ETHNIC VARIATIONS OF SELECTED CERVICAL SPINE RADIOGRAPHIC PARAMETERS OF FEMALES IN KWAZULU NATAL

By

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I, Janeene Tamara Naicker, do hereby declare that this dissertation is representative of my own work in both conception and execution (except where acknowledgements indicate to the contrary)

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DEDICATION

I dedicate this dissertation to:

My heavenly father Jesus Christ, I thank You for Your guidance, unconditional love and hand of protection over my life, and I acknowledge that I am nothing without You.

My parents, Mrs. Charmaine Naicker and Mr. Indresin Naicker and my stepfather Mr.Thiagaraj John, thank you for all the sacrifices you have made throughout the years so that I could achieve my goals; but most of all thank you for all the love and support you have given me and for the good morals and faith that you have instilled in me. I love you.

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ABSTRACT

Aim: To evaluate the normal selected cervical spine radiographic parameters i.e. the cervical lordosis (CL), sagittal canal diameter (SCD), interpedicular distance (IPD) and cervical gravity line (CGL) in asymptomatic young to middle-aged females across four ethnic groups (Black, White, Indian and Coloured) in Durban, KwaZulu Natal, South Africa.

Participants: Eighty apparently healthy females between the ages of 18 and 45 years from the Black, Indian, Coloured and White ethnic groups in Durban, KwaZulu Natal.

Methodology: Written informed consent was obtained from each participant. A case history, physical examination and an orthopaedic assessment of the cervical spine was conducted for each participant. Study specific data such as ethnicity, age, height and weight was recorded. A lateral and an A-P radiograph of the cervical spine were taken for each participant. The selected radiographic parameters viz. cervical lordosis (CL), sagittal canal diameter (SCD), interpedicular distance (IPD) and cervical gravity line (CGL) were evaluated according to methods described previously. SPSS version 15.0 (SPSS Inc., Chicago, Illinois, USA) was used for data analysis. Coefficients of variation were calculated within ethnic groups to assess intra-group variation. Inter-group variation was assessed using ANOVA testing with Bonferroni-adjusted *post-hoc* tests in the case of a significant ANOVA test. Pearson's chi square test was used to assess the association between ethnic groups and position of the CGL. T-tests were used to compare mean CL between those with anterior and normally placed CGL within each ethnic group.

Results:

The mean ± SD of the CL in South African females by ethnic group using the C1-C7 and C2-C7 methods

CERVICAL LORDOSIS (mean ± SD) (°)		
ETHNICITY	**C1-C7**	**C2-C7**
Black	42.1° (±13.4)	16.3° (±8.3)
White	37.4° (±10.3)	9.9° (±4.8)
Indian	33.7° (±9.7)	6.9° (±4.8)
Coloured	42.5°(±10.9)	12.1° (±9.5)

The mean ± SD of the SCD in South African females by ethnic group

SAGITTAL CANAL DIAMETER (mean ±SD)(mm)						
ETHNICITY	**SCDC2**	**SCDC3**	**SCDC4**	**SCDC5**	**SCDC6**	**SCDC7**
Black	20.2 (±1.7)	17.4 (±1.4)	17.2 (±1.4)	17.0 (±1.4)	17.6 (±1.3)	17.5 (±1.4)
White	20.8 (± 2.2)	17.9 (±1.6)	17.6 (±1.6)	17.4 (±1.6)	17.6 (±1.4)	16.9 (±1.4)
Indian	21.0 (±2.0)	18.2 (±1.7)	17.5 (±1.5)	17.4 (±1.7)	17.6 (±1.6)	17.1 (±1.5)
Coloured	20.3 (±1.6)	17.5 (±1.8)	17.4 (±1.5)	17.7 (±1.2)	17.6 (±1.3)	16.9 (±1.2)

The mean ± SD of the IPD in South African females by ethnic group

INTERPEDICULAR DISTANCE (mean ±SD)(mm)					
ETHNICITY	**IPDC3**	**IPDC4**	**IPDC5**	**IPDC6**	**IPDC7**
Black	27.0 (±2.8)	27.6 (±3.2)	28.2 (±4.0)	28.9 (±4.2)	27.5 (±3.5)
White	28.4 (±2.6)	28.8 (±2.2)	29.5 (±2.3)	29.3 (±2.5)	28.2 (±2.9)
Indian	27.2 (±1.8)	27.5 (±1.8)	27.9 (±1.6)	27.9 (±1.6)	27.5 (±2.0)
Coloured	27.9 (±2.3)	27.8 (±2.3)	28.3 (±2.2)	28.4 (±1.8)	28.2 (±1.7)

The placement of the CGL in South African females in each ethnic group

CERVICAL GRAVITY LINE	
ETHNICITY	**PLACEMENT OF CGL**
Black	70% anterior placement
White	70% anterior placement
Indian	60% anterior placement
Coloured	60% anterior placement

The C1-C7 measurements and the C2-C7 CL measurements were significantly different amongst the ethnic groups. For the C2-C7 method, Blacks differed significantly from both Whites (p = 0.037) and Indians (p = 0.001; Bonferroni adjusted *post-hoc* test); with the values for the Blacks being higher than both Whites and Indians. There was no correlation between CL and BMI amongst any of the selected ethnic groups. There were no significant differences in the mean SCD and IPD amongst the ethnic groups (p > 0.05; ANOVA test). There was no significant association between any ethnic group and the position of the CGL (p = 0.830; Pearson's chi square test). In Black females, those with a normally positioned CGL had significantly higher C2-C7 CL measurements (p = 0.008; T-tests). There was no correlation between the CL and anterior placing of the CGL in any of the ethnic groups.

Conclusion: No individual differences were observed in the CL amongst the ethnic groups when using the C1-C7 method. However, significant differences were observed when the C2-C7 method was used. There were no significant differences observed in the mean SCD and IPD amongst the ethnic groups. In Black females, those with a normally positioned CGL had significantly higher C2-C7 CL measurements. The trends observed in this research study and the differences in the findings to those of previous studies lay the platform for a larger population-based study across South Africa to establish normative reference values for each radiographic parameter specific for gender and ethnicity.

LIST OF SYMBOLS AND ABBREVIATIONS

=:	Results are the same as those of previous studies
>:	Greater than
<	Less than
°:	Degrees
↑**:**	Increase
↓**:**	Decrease
ABCS:	Alignment, Bone, Cartilage and Soft tissue
ALL:	Anterior longitudinal ligament
ANOVA:	Analysis of variance
A-P:	Anterior to posterior
B:	Black
BMI:	Body mass index
C:	Coloured
CDC:	Chiropractic Day Clinic
CL:	Cervical lordosis
CGL:	Cervical gravity line
CT:	Computed tomography
DISH:	Diffuse idiopathic skeletal hyperostosis
DUT:	Durban University of Technology
EOP:	External occipital protuberance
F:	Female

FFD:	Focal film distance
I:	Indian
IVD:	Intervertebral disc
IVDs	Intervertebral discs
IVF:	Intervertebral foramina
IPD:	Interpedicular distance
kg:	Kilograms
$kg.m^{-2}$	Kilograms per meter squared
kV:	Kilovolt
M:	Male
m:	Metres
mAs:	Milliamperes per second
mm:	Millimetres
MRI:	Magnetic resonance imaging
***n*:**	Sample size or count
N/A:	Not applicable or Not available
OFD:	Object film distance
PLL:	Posterior longitudinal ligament
SCD:	Sagittal canal diameter
SPSS:	Statistical Package for the Social Sciences
TVP:	Transverse process
TVPs	Transverse processes
USA:	United States of America
VP:	Vertebra prominens

viz:	Namely
W:	White
yrs:	Years

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CHAPTER ONE

INTRODUCTION

1.1 INTRODUCTION TO THE STUDY

Radiographs are the primary investigation of choice in the diagnosis of cervical spinal disorders, injuries and congenital malformations (Yochum and Rowe, 2005a; Dai *et al.,* 2008). The analysis of cervical spinal radiographs is important to chiropractors as a diagnostic means of assessing structure, and to some extent, function of the cervical spine. The radiographic parameters serve as a reference point from which to distinguish variations from the accepted standard (McAviney *et al*., 2005; Yochum and Rowe, 2005a). Therefore, knowledge of the variations in the normative values of the radiographic parameters, between genders and different ethnic groups, is of significant value to chiropractors and medical practitioners.

The method of assessing spinal radiographs described by Yochum and Rowe (2005a) ensures important radiographic parameters such as alignment, bone, cartilage and soft tissue factors are taken into consideration during the evaluation of x-rays. During the assessment of a cervical spine radiograph the following alignment parameters amongst others, are evaluated:

- Cervical lordosis (CL)
- Sagittal canal diameter (SCD)
- Cervical gravity line (CGL)
- Interpedicular distance (IPD) (this parameter is, however, not commonly evaluated during routine assessment of cervical spine radiographs).

Difficulties arise when evaluating alignment parameters between gender and different ethnic groups as there are few widely accepted benchmarks to be utilised as a guide in the identification of abnormal structural and alignment findings (McAviney *et al*., 2005). Several studies have been conducted on the measurement parameters and radiographic alignment of the cervical spine with conflicting results (Jochumsen, 1969; Cooke and Wei, 1988; Owens and Hoiris, 1990; Lim and Wong, 2004; Gore *et al.,* 2006; Tecco and Festa, 2007; Tossel, 2007).The possible reasons for these discrepancies include different methods of assessment and differences in gender and ethnic composition of the population studied.

There are several studies that have reported differences in the radiographic alignment parameters in the different ethnic groups (Payne and Spillane, 1957; Murone, 1974; Solow *et al*., 1982; Lee *et al.,* 1994; Lim and Wong, 2004), but none have been conducted in the four main ethnic groups in a South African female population. Therefore, the aim of this study was to evaluate the normal selected cervical spine radiographic parameters in apparently healthy young to middle-aged females across four ethnic groups in the greater Durban area.

1.2 AIM AND OBJECTIVES OF THE STUDY

The aim of this study was to evaluate the normal selected cervical spine radiographic parameters i.e. the cervical lordosis (CL), sagittal canal diameter (SCD), interpedicular distance (IPD) and cervical gravity line (CGL) in asymptomatic young to middle-aged females across four ethnic groups (Black, White, Indian and Coloured) in Durban, KwaZulu Natal, South Africa.

Specific objectives were identified and these included:

1.2.1 To assess the selected radiographic parameters (CL, SCD, IPD and CGL) in young to middle-aged females across four ethnic groups.

1.2.2 To determine if there was a variation in the selected radiographic parameters within and amongst these ethnic groups.

1.2.3 To determine if there was a significant association between CL and body mass index (BMI).

1.2.4 To determine if the CL had a significant influence on the position of the CGL.

1.3 HYPOTHESES OF THE STUDY

The Alternate Hypothesis (Ha) was set which stated that:

1.3.1 There will be a significant association between the CL and BMI.

1.3.2 The CL will significantly influence the position of the CGL.

1.4 SCOPE OF THE STUDY

The results of 80 healthy adult female participants who met all the inclusion criteria of this study are reported in this dissertation. These participants were recruited using convenience sampling from the general population of Durban, KwaZulu Natal. All the participants were briefed on the nature of the study and each of them signed an informed consent form. All participants underwent a case history, a physical examination and an orthopaedic examination of the cervical spine. An erect anterior to posterior (A-P) and lateral radiograph of the cervical spine was taken for each subject. The selected radiographic alignment parameters of the cervical spine were then evaluated by the researcher according to the techniques originally described by Jochumsen (1969), Wolf *et al*. (1956), Hinck *et al*. (1962), Hinck *et al*. (1966), Fox and Young (1954) and Harrison *et al*. (2000).

1.5 LIMITATIONS OF THE STUDY

The sample size was limited to 20 individuals in each of the selected ethnic groups due to budgetary constraints. The research participants were between the ages of 18 and 45 years. According to the South African Medical Research Council (South African Medical Research Council Guidelines on Ethics for Medical Research, 2002), those younger than 18 years of age are not recommended as participants for research studies. Individuals older than 45 years have a higher incidence of degenerative changes in the cervical spine (Grob *et al.,* 2007). This limited the study of age-related changes to the selected radiographic parameters.

Standard radiographic views of the cervical spine include the A-P, lateral, and A-P open mouth views. The A-P open mouth view is beneficial in assessing atlantoaxial alignment which is altered by a dens fracture, alar ligament instability or atlantoaxial subluxation (Yochum and Rowe, 2005b). The A-P open mouth view was excluded due to financial constraints and also to reduce the radiation exposure to the participants. Therefore, alignment parameters involving the upper two cervical vertebrae and the dens in particular are not reported in this study.

CHAPTER TWO

LITERATURE REVIEW

2.1 INTRODUCTION

The evaluation of cervical spine radiographs provides a conventional investigative measure which assists in the diagnosis and management of cervical spine conditions. Parameters such as the CL, SCD, IPD and CGL serve as a point of reference during radiographic evaluation of the cervical spine. However, discrepancies in the normative reference values of these parameters between genders and the different ethnic groups compromise their value in a clinical setting. Therefore, establishing measurement values for each parameter for the chosen ethnic groups in this study will be of value to South African spine health-care practitioners who rely on these values for determining accurate diagnoses which impacts on the management of patients.

2.2 AN OVERVIEW OF THE RELEVANT BONY ANATOMY OF THE CERVICAL SPINE

The seven cervical vertebrae form the bony skeleton of the neck. They represent the smallest of the 24 movable vertebrae and are located between the skull and thorax (Moore and Dalley, 1999). The atlas (C1) and the axis (C2) are classified as atypical cervical vertebrae whereas vertebrae C3 to C7 are termed the typical vertebrae. The most distinctive feature of cervical vertebrae is the presence of an oval foramen (*pl. foramina*) on the transverse process (TVP) of each vertebra. These foramina are usually smaller or in some cases absent in C7. Vertebral arteries pass through the transverse foramina except those in C7, which transmit only small accessory vertebral veins (Moore and Dalley, 1999).

The atlas is annular-shaped; it supports the skull and cradles the occiput. The union between the head and atlas through the atlanto-occipital joints is strong, and allows only for nodding and lateral movements of the head (Collins *et al.*, 2005). In all other respects the head and atlas move and function essentially as one unit (Bogduk and Mercer, 2000). The elongated and somewhat reniform-shaped, concave superior articular facets of C1 face upwards and medially, and receive two large protuberances at the sides of the foramen magnum known as the occipital condyles (Collins *et al.*, 2005).The atlas does not possess a spinous process or a vertebral body; but consists of a short anterior arch and a longer curved posterior arch, each of which has a tubercle and lateral mass (Collins *et al.*, 2005). The inferior surface of each lateral mass is almost circular, flat or vaguely concave and articulates with a similar articular facet of the axis. The inferior facets of the atlas face downwards, medially and slightly backwards (Collins *et al.*, 2005).

The axis has two large flat surfaces known as the superior articular facets on which the atlas rotates. The most distinguishing feature of the axis is the presence of the tooth-like projection known as the odontoid process or dens, which projects vertically upwards from its body and acts as the pivot around which the atlas and the head rotates (Collins *et al.*, 2005). The odontoid process is held in place by the transverse ligament of the atlas which discourages horizontal displacement of the atlas. The axis has a bifid spinous process unlike the atlas (Moore and Dalley, 1999).

