.29 | 3.72 | | 16.84 | 5.16 | |
| C5 | R | 42.28 | 4.33 | 0.28 | 17.11 | 5.99 | 0.92 |
| | L | 42.16 | 4.78 | | 17.12 | 5.94 | |
| | M | 42.45 | 4.60 | 0.40 | 17.66 | 6.25 | 0.35 |
| | F | 41.96 | 4.13 | | 16.51 | 5.55 | |
| C6 | R | 41.63 | 3.48 | 0.20 | 14.00 | 1.15 | **0.01** |
| | L | 41.6 | 3.90 | | 14.82 | 9.47 | |
| | M | 41.99 | 3.41 | 0.63 | 14.20 | 5.08 | **0.01** |
| | F | 41.19 | 3.21 | | 14.64 | 7.23 | |
| C7 | R | 38.62 | 3.43 | 0.53 | 14.80 | 4.48 | 0.96 |
| | L | 38.60 | 3.63 | | 14.788 | 4.5075 | |
| | M | 38.86 | 3.61 | 0.16 | 14.34 | 4.1817 | 0.30 |
| | F | 38.33 | 3.02 | | 15.31 | 4.771 | |

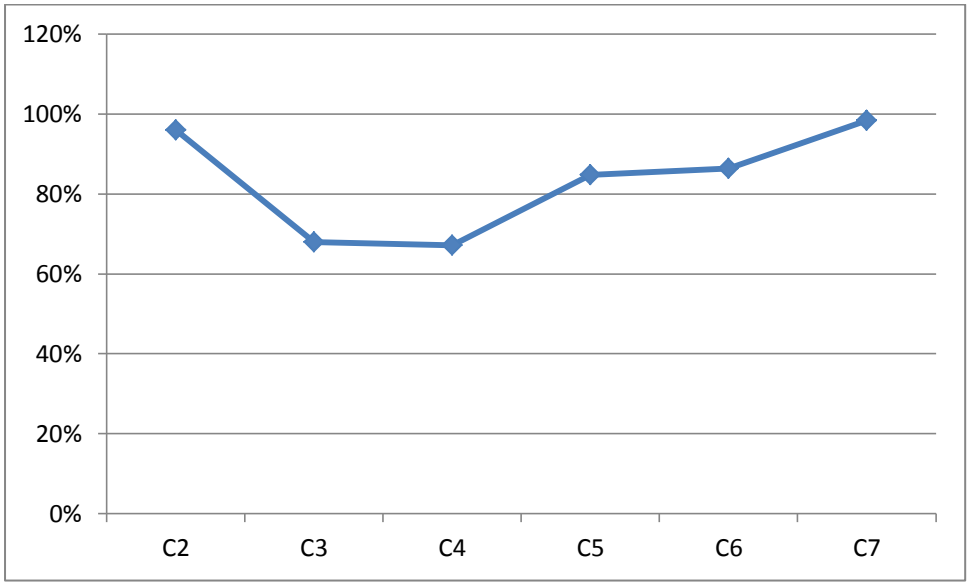
### 4.4 Feasibility of trans-pedicle screw

Current used pedicle screws have a diameter of 3.5mm and the safety for fixation requires at least 4.5mm of both Pedicle Width and Pedicle Height. Likelihood of safe trans-pedicle fixation in our study is highest at C7 with a percentage of 98%, followed by C2 (96%), C6 (86.4%), C5 (84.80%), C3 (68%) then C4 (67.20%).

**Table 5: Percentages of PW and PH with ≥4.5mm**

| | | n | Percentage |
|---|---|---|---|
| C2 | Bilateral PW≥ 4.5 | 120 | 96% |
| | Bilateral PH≥ 4.5 | 125 | 100% |
| | Combined bilateral PW and PH | 120 | **96%** |
| C3 | Bilateral PW≥ 4.5 | 85 | 68% |
| | Bilateral PH≥ 4.5 | 121 | 96.80% |
| | Combined bilateral PW and PH | 85 | **68%** |
| C4 | Bilateral PW≥ 4.5 | 84 | 67.20% |
| | Bilateral PH≥ 4.5 | 122 | 97.60% |
| | Combined bilateral PW and PH | 84 | **67.20%** |
| C5 | Bilateral PW≥ 4.5 | 109 | 87.20% |
| | Bilateral PH≥ 4.5 | 121 | 96.80% |
| | Combined bilateral PW and PH | 106 | **84.80%** |
| C6 | Bilateral PW≥ 4.5 | 109 | 87.20% |
| | Bilateral PH≥ 4.5 | 124 | 99.20% |
| | Combined bilateral PW and PH | 108 | **86.40%** |
| C7 | Bilateral PW≥ 4.5 | 123 | 98.40% |
| | Bilateral PH≥ 4.5 | 125 | 100% |
| | Combined bilateral PW and PH | 123 | **98.40%** |

