The Evaluation of Normal Radiographic Measurements of the Lumbar Spine in Young to Middle Aged Indian Females in Durban

By

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I, Melanee Naidoo, do declare that this dissertation is representative of my own work in both conception and execution

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DEDICATION

I dedicate this dissertation to my parents, Michael and Tammy Naidoo. Everything I am and everything I have become I owe to them both. They have inspired and motivated me throughout my life, and I hope this humble dissertation fills them with pride.

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ABSTRACT

Objectives:

To evaluate the lumbar lordosis, lumbosacral angle, lumbosacral disc angle, lumbosacral lordosis angle, intervertebral disc angles and heights, interpedicular distances, sagittal canal diameters and the lumbar gravity line (selected radiographic parameters) in young to middle aged Indian females in Durban.

To determine any association between the selected radiographic parameters and the age of the subjects, weight, height and body mass index of the subjects, occupation, smoking, previous pregnancy and leg length inequality (selected anthropometric and demographic factors).

Methods:

Sixty healthy, asymptomatic, young to middle aged, Indian females were recruited for this study. All subjects underwent a case history, a physical examination and radiographic evaluation (AP and lateral views) of the lumbar spine. SPSS version 15.0 (SPSS Inc., Chicago, Ill, USA) was used to analyze the data.

Results:

The mean (± SD) of the lumbar lordosis, lumbosacral angle, lumbosacral disc angle and lumbosacral lordosis angle was 49º (± 6º), 39º (± 8º), 12º (± 5º) and 143.2º (± 5º) respectively. For the lumbar intervertebral disc angles at L1-L2, L2-L3, L3-L4, L4-L5 and L5-S1 levels, the mean (± SD) was 6º (± 2º), 8º (± 2º), 10º (± 3º), 12º (± 4º) and 12º (± 5º) respectively. The anterior and posterior intervertebral disc heights at the respective vertebral levels were: L1-L2: anterior: 8 mm (± 2), posterior 5 mm (± 2); L2-L3: anterior: 10 mm (± 2), posterior 5 mm (± 2); L3-L4: anterior: 12 mm (± 2), posterior 5 mm (± 2); L4-L5: anterior: 14 mm (± 3), posterior 5 mm (± 2) and L5-S1: anterior: 13 mm (± 4), posterior 6 mm (± 2). The mean (± SD) of the interpedicular distance at the L1, L2, L3, L4 and L5 vertebral levels was 23 mm (± 2), 24 mm (± 2), 25 mm (± 2), 27 mm (± 2) and 31 mm (± 3) respectively. For the sagittal canal diameter at the L1, L2, L3, L4 and L5 vertebral levels, the mean (± SD) was 20 mm (± 5), 21 mm (± 3), 21 mm (± 3), 21 mm (± 3) and 19 mm (± 3) respectively. The lumbar gravity line intersected the sacrum in 67.3% of the subjects. In 29.1% of the subjects, the lumbar gravity line passed anterior to the sacrum while in 3.6% of the subjects, it passed posterior to the sacrum.

A significant association was found between lumbar lordosis and the height of the subjects in this study (p = 0.004). A decrease in the intervertebral disc height at L5-S1 was associated with smoking (p = 0.005). A decrease in the intervertebral disc height at L4-L5 was associated with previous pregnancy (p = 0.016). Body mass index of 26–30 $kg.m^{-2}$ was significantly associated with an increase in the intervertebral disc angles at L3-L4 (p = 0.028) and L4-L5 (p = 0.031). A decrease in the L5-S1 intervertebral disc angle was also significantly associated with smoking (p = 0.023). There was a significant association between previous pregnancy and an increase in the intervertebral disc angle at L3-L4 (p = 0.016). A significant association was found between the age of the subjects and the L5-S1 intervertebral disc angle (p = 0.007). Specifically it was the 23–27 year group and 33–37 year group who were significantly different from each other (p = 0.033).