Typical cervical vertebrae (C3-C7) consist of a body from which seven processes project: paired transverse processes (TVPs), paired superior and inferior articular processes and a single spinous process. The body is small and is wider transversely than it is anteroposteriorly. The superior surface is concave, whereas the inferior surface is convex (Moore and Dalley, 1999). The vertebral foramen is large and triangular, with two pedicles which are short, thick, rounded bars that project laterally and backwards from the body at the junction between its lateral and dorsal surfaces. Two laminae that are vertical, broad and plate-like are continuous with the pedicles. The laminae are angled from the pedicles in a backwards and medial direction and fuse in the midline with the spinous process completing the vertebral foramen. The spinous process projects dorsally and often downwards from the intersection of the laminae. The spinous process of the typical vertebrae is short from C3 to C5, but at C6 and C7 it is longer (C7 has the longest spinous process in the cervical spine and is often referred to as vertebra prominens) (Collins *et al.*, 2005).The TVPs project laterally from the junctions of the pedicles and laminae and act as levers for the muscles and ligaments (Collins *et al.*, 2005).

The boundary of the spinal canal comprises of the anterior aspect of the laminae and the adjacent ligament flava; it is bounded by the pedicles laterally and by the posterior aspect of the intervertebral discs (IVDs) and vertebral bodies (Collins *et al.*, 2005). The cervical vertebral canal is triangular or funnel-shaped, being widest at the atlantoaxial level, and narrowing to its smallest sagittal diameter at the posterior inferior edge of the body of C5 and the lamina of C6 (Bland, 1987; Collins *et al.*, 2005).

Figure 2.1 A typical cervical vertebra

‘Cervical Vertebra’ (Features of selected bones 2011)

The joints of the vertebral arch are called zygapophyseal joints or facet joints. These are synovial joints formed between the superior and inferior articular facets. The superior articular facets are directed in a superior-posterior direction whereas the inferior articular facets are directed in an inferior-anterior direction (Moore and Dalley, 1999). The superior and inferior articular facets form an articular pillar which protrudes laterally at the junction of the pedicle and lamina (Collins *et al.*, 2005). The joints of Luschka, also known as the uncovertebral joints are found between the uncinate processes of the lower five cervical vertebrae and the corresponding margins of the vertebrae above (Bland,1987). These joints are formed during the second decade of life and become significant to the cervical spine, as they act as barriers preventing the extrusion of intervertebral disc (IVD) material posterolaterally, which may aid in preventing compression of nerve roots (Bland, 1987).

Cervical intervertebral foramina (IVF) are short tunnel-like structures which enclose and transmit the lateral termination of the anterior and posterior nerve roots together with spinal radicular arteries, intervertebral veins and plexuses, an extension of the epidural space and a small amount of fatty tissue. They are bound ventromedially by the uncovertebral joint and cervical IVD covered by the posterior longitudinal ligament and dorsolaterally by the zygapophyseal joint and superior articular process of the subjacent vertebra (Bland, 1987). They are shaped like a figure eight and open obliquely forward, laterally and inferiorly. Largest at the level of C2-C3, they become progressively smaller down to the C6-C7 level. The nerve roots occupy one quarter to a third of the foraminal space whilst the small arteries, veins and fatty tissue provide a protective cushion for the nerve roots (Bland, 1987).

2.3 AN OVERVIEW OF THE LIGAMENTS OF THE CERVICAL SPINE

The vertebral bodies are unified by the anterior and posterior longitudinal ligaments and by the fibrocartilage IVDs. The smaller ligaments such as the supraspinous, interspinous and atlanto-axial are described in published anatomical texts (Moore and Dalley, 1999; Collins *et al.*, 2005) and are not discussed here.

The anterior longitudinal ligament (ALL) extends along the anterior surfaces of the vertebral bodies. It is attached to the basilar part of the occipital bone and extends to the anterior tubercle of the atlas and the anterior aspect of the body of the axis and continues down to the upper part of the front of the sacrum (Collins *et al.*, 2005). The ALL helps maintain stability of the joints between the vertebral bodies and prevent hyperextension of the cervical spine (Moore and Dalley, 1999).

The posterior longitudinal ligament (PLL) lies inside the vertebral canal attached to the posterior surfaces of the vertebral bodies. Superiorly, it is attached to the body of the axis and continues downward toward the sacrum. The PLL prevents hyperflexion of the vertebral column and posterior protrusion of the IVDs (Moore and Dalley, 1999). Clinically, pathological thickening or ossification of the PLL compromises the capacity of the vertebral canal even in the absence of osteophytes or IVD herniation (Bland, 1987).

The ligamentum flavum is a strong and elastic ligament which spans the space between the laminae in pairs. It is attached to the anterior inferior surface of the lamina above and the posterior superior margin of the lamina below. They extend laterally to the zygapophyseal joint and enter the fibrous composition of the joint. They serve to support the neck in the erect position and aid the muscles to extend the flexed neck, limit motion of the zygapophyseal joints and restrain abrupt movements between vertebrae (Bland, 1987).

2.4 INTERVERTEBRAL DISCS OF THE CERVICAL SPINE

Intervertebral discs occur between adjacent surfaces of vertebral bodies from the axis to the sacrum. There is no IVD between the atlas and axis. Their shape conforms to that of the vertebral bodies between which they lie. They are thicker anteriorly than posteriorly in the cervical and lumbar regions. This contributes to the anterior convexity of the curvatures in these regions (Collins *et al.*, 2005). Each IVD is composed of an outer laminated annulus fibrosus and an inner nucleus pulposus. IVDs are relatively thick in the cervical spine and are usually thickest at the level of C6-C7. The annulus fibrosus absorbs shock energy and the nucleus pulposus distributes forces acting on the vertebral column equally and uniformly in all directions (Bland, 1987).

2.5 A SUMMARY OF THE MUSCLES OF THE CERVICAL SPINE

A high degree of finely co-ordinated muscle balance is required to support and move the head and neck. This occurs by means of a complex interaction between muscle groups working on the rigid osseous framework supported by the ligaments of the cervical spine (Moore and Dalley, 1999). It is convenient to consider the muscles in terms of the movements they produce as shown in **Table 2.1**. The attachments and other anatomical descriptions of these muscles can be found in published anatomical texts (Moore and Dalley, 1999; Collins *et al.*, 2005).

Trauma to the cervical spine such as whiplash can result in muscle spasm and injury. The cervical muscles contract rapidly in response to impact and the potential exists for muscle injury to occur due to lengthening contractions of the muscle (Brault *et al.,* 2000) which in turn may lead to a reduction in the cervical lordosis which can be seen on a cervical spine lateral radiograph (White and Panjabi, 1990).

Table 2.1 Muscles of the cervical spine and the movements they produce

Extension	Flexion	Rotation and Lateral Flexion
Splenius capitis	Sternocleidomastoid(anterior fibres)	Sternocleidomastoid
Splenius cervicis	Longuscolli	Scalene group
Semispinalis capitis	Longus capitis	Splenius capitis
Semispinalis cervicis	Rectus capitis anterior	Splenius cervicis
Longissimus capitis		Longissimus capitis
Longissimus cervicis		Levator scapulae
Trapezius		Longuscolli
Interspinalis		Illiocostalis cervicis
Rectus capitis posterior major		Multifidi
Rectus capitis posterior minor		Intertransversarii
Sternocleidomastoid (posterior fibres		Obliquus capitis inferior
Obliquus capitis superior		Obliquus capitis superior
		Rectus capitislateralis

(Park and Sherk, 1989; Moore and Dalley, 1999; Collins *et al.*, 2005)

2.6 CURVATURES OF THE SPINE

The spinal column is made up of four curves: the cervical, thoracic, lumbar and sacral curves (Moore and Dalley, 1999). The thoracic and sacral curves are concave anteriorly and are described as primary curvatures as they develop during the foetal period whereas the cervical and lumbar curves are concave posteriorly and are described as secondary curvatures, which appear during the foetal period, but only become obvious during infancy (Collins *et al*., 2005). The cervical curve (called the cervical lordosis) begins to develop during the foetal period at around nine and a half weeks and becomes more pronounced after birth; when the infant begins to hold its head erect at around three to four months and begins to sit upright at around nine months of age (Bagnall *et al*., 1977); whereas the lumbar curvature only begins to develop when the infant starts to stand and walk (Moore and Dalley, 1999).

2.7 RADIOGRAPHIC EVALUATION OF THE CERVICAL SPINE

2.7.1 The Role and Evaluation of Radiographs of the Cervical Spine

Radiographic evaluation of the cervical spine contributes to the diagnosis of disorders and pathologies of the cervical spine. It also allows for the assessment of disease progression and provides a better understanding of cervical biomechanics (Bland, 1987). Visualisation of trauma to the cervical spine is also made possible through radiographic assessment. A considerable number of trauma patients present at an emergency department of hospitals and clinics. These patients are frequently suspected of having cervical spine injuries and the detection of such injury can be of lifesaving importance to the patient (Vandemark, 1990). Radiographic imaging is used in instances of trauma to the cervical spine to detect and assess the extent of osseous, ligamentous, neural and other soft tissue injuries and to help evaluate instability. These objectives must be carried out expeditiously, at an affordable cost to the patient and with a small margin of diagnostic error (El-Khoury *et al.,* 1995). Radiographs as a screening mechanism, however, will not always detect every injury, but will rather detect evidence of injury. Other modalities such as computed tomography (CT) and magnetic resonance imaging (MRI) can then be used to carefully evaluate for additional injuries (Mower *et al.*, 2001).

Degenerative joint disease of the cervical spine is a chronic disease and a common physiological manifestation which causes deterioration of the joint cartilage and the formation of new bone at the margins of the joints (Wiegand *et al.,* 2003; Pouletaut *et al.,* 2010). Plain film radiography is often the initial means of evaluating degenerative joint disease in the cervical spine (Wiegand *et al.,* 2003; Pouletaut *et al.,* 2010). A decrease in the A-P diameter of the cervical spine canal can result in cervical canal stenosis, which may occur as a result of thickening of the PLL due to ossification, degenerative IVD disease, osteophytes and osteoarthritis of the facet joints, all of which may be visualised on cervical spine radiographs in the appropriate views (White and Panjabi, 1990; Giles and Singer, 1998; Yochum and Rowe, 2005b).

The cervical spine can be affected by inflammatory arthritides such as rheumatoid arthritis. Joint, bone and ligament damage in the cervical spine may lead to subluxation which can cause cervical cord compression. Cervical subluxations are often clinically silent; therefore, the evaluation of plain film radiographs serves as a means of detection of the warning signs of subluxation of the cervical spine (e.g. atlanto-dental subluxation) in conditions such as rheumatoid arthritis (Roche *et al.,* 2002).

Plain film radiography is commonly utilised in clinical practice to detect bone metastases (Rybak and Rosenthal, 2001). Primary neoplasms of the skeleton are rare, but skeletal metastases are common and radiography is used to evaluate symptomatic sites although the sensitivity is poor (Rybak and Rosenthal, 2001). Certain features on a cervical radiograph may help to distinguish metastases from other conditions. If the lesion is osteolytic these features include pedicle erosion, focal osteoporosis or radiolucency of a vertebral body, pathological compression fractures with loss of height anteriorly and posteriorly and destruction of endplate integrity with a decrease in IVD height causing malignant Schmorls nodes. Osteoblastic metastases may present as a localised or diffuse radiopacity of the vertebral body, commonly referred to as ivory vertebra. Variants of metastatic carcinoma to the bone may present as solitary expansile soap bubble lesions on radiographs (Yochum and Rowe, 2005b).

The standard radiographic views for the clinical evaluation of the cervical spine include the following:

- Anteroposterior view (A-P):
    - uncovertebral joints and zygapophyseal joints
    - IPD
    - pedicles
    - spinous process
    - vertebral body
- A-P open mouth view:

  - odontoid process
  - skull
  - atlas and axis complex
  - lateral masses of the atlas and the atlantoaxial joint
- Lateral view:
  - IVD joints
  - zygapophyseal joints
  - skull
  - odontoid process
  - atlas and axis complex
  - Evaluation of the lateral view of the cervical radiograph is essential for assessing instability, fractures, dislocations, IVD space integrity, anomalies and spinal stenosis (Lim and Wong, 2004; Yochum and Rowe, 2005b).
- Oblique views:
  - IVF
  - uncovertebral joints
  - IVD
  - zygapophyseal joints

A useful approach to evaluate cervical spine radiographs is the one proposed by Yochum and Rowe (2005a) viz. the **A**lignment, **B**one, **C**artilage and **S**oft tissue (ABCS) method which ensures all aspects of a radiograph are taken into account in a methodical fashion.

2.7.2 Radiographic Alignment and Measurement Parameters of the Cervical Spine

The following cervical spine radiographic parameters were evaluated in this dissertation:

- Cervical lordosis**,**
- Sagittal canal diameter
- Interpedicular distance
- Cervical gravity line

2.7.2.1 Cervical Lordosis

The CL refers to the posteriorly-concave curve of the cervical spine and is assessed on the lateral view of the radiograph. Several methods of measurement and models of normal lordosis have been proposed, but the results are inconsistent in terms of normative mean value or range of values for a normal CL. A summary of the methods utilised to evaluate the CL radiographically and values obtained is shown in **Table 2.2**.