**Figure 9: Graph of safe feasibility of pedicle screws fixation by vertebra**



# CHAPTER FIVE: DISCUSSION

## 5.1 Introduction

The knowledge of cervical spine anatomy and good interpretation of CT-scan images are useful for spine surgeons and implants designers to avoid damage to regional vital structures. Variability in vertebral dimensions exists amongst different populations and prevents the standardization fixation. This has led many researchers to describe the morphological characteristics of cervical column and study its dimensions via direct measurement by CT-scans of bony structures harvested on cadavers.

Our sample was comparable to those reported in similar studies. Leonard Westermann used 100 CT-scan when he was doing a study in Germany (25), Singh used also 100 C-spines in Nepal (20). Others used the sample sizes ranging from 51 to 100. (3), (11), (21), (22)

### 5.2 Description of values

### 5.2.1 Pedicle width

The pedicle width is an important variable to determine the safety of screw insertion. As indicated by Table 2 and Figure3, the pedicle widths were bigger on C2, with the mean of 6.38mm. The mean declined to 5.03mm on C3 then gradually increased up to 6.67mm on C7. The same trend from C3-C7 was also seen by other researchers (2), (11), (14), (34).

The mean of PW for all levels was 5.76mm and it was comparable to other populations. As reported by Saluja in a review which was comparing Indians with other populations, Americans had the mean PW of 5.98mm, Turkish have 5.58mm and Indians had 4.76mm for (11).

Our values for C2 showing the mean of 6.38mm which is higher than that for Moroccans as reported by Hilman in 100 cases study, the mean PW for C2 was 5.3mm (35). However, there are researchers who found higher values compared to our findings. In New Orleans, USA, Howington reported the mean PW for C2 of 7.9mm, (36), in Georgia the PW of the population was found to be 8.0mm (37) and then one study in Turkey on dry bones, Naderi found PW of C2 of 11.1mm (38).

The big PW of C2 provides safety for pedicle screw fixation but surgery becomes precarious when going down to C3, C4 and C5. The width becomes gradually bigger from C3 to C7.

On table below, we can compare sub-axial C-spine of our population to others

**Table 6: Comparison of PW means of our study with others in millimetres (mm)**

| **Study** | **State/country** | **Year of study** | **C3** | **C4** | **C5** | **C6** | **C7** |
|---|---|---|---|---|---|---|---|
| Present study | Rwanda | 2019 | 5.03 | 5.22 | 5.57 | 5.71 | 6.67 |
| (14) | China | 2007 | 4.9 | 5.1 | 5.8 | 6.0 | 6.5 |
| (2) | Egypt | 2014 | 4.6 | 4.8 | 5.1 | 5.7 | 6.45 |
| (39) | India | 2013 | 7.50 | 7.99 | 7.85 | ------ | ----- |
| (3) | India | 2012 | 4.71 | 4.76 | 4.96 | 5.34 | 6.03 |
| (40) | Japan | 2008 | 5.4 | 5.5 | 5.7 | 5.9 | 6.7 |
| (34) | Austria | 2007 | 5.7 | 5.6 | 6.2 | 6.7 | 7.9 |
| (37) | Georgia | 1997 | 4.8 | 5.2 | 6.1 | 6.5 | 6.9 |
| (19) | Thailand | 2014 | 5.17 | 5.46 | 5.69 | 5.89 | 6.49 |

On the table above, considering the PW means, we can clearly see the position of our people. Our values are larger compared to those of China, India and Egyptians but less to those of Japanese, Thais and Austrians.

Different anatomical findings within the same population can be explained by the type of measurement tool used but also their ethnicity and different locations within their country. Good examples are reported in the article review by Chazono in which he detailed differences in findings depending on ethnicity and the quality of CT-scan machine and tool of measurement (8).

Pedicle widths at all levels were showing males predominance which are not statistically significant, p-value>0.05). same findings were reported by researchers (3), (11), (25), (40).