Conclusion:

Similarities and differences were found in the mean values of the radiographic parameters measured in this study and those reported in the literature. A number of the selected anthropometric and demographic factors were associated with some of the lumbar radiographic parameters. Further studies are required to establish the clinical significance of these findings.

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LIST OF ABBREVIATIONS

A	Angle between the midline and the axis of the nerve root in the frontal plane or anterior disc height
AF	Annulus fibrosus
AP	Antero-posterior
Av	Average
bet	Between
BMI	Body mass index
BMPs	Bone morphogenic proteins
CDC	Chiropractic Day Clinic
CHIROs	Chiropractors
CT	Computed tomography
D	Diameter
det	Determined
DI	Distance from the pedicle to the nerve root inferiorly
DM	Distance from the pedicle to the dural sac medially
DS	Distance from the pedicle to the nerve root superiorly
DUT	Durban University of Technology
e.g.	Example
ed.	Edition or editors
F	Females
GAGs	Glycoaminoglycans
H/W	Housewives
Ht	Height
i.e.	That is
IAF	Inferior articular facet
IAP	Inferior articular process
IAPs	Inferior articular processes
IPD	Interpedicular distance
IPDs	Interpedicular distances
IVD	Intervertebral disc
IVDs	Intervertebral discs

kg	Kilogram
kg.m^{-2}	Kilogram per meter squared
L1	First lumbar vertebra
L2	Second lumbar vertebra
L3	Third lumbar vertebra
L4	Fourth lumbar vertebra
L5	Fifth lumbar vertebra
LAB TECH	Laboratory technician
LBP	Low back pain
LL	Lumbar lordosis
LLI	Leg length inequality
LS	Lumbosacral angle
LSD	Lumbosacral disc angle
LSL	Lumbosacral lordosis angle
m	Meter
M	Males
mm	Millimeter
MRI	Magnetic resonance imaging
N/A	Not available
NP	Nucleus pulposus
NRH	Nerve root height
P	Posterior disc height
PG	Prospective group
PGs	Proteoglycans
Pt	Patient
Pts	Patients
RG	Retrospective group
ROM	Range of motion
S1	First sacral segment
S2	Second sacral segment
SAF	Superior articular facet
SAP	Superior articular process
SAPs	Superior articular processes
SD	Standard deviation

Sp	Spinous process
TGF-β	Transforming growth factor beta
TRALL	Tangential radiologic assessment of lumbar lordosis
TVPs	Transverse processes
UNEMP	Unemployed
VB	Vertebral body
VBs	Vertebral bodies
viz.	Namely
Wt	Weight
y.o.a.	Years of age
yrs	Years

LIST OF DEFINITIONS

Low back pain: The term refers to pain in the lumbosacral area of the spine encompassing the distance from the first lumbar vertebra to the first sacral vertebra (Kravitz and Andrews, 1990).

Hip pain: ‘Hip’ refers to a wide area between the upper buttock, trochanter and groin. Hip pain may be felt in the groin, lower buttock and anterior thigh and may radiate into to the knee (Kumar and Clark, 2002).

Young to middle aged adult: According to Erikson (2001), a young adult is a person between the ages of 19 and 25 years whereas a middle aged adult is defined as a person between the ages 40-65 years.

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CHAPTER ONE

INTRODUCTION

1.1 INTRODUCTION TO THE STUDY

Wilhelm Conrad Roentgen accidentally discovered x-rays in 1895 while conducting some experiments in his laboratory (Yochum and Rowe, 2005). The “X” in x-rays represented the unknown quantity as Roentgen did not know what to name the invisible rays. One of the significant aspects of this discovery was the development of the clinical radiograph which allowed an individual to “see” the internal structures of the body especially the bony tissue. For his momentous discovery, Roentgen was awarded the first Nobel Prize for physics in 1901 (Yochum and Rowe, 2005). Although the x-ray was considered an excellent diagnostic imaging tool, the harmful aspect of radiation could not be ignored (Yochum and Rowe, 2005). Since its discovery, however, there have been several advancements in technology and plain film radiography is still the primary investigation of choice in clinical practice, especially in the evaluation of skeletal disorders (Kendrik *et al.,* 2001; Yochum and Rowe, 2005). Amongst the many radiographic parameters evaluated during an assessment of a lumbar spine radiograph, the following are likely to be evaluated:

Lumbar lordosis (LL), lumbosacral (LS) angle, lumbosacral disc (LSD) angle, lumbosacral lordosis (LSL) angle, intervertebral disc (IVD) angles and heights, interpedicular distances, sagittal canal diameters and lumbar gravity line.