Table 2.2 A summary of the methods utilised to evaluate the CL and the reported values

Reference	Sample	Method	Reported value of CL
Borden *et al*. (1960)	180 asymptomatic males and females (90 each) between 21- 80 yrs.	**Depth of the cervical curve**: A straight line (A) is drawn from the superior posterior aspect of the odontoid process to the posterior inferior aspect of the body of C7. Another line (B) is traced along the posterior aspect of the intervening cervical vertebral bodies. A third line (C) intersects A perpendicularly at the point of the longest distance between A and B. The length of C is the depth of CL.	Females: mean of 12.16 mm Males: mean of 11.56 mm
Drexler (1962)	N/A	**Drexler's method***	Mean of 40°
Jochumsen (1970)	N/A	**Method of Jochumsen*** A line is constructed from the anterior border of the atlas anterior tubercle to the anterosuperior corner of the C7 body, the distance from this line to the anterior border of the C5 body is then measured (Yochum and Rowe, 2005a)	Range of 3-8mm
Gore *et al*. (1986)	100 males and 100 females (all asymptomatic) between 20- 65 yrs.	The CL was measured as the angle formed by lines parallel to the posterior surface of the bodies of C2 and of C7.	Mean of 23°
Owens and Hoiris (1990)	N/A	**Posterior tangent method**. Tangents are drawn on the posterior vertebral body margins of C2 to C7. Segmental angles (relative rotation angles) are formed at each pair of neighbouring tangents, and a global angle of the curvature (absolute rotation angle) is measured between the tangents on C2 and C7.	Mean of 22.3 °
Harrison *et al*. (1996)	400 randomly selected lateral cervical radiographs of subjects with some form of micro or macro trauma. 237 males and 163 females with an average age of 35.4 yrs. A subgroup of 252 subjects who did not have cervicocranial symptomatology was determined.	Lines were constructed along the posterior vertebral body margins of C2-C7,the cervical lordosis was measured as an angle between Jacksons physiologic lines at the posterior margins of C2 and C7	Mean ± SD: 34° ± 9° Range of 16.5°- 66°

Hardacker *et al.* (1997)	100 asymptomatic adults in the erect posture.	**Cobb method (C0-C7)** A straight line is constructed along the foramen magnum and another line is constructed through and parallel to the inferior endplate of C7. Perpendiculars are constructed to the point of intersection and the resultant angle is measured	Mean ± SD: 40° ± 9.7°
Harrison *et al.* (2000)	30 lateral radiographs were selected from clinical files and digitized twice by each of the three examiners to test their reliability.	**Cobb method (C1-C7)** A line is drawn through and parallel to the inferior endplate of C7 and another is drawn through the midpoints of the anterior and posterior tubercles of the atlas. Perpendiculars are constructed to the point of intersection and the resultant angle is measured.	Mean of 53.6°
		Cobb method (C2-C7) A line is constructed through and parallel to the inferior endplate of C7 and another is drawn through and parallel to the inferior endplate of C2, perpendiculars are constructed to the point of intersection and the resultant angle is measured.	Mean of 17.2°
		Posterior tangent method.	Mean of 25.8°
McAviney *et al*. (2005)	Retrospective study of 277 randomly selected lateral cervical radiographs of symptomatic and asymptomatic patients. Age range of 9 -78 yrs.	**Posterior tangent method.** Method is similar to that of Gore *et al*. (1986) whereby only the absolute rotation angle is measured.	Symptomatic: Mean of 9.6° Asymptomatic: Mean of 23.4°
Harrison *et al.* (2005)	36 males and 60 females with neck pain. Mean ± SD of the age 40.1 ± 17.9 yrs.	**Flexicurve ruler measurement** Measured in neutral posture using a flexicurve ruler to measure the sagittal contour of the skin over the cervical spine from the EOP to the VP (C7). Flexicurve skin contour and neutral lateral radiographs were digitized and compared.	Mean ± SD: 22.2° ± 5.7°
Yochum and Rowe (2005a)	N/A	**Angle of cervical curve Cobb method (C1-C7)** The method is the same as the Cobb method (C1-C7)	Mean of 40° (mean) Range of 35°- 45°
Roopnarain (2011)	80 healthy, asymptomatic males in four different ethnic groups between 18-45 yrs.	**Cobb method (C1-C7)**	Overall mean ± SD: 45.7°± 10.2°
		Cobb method (C2-C7)	Overall mean ± SD:15.9° ± 9.1°

CL = Cervical lordosis; EOP = external occipital protuberance; VP = vertebral prominens; yrs = years; N/A = Not available

Table adapted from Roopnarain (2011)

***The researcher was unable to view the original references despite an exhaustive literature search**

Borden *et al.* (1960) reported that there were no readily available radiographic criteria for evaluating the CL in normal, asymptomatic individuals. Their study included White adults as the sample population and results for the mean CL was determined for each gender (**Table 2.2**). Their method of assessing the CL on lateral radiographs, known as the depth of the cervical curve method (**Table 2.2**) did not gain popularity. Without further information the depth measurements could not be converted into angular measurements and in order to compare values for the same patient over time or to compare values among patients, corrections into actual values are required unless the same tube to film distance and the same cervical spine to film distance was used. Moreover, a patient with a longer distance between the odontoid and seventh cervical vertebral body would appear to have a larger measurement of CL depth than a shorter patient with the same angular measurement (Gore *et al.,* 1986). In 1962, Drexler proposed a method whereby each individual cervical vertebral segment was assessed by drawing lines along the endplates and measuring the resultant angle. The CL value was the sum of each intersegmental measurement (Drexler, 1962; Yochum and Rowe, 2005a). Although this method was accurate, it was also laborious and not ideal for a clinical setting (Yochum and Rowe, 2005a). Scarce literature exists on the method employed by Jochumsen (1970; **Table 2.2**).

The technique utilised by Gore *et al.* (1986; **Table 2.2**) was simpler and reproducible in comparison to the depth of the cervical curve method, as there would be no inherent distortion of angular measurements based on magnification due to roentogenographic technique or variation because of patient size. The mean value for CL reported by Gore *et al.* (1986) was similar to those of asymptomatic individuals (McAviney *et al*., 2005; **Table 2.2**).

The posterior tangent method is not commonly used in a clinical setting (Harrison *et al*., 2000) and this can be attributed to the tedious manner in which it is measured (**Table 2.2**), and unless this method is digitized, it increases the possibility of human error. However, in comparison to the Cobb method the posterior tangent method has a smaller standard error of measurement, and where the Cobb angles compare only the ends of the curves and are unable to outline what happens to the curve internally, the posterior tangent method utilises slopes along the curve that provide an analysis of any buckled areas of the cervical curve (Harrison *et al*., 2000).

According to Cote *et al.* (1997), the Cobb method of measurement is the method of choice to intuitively determine the CL. There are, however, differences in opinion on the proper anatomical landmarks that need to be utilised (C0-C7 or C1-C7 or C2-C7)

(Hardacker *et al*., 1997; Harrison *et al*., 2000). Harrison *et al.* (2000) observed that the Cobb method at C1-C7 overestimated the cervical curvature and at C2-C7 it underestimated the cervical curvature. According to Harrison *et al.* (2003), overestimation of the curve using the C1-C7 method was due to extra extension of C1-C2 and underestimation of the curve using the C2-C7 method was caused by the hooked nose-shape of the anterior-inferior body of C2. However, Cote *et al.* (1997) reported high interexaminer reliability for both methods. A slightly superior interexaminer agreement was observed with the C2-C7 method with an intraclass correlation coefficient of 0.96 (95% confidence interval, 0.88 – 0.98) and an interexaminer error of 8.3° in comparison to the C1-C7 intraclass correlation coefficient of 0.94 (95% confidence interval, 0.90 – 0.97) and interexaminer error of 9.1°.

Harrison *et al.* (2005; **Table 2.2**) used a flexicurve ruler to determine and measure CL by measuring the sagittal skin contour of the neck. The results were digitized and compared to digitized radiographic measurements (using the posterior tangent method) obtained from the subjects' lateral cervical radiographs. This was shown to be an unreliable means of determining an accurate CL as the flexicurve tracings overestimated lordosis when compared to radiographic values (Harrison *et al.,* 2005).

2.7.2.1.1 Reported ethnic and gender differences in the cervical lordosis

The role of gender and age in influencing the value of the CL is ambivalent. Gore *et al.* (1986) reported that there was little difference between the average CL of males and females. However, after a ten-year follow-up, it was observed that the CL tended to increase with age in men more so than in women (Gore, 2001). Hardacker (1997) reported that CL became more pronounced with increasing age in both males and females. On the other hand, Boyle *et al*. (2002) observed that a progressive flattening of the cervical curve occurred with increasing age in both genders; this trend continued until middle-age, but in older age groups the CL was increased in females. This observation was first reported by Borden *et al.* (1960) who found that after the age of fifty, the CL tended to increase in females and decrease in males. Cooke and Wei (1988) reported that females possess a larger CL, but McAviney *et al*. (2005) observed that males possessed a larger median CL than females. On the contrary, Tecco and Festa (2007) reported that gender and age did not influence CL.

The influence of ethnicity on CL was reported by Solow *et al*. (1982) who found that young Australian Aboriginal males possessed a less pronounced CL when compared to young Danish males. Differences in CL were also observed between 12-year old males and females from the British Caucasian and Chinese population groups (Cooke and Wei, 1988). In a recent study conducted by Roopnarain (2011; **Table 2.2**) involving South African Black, White, Coloured and Indian males, the mean and standard deviation of CL for the selected ethnic groups was evaluated using the C1-C7 and C2-C7 Cobb methods (**Table 2.3)**. A smaller mean, minimum and maximum value for the CL using the C2-C7 Cobb method was observed in all the ethnic groups when compared to the C1-C7 method for CL. No significant difference in mean CL was observed between the different ethnic groups ($p > 0.05$, ANOVA; **Table 2.4)**. It would be interesting to determine if similar trends are observed in this study between South African females of different ethnicities.

Table 2.3 The mean, standard deviation and range of the CL by ethnic group in South African males using the C1-C7 and C2-C7 Cobb methods

	Ethnicity	Mean (°)	*n*	Std. Deviation	Minimum (°)	Maximum (°)
C1-C7 Cobb method	Black	42.6	19	9.6	25.0	61.0
	White	46.2	18	11.0	18.0	63.5
	Indian	46.5	17	11.3	25.0	67.0
	Coloured	47.7	17	9.1	31.0	63.2
	Total	45.7	71	10.2	18.0	67.0
C2-C7 Cobb method	Black	15.1	19	6.4	7.0	30.0
	White	17.4	18	9.3	6.0	33.0
	Indian	13.1	17	10.2	3.0	34.0
	Coloured	18.1	17	10.4	3.0	37.0
	Total	15.9	71	9.1	4.8	33.5

Table adapted from Roopnarain (2011)

Table 2.4 ANOVA test to compare the mean CL between South African males of different ethnic groups

	Sum of Squares	Df	Mean Square	F	*p-value*
Between groups	258.605	3	86.202	0.810	0.493
Within groups	7133.150	67	106.465		
Total	7391.755	70			

Table adapted from Roopnarain (2011)

2.7.2.1.2 Other factors that could influence the cervical lordosis

The CL can be influenced by the effects of arthritic disorders on the cervical spine (Yochum and Rowe, 2005b). Degeneration of the IVDs results in IVD space narrowing in the cervical spine especially in the elderly which in turn causes a decrease in CL (Gore *et al*., 1986). Diffuse idiopathic skeletal hyperostosis (DISH) is a generalised articular disorder with spinal and extraspinal involvement. It is characterised by ligamentous calcification and ossification especially of the ALL and eventually results in a decrease of the CL (Yochum and Rowe, 2005b). A decrease in the CL is also seen in systemic inflammatory arthritic disorders such as rheumatoid arthritis and ankylosing spondylitis (Collins *et al.*, 2005; Yochum and Rowe, 2005b). Tumours and infections of the spine are also known to affect the CL due to destructive effects on the vertebrae (Collins *et al.*, 2005)

A rapid flexion-extension injury to the neck such as whiplash following a motor vehicle collision results in muscle spasm and the straightening of the CL (Bland, 1987; White and Panjabi, 1990). An altered CL causes an uneven distribution of forces on the anterior cervical vertebral body eventually leading to degeneration of the affected area (Harrison *et al*., 2001). It may also be possible that changes in other regions of the spine may affect the CL. It has been previously reported that an accentuated thoracic kyphosis results in an increased CL due to compensatory actions of the head in order to maintain a forward gaze (Boyle *et al*., 2002).

2.7.2.2 Sagittal Canal Diameter

The sagittal dimension of the cervical spinal canal is measured from the posterior surface of the mid-vertebral body to the nearest surface of the same segmental spinolaminar junction line; and is an important indicator of cervical spinal stenosis, spinal cord neoplasms and syringomyelia (Hinck *et al.,* 1962; Yochum and Rowe, 2005a). A summary of the studies that have investigated the SCD in the cervical spine is shown in **Table 2.5**

Table 2.5 A summary of the reported investigations on SCD

Reference	Sample	Method	SCD (mm)	
Oon (1974)	Lateral radiographs of asymptomatic individuals: 200 males and 200 females aged 20-80 yrs. Mixed sample of Chinese, Indians, Malaysians and others. (183cm FFD).	Measured from the midpoint of the posterior border of the vertebral body to the nearest point on the lamina of the respective vertebra.	Combined mean values for male and female as well as ethnic groups: C1: 20.3 C2: 18.5 C3: 15.5 C4: 14.9 C5: 15.2 C6: 15.5 C7: 15.4	
Gupta *et al.* (1982)	Lateral radiographs of 300 normal Indians: 207 males and 93 females. Aged 18-34 yrs. (180cm FFD).	SCD measured on lateral radiograph from the midpoint of the posterior surface of the vertebral body to the spinolaminar line of each respective vertebra.	Indian Males: mean values C2: 19.66 C3: 17.07 C4: 16.59 C5: 16.64 C6: 16.73 C7: 16.42	Females: mean values C2: 18.60 C3: 16.13 C4: 15.60 C5: 15.72 C6: 15.84 C7: 15.54
Lee *et al.* (1994)	90 dried Korean human cervical vertebral columns: 63 male and 27 female aged 19-70 yrs.	Measured from the midpoint of the posterior aspect of the vertebral body to the nearest point on the corresponding spinolaminar line.	Korean Males: mean ± SD C3: 13.3 ± 1.3 C4: 12.8 ± 1.4 C5: 13.0 ± 1.4 C6: 13.2 ± 1.3 C7: 13.4 ± 1.3	Females: mean ± SD C3: 13.3 ± 2.5 C4: 12.9 ± 2.7 C5: 13.0 ± 2.7 C6: 13.2 ± 2.6 C7: 13.4 ± 2.3
Tan *et al*. (2004)	Cadaveric study of Chinese Singaporeans based on 10 cadavers: aged between 56-77yrs. Gender was not stated.	Measurements were taken with the aid of a direct contact three - dimensional digitiser.	Mean ± SD C3: 10.3 ± 0.3 C4: 10.3 ± 0.3 C5: 10.3 ± 0.3 C6: 10.3 ± 0.3 C7: 11.0 ± 0.2	
Lim and Wong (2004)	80 lateral radiographs of Chinese males and females (40 of each): aged 21-46 yrs. (180cm FFD).	Distance between the cephalocaudal midpoint of the posterior aspect of the vertebral body to the nearest point on the corresponding spinal laminar line with a vernier calliper.	Chinese Male: mean values C2: 19.1 C3: 16.8 C4: 16.2* C5: 16.8 C6: 17.2 C7: 17.1	Female: mean values C2: 18.5 C3: 16.1 C4: 15.7* C5: 16.0 C6: 16.1 C7: 16.0
Tatarek (2005)	321 individual human skeletons : 160 males and 161 females of African American and Caucasian ethnicity.	A-P diameter of each vertebral canal was measured with a vernier calliper.	African-American Male: mean ± SD C2: 16.40 ± 1.31 C3: 14.43 ± 1.20 C4: 13.98 ± 1.32 C5: 14.12 ± 1.22 C6: 14.25 ± 1.13 C7: 14.37 ± 0.97 Female: mean ± SD C2: 15.09 ± 1.57 C3: 13.33 ± 1.37 C4: 13.16 ± 1.44 C5: 13.28 ± 1.31 C6: 13.32 ± 1.29 C7: 13.57 ± 1.21	Caucasian Male: mean ± SD C2: 16.80 ± 1.54 C3: 15.02 ± 1.34 C4: 14.58 ± 1.33 C5: 14.50 ± 1.42 C6: 14.26 ± 1.37 C7: 14.33 ± 1.41 Female: mean ± SD C2: 16.61 ± 1.14 C3: 14.44 ± 1.39 C4: 13.73 ± 1.34 C5: 13.61 ± 1.26 C6: 13.39 ± 1.08 C7: 13.42 ± 1.07

Yochum and Rowe (2005a)	Ethnicity not stated.	Measured from the posterior surface of the mid vertebral body to the nearest surface of the same segmental spinolaminar junction line.	Combined mean values for male and female: C1: 22 C2: 20 C3: 18 C4: 17 C5: 17 C6: 17 C7: 17	
Tossel (2007)	179 skeletal remains of Blacks were measured: 90 males and 89 females 30 – 75 years of age.	The A-P diameter of the vertebral canal measured with a digital vernier calliper.	Black Male: mean values C3: 13.89 C4: 13.60 C5: 13.94 C6: 14.07 C7: 14.32	Female: mean values C3: 14.01 C4: 13.80 C5: 13.81 C6: 13.82 C7: 13.77
Roopnarain (2011)	Lateral radiographs of 80 healthy South African Black, White, Indian and Coloured males between the ages of 18-45 yrs: 20 in each ethnic group.	Measured from the posterior surface of the mid vertebral body to the nearest surface of the same segmental spinolaminar junction line.	Black Male: mean values C2: 22.1 C3: 19.5 C4: 18.6 C5: 18.9 C6: 18.8 C7: 18.5	White Male: mean values C2: 24.1 C3: 20.6 C4: 19.9 C5: 20.0 C6: 20.4 C7: 20.3
			Indian Male: mean values C2: 22.8 C3: 19.7 C4: 19.1 C5: 19.3 C6: 19.5 C7: 19.4	Coloured Male: mean values C2: 22.9 C3: 20.0 C4: 19.5 C5: 19.8 C6: 20.0 C7: 19.7

FFD = Focal film distance; A-P = Anteroposterior; yrs = years

Table adapted from Roopnarain (2011)

There are numerous methods of assessing SCD; they range from simple direct measurements from plain film radiographs (**Table 2.5**) to CT and MRI with digitisers. Measurement of the SCD from standardized lateral radiographs remains an accurate method of assessing patients for cervical spinal stenosis and is an important parameter to assess in patients with cervical myelopathy (Hinck *et al.,* 1962; Roche *et al*., 2002; Lim and Wong, 2004; Yochum and Rowe, 2005b), but Tossel (2007) is of the opinion that if stenosis is suspected, CT is the better alternative to assess SCD. Although CT may be the investigation of choice for assessing stenosis, it is an expensive diagnostic test.