### 5.2.2 Pedicle Axis Length

The pedicle Axis length is calculated as the length of the line passing along the pedicle from the most posterior cortex up to the most anterior cortex.

Its surgical application is to determine the maximum length of the screw from posterior point of screw entrance up to the most anterior cortex of the vertebral body. It helps the surgeon to choose the appropriate screw length which cannot go beyond the length of the vertebra in order to avoid further damages.

Findings showed a gradual increase from C2-C7. These results were comparable with those found by Banerjee in Indian population who did the analysis of subaxial C-spine and had the results as follow 28.72mm, 28.77mm, 30.51mm, 32.97mm and 34.79mm for C3, C4, C5, C6 and C7 (3). Mohi Eldin had almost the same results for Egyptians population, in radiological measurements; he found the means of PAL of follow 32.3mm, 33.3mm, 36.6mm, 34.2mm and 36.5mm at C3, C4, C5, C6 and C7.(2)

In our study, the left sided pedicle axis length (PAL) was found to be predominant with statistical significance at C4, C5 and at C6. Female predominance was also seen at C3.The left sided dominance was also reported by Banerjee at the level of C4, C5, C6 and C7 (3).

### 5.2.3 Pedicle Length

It is the linear measurement from the most posterior cortex along the pedicle up to the most posterior cortex of the vertebral body. Surgically it is the shortest screw size that can cross the pedicle.

Findings from our study showed a progressive increase from C2, C3, C4, C5, C6 and C7. The distribution with sides showed the right side dominance at C3. However, the left side had bigger values compared to the right at C6. Almost same results were reported in China by Su, with 14.9mm, 14.3mm, 14.9mm, 15.1mm and 15,4mm for C3, C4, C5, C6 and C7 (14). In Thailand, results were almost similar but a bit higher than our population with 14.92mm, 14.84mm, 15.74mm, 15.76mm, and 15.10mm at C3, C4, C5, C6 and C7. (19)

This parameter was not studied by many researchers as it is not very sensitive in surgical fixation of the spine.

### 5.2.4 Pedicle Height

It's an important parameter to analyse because pedicle screw fixation is risky for patients with values less than 4.5mm. The cut-out of the screw in the sagittal plane of the pedicle may result in nerve root injury. In our study, it was found to be bigger compared to the pedicle width. Its trend along the C-spine was the same as pedicle width as it was big at C2, and smaller at C3. It was then increasing from C3 to C7.

In relation to other population, the sizes were comparable with the population of Thailand where values are 9.37mm, 6.52mm, 6.96mm, 6.96mm and 7.47mm from C3, C4, C5, C6 and C7 (19). In another Thailand study by Reinhold, the values of PH were almost similar but with C3 which was bigger compared to the rest of subaxial spine. He found 7.5mm, 7.1mm, 6.8mm, 6.7mm and 7.2mm for C3, C4, C5, C6 and C7 (34). Our pedicle heights were also comparable to Egyptians (2) and a bit bigger to Chinese (14).

However, our measurements were smaller to those found by Joses in Georgia especially at the level of C2, C3 and C4. In his study, he had 9.4mm, 7.4mm, 8.0mm, 7.4mm, 6.7mm and 7.1mm for C2, C3, C4, C5, C6 and C7 (37).

The results of our study showed that males had big PH at all levels compared to female but statistically significant at C2 where the mean for males was 8.4mm against 8.0 for female [p-value<0.05]. The left sided pedicle length means in our study were also bigger than right al

almost all levels and significant at C2. In his study from C3-C5, Liu didn't find the difference in sides (39) and it was also the same for saluja (11)

### 5.2.5 Angular measurements

Angular measurements were calculated from axial views for Pedicle Transverse angle (PTA) and on Sagittal view for pedicle sagittal angle (PSA). Their surgical importance is the orientation of the screw during the fixation through the pedicle.

Our values for PTA were showing a decrease in values from C2 to C7. Same trend and values were found by Su in Chinese population with values in degrees of 48.0, 48.3, 47.3, 43.6 and 38.7 for C3, C4, C5, C6 and C7 (14). Bigger PTA were reported by Kanthika in Thailand with 46.36°, 48.5°, 48.89°, 44.30° , 38.79° for C3, C4, C5, C6 and C7 (19). No clear dominance in sides or gender was seen in our study and similar results were noted by other researcher (19), (34), (40).