Herzog *et al*. (1991) found that direct measurements from lateral plain film cervical radiographs accurately represented the SCD. However, direct measurements can be misleading as they are subject to variation due to magnification error being present as a result of differences in focal film distance (FFD) and object film distance (OFD) (Blackley *et al*., 1999; Yue *et al*., 2001). This is a possible reason for the discrepancies in measurement values reported in previous studies (Lee *et al*., 1994). In order to address this problem Torg *et al*. (1986) devised a ratio method to assess for cervical spinal stenosis whereby the sagittal diameter of the vertebral canal is divided by the diameter of the corresponding vertebral body. This ratio is commonly referred to as the Torg ratio, Pavlov ratio, Torg-Pavlov ratio or canal to body ratio. Torg *et al*. (1986) reported that a measurement of less than 0.80 indicated significant spinal stenosis when using the ratio method. Lee *et al.* (1994) also concurred that the Torg ratio is more reliable than direct measurement of the SCD from the lateral radiograph as it is not affected by radiographic magnification. However, Blackley *et al*. (1999) reported a poor correlation between the true diameter of the vertebral canal and the Torg ratio due to variability in anatomical morphology. In their study on a Chinese population, Lim and Wong (2004) also established the Torg ratio to be an inconsistent indicator of SCD which could not be used reliably to assess the presence of stenosis due to the variation of the SCD across ethnicity and the incapacity of the vertebral body to vary in proportion to the changes in the SCD.

Another possible reason for the discrepancies observed in measurement values for the SCD between different studies is due to the variation in study subjects. Skeletal specimens were used by Lee *et al*. (1994), Tan *et al.* (2004), Tatarek (2005) and Tossel (2007) whereas the other studies were of a radiographic nature (**Table 2.5**). Although both Lee *et al.* (1994) and Tatarek (2005) conducted cadaveric studies, they had dissimilar results **(Table 2.5)**. Lee *et al*. (1994) concluded that by measurement of actual bony specimens no differences were present between genders at each vertebral level; whereas Tatarek (2005) found significant variations in cervical canal dimensions, and that significant differences in cervical canal dimensions were due to sexual dimorphism first and then to ancestry.

2.7.2.2.1 Gender and ethnicity factors affecting the SCD

The SCD tends to vary at different levels and females were found to have a smaller SCD than males (Lee *et al*., 1994; Lim and Wong, 2004; Tatarek, 2005; Tossel, 2007). Furthermore, a variation in SCD between certain ethnic groups was also observed. According to Lim and Wong (2004) a consistent variation in SCD, with differences in Japanese, Chinese, Indian and White participants were observed with Japanese participants' SCD being the smallest. Earlier in 1974, Murone also reported that the diameter of the mid-sagittal canal in the cervical spine of Japanese adults was narrower than those of European adults (Payne and Spillane, 1957). Lee *et al.* (1994) reported that Koreans had a smaller SCD than those of Whites and Blacks with Whites having the largest canal diameter amongst the three groups. Similarly, Oon (1974) reported that the

Singaporean Chinese, Malay, and Indian subjects, on average possessed a narrower A-P diameter of the cervical spinal canal in comparison to Western subjects.

In a recent study involving South African Black, White, Coloured and Indian males, Roopnarain (2011) noted a significant difference overall amongst the four ethnic groups at vertebral levels C2, C6 and C7 (p = 0.002, 0.030 and 0.017 respectively; ANOVA). For these three vertebral levels, the difference in the measurement was between Blacks and Whites only (p = 0.001, 0.028 and 0.011 respectively, Bonferroni *post-hoc* test).

The results of several of the studies in **Table 2.5** report variations in the SCD in different ethnic groups and genders. Therefore, the assessment of spinal stenosis should not be based on universal definitions, but rather according to normative reference values for gender and different ethnic groups (Tatarek, 2005).

2.7.2.2.2 Clinical factors that affect the SCD

Several pathological, inflammatory, degenerative or traumatic conditions can result in changes to the SCD of the cervical spine, causing either a decrease or an increase in the diameter. Spinal tumors are capable of causing pressure atrophy and bony erosion which may result in subsequent widening of the spinal canal (Boijsen, 1954; Yochum and Rowe, 2005b). Syringomyelia can also result in a widening of the canal; whereas degenerative conditions may result in osteophyte formation that may reduce the width of the canal (Yochum and Rowe, 2005a). Burst fractures may cause fragments of the vertebral body to be retropulsed into the spinal canal decreasing the canal diameter and resulting in possible neurological deficits (Dai *et al*., 2008).

2.7.2.3 Interpedicular Distance

The IPD is the shortest measurement between the medial cortical surfaces of pedicles in a given vertebra (Hinck *et al*., 1966). This measurement is useful to surgeons and chiropractors, in the evaluation of spinal stenosis, intraspinal neoplasms, congenital malformations (Yochum and Rowe, 2005b) and during preoperative trans-pedicular screw fixation (Ugur *et al*., 2000). A summary of the studies that have investigated the IPD is shown in **Table 2.6**

Table 2.6 A summary of the reported investigations on the IPD

Reference	Sample	Method	IPD (mm)	
Hinck *et al.* (1966)	Radiographs of 373 children and 121 adults (white males and females combined).	Shortest measurement between the medial surfaces of a pedicle of a specific vertebra.	Caucasian Adults: male and female combined C3: 28.0 C4: 28.8 C5: 29.4 C6: 29.3 C7: 28.0	
Ugur *et al.* (2000)	20 cadavers: 14 males and 6 females; 24 to 72 years of age (Ethnicity not stated).	Goniometer used by neurosurgeons. No measurement sites were stated.	Male: mean ± SD C3: 21.6 ± 1.1 C4: 20.8 ± 1.0 C5: 20.7 ± 1.6 C6: 21.6 ± 2.0 C7: 22.9 ± 2.4	Female: mean ± SD C3: 22.4 ± 0.7 C4: 22.5 ± 1.6 C5: 23.2 ± 0.0 C6: 25.1 ± 0.1 C7: 24.5 ± 1.1
Tatarek (2005)	321 skeletons: 160 African -American and Caucasian males and 161 African- American and Caucasian females.	Skeletal samples: measured using vernier calipers accurate to 1mm.	African-American Male: mean ± SD C2: 23.39 ± 1.23 C3: 23.32 ± 1.22 C4: 24.31 ± 1.23 C5: 25.02 ± 1.36 C6: 25.46 ± 1.44 C7: 24.48 ± 1.31 Female: mean ± SD C2: 22.52 ± 1.39 C3: 22.68 ± 1.22 C4: 23.47 ± 1.48 C5: 23.98 ± 1.46 C6: 24.49 ± 1.60 C7: 23.53 ± 1.35	Caucasian Male: mean ± SD C2: 23.79 ± 1.47 C3: 23.43 ± 1.35 C4: 24.13 ± 1.46 C5: 24.86 ± 1.60 C6: 25.21 ± 1.65 C7: 24.33 ± 1.61 Female: mean ± SD C2: 22.90 ± 1.51 C3: 22.48 ± 1.31 C4: 23.47 ± 1.29 C5: 24.42 ± 1.28 C6: 24.32 ± 1.41 C7: 23.41 ± 1.33
Yochum and Rowe (2005a)	Data obtained from study conducted by Hinck *et al.* (1966).	The IPD was considered the shortest distance between the inner convex cortical surfaces of the opposing segmental pedicles.	C3: 28 C4: 29 C5: 29 C6: 29 C7: 28 (The measurements from Hinck *et al.* (1966) study were rounded-off to 0 decimal place)	
Roopnarain (2011)	Radiographic study of 80 healthy asymptomatic South African males from four different ethnic groups - 20 in each group.	The IPD was considered the shortest distance between the inner convex cortical surfaces of the opposing segmental pedicles.	Black Male: mean ± SD C3: 28.2 ± 1.2 C4: 28.6.± 1.4 C5: 29.4 ± 1.2 C6: 29.3 ± 1.6 C7: 29.3 ± 1.2 Indian Male: mean ± SD C3: 27.8 ± 1.1 C4: 28.5 ± 1.4 C5: 28.8 ± 1.2 C6: 30.0 ± 1.6 C7: 29.6 ± 1.6	White Male: mean ± SD C3: 28.9 ± 1.8 C4: 29.6 ± 1.8 C5: 30.0 ± 1.7 C6: 30.7 ± 1.6 C7: 30.1 ± 1.5 Coloured Male: mean ± SD C3: 29.1 ± 1.4 C4: 29.5 ± 1.6 C5: 30.1 ± 1.5 C6: 30.1 ± 1.5 C7: 30.3 ± 1.9

Table adapted from Roopnarain (2011)

A study involving African-American and Caucasian males and females reported that the IPD was narrowest at the levels of C2 and C3 and widest at C6 and generally increased from C2 to C7 in all individuals regardless of ethnicity (Tatarek, 2005). Ugur *et al*. (2000) observed that the IPD was widest at the level of C7. Both of these studies utilised male and female cadavers as opposed to measurements from radiographs (Hinck *et al.,* 1966; Roopnarain, 2011), but the IPD measurements reported by Tatarek (2005) and Ugur *et al*. (2000) were smaller than those reported in other studies. This difference could be due to the measurements being taken from skeletal samples. Furthermore, the radiographic studies above (**Table 2.6**) were not adjusted for radiographic magnification error. Another possible reason for the discrepancies in measurement values could be attributed to the fact that the tolerances of the different instrumentation used to measure IPD varied e.g. Taterek (2005) utilised vernier callipers which is accurate to one millimetre; whereas Ugur *et al*. (2000) used a goniometer which is a device that is usually used for the precise measurement of angles (Watkins *et al.,* 1991).

2.7.2.3.1 The influence of gender and ethnicity on IPD

In their study to determine the maximum normal IPD measurements for use in the diagnosis of intraspinal tumours and spinal stenosis, Hinck *et al*. (1966) observed that the average IPD measurement in males was consistently larger than those of females by one millimetre. Tatarek (2005) also reported that females generally had a smaller IPD and the level of the narrowest IPD varied amongst the genders regardless of ancestry, with the narrowest level at C2 for females and C3 for males.

In one of the few South African studies addressing cervical IPD in different ethnic groups, Roopnarain (2011) found that there were significant differences amongst the ethnic groups for the mean IPD at C3, C4, and C5 levels (p = 0.020, 0.048 and 0.016 respectively, ANOVA). For the mean IPD at C3 and C5 the difference was between the Indian and Coloured ethnic groups (p = 0.048 and 0.027 respectively, Bonferroni *post–hoc* test).The study only involved male participants and the results could not be compared to those of females. Therefore, this study would provide the relevant measurements required in order to make a comparison of IPD between South African females of similar ethnic groups.

Earlier, Eisenstein (1976) reported that a difference in IPD in the lumbar spine exists between the South African Black and White populations with Blacks possessing a less spacious spinal canal than Whites, and males had a larger IPD than females. Naidoo

(2008) reported that Indian females in South Africa possessed a larger mean IPD in the lumbar spine than White and Black females. From these studies one can extrapolate that differences may exist in the IPD values in the cervical spine between different genders and amongst the various South African ethnic groups.

2.7.2.3.2 Other factors that can affect the IPD

According to morphometric studies of the cervical pedicle, it was found that a discrepancy existed in measurement values for pedicle width (Ebraheim *et al.,* 1997; Ugur *et al.,* 2000). It stands to reason that pedicle width will affect the IPD, as it is measured between the medial surfaces of the pedicles of a given vertebra; therefore, an increase or decrease in the width of a pedicle will affect the measurement value of the IPD. The results of the study conducted by Ugur *et al.* (2000) reported larger measurement values for pedicle width in comparison to the study conducted by Ebraheim *et al.* (1997). According to Ebraheim *et al.* (1997), the pedicle width was shown to increase in both males and females from cephalad to caudad.

Paget's disease and congenital malformations such as achondroplasia, which cause thickening of the pedicles, can cause a decrease in the IPD resulting in spinal stenosis. Intraspinal neoplasms, with time, can cause erosion of the pedicles, which could result in widening of the IPD (Yochum and Rowe, 2005b). In rare instances, a unilateral pedicle agenesis may also result in one being unable to assess the IPD (Yochum and Rowe, 2005b).

2.7.2.4 Cervical Gravity Line

The CGL is a line drawn through the apex of the odontoid process and seventh cervical vertebra which allows for the gross assessment of where the gravitational stresses are acting at the cervicothoracic junction (Fox and Young, 1954; Yochum and Rowe, 2005a). Features of degeneration such as osteophytes tend to occur at areas of altered stress and strain (Harrison *et al*., 2001). Hardacker *et al.* (1997) reported that the mean ± SD measurement from the centre of the C7 vertebral body anterior to the cervical plumb line (also known as the CGL by Yochum and Rowe (2005a)) was 16.8 ± 11.2mm in asymptomatic adults.

The CL allows for the forces acting on the vertebral body both anteriorly and posteriorly to be minimal (Harrison *et al*., 2001). Roopnarain (2011) evaluated the effect of the CL on CGL in South African Black, White, Indian and Coloured males. He found that there was no significant difference amongst the ethnic groups and the position of the CGL (p = 0.733). The percentage of each ethnic group with anterior, normal and posterior position was relatively similar; overall he found that 53% of the participants had an anterior position of the CGL. This varied from 45% in Whites to 60% in Blacks. Only two individuals had a posterior placing (one Black and one Indian). There were no significant differences in the mean CL (C1 – C7 method and C2-C7 method) between those with anterior and normal CGL in any of the ethnic groups. His data suggests that CL (C1 – C7 method) does not influence the position of the CGL in any of the ethnic groups and that CL does not influence CGL. There were no significant differences noted amongst or within the ethnic groups for the CL (C2 – C7) Cobb method and the CGL. It would be interesting to determine if similar trends are observed in the females of the four main South African ethnic groups.

2.8 CONCLUSION

Although, there are numerous studies and various methods of measurement to assess CL and SCD (**Tables 2.2** and **2.5** respectively), no consensus has been reached on single normative reference values. The value of these two parameters and IPD are influenced by various factors including gender and ethnicity. The discrepancies in the results of previous studies may be attributed to differences in sample size, the population studied and methods of measurement.

This study would, therefore, be beneficial to South African doctors, surgeons and chiropractors in helping to increase awareness of the differences in measurement values for the above mentioned parameters across gender and within the different South African ethnic groups. It would also enable them to arrive at more accurate diagnoses for conditions such as cervical stenosis, cervical spine spondylosis, spinal neoplasms, and tumours and for pre- surgical and post-surgical assessments.

There are currently no studies that have evaluated CL, SCD, IPD and CGL in young to middle-aged South African Black, White, Indian and Coloured females. This study would, therefore, help to initiate guidelines for these parameters in females in the different South African ethnic groups.

CHAPTER THREE

MATERIALS AND METHODS

3.1 STUDY DESIGN AND PERMISSION TO CONDUCT THE STUDY

This research was designed as a quantitative, non-interventional, cross-sectional study. Primary data was obtained from the cervical spine radiographs and the selected anthropometric assessments of the participants. Approval to conduct this study was obtained from the Durban University of Technology (DUT) Faculty of Health Sciences Research Committee. (Ethics certification no. 041/10)

3.2 SUBJECT RECRUITMENT

An advertisement was published in the local newspapers, as well as in the form of pamphlets (**Appendix A**) which were posted in surrounding stores and campuses, DUT libraries and campuses, Chiropractic Day Clinic (CDC) and Homeopathy Clinic at DUT. Prospective participants were requested to contact the researcher telephonically.

3.2.1 Telephonic Interview with Prospective Participants

When the prospective participants contacted the researcher telephonically, they were asked the following questions:

1) “Do you have neck pain?”

2) “Are you between the ages of 18–45 years?”

3) “Have you had any x-rays done on any region of your body within the last month?”

4) “Have you undergone surgery or sustained injury to your neck region at any time?”

If the prospective participant answered “Yes” to Question 2 and “No” to Questions 1, 3 and 4 they were asked to present to the CDC for a consultation otherwise they were not considered for participation in this study.

3.3 SAMPLE PROCEDURE AND SAMPLE SIZE

Convenience sampling was utilised (Brink, 2007). The sample size was: *n* = 80 female participants who were grouped as follows:

Group 1: 20 White females (South African-born women of European Descent)

Group 2: 20 Black females (South African-born women of Sub-Saharan African Descent)

Group 3: 20 Indian females (South African-born women of Indian Descent)

Group 4: 20 Coloured females (South African-born women of mixed Black and White or Malay ancestry)

The sample size was selected having taken into cognisance the limited research funds and the limited human resources. Furthermore, in consultation with an experienced biostatistician (Esterhuizen, 2011) consideration was given to the time constraints faced by the researcher in completing this study.

3.4 INCLUSION AND EXCLUSION CRITERIA

3.4.1 Inclusion Criteria

- All participants had to be healthy individuals between the ages of 18 and 45 years. According to the South African Medical Research Council (South African Medical Research Council Guidelines on Ethics for Medical Research, 2002), those younger than 18 years required parental consent and are, therefore, not recommended as participants in research studies. Individuals older than 45 years have a higher incidence of degenerative changes in the cervical spine and hence not included (Grob *et al.,* 2007).
- All participants had to be female in order to maintain sample homogeneity. Several researchers reported differences between genders with respect to radiographic parameters of the cervical spine (Lim and Wong, 2004; McAviney *et al.,* 2005; Tossel, 2007).
- Participants had to be South Africans born in South Africa of either the Black, White, Indian or Coloured ethnic groups as this was in keeping with the aim and rationale of this study.
- Participants had to have no medical complaints on case history and physical examination.

3.4.2 Exclusion Criteria

- Pregnant females and females who suspected they were pregnant.
- Individuals who sustained an injury to the neck region or developed neck pain between the first consultation and the radiographic consultation.
- Individuals who had radiographs taken in the month prior to participating in this study in order to minimise exposure to radiation.

3.5 RESEARCH PROCEDURES

The prospective participants presented to the CDC for a consultation

↓

Each prospective participant was given a copy of the letter of information and informed consent (**Appendix B**) to read

↓

The researcher then answered any questions the prospective participants may have had regarding their participation and involvement in the study

↓

If the prospective participant expressed a willingness to participate in this study, she was requested to sign the informed consent form

↓

The participant then progressed to **Phase 1** of the study

Phase 1

A case history (**Appendix D**), physical examination (**Appendix E**) and orthopaedic examination of the cervical spine (**Appendix F)** was undertaken and completed for all participants. If time allowed, the researcher and participant proceeded to the Radiography Clinic; otherwise an appointment was made for a radiographic consultation within one week of the initial consult.

Phase 2

Participants arrived at the Radiography Clinic. If there was an interval between the first consultation and the radiographic consultation, the participants were asked if they sustained any injury to their neck or developed neck pain since their initial consultation. If they sustained any injury or developed neck pain they were excluded. The participants were prepared for their radiograph in accordance with the Radiography Clinic's protocol which included the removal of clothing and the wearing of a gown that was provided, as well as breast and gonad protection in the form of a lead protection shield on wheels and collimation of the radiographic field to include only the area of interest. The participant stood barefoot on a flat floor with their arms at their sides, shoulders relaxed, and legs straight. They then had an erect A-P and lateral cervical spine radiograph taken by the researcher in accordance with the technique described by Yochum and Rowe (2005a). The generator of the x-ray unit was set such that the exposure factors for the A-P view was an average of 63 kV and 10 mAs and the lateral view was an average of 70 kV and 20 mAs in accordance with guidelines set out by the Radiography Clinic. The x-ray beam was collimated to include only relevant structures required to measure the selected parameters. All of the above settings and protocols were discussed with the appointed radiographer at the Radiography Clinic (Gqweta, 2010). The researcher is sufficiently trained and legally permitted to take radiographs which were conducted under the supervision of the radiographer at the Radiography Clinic or under the supervision of a registered chiropractor when the radiographer was not present.

Phase 3

The cervical spine radiographs were evaluated utilising the Alignment, Bone, Cartilage and Soft tissue (ABCS) approach (Yochum and Rowe, 2005a). The radiographic parameters were determined according to the techniques described in **Table 3.1.**

Table 3.1 Methods of measurement for the selected radiographic parameters

Parameter	Reference	Method
Cervical lordosis	Jochumsen (1969); Harrison *et al.* (2000)	Angle of cervical curve / Modified Cobb method / **C1-C7 Cobb method :** One line was drawn through and parallel to the inferior endplate of C7 body and the other line through the midpoints of the anterior and posterior tubercles of the atlas. Perpendiculars were constructed to the point of juncture and the resultant angle was then measured. **C2-C7 Cobb method:** A line was constructed through and parallel to the inferior endplate of C7 and another was drawn through and parallel to the inferior endplate of C2, perpendiculars were constructed to the point of intersection and the resultant angle was measured.
Sagittal dimension of the cervical spinal canal	Wolf *et al*. (1956); Hinck *et al*. (1962)	This was measured from the posterior surface of the midvertebral aspect of the body to the nearest surface of the spinolaminar junction line in the same segment.
Interpedicular distance	Hinck *et al*. (1966)	The shortest distance between the medial convex surfaces of the segmental pedicles was measured.
Cervical gravity line	Fox and Young (1954)	A vertical line was drawn through the apex of the odontoid process which should have passed through the C7 body.

All data gathered from the radiographs and study-specific data such as height, weight, ethnicity, occupation, the focal film distance (FFD), kV and mAs were recorded on the data collection sheet (**Appendix C**) for each participant.

The following instruments and tools were utilised in this study:

- X-ray viewing box: for viewing radiographs (For consistency, the same x-ray viewing box with sufficient lighting was utilised by the researcher throughout the study. This eliminated variability in lighting).
- 30 cm ruler: to measure distances between anatomical landmarks.
- Divider: for accurate marking of distances between anatomical landmarks.

- Protractor: for measuring angles.
- Marking pens: for marking lines.
- T-square: to ensure that the film was correctly aligned to the viewing box.

3.6 ETHICAL CONSIDERATIONS

Only healthy asymptomatic female participants who were not pregnant or did not suspect that they were pregnant were considered for participation. Participants were exposed to a low dose of radiation for a short duration. To further minimise the radiation exposure to research participants, only those participants who did not have x-rays taken in the month prior to their participation were considered. Precautions were taken by the researcher in accordance with the Radiography Clinics' safety protocol in order to ensure both the researcher and participant was protected from unnecessary exposure to radiation. Participant confidentiality was maintained throughout the research process by means of a coding system. The participants' names did not appear in the data analysis and only the researcher and supervisor had access to their clinical and radiographic records. All participants signed a letter of informed consent before participating in the study.

3.7 STATISTICAL ANALYSIS

SPSS version 15.0 was used to analyse the data. A p value ≤ 0.05 was used to indicate statistical significance. Coefficients of variation were calculated within the various ethnic groups to assess intra-group variation. Inter-group variation was assessed using ANOVA testing with Bonferroni-adjusted *post-hoc* tests in the case of a significant ANOVA test. Pearson's chi square test was used to assess the association between the various ethnic groups and the position of the CGL. T-tests were used to compare mean CL between those with anterior and normally placed CGL within each ethnic group (Esterhuizen, 2011).

CHAPTER FOUR

RESULTS

4.1 AGE AND ANTHROPOMETRIC CHARACTERISTICS OF THE PARTICIPANTS

The mean and standard deviation of the age, height and weight of the 80 female participants is shown in **Table 4.1** by ethnic group and in total for all who met the inclusion criteria. The overall ages of the participants ranged from 18 to 45 years. The mean ± standard deviation of the body mass index (BMI) of the respective ethnic groups is depicted graphically in **Figure 4.1**.

Table 4.1 Mean and standard deviation of the age, height and weight of the participants

Group		Age (yrs)	Height (m)	Weight (kg)
Black	Mean	21.1	1.7	60.3
	n	20	20	20
	Std. deviation	2.4	0.1	14.1
White	Mean	25.0	1.7	64.0
	n	20	20	20
	Std. deviation	4.9	0.0	11.2
Indian	Mean	24.4	1.6	57.6
	n	20	20	20
	Std. deviation	5.9	0.1	11.9
Coloured	Mean	24.1	1.6	59.3
	n	20	20	20
	Std. deviation	6.9	0.1	14.4
Total	Mean	23.6	1.6	60.3
	n	80	80	80
	Std. deviation	5.4	0.1	12.9

yrs = years; m = metres; kg = kilograms

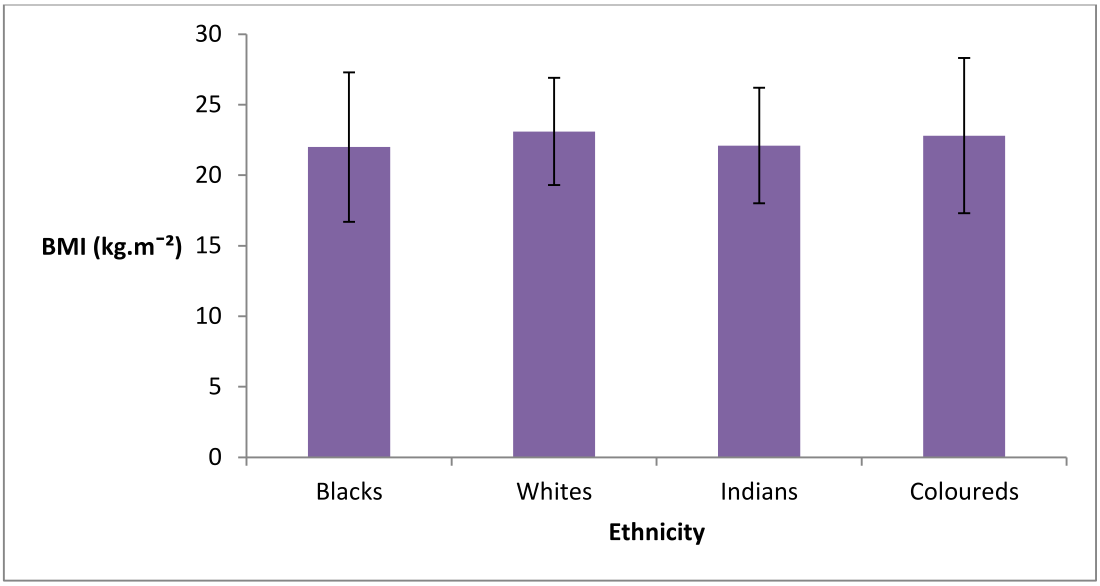

Figure 4.1 The mean ± SD of the BMI ($kg.m^{-2}$) of the participants

4.2 THE SELECTED RADIOGRAPHIC PARAMETERS

4.2.1 Cervical Lordosis

The mean, standard deviation and range of CL for the selected ethnic groups using the C1-C7 and C2-C7 methods are shown in **Tables 4.2** and **4.3**. The mean total and standard deviation for the C1-C7 method was greater than the C2-C7 method. The C1-C7 measurements and the C2-C7 CL measurements were significantly different amongst the ethnic groups (**Table 4.4**). The Bonferroni adjusted *post-hoc* tests (**Table 4.5**) showed that for the C1-C7 method no individual differences existed, but for the C2-C7 method the Blacks differed significantly from both the Whites (p = 0.037) and the Indians (p = 0.001) with the values for the Blacks being higher than both Whites and Indians. There was no correlation between CL and BMI between any of the selected ethnic groups (**Table 4.6**).