The values of PSA were smaller on C2, C6 and C7. The orientation was also not the same for all vertebras. The orientation was cephalic on C2 and caudal on others. The change in orientation was described by Chazono as C2 and C3 angles directing cephalic with transition to C4 for caudal orientation (40), and same results also found by Reinholh (34).

The high variations in angles has led to researchers to the conclusion of not relying on known gender, ethnic and sides dominance, but use individual analysis of CT-scan and the image intensifier during spine fixation (8), (19), (34).

## 5.3 Age- related variations

The regression slop as seen on **table 2**, shows that the variations are significant for some measured variables. Statistical significance for our measurements is defined as the deviation from 0mm/year or 0degree/year. Considering the variables trends along years, we had linear measurements increase and angular measurements decrease.

For example, as seen on table2, we had the increase of PW on C2 of 0.001666 mm every year. This mean that when considering 18 years old person and 90 years old, the age difference is 72 years but PW difference is not above 0.12mm [0.001666x72]. The difference was still around zero, and considered not significant.

Significant variations with age were noted on Pedicle axis length and on angular measurement. The biggest variation was seen on PTA of C5 where the slop was -0.1070

degrees per year, and we expect the decrease of 7.704 degrees of transverse angle deviation between 18 years old person compared to a 90 years old. It waas statistically significant as p-value is <0.0001.

The influence of aging in morphometric changes was reported in paediatric population but not in adult people by Chazono (8), but bony spurs and compression load on vertebral end-plates may change linear and angular measurements as reported by (41).

**5.4 Safe surgery fixation with pedicle screws**

The safety of pedicle fixation with current screw of 3.5mm is guaranteed when two of 6 measured variables, Pedicle Width (PW) and Pedicle Height values are equal or more than 4.5mm on both sides.

From our measurements, the percentage of safe fixation was higher on **C2** and **C7** with the percentages **96%** of and **98.4%.** For other vertebras, the pedicle screws fixation was found risky because the percentages of safety were 86.4%, 84.8%, 67.2% and 68% for C6, C5, C4 and C3. No significant gender difference seen in our values.

From other researchers, a French Ould analysed 100 CT-scan and found that surgery by pedicle screws on C2 was safe for 92.5%, safer were males with 93.2% (42). Chazono, in his study of Japanese, he defined unsafe pedicle fixation as those done for patients with PW<4.0mm, and found the safety of surgery to be 91.5% at C3, 92.1% at C4, 98.4% at C5 , 98.4% at C6 and 100% at C7 (40). Reinhold did a study in Austria on C-spine, he harvested vertebra on cadavers and did manual instrumentation with pedicle screws then did a CT-scan of them; he found more cortical injuries on C3 and C4 which is the same for our study (34).

Current literatures recommend transpedicle screws fixation on C2 and C7 and use lateral masses fixation on other subaxal cervical spine (19). Yukawa did also CT-scan analysis on 144 operated patient from C2 up to T2 by using pedicle screws fixation and found 0% of screw perforation on C7, 2% on C6, 5% on C5, 6% on C4, 4% on C3 and 7% on C2(6).

In the same study, done from 1995 up to 2008, the total placed screws were 620. They found a high percentage of pedicle perforation of 9.2% and only in one case the vertebral artery was injured and one case of spinal cord injury with persistent radiculopathy. (6)

In the same country a multicentre study showed malposition rate of 19.5%. Five patients had complications related to pedicle screws including 3 with nerve root injury and 2 with vertebral artery injury. (7)

In some centres, they even tried to use EMG (electromyography) for pedicle screws fixation to monitor injury to the neural elements. Robert Holdefer and colleagues of USA in 2013 showed that a proper preoperative CT-scan analysis is far better than EMG. (43)

At the end of all, the morphometric analysis of the spine by use of CT-scan was found the best way to predict the safety of pedicle screws fixation because of variety in population. (2), (9), (15)

### 5.5 Study limitations

The study was focusing on two parameters that affect the morphometry of cervical spine pedicles, age and sex. The body mass index was not included in our study.

# CHAPTER SIX: CONCLUSION AND RECOMMENDATION

## 6.1 INTRODUCTION

Morphometric analysis of cervical spine, as anatomical study of the morphology, it is done in different ways and variables may differ according to the aim of the researcher. Our study was mainly focusing on surgical anatomy for the safety use of pedicle screws as a guaranteed stable fixation in our population.

The results may be of great importance in our settings and may be used by other researchers in our region and worldwide.