Table 4.2 The mean, standard deviation and range of the CL by ethnic group using the C1–C7 Cobb method

Ethnicity	Mean (°)	*n*	Std. deviation	Minimum (°)	Maximum (°)
Black	42.1	20	13.4	14	60
White	37.4	20	10.3	15	59
Indian	33.7	20	9.7	23	60
Coloured	42.5	20	10.9	21	63
Total	38.9	80	11.5	14	63

Table 4.3 The mean, standard deviation and range of the CL by ethnic group using the C2-C7 Cobb method

Ethnicity	Mean (°)	*n*	Std. deviation	Minimum (°)	Maximum (°)
Black	16.3	20	8.3	4	40
White	9.9	20	4.8	2	20
Indian	6.9	20	4.8	2	20
Coloured	12.1	20	9.5	1	30
Total	11.3	80	7.8	1	40

Table 4.4 ANOVA test to compare the mean CL amongst and within ethnic groups

		Sum of Squares	df	Mean square	F	*p*-value
C1-C7	Between groups	1046.738	3	348.913	2.800	0.046
	Within groups	9471.250	76	124.622		
	Total	10517.988	79			
C2-C7	Between groups	932.050	3	310.683	6.036	0.001
	Within groups	3911.900	76	51.472		
	Total	4843.950	79			

Table 4.5 Bonferroni adjusted *post-hoc* test to assess inter-group variation of the C1-C7 and C2-C7 Cobb methods

Multiple Comparisons

Bonferroni

Dependent Variable	(I) group	(J) group	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
						Lower bound	Upper bound
C1-C7	Black	White	4.650	3.530	1.000	-4.91	14.21
		Indian	8.400	3.530	0.119	-1.16	17.96
		Coloured	-0.400	3.530	1.000	-9.96	9.16
	White	Black	-4.650	3.530	1.000	-14.21	4.91
		Indian	3.750	3.530	1.000	-5.81	13.31
		Coloured	-5.050	3.530	0.940	-14.61	4.51
	Indian	Black	-8.400	3.530	0.119	-17.96	1.16
		White	-3.750	3.530	1.000	-13.31	5.81
		Coloured	-8.800	3.530	0.089	-18.36	0.76
	Coloured	Black	0.400	3.530	1.000	-9.16	9.96
		White	5.050	3.530	0.940	-4.51	14.61
		Indian	8.800	3.530	0.089	-0.76	18.36
C2-C7	Black	White	6.400*	2.269	0.037	0.25	12.55
		Indian	9.350*	2.269	0.001	3.20	15.50
		Coloured	4.150	2.269	0.428	-2.00	10.30
	White	Black	-6.400*	2.269	0.037	-12.55	-0.25
		Indian	2.950	2.269	1.000	-3.20	9.10
		Coloured	-2.250	2.269	1.000	-8.40	3.90
	Indian	Black	-9.350*	2.269	0.001	-15.50	-3.20
		White	-2.950	2.269	1.000	-9.10	3.20
		Coloured	-5.200	2.269	0.148	-11.35	0.95
	Coloured	Black	-4.150	2.269	0.428	-10.30	2.00
		White	2.250	2.269	1.000	-3.90	8.40
		Indian	5.200	2.269	0.148	-0.95	11.35

* The mean difference is significant at the 0.05 level.

Table 4.6 The correlation between CL and BMI in each ethnic group

Group			BMI
Black	C1-C7	Pearson's correlation	-0.092
		Sig. (2-tailed)	0.700
		n	20
	C2-C7	Pearson's correlation	0.227
		Sig. (2-tailed)	0.336
		n	20
White	C1-C7	Pearson's correlation	0.046
		Sig. (2-tailed)	0.847
		n	20
	C2-C7	Pearson's correlation	-0.020
		Sig. (2-tailed)	0.934
		n	20
Indian	C1-C7	Pearson's correlation	-0.003
		Sig. (2-tailed)	0.991
		n	20
	C2-C7	Pearson's correlation	0.097
		Sig. (2-tailed)	0.683
		n	20
Coloured	C1-C7	Pearson's correlation	-0.198
		Sig. (2-tailed)	0.402
		n	20
	C2-C7	Pearson's correlation	-0.408
		Sig. (2-tailed)	0.074
		n	20

BMI = Body Mass Index

4.2.2 Sagittal Canal Diameter

The mean and standard deviation of SCD at the respective vertebral levels by ethnic group is shown in **Table 4.7**. A decrease in the mean SCD was observed at C3 in the Black, White and Indian ethnic groups which decreased further at C4 and C5, increased at C6 and then decreased at C7 again. Similarly, in Coloureds the mean SCD decreased at C3 and C4, but increased at C5 and then decreased at C6 and C7. There were no significant differences in the mean SCD between the ethnic groups ($p > 0.05$, ANOVA; **Table 4.8**).

Table 4.7 The mean and standard deviation of the SCD at the respective cervical vertebral levels by ethnic group

Group		SCDC2	SCDC3	SCDC4	SCDC5	SCDC6	SCDC7
Black	Mean	20.2	17.4	17.2	17.0	17.6	17.5
	n	20	20	20	20	20	20
	Std. deviation	1.7	1.4	1.4	1.4	1.3	1.4
White	Mean	20.8	17.9	17.6	17.4	17.6	16.9
	n	20	20	20	20	20	20
	Std. deviation	2.2	1.6	1.6	1.6	1.4	1.4
Indian	Mean	21.0	18.2	17.5	17.4	17.6	17.1
	n	20	20	20	20	20	20
	Std. deviation	2.0	1.7	1.5	1.7	1.6	1.5
Coloured	Mean	20.3	17.5	17.4	17.7	17.6	16.9
	n	20	20	20	20	20	20
	Std. deviation	1.6	1.8	1.5	1.2	1.3	1.2
Total	Mean	20.6	17.7	17.4	17.4	17.6	17.1
	n	80	80	80	80	80	80
	Std. deviation	1.9	1.6	1.5	1.5	1.4	1.4

SCD = Sagittal canal diameter (the values are given in mm)

Table 4.8 ANOVA test to compare the mean SCD amongst the ethnic groups

		Sum of Squares	df	Mean Square	F	*p*-value
SCDC2	Between groups	9.086	3	3.029	0.834	0.480
	Within groups	276.150	76	3.634		
	Total	285.236	79			
SCDC3	Between groups	7.934	3	2.645	1.009	0.393
	Within groups	199.164	76	2.621		
	Total	207.098	79			
SCDC4	Between groups	1.545	3	0.515	0.223	0.880
	Within groups	175.614	76	2.311		
	Total	177.159	79			
SCDC5	Between groups	4.639	3	1.546	0.716	0.545
	Within groups	164.101	76	2.159		
	Total	168.740	79			
SCDC6	Between groups	.020	3	0.007	0.003	1.000
	Within groups	148.505	76	1.954		
	Total	148.524	79			
SCDC7	Between groups	4.687	3	1.562	0.844	0.474
	Within groups	140.727	76	1.852		
	Total	145.415	79			

4.2.3 Interpedicular Distance

The mean and standard deviation of the IPD at the respective level for each ethnic group is shown in **Table 4.9**. The mean IPD measurement for Blacks increased at C4, C5 and C6 and then decreased at C7. For Whites, the mean IPD increased at C4 and C5 and then decreased at C6 and C7. The mean IPD measurement for Indians increased at C4 and C5, remained constant at C6 and then decreased at C7 whereas; the measurements for Coloureds decreased at C4 and then increased at C5 and C6 and then decreased slightly at C7. There were no significant differences in the mean IPD between the ethnic groups ($p > 0.05$, ANOVA test; **Table 4.10**).

Table 4.9 The mean and standard deviation of the IPD at the respective cervical vertebral levels by ethnic group

Group		IPDC3	IPDC4	IPDC5	IPDC6	IPDC7
Black	Mean	27.0	27.6	28.2	28.9	27.5
	n	20	20	20	20	20
	Std. deviation	2.8	3.2	4.0	4.2	3.5
White	Mean	28.4	28.8	29.5	29.3	28.2
	n	20	20	20	20	20
	Std. deviation	2.6	2.2	2.3	2.5	2.9
Indian	Mean	27.2	27.5	27.9	27.9	27.5
	n	20	20	20	20	20
	Std. deviation	1.8	1.8	1.6	1.6	2.0
Coloured	Mean	27.9	27.8	28.3	28.4	28.2
	n	20	20	20	20	20
	Std. deviation	2.3	2.3	2.2	1.8	1.7
Total	Mean	27.6	27.9	28.5	28.6	27.8
	n	80	80	80	80	80
	Std. deviation	2.4	2.4	2.7	2.7	2.6

IPD = Interpedicular distance (the values given are in mm)

Table 4.10 ANOVA test to compare the mean IPD amongst the ethnic groups

		Sum of squares	df	Mean square	F	*p*-value
IPDC3	Between groups	24.529	3	8.176	1.388	0.253
	Within groups	447.588	76	5.889		
	Total	472.117	79			
IPDC4	Between groups	21.667	3	7.222	1.214	0.311
	Within groups	452.291	76	5.951		
	Total	473.958	79			
IPDC5	Between groups	27.715	3	9.238	1.283	0.286
	Within groups	547.235	76	7.200		
	Total	574.949	79			
IPDC6	Between groups	21.508	3	7.169	.963	0.414
	Within groups	565.525	76	7.441		
	Total	587.033	79			
IPDC7	Between groups	10.278	3	3.426	.505	0.680
	Within groups	515.159	76	6.778		
	Total	525.437	79			

4.2.4 Cervical Gravity Line

In total, 65% of the participants had an anterior positioning of the CGL, 35% had a normal position and none presented with a posterior positioning of the CGL (**Table 4.11**). There were no significant associations among any of the ethnic groups and the position of the CGL ($p = 0.830$; Pearson's chi square test). The percentage of an anteriorly-placed CGL was similar in all ethnic groups (**Table 4.11**). T-tests were done to determine if the CL significantly influenced the position of the CGL using the C1-C7 and C2-C7 Cobb methods (**Tables 4.13 and 4.14**) respectively. In Black females, those with a normally positioned CGL had significantly higher C2-C7 CL measurements ($p = 0.008$) (**Table 4.14**). There were no significant associations observed in the other ethnic groups. There was no correlation between the CL and anterior placing of the CGL in any of the ethnic groups ($p > 0.05$, Pearson's correlation test; **Table 4.15**).

Table 4.11 Cross tabulation of ethnic group and position of the CGL

Group			CGL at C7		Total
			anterior	normal	
	Black	Count	14	6	20
Total		% within group	70.0%	30.0%	100.0%
	White	Count	14	6	20
		% within group	70.0%	30.0%	100.0%
	Indian	Count	12	8	20
		% within group	60.0%	40.0%	100.0%
	Coloured	Count	12	8	20
		% within group	60.0%	40.0%	100.0%
		Count	52	28	80
			65.0%	35.0%	100.0%

Table 4.12 CGL anterior measurement by ethnic group

Group		CGL anterior to C7 VB (mm)
Black	Mean	12.1
	n	14.0
	Std. deviation	7.2
White	Mean	9.6
	n	14.0
	Std. deviation	6.7
Indian	Mean	7.1
	n	12.0
	Std. deviation	3.6
Coloured	Mean	10.7
	n	12.0
	Std. deviation	6.7
Total	Mean	9.9
	n	52.0
	Std. deviation	6.4

Table 4.13 T-tests to compare the mean CL (C1 – C7 Cobb method) between those with an anterior and normal CGL by ethnic group

Group			*n*	Mean	Std. deviation	Std. error mean	*p* -value
Black	C1-C7	anterior	14	38.5	13.988	3.738	0.069
		normal	6	50.3	7.474	3.051	
White	C1-C7	anterior	14	37.5	11.719	3.132	0.949
		normal	6	37.2	6.494	2.651	
Indian	C1-C7	anterior	12	33.0	8.780	2.535	0.725
		normal	8	34.6	11.563	4.088	
Coloured	C1-C7	anterior	12	43.1	12.544	3.621	0.760
		normal	8	41.5	8.652	3.059	

Table 4.14 T-tests to compare the mean CL (C2 – C7 Cobb method) between those with an anterior and normal CGL by ethnic group

Group			*n*	Mean	Std. deviation	Std. error mean	*p* - value
Black	C2-C7	anterior	14	13.2	5.727	1.531	0.008
		normal	6	23.3	9.352	3.818	
White	C2-C7	anterior	14	9.4	5.302	1.417	0.566
		normal	6	10.8	3.764	1.537	
Indian	C2-C7	anterior	12	7.3	4.619	1.333	0.637
		normal	8	6.3	5.418	1.916	
Coloured	C2-C7	anterior	12	11.3	10.316	2.978	0.672
		normal	8	13.3	8.779	3.104	

Table 4.15 Pearson's correlation between CL and CGL anterior measurements

Group			CGL anterior to C7 VB (mm)
Black	C1-C7	Pearson's correlation	-0.117
		Sig. (2-tailed)	0.690
		n	14
	C2-C7	Pearson's correlation	0.022
		Sig. (2-tailed)	0.939
		n	14
White	C1-C7	Pearson's correlation	-0.452
		Sig. (2-tailed)	0.105
		n	14
	C2-C7	Pearson's correlation	0.201
		Sig. (2-tailed)	0.491
		n	14
Indian	C1-C7	Pearson's correlation	-0.262
		Sig. (2-tailed)	0.410
		n	12
	C2-C7	Pearson's correlation	-0.169
		Sig. (2-tailed)	0.600
		n	12
Coloured	C1-C7	Pearson's correlation	-0.147
		Sig. (2-tailed)	0.649
		n	12
	C2-C7	Pearson's correlation	0.175
		Sig. (2-tailed)	0.587
		n	12

4.3 VARIATION IN THE SELECTED RADIOGRAPHIC PARAMETERS WITHIN THE ETHNIC GROUPS

The coefficients of variation (%) are all relatively small within the ethnic groups (**Table 4.16**). For CL the variations tended to be larger than for the other measures since the standard deviations for this measure were relatively high (**Tables 4.2** and **4.3**).

Table 4.16 Coefficient of variation (%) within each ethnic group

Ethnic group	SCDC2	SCDC3	SCDC4	SCDC5	SCDC6	SCDC7	C1-C7	C2-C7	IPDC3	IPDC4	IPDC5	IPDC6	IPDC7
Black	8.6	7.9	8.0	8.1	7.4	7.9	31.9	50.8	10.4	11.8	14.1	14.5	12.7
White	10.6	8.8	9.4	9.1	8.0	8.1	27.4	49.1	9.3	7.7	7.9	8.6	10.2
Indian	9.7	9.2	8.6	9.6	9.0	8.7	28.9	70.2	6.7	6.5	5.8	5.8	7.2
Coloured	7.8	10.4	8.8	6.8	7.4	7.1	25.7	78.8	8.4	8.2	7.8	6.2	6.0

CHAPTER FIVE

DISCUSSION

5.1 AGE AND ANTHROPOMETRIC CHARACTERISTICS OF THE PARTICIPANTS

The age range of the participants was due to the inclusion criteria of the study; all participants were young to middle-aged adults between 18 and 45 years of age. The age range of the participants was similar to the age range of the participants in the study by Roopnarain (2011). The mean age of participants (**Table 4.1**) was lower than that of the participants of the previous studies (Hardacker *et al.*, 1997; McAviney *et al*., 2005; Roopnarain, 2011). The mean height of participants **(Table 4.1)** was lower than that reported by Hardacker *et al.* (1997). The mean BMI for each ethnic group (**Figure 4.1**) fell into the normal range for adults as per the guidelines of the World Health Organisation (World Health Organization Global Data Base on Body Mass Index, 2011). No other study which investigated the selected radiographic parameters of the cervical spine reported on the BMI of the participants except Roopnarain (2011). Black and White females had slightly higher mean BMI values and Indian and Coloured females had lower BMI values when compared to the BMI values of males of the respective ethnic groups who participated in Roopnarain's (2011) study.

5.2 SELECTED RADIOGRAPHIC PARAMETERS OF THE CERVICAL SPINE

5.2.1 Cervical Lordosis

The overall mean CL (C1- C7 method; **Table 4.2)** was larger by 2.1° and 2.5° in the Black and Coloured females respectively and smaller by 2.6° and 6.3° in White and Indian females respectively when compared to the mean CL reported by Drexler (1962) and Yochum and Rowe (2005_a). The researcher was unable to find the actual method described by Drexler (1962) for the determination of the mean CL despite an exhaustive literature search. The overall mean CL (C1- C7 method) observed in this study was slightly smaller than that of asymptomatic females (C0-C7 method) (Hardacker *et al*., 1997). The mean CL value of 38.9° (C1- C7 method; **Table 4.2)** was smaller than that of the mean CL value of 53.6° reported by Harrison *et al*. (2000) **(Table 2.2**) who utilised the same method. It was also consistently smaller than the reported mean CL (C1-C7 method) of males (Roopnarain, 2011). This result is presented in **Table 5.1**. The mean CL (C2-C7 method) of females in this study was smaller than that of males of the same ethnic group (Roopnarain, 2011) with the exception of Black females who were observed to have a slightly larger mean CL than that of their male counterparts **(Table 5.1)**. This finding emphasizes the importance of establishing sex-specific ranges for CL for each ethnic group.

Differences were observed when the mean CL (C2-C7 method) observed in this study was compared to that of Harrison *et al*. (2000) (C2-C7 method). It was 0.9° less in Black females, 7.7° less in White females, 10.3° less in the Indian females and 5.1° less in Coloured females. The differences in the mean values between the C1-C7 and C2-C7 methods emphasizes the importance of stating which method was utilized for evaluating the CL to aid the clinician in determining its clinical significance.

In comparison to studies that utilized the posterior tangent method to determine the total mean CL (Harrison *et al*., 2000; McAviney *et al*., 2005) **(Table 2.2)**, it was found that the total mean CL (C1-C7 method) observed in this study was greater in all four ethnic groups. This could be due to the propensity of the C1-C7 Cobb method to overestimate the CL, since most of the lordosis in the cervical spine occurs at the atlas (Harrison *et al*., 2000). The mean CL obtained using the posterior tangent method (Harrison *et al*., 2000; McAviney *et al*., 2005) **(Table 2.2)**, was found to be greater than the mean CL value (C2-C7 method; **Table 4.3**). Roopnarain (2011) reported similar findings in the male participants. This could be due to the tendency of C2-C7 method to underestimate the CL (Harrison *et al*., 2000; Roopnarain, 2011). The Cobb method is the most commonly used method by clinicians to determine CL, but they should be aware that the C2-C7 method is a more accurate determinant of CL than the C1-C7 method (Cote *et al*., 1997; Harrison *et al*., 2000; Roopnarain, 2011). According to Cote *et al*. (1997), the C2-C7 method demonstrated superior interexaminer reliability in comparison to the C1-C7 method; it was easily reproduced and showed excellent intraclass coefficients. Therefore, it is recommended that the C2-C7 Cobb method be utilized by clinicians when determining the CL. This is also in keeping with the recommendation by Roopnarain (2011). It is also recommended that a future study with a larger sample size across the four ethnic groups in South Africa be conducted in order to establish whether a mean of 38.9° (C1-C7 method) or 11.3° (C2-C7 method) can be utilized as a norm reference for CL for females in the South African context.

No significant correlation was found between BMI and CL (C1-C7 and C2-C7 Cobb method) in females **(Table 4.6)**. These findings were similar to those of Roopnarain (2011) who also observed that there was no significant association between BMI and CL in males. None of the other studies that evaluated the CL investigated an association between BMI and CL. However, Hardacker *et al.* (1997) investigated the possible association between CL and height, but found no significant association. Although the results of this study show no association between CL and BMI, this finding needs to be verified in a study with a larger sample size and with a broader range of BMI.

Table 5.1 Comparison of the mean CL between males and females of the same ethnic group

	C1-C7		C2-C7	
	Current study (F)	**Roopnarain (2011) (M)**	**This study (F)**	**Roopnarain (2011) (M)**
Ethnicity	**Mean (°)**	**Mean (°)**	**Mean (°)**	**Mean (°)**
Black	42.1	42.6	16.3	15.1
White	37.4	46.2	9.9	17.4
Indian	33.7	46.5	6.9	13.1
Coloured	42.5	47.7	12.1	18.1
Total	38.9	45.7	11.3	15.9

M = Males; F = Females

5.2.2 Sagittal Canal Diameter

The widest SCD was observed at C2 for all four ethnic groups (**Table 4.7**). Roopnarain (2011) also found C2 to have the widest SCD in males from all four ethnic groups. This trend was also reported by Lim and Wong (2004) and Tatarek (2005) for both males and females (**Table 2.5**) and is in keeping with the reports of Bland (1994). On the other hand, Lee *et al*. (1994) and Tossel (2007) reported that the SCD was widest at C7 in both sexes in Koreans and South African Blacks respectively. However, Lee *et al*. (1994) and Tossel (2007) did not evaluate the SCD at C2 which could account for their findings.

The narrowest mean SCD was observed at C5 and C7 for White females. This is in contrast to the findings of Tatarek (2005) who reported that the SCD was narrowest at C6 in American Caucasian males and females and Roopnarain who reported that the SCD was narrowest at C4 in South African White males. The narrowest SCD in Black females was observed at C4 and C5 (**Table 4.7**). This is similar to the findings of Roopnarain (2011) who observed that narrowest SCD in Black males was at C4. The narrowest SCD in South African Indian females was found to be at C4 and C7. This finding was in keeping with that observed by Gupta *et al*. (1982) in indigenous Indian males and females. It was also similar to the observations of Roopnarain (2011) (**Table 2.5**). The narrowest SCD observed in Coloured females was at C4 and C7, which were also similar to the findings reported by Roopnarain (2011).

Table 5.2 The mean SCD observed in this study compared to the reported mean SCD in combined male and female cohorts

Cervical vertebral level	Current study mean SCD (mm)	Oon (1974)	Yochum and Rowe (2005a)
C2	**B**: 20.2	↑1.7	↑0.2
	W: 20.8	↑2.3	↑0.8
	I: 21.0	↑2.5	↑1.0
	C: 20.3	↑1.8	↑0.3
C3	**B**: 17.4	↑1.9	↓0.6
	W: 17.9	↑2.4	↓0.1
	I: 18.2	↑2.7	↑0.2
	C: 17.5	↑2.0	↓0.5
C4	**B**: 17.2	↑2.3	↑0.2
	W: 17.6	↑2.7	↑0.6
	I: 17.5	↑2.6	↑0.5
	C: 17.4	↑2.5	↑0.4
C5	**B**: 17.0	↑1.8	↑0.0
	W: 17.4	↑2.2	↑0.4
	I: 17.4	↑2.2	↑0.4
	C: 17.7	↑2.5	↑0.7
C6	**B**: 17.6	↑2.1	↑0.6
	W: 17.6	↑2.1	↑0.6
	I: 17.6	↑2.1	↑0.6
	C: 17.6	↑2.1	↑0.6
C7	**B**: 17.5	↑2.1	↑0.5
	W: 16.9	↑1.5	↓0.1
	I: 17.1	↑1.7	↑0.1
	C: 16.9	↑1.5	↓0.1

B = Black; W = White; I = Indian; C = Coloured; ↑ = increase; ↓ = decrease

***Adapted from Roopnarain (2011)**

In comparison to the mean SCD values reported by Oon (1974) and Yochum and Rowe (2005_a) (**Table 5.2**), the mean SCD values observed in this study were larger except at C3 where the mean SCD of Black, White and Coloured females was slightly larger than the mean SCD reported by Yochum and Rowe (2005_a). The mean SCD value of White and Coloured females at C7 was larger than that reported by Yochum and Rowe (2005_a) although this difference was very minor **(Table 5.2)**. A possible reason for the difference in the mean SCD value reported by Oon (1974) and this study is that a mixed sample was used by Oon (1974) which comprised of an equal number of males and females from different ethnic groups with an age range of 20 to 80 years. Furthermore, those subjects either experienced trauma to their neck or were suspected of having nasopharyngeal carcinoma. No mention was made of the ethnicity or gender of the subjects in the report by Yochum and Rowe (2005a).

Table 5.3 A comparison of the mean SCD of the current study to those of previous studies

					Tatarek (2005)			
Cervical vertebral level	**Current study mean SCD (mm)**	**Gupta *et al.* (1982) F: (M)**	**Lee *et al.* (1994) F: (M)**	**Lim and Wong (2004) F: (M)**	**African-American F: (M)**	**Caucasian F: (M)**	**Tossel (2007) F: (M)**	**Roopnarain (2011) (M):**
C2	**B**: 20.2	↑1.6 : ↑(0.5)	*	↑ 1.7: ↑(1.1)	↑ 5.1: ↑(3.8)	↑ 3.6: ↑(3.4)	*	↓(1.9)
	W: 20.8	↑ 2.2: ↑ (1.1)	*	↑ 2.3: ↑(1.7)	↑ 5.7: ↑(4.4)	↑ 4.2: ↑(4.0)	*	↓(3.3)
	I: 21.0	↑ 2.4: ↑ (1.3)	*	↑ 2.5: ↑(1.9)	↑ 5.9: ↑(4.6)	↑4.4: ↑(4.2)	*	↓(1.8)
	C: 20.3	↑ 1.7: ↑ (0.6)	*	↑ 1.8: ↑(1.2)	↑ 5.2: ↑(3.9)	↑ 3.7: ↑(3.5)	*	↓(2.6)
C3	**B**: 17.4	↑ 1.3: ↑ (0.3)	↑ 4.1: ↑(4.1)	↑ 1.3: ↑(0.6)	↑ 4.1: ↑(3.0)	↑ 3.0: ↑(2.4)	↑ 3.4: ↑(3.5)	↓(2.1)
	W: 17.9	↑ 1.8: ↑ (0.8)	↑ 4.6: ↑(4.6)	↑ 1.8: ↑(1.1)	↑ 4.6: ↑(3.5)	↑ 3.5: ↑(2.9)	↑ 3.9: ↑(4.0)	↓(2.7)
	I: 18.2	↑ 2.1: ↑ (1.1)	↑ 4.9: ↑(4.9)	↑ 2.1: ↑(1.4)	↑ 4.9: ↑(3.8)	↑ 3.8: ↑(3.2)	↑ 4.2: ↑(4.3)	↓(1.5)
	C: 17.5	↑ 1.4: ↑ (0.4)	↑ 4.2: ↑(4.2)	↑ 1.4: ↑(0.7)	↑ 4.2: ↑(3.1)	↑ 3.1: ↑(2.5)	↑ 3.5: ↑(3.6)	↓(2.5)
C4	**B**: 17.2	↑ 1.6: ↑ (0.6)	↑ 4.3: ↑(4.4)	↑ 1.5: ↑(1.0)	↑ 4.0: ↑(3.2)	↑ 3.5: ↑(2.6)	↑ 3.4: ↑(3.6)	↓(1.4)
	W: 17.6	↑ 2.0: ↑ (1.0)	↑ 4.7: ↑(4.8)	↑ 1.9: ↑(1.4)	↑ 4.4: ↑(3.6)	↑ 3.9: ↑(3.0)	↑ 3.8: ↑(4.0)	↓(2.3)
	I: 17.5	↑ 1.9: ↑ (0.9)	↑ 4.6: ↑(4.7)	↑ 1.8: ↑(1.3)	↑ 4.3: ↑(3.5)	↑ 3.8: ↑(2.9)	↑ 3.7: ↑(3.9)	↓(1.6)
	C: 17.4	↑ 1.8: ↑ (0.8)	↑ 4.5: ↑(4.6)	↑ 1.7: ↑(1.2)	↑ 4.2: ↑(3.4)	↑ 3.7: ↑(2.8)	↑ 3.6: ↑(3.8)	↓(2.1)
C5	**B**: 17.0	↑ 1.3: ↑ (0.4)	↑ 4.0: ↑(4.0)	↑ 1.0: ↑(0.2)	↑ 3.7: ↑(2.9)	↑ 3.4: ↑(2.5)	↑ 3.2: ↑(3.1)	↓(1.9)
	W: 17.4	↑ 1.7: ↑ (0.8)	↑ 4.4: ↑(4.4)	↑ 1.4: ↑(0.6)	↑ 4.1: ↑(3.3)	↑ 3.8: ↑(2.9)	↑ 3.6: ↑(3.5)	↓(2.6)
	I: 17.4	↑ 1.7 : ↑ (0.8)	↑ 4.4: ↑(4.4)	↑ 1.4: ↑(0.6)	↑ 4.1: ↑(3.3)	↑ 3.8: ↑(2.9)	↑ 3.6: ↑(3.5)	↓(1.9)
	C: 17.7	↑ 2.0: ↑ (1.1)	↑ 4.7: ↑(4.7)	↑ 1.7: ↑(0.9)	↑ 4.4: ↑(3.6)	↑ 4.1: ↑(3.2)	↑ 3.9: ↑(3.8)	↓(2.1)
C6	**B**: 17.6	↑ 1.8: ↑ (0.9)	↑ 4.7: ↑(4.4)	↑ 1.5: ↑(0.4)	↑4.3 : ↑(3.4)	↑ 4.2: ↑(3.3)	↑ 3.8: ↑(3.5)	↓(1.2)
	W: 17.6	↑ 1.8: ↑ (0.9)	↑ 4.7: ↑(4.4)	↑ 1.5: ↑(0.4)	↑ 4.3: ↑(3.4)	↑ 4.2: ↑(3.3)	↑ 3.8: ↑(3.5)	↓(2.8)
	I: 17.6	↑ 1.8: ↑ (0.9)	↑ 4.7: ↑(4.4)	↑ 1.5: ↑(0.4)	↑ 4.3: ↑(3.4)	↑ 4.2: ↑(3.3)	↑ 3.8: ↑(3.5)	↓(1.9)
	C: 17.6	↑ 1.8: ↑ (0.9)	↑ 4.7: ↑(4.4)	↑ 1.5: ↑(0.4)	↑ 4.3: ↑(3.4)	↑ 4.2: ↑(3.3)	↑ 3.8: ↑(3.5)	↓(2.4)
C7	**B**: 17.5	↑ 2.0: ↑ (1.1)	↑ 4.2: ↑(4.1)	↑ 1.5: ↑(0.4)	↑ 3.9: ↑(3.1)	↑ 4.1: ↑(3.2)	↑ 3.7: ↑(3.2)	↓(1.0)
	W: 16.9	↑ 1.4: ↑ (0.5)	↑ 3.6: ↑(3.5)	↑ 0.9: ↓(0.2)	↑ 3.3: ↑(2.53)	↑ 2.7: ↑(2.6)	↑ 3.1: ↑(2.6)	↓(3.4)
	I: 17.1	↑ 1.6: ↑ (0.7)	↑ 3.8: ↑(3.7)	↑ 1.1: (0.0)	↑ 3.5: ↑(2.63)	↑ 3.7: ↑(2.8)	↑ 3.3: ↑(2.8)	↓(2.3)
	C: 16.9	↑ 1.4: ↑ (0.5)	↑ 3.6: ↑(3.5)	↑ 0.9: ↓(0.2)	↑ 3.3: ↑(2.53)	↑ 2.7: ↑(2.6)	↑ 3.1: ↑(2.6)	↓(2.8)

Adapted from Roopnarain (2011) **B = Black; W = White; I = Indian; C = Coloured; * = did not measure; ↑ = increase; ↓ = decrease; F = female; M = male; ( ) = male value**

The mean SCD of the females of the four different ethnic groups of this study was larger in comparison to the SCD of females reported in previous studies (**Table 5.3**). The mean SCD of the females of this study was smaller at all vertebral levels in comparison to the mean SCD of males as reported by Roopnarain (2011) (**Table 5.3**). This observation is also in keeping with previous studies that evaluated the SCD in males and females (Lee *et al*., 1994; Lim and Wong, 2004; Tatarek, 2005; Tossel, 2007). The findings can be attributed to the female cervical canal being smaller than that of males (Bland, 1994).