## 6.2 CONCLUSION

- Our findings regarding Pedicle Widths and Pedicle Heights values, as major determinants of safe surgery in cervical pedicle fixation reassured us at the level of C2 and C7. But many precautions have to be considered when the surgeon has to fix C3, C4, C5 and C6.
- We found Pedicle widths have non-significant side or gender predominance and then not considerable in cervical spine surgery. It is then different from other studies which reported significant predominance.
- From our study, Pedicle Length and Pedicle Axis length as the linear measurements which determine the maximum and minimum screw length gradually increasing from C2 to C7 and no side or gender dominance. The important message is that, Screws to be used have to be gradually longer from C2-C7.
- Cervical spines of our population had Pedicle Transverse Angles which were gradually decreasing from C2 to C7 with no side or gender dominance. Hence, the coronal inclination of screws from lateral to medial must decrease as the surgeon moves caudally during C-spine pedicle fixation.
- Pedicle Sagittal angles were directed cephalic for C2 and caudal from C3 to C7, the same pedicle screws orientations have to be applied in C-spine fixation.
- Age related variations were mainly affecting angular measurements but more variable from person to another. Individual analysis of CT-scan before surgery is indicated.

## 6.3. RECOMMENDATIONS

- The use of pedicle screws of 3.5mm diameter for fixing C2 and C7 is safe in our population. However, we recommend the use the lateral mass instrumentation on the remaining subaxial cervical spine when the posterior fixation is required, because complications may be rated at around 20% based on our pedicle values.
- Research on the safe use of 3mm pedicle screws fixation for subaxial cervical spine.
- We recommend considering individual analysis of cervical spine CT-scan prior to the surgical fixation of cervical spine as we have seen significant variations in our population.
- Cadaveric researches are encouraged to be done in coming days for the proper anatomical knowledge.

## REFERENCE


1. Aydogan M, Enercan M, Hamzaoglu A, Alanay A. Reconstruction of the subaxial cervical spine using lateral mass and facet screw instrumentation. Spine (Phila Pa 1976). 2012;37(5):349–56.

2. Mohi Eldin MM. Cervical pedicle screw fixation: Anatomic feasibility of pedicle morphology and radiologic evaluation of the anatomical measurements. Asian Spine J. 2014;8(3):273–80.

3. Banerjee P. Morphometric analysis of the cervical spine of Indian population by using computerized tomography. J Med Al l i e d S c i. 2012;2(2):66–76.

4. Abdullah KG, Steinmetz MP, Mroz TE. Morphometric and volumetric analysis of the lateral masses of the lower cervical spine. Spine (Phila Pa 1976). 2009;34(14):1476–9.

5. Ito Z, Higashino K, Kato S, Kim S, Wong E, Yoshioka K. The limitation of lateral mass screws as compared to pedicle screws for cervical fixation: a biomechanical study. 2011;(733):2011.

6. Yukawa Y, Kato F, Ito K, Horie Y, Hida T, Nakashima H, et al. Placement and complications of cervical pedicle screws in 144 cervical trauma patients using pedicle axis view techniques by fluoroscope. Eur Spine J. 2009;18(9):1293–9.

7. Nakashima H, Yukawa Y, Imagama S, Kanemura T, Kamiya M, Yanase M, et al. Complications of cervical pedicle screw fixation for nontraumatic lesions: a multicenter study of 84 patients. J Neurosurg Spine. 2011;16(3):238–47.

8. Chazono M et al. Ethnic differences in pedicle and bony spinal canal dimensions calculated from computed tomography of the cervical spine: A review of the English-language literature. Eur Spine J. 2012;21(8):1451–8.

9. Munusamy T, Thien A, Anthony MG, Bakthavachalam R, Dinesh SK. Computed tomographic morphometric analysis of cervical pedicles in a multi-ethnic Asian population and relevance to subaxial cervical pedicle screw fixation. Eur Spine J. 2014;24(1):120–6.

10. Kabins MB, Weinstein JN. The History of Vertebral Screw and Pedicle Screw Fixation. Iowa Orthop J. 1991;11:127–36.

11. Saluja S, Patil S, Vasudeva N. Morphometric analysis of sub-axial cervical vertebrae and its surgical implications. J Clin Diagnostic Res. 2015;9(11):AC01–4.

12. Rao. K EV, Rao BS, Vinila BHS. Morphometric Analysis of Typical Cervical Vertebrae and Their Clinical Implications: a Cross Sectional Study. Int J Anat Res [Internet]. 2016;4(4.1):2988–92. Available from: http://www.ijmhr.org/ijar.4.4/IJAR.2016.390.html

13. Oh SH, Min WK. Analysis of cervical pedicle with reconstructed computed tomography imaging in Korean population feasibility and surgical anatomy. J Spinal Disord Tech. 2014;27(3):99–103.

14. Su P, Ma R, Li C, Liu S, Huang D. Pedicle screw fixation of the cervical spine: Guidance by computed tomography. Clin Orthop Relat Res. 2007;(462):99–104.

15. Al-Saeed O, Marwan Y, Kombar OR, Samir A, Sheikh M. The feasibility of transpedicular screw fixation of the subaxial cervical spine in the Arab population: a computed tomography-based morphometric study. J Orthop Traumatol. 2016;17(3):231–8.

16. Schneider E, Linke B. Biomechanical analysis of transpedicular screw fixation in the subaxial cervical spine. Spine (Phila Pa 1976). 2004;29(17):1869–75.

17. Pelton MA. Subaxial Cervical and Cervicothoracic Fixation Techniques-Indications, Techniques, and Outcomes [Internet]. Vol. 43, Orthopedic Clinics of North America. Elsevier Inc; 2012. p. 19–28. Available from: http://dx.doi.org/10.1016/j.ocl.2011.08.002

18. Vincent J. Devlin M. Spine secrets Plus. 2nd editio. Barbara Cicales, editor. Vol. 91. Riverport Lane St. Louis, Missouri: Anne Altepeter; 2012. 001–541 p.

19. Kanthika W, Permsak P, Panya T, Winai S, Taweechok W, Weerachai K. Morphological Study of Subaxial Cervical Pedicles by Using Three-Dimensional Computed Tomography Reconstruction Image. 2014;(c):736–45.

20. Singh S, Balakrishnan M. Morphometric study of cervical spine vertebrae in eastern region Nepalese population. 2013;11(May 2003):224–8.

21. Murahari P, Bhargav H, Kumar AL, Santosh KV, Reddy LJ, Banala RR, et al.

Subaxial Cervical Pedicle Morphometric Assessment in Normal South Indian Subjects using Computed Tomography Scan Images. J Spinal Surg. 2017;4(4):158–63.

22. Devaraj B, Thangavel M, RR DVA, Nallan R, Manoranjitham D, Thangavel M. Morphometric analysis of typical cervical vertebral pedicle - An osteological study. Int J Orthop Sci. 2018;3(4j):704–8.

23. Reinhold M, Magerl F, Rieger M, Blauth M. Cervical pedicle screw placement: Feasibility and accuracy of two new insertion techniques based on morphometric data. Eur Spine J. 2007;16(1):47–56.

24. Wakao N, Takeuchi M, Nishimura M, Riew KD, Kamiya M, Hirasawa A, et al. Risks for vascular injury during anterior cervical spine surgery. Spine (Phila Pa 1976). 2016;41(4):293–8.

25. Westermann L, Spemes C, Eysel P, Simons M, Scheyerer MJ, Siewe J, et al. Computer tomography-based morphometric analysis of the cervical spine pedicles C3–C7. Acta Neurochir (Wien). 2018;160(4):863–71.

26. Zhao L, Li G, Liu J, Benedict GM, Ebraheim NA, Ma W, et al. Radiological studies on the best entry point and trajectory of anterior cervical pedicle screw in the lower cervical spine. Eur Spine J. 2014;23(10):2175–81.

27. Evangelopoulos D, Kontovazenitis P, Kouris S, Zlatidou X, Benneker L, Vlamis J, et al. Computerized Tomographic Morphometric Analysis of the Cervical Spine. Open Orthop J. 2012;6(1):250–4.

28. Johnson KT, Al-Holou WN, Anderson RCE, Wilson TJ, Karnati T, Ibrahim M, et al. Morphometric analysis of the developing pediatric cervical spine. J Neurosurg Pediatr. 2016;18(3):377–89.

29. Morales-Avalos R, Martínez-González B, Villarreal-Garcia FI, Requena-Araujo PM, Martínez-Gutiérrez OA, Reyes-Fernández PM, et al. Variations in the Torg-Pavlov Cervical Ratio with Regard to Age and Sex. A Comprehensive Anatomical and Morphometric Study on Contemporary Cadaveric Specimens. Int J Morphol. 2018;36(2):598–607.