The mean SCD values of females reported by Tatarek (2005) and Tossel (2007) (**Table 2.5**) were significantly smaller than those observed in this study. A possible reason for this can be attributed to the effect of radiographic magnification which may have increased the SCD values of the females. Tatarek (2005) obtained her measurement values directly from skeletal remains whereas Tossel (2007) obtained her measurement values from CT scans. Tatarek (2005) reported that the SCD of Caucasian females was larger at C2, C3, C4, C5 and C6 in comparison to African-American females, except at C7 where it was larger in African-American females. A similar trend was observed in this study between the South African Black and White females (**Table 4.7**). The mean SCD of White females was larger than that of Black females at all levels except at C7 where it was larger in Black females and at level C6 where it was the same for both Black and White females. Roopnarain (2011) reported similar findings in Black and White males with the difference being a larger SCD was observed in White males than in Black males at all levels including that of C7.

5.2.3 Interpedicular Distance

The total mean IPD values for the cervical spine were shown to increase at C4, C5 and C6 and decrease at C7 (**Table 4.9)**. Roopnarain (2011) also reported this trend in his study of South African males. This increase can be attributed to the normal enlargement of the spinal cord that occurs in the cervical spinal region. The enlargement begins at the level of C3 and tapers toward the thoracic spine at C7 and T1 (Crossman and Neary, 2000). Therefore, the increase in the mean IPD values observed at C4, C5 and C6 can be attributed to the compensation of the spinal canal to accommodate the cervical cord enlargement and the decrease in the mean IPD value at C7 could be as a result of the spinal canal tapering as it nears the thoracic spine.

Table 5.4 The mean IPD observed in this study compared to the reported mean IPD in combined male and female cohorts

Cervical vertebral level	Current study mean IPD (mm)	Hinck *et al*. (1966)
C3	**B**: 27.0	↓ 1.0
	W: 28.4	↑ 0.4
	I: 27.2	↓ 0.8
	C: 27.9	↓ 0.1
C4	**B**: 27.6	↓ 1.2
	W: 28.8	=
	I: 27.5	↓ 1.3
	C: 27.8	↓ 1.0
C5	**B**: 28.2	↓ 1.2
	W: 29.5	↑ 0.1
	I: 27.9	↓ 1.5
	C: 28.3	↓ 1.1
C6	**B**: 28.9	↓ 0.4
	W: 29.3	=
	I: 27.9	↓ 1.4
	C: 28.4	↓ 0.9
C7	**B**: 27.5	↓ 0.5
	W: 28.2	↑ 0.2
	I: 27.5	↓ 0.5
	C: 28.2	↑ 0.2

B = Black; W = White; I = Indian; C = Coloured; ↑ = increase; ↓ = decrease; same value (=)

*** Table adapted from Roopnarain (2011)**

When compared to the combined male and female IPD values reported by Hinck *et al*. (1966), the mean IPD of the Black and Indian females was lower at all levels **(Table 5.4)**. For White females the mean IPD was larger at C3, C5 and C7 and equal at the level of C4. The mean IPD of the Coloured females was smaller at all vertebral levels except C7, where it was larger than that reported by Hinck *et al*. (1966). This finding is suggestive of differences in IPD between the different ethnic groups and gender.

Table 5.5 A comparison of the mean IPD of the current study to those of previous studies

			Tatarek (2005)		
Cervical vertebral level	**Current study mean IPD F: (mm)**	**Ugur *et al*. (2000) F: (M)**	**African-American F: (M)**	**Caucasian American F: (M)**	**Roopnarain (2011) (M):**
C3	**B**: 27.0	↑ 4.6: ↑(5.4)	↑ 4.3: ↑(3.7)	↑ 4.5: ↑(3.6)	↓(1.2)
	W: 28.4	↑ 6.0: ↑(6.8)	↑5.7 : ↑(5.1)	↑ 5.9: ↑(5.0)	↓(0.5)
	I: 27.2	↑ 4.8: ↑(5.6)	↑ 4.5: ↑(3.9)	↑ 4.7: ↑(3.8)	↓(0.6)
	C: 27.9	↑ 5.5: ↑(6.3)	↑ 5.2: ↑(4.6)	↑ 5.4: ↑(4.5)	↓(1.2)
C4	**B**: 27.6	↑ 5.1: ↑(6.8)	↑ 4.1: ↑(3.3)	↑ 4.1: ↑(3.5)	↓(1.0)
	W: 28.8	↑ 6.3: ↑(8.0)	↑ 5.3: ↑(4.5)	↑ 5.3: ↑(4.7)	↓(0.8)
	I: 27.5	↑ 5.0: ↑(6.7)	↑ 4.0: ↑(3.2)	↑ 4.0: ↑(3.4)	↓(1.0)
	C: 27.8	↑ 5.3: ↑(7.0)	↑ 4.3: ↑(3.5)	↑ 4.3: ↑(3.7)	↓(1.7)
C5	**B**: 28.2	↑ 5.0: ↑(7.5)	↑ 4.2: ↑(3.2)	↑ 4.0: ↑(3.3)	↓(1.2)
	W: 29.5	↑ 6.3: ↑(8.8)	↑ 5.5: ↑(4.5)	↑ 5.3: ↑(4.6)	↓(0.5)
	I: 27.9	↑ 4.7: ↑(7.2)	↑ 3.9: ↑(2.9)	↑ 3.7: ↑(3.0)	↓(0.9)
	C: 28.3	↑ 5.1: ↑(7.6)	↑ 4.3: ↑(3.3)	↑ 4.1: ↑(3.4)	↓(1.8)
C6	**B**: 28.9	↑ 3.8: ↑(7.3)	↑ 4.4: ↑(3.4)	↑ 4.6: ↑(3.7)	↓(0.4)
	W: 29.3	↑ 4.2: ↑(7.7)	↑ 4.8: ↑(3.8)	↑ 5.0: ↑(4.1)	↓(1.4)
	I: 27.9	↑ 2.8: ↑(6.3)	↑ 3.4: ↑(2.4)	↑ 3.6: ↑(2.7)	↓(2.1)
	C: 28.4	↑ 3.3: ↑(6.8)	↑ 3.9: ↑(2.9)	↑ 4.1: ↑(3.2)	↓(1.7)
C7	**B**: 27.5	↑ 3.0: ↑(4.6)	↑ 4.0: ↑(3.0)	↑ 4.1: ↑(3.2)	↓(1.8)
	W: 28.2	↑3.7: ↑(5.3)	↑ 4.7: ↑(3.7)	↑ 4.8: ↑(3.9)	↓(1.9)
	I: 27.5	↑ 3.0: ↑(4.6)	↑ 4.0: ↑(3.0)	↑ 4.1: ↑(3.2)	↓(2.1)
	C: 28.2	↑ 3.7: ↑(5.3)	↑ 4.7: ↑(3.7)	↑ 4.8: ↑(3.9)	↓(2.1)

B = Black; W = White; I = Indian; C = Coloured; ↑ = increase, ↓ = decrease; mm= millimetres

Table adapted from Roopnarain (2011)

The mean IPD values of the females in all four of the ethnic groups were greater at all cervical vertebral levels from C3 to C7 when compared to the findings of Ugur *et al*. (2000) and Tatarek (2005) (**Table 5.5**). However, Ugur *et al*. (2000) and Tatarek (2005) obtained their measurements from cadaveric and skeletal specimens respectively. The mean IPD values of the females in each ethnic group were smaller at all vertebral levels in comparison to those of males from the corresponding ethnic groups (Roopnarain, 2011) **(Table 5.5)**. Similarly, Tatarek (2005) observed that both African-American and Caucasian females had smaller mean IPD values in comparison to their male counterparts. Tatarek (2005) found that African-American females had larger mean IPD values at the levels of C3, C5, C6 and C7 and an equal measurement value at C4 in comparison to Caucasian females (**Table 2.4**). This trend was not observed in this study (**Table 4.9**). The White females had larger mean IPD values at C3, C4, C5, C6 and C7. Roopnarain (2011) observed a similar trend when he compared the mean IPD values of South African Black males to South African White males.

The mean IPD values for South African Indian and Coloured females are presented for the first time in this study (**Table 4.9**). The Indian females had the smallest mean IPD values when compared to White and Coloured females, and were smaller at levels C4, C5 and C6 and equal at C7 in comparison to the Black females. The mean IPD of Coloured females were smaller at all levels in comparison to the White females and larger at all levels in comparison to the Indian and Black females, except at the level of C6 where it was larger in Black females.

The results of this study support the recommendations of previous researchers (Lee *et al*., 1994; Lim and Wong, 2004; Tatarek, 2005; Tossel, 2007; Roopnarain, 2011) that normative reference values for the SCD and IPD should be based on ethnicity and gender. However, the sample size of this study was small; therefore, a study with a larger sample size needs to be conducted across South Africa to confirm the findings of this study.

5.2.4 Cervical Gravity Line

Hardacker *et al.* (1997) observed an anterior placement of the CGL in all 100 of their asymptomatic research subjects; they regarded this finding as the normal position of the lateral cervical plumb line; also referred to as the CGL by Yochum and Rowe (2005a). Similarly, Roopnarain (2011) observed that the majority of healthy, asymptomatic males had a CGL that was anterior to the anterior-inferior border of the C7 vertebral body. The results of this study were also similar to the findings of Hardacker *et al*. (1997) and Roopnarain (2011) as the majority of the female participants had an anteriorly-placed CGL (**Table 4.11**). The reference point selected for the CGL by Roopnarain (2011) and this study differed from Hardacker *et al.* (1997). They assessed the CGL according to its distance from the centre of the C7 vertebral body, whereas both this study and Roopnarain (2011) used the anterior-inferior border of C7 as the reference point as described by Yochum and Rowe (2005a) because it provides a method of assessing where the gravitational forces acting on the cervical spine fall.

No significant association was found amongst any of the ethnic groups and the position of the CGL; however, the percentage of the anteriorly-placed CGL was similar in all ethnic groups **(Table 4.11)**. This observation was similar to that of Roopnarain (2011) who reported that all four of the ethnic groups (males) had similar results for anterior, normal and posterior placement of the CGL. Hardacker *et al*. (1997) did not mention the ethnicity or gender of the participants in their study.

An interesting observation was made when T-tests were conducted to determine if the CL (both C1-C7 and C2-C7 Cobb methods) significantly influenced the position of the CGL (**Tables 4.13** and **4.14**). It was found that the CL determined by using the C1-C7 Cobb method, did not influence the CGL in any of the four ethnic groups; however in Black females, those with a normally positioned CGL had significantly higher mean CL values assessed by using the C2-C7 method (**Table 4.14**). The Black females in this study did, however, possess a larger CL in comparison to the White and Indian females when the C2-C7 Cobb method was used to assess the CL (**Table 4.5**). The results of this study are in contrast to those of Roopnarain (2011) who found that the mean CL values obtained using both the methods, did not influence the CGL significantly in all four of the ethnic groups (males). He stated that this could possibly be due to the small sample size or selection of normal participants who were free of neck pain, with no history of trauma to the neck or arthritic diseases. However, a larger sample size is needed before any firm conclusions can be drawn as to whether or not the CL, when measured using the C2-C7 Cobb method, has an effect on the position of the CGL in South African Black females.

Prior to the study conducted by Roopnarain (2011), no other study investigated the significance of the potential influence that the CL might have on the CGL. This study was the first to evaluate the potential influence that the CL might have on the CGL in females. The importance of assessing the CGL lies in the evaluation of the gravitational forces acting at the cervicothoracic junction (Fox and Young, 1954; Yochum and Rowe, 2005a) and for radiographic assessment of the cervical spine in the sagittal plane (Hardacker *et al*., 1997). Although the CL may not have had a significant influence on the CGL of the participants in this study, except for Black females (C2-C7 Cobb method), a clinician should always evaluate both the CL and CGL in lateral cervical spine radiographs. This is because the CL ensures that the forces acting on the vertebral body both anteriorly and posteriorly are minimal (Harrison *et al*., 2001). Anterior head carriage which may occur as a result of altered CL causes an uneven distribution of forces on the anterior cervical vertebral bodies resulting in degeneration (Harrison *et al*., 2001).

CHAPTER SIX

CONCLUSION AND RECOMMENDATIONS

6.1 CONCLUSION

The C1-C7 Cobb method measurements and the C2-C7 Cobb method measurements were significantly different amongst the various ethnic groups used in this study. No individual differences amongst the ethnic groups were found using the C1-C7 method; however, significant differences amongst the ethnic groups were found using the C2-C7 method. Since the literature suggests that the C2-C7 method is the more reliable method to assess CL, the results of this study indicate that it should be assessed according to ethnicity as well. It is also imperative that clinicians state which method for CL evaluation is used. In Black females it was found that those with a normally positioned CGL had significantly higher C2-C7 CL measurements; this implies that CL does play a role in determining the forces that act on the cervical spine in different ethnic groups and it requires further investigation in a larger study.

There were no significant differences in the mean SCD and IPD amongst the ethnic groups of this study. These results require verification in a study with a larger sample size; however, variations in trend at different cervical levels amongst the various ethnic groups and gender were found. Therefore the SCD and IPD should be evaluated according to ethnicity and gender in a South African context. The results and trends observed in this study will assist South African health care practitioners with the evaluation of post-surgical and post-traumatic states and for the presence of stenosis or tumours specific to patient ethnicity and gender.

6.2 RECOMMENDATIONS

The major recommendations arising from the results of this study are:

- A larger study across South Africa which incorporates a more diverse population base should be conducted. By using digitized diagnostic imaging modalities such as radiographs, CT and MRI scans the potential for errors during manual assessment will be significantly reduced and it will help to determine whether or not the trends observed in this study are similar to the broader female population in South Africa.

- The results of this study be published in a peer-reviewed accredited journal and presented to health care professionals such as spinal surgeons, radiologists and chiropractors in order to promote awareness of the different trends in the normative reference values of the selected radiographic parameters in the South African female population.

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