30. Kasiulevičius V, Šapoka V, Filipavičiūtė R. GERONTOLOGIJA Sample size

calculation in epidemiological studies. Vol. 7, Gerontologija. 2006.

31. Nkusi AE, Muneza S, Hakizimana D, Nshuti S, Munyemana P. Missed or Delayed Cervical Spine or Spinal Cord Injuries Treated at a Tertiary Referral Hospital in Rwanda. World Neurosurg [Internet]. 2016;87:269–76. Available from: http://dx.doi.org/10.1016/j.wneu.2015.11.092

32. Allen Ingabire JC, Byiringiro JC, Calland JF, Petroze RT, Ntakiyiruta G, Jayaraman S. Using a Trauma Registry and Quality Indicators to Evaluate Trauma Care in Rwanda. J Am Coll Surg [Internet]. 2014;219(3):S105. Available from: http://linkinghub.elsevier.com/retrieve/pii/S1072751514007856

33. E. Okello, M. Nyati EKN. Prevalence and presentation of spine injury in patiennts with major trauma admitted in Mulago hospital. East Cent Afr J surg Outcome. 2013;18(April):31–9.

34. Reinhold M et al. Cervical pedicle screw placement: Feasibility and accuracy of two new insertion techniques based on morphometric data. Eur Spine J. 2007;

35. Hilmani S, Amzil R, El-Azhari A. CT Evaluations for C2 Pedicle Screw Fixation: Multiplanar Computerized Tomography Measurements in 100 Moroccan Patients. J Spine. 2017;06(02):6–9.

36. Howington JU, Kruse JJ, Awasthi D. Surgical anatomy of the C-2 pedicle. J Neurosurg Spine. 2009;

37. Jones et al. Cervical spine pedicle screws versus lateral mass screws. Atlanta, Georgia: Spine, vol22; 1997.

38. Naderi S, Arman C, Güvençer M, Korman E, ŞsenoğLu M, Tetik S, et al. An anatomical study of the C-2 pedicle. J Neurosurg Spine. 2009;

39. Liu, Jingchen et al. A novel method of cervical pedicle screw placement from C3 to C5 and its clinical applications. Spine (Phila Pa 1976). 2013;38(8).

40. Chazono M et al. Anatomical considerations for cervical pedicle screw insertion: the use of multiplanar computerized tomography reconstruction measurements. J Neurosurg Spine. 2008;4(6):472–7.

41. Ferguson SJ. Biomechanics of the aging spine. 2003;12:97–103.

42. Ould-Slimane M, Le Pape S, Leroux J, Foulongne E, Damade C, Dujardin F, et al. CT analysis of C2 pedicles morphology and considerations of useful parameters for screwing. Surg Radiol Anat. 2014;36(6):537–42.

43. Holdefer RN, Heffez DS, Cohen BA. Utility of evoked EMG monitoring to improve bone screw placements in the cervical spine. J Spinal Disord Tech. 2013;26(5):163–9.

# APPENDIX

## 1. Time of research

| Item | February-April 2019 | May 2019 | June 2019 |
|---|---|---|---|
| Proposal writing | | | |
| Proposal submission | | | |
| Data collection | | | |
| Data analysis | | | |
| Submission of final report | | | |

## 2. Budget

| Item | Quantity | Unity cost | Total cost |
|---|---|---|---|
| Research Assistant/Radiographer | 1 | 100.000 Frw | 100.000 frw |
| Statistician | 1 | 100.000 Frw | 100.000 frw |
| Communication and transport | | | 100.000 frw |
| External Hard Disc | 1 | | 80.000 frw |
| Report writing, printing and bundling | 3 books | 30.000 frw | 90.000 frw |
| Total cost | | | **470.000 frw** |

The total budget was from the principle investigator

## 3. DATA EXTRACTION FORM

Age:

Sex:

Study ID:

| Vertebral level | Pedicle Width | | Pedicle Axis Length | | Pedicle Length | | Pedicle Transverse Angle | | Pedicle Height | | Pedicle Sagittal Angle | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | R | L | R | L | R | L | R | L | R | L | R | L |
| C2 | | | | | | | | | | | | |
| C3 | | | | | | | | | | | | |
| C4 | | | | | | | | | | | | |
| C5 | | | | | | | | | | | | |
| C6 | | | | | | | | | | | | |
| C7 | | | | | | | | | | | | |

R: Right side

L: Left side

## 4. Letter of IRB approval and clearance