Although many researchers have reported on the “normal” values of these radiographic parameters, these have often been inconsistent (Farfan *et al*., 1972; Torgerson and Dotter, 1976; Chen and Lee, 1997; Saraste *et al*., 1985; Tibrewal and Pearcy, 1985; Brinckmann *et al*., 1998; Chernukha *et al*., 1998; Nourbakhsh *et al*., 2001; Shao *et al*., 2002; Yochum and Rowe, 2005; Kim *et al*., 2006). Some of the reasons for the contrasting findings include differences in population profile, differences in sample size and different methods of measurement. The literature is also ambivalent with respect to an association between these radiographic parameters and certain anthropometric and demographic factors. A few studies have reported significant associations between some of the radiographic parameters and certain demographic and anthropometric factors (Amonoo-Kuofi, 1992; Nourbakhsh *et al*., 2001; Livshits *et al*., 2001; Murrie *et al*., 2003) while other studies have found no such associations (Farfan *et al*., 1972; Milne and Lauder, 1974; Korovessis *et al.*, 1998; Luoma *et al*., 1998). Few studies (Eisenstein, 1976; Fernand and Fox, 1985; Mosner *et al*., 1989) have been conducted in order to determine any ethnic differences in the radiographic parameters of the lumbar spine.

1.2 AIMS AND OBJECTIVES OF THE STUDY

The primary aim of this study was:

- To evaluate the normal radiographic measurements of the lumbar spine in young to middle aged Indian females in Durban.

Specific objectives were identified and these included:

1.2.1 The recording of the radiographic measurements of the lumbar spine with respect to the following:

1. LL
2. LS angle
3. LSD angle
4. LSL angle
5. Lumbar IVD angles
6. Lumbar IVD heights
7. Interpedicular distance (IPD)
8. Sagittal canal diameter
9. Lumbar gravity line

1.2.2 To determine any association between the above radiographic parameters (in objective **1.2.1)** and the selected anthropometric and demographic data (age, height, weight, body mass index, occupation, leg length inequality (LLI), smoking and previous pregnancy).

1.3 HYPOTHESES OF THE STUDY

For objective **1.2.2** with respect to the LL:
The Null Hypothesis (H_o) which stated that there would be no significant association between LL and the different age groups in this study was set based on the conflicting results of Milne and Lauder (1974), Korovessis *et al*. (1998), Nourbakhsh *et al*. (2001) and Murrie *et al*. (2003).

The Alternate Hypothesis (H_a) which stated that there would be a significant association between LL and weight, height and body mass index was set based on the studies of Nourbakhsh *et al*. (2001), Pietilä *et al*. (2001) and Murrie *et al*. (2003).

The Null Hypothesis (H_o) which stated that there would be no significant association between LL and the occupation of the subjects in this study was set based on the conflicting results of Nourbakhsh *et al*. (2001), Milosavljevic *et al*. (2005) and Sarikaya *et al*. (2006)

The Alternate Hypothesis (H_a) which stated that there would be a significant association between LL and previous pregnancies was set based on the study of Nourbakhsh *et al*. (2001).

With respect to the association between smoking and LL and LLI and LL, the Null Hypothesis (H_o) was set which stated that there would be no significant association between LL and smoking and LLI.

For objective **1.2.2** with respect to the LS angle, LSD angle and LSL angle:
The Null Hypothesis (H_o) was set which stated that there would be no significant association between LS angle, LSD angle and LSL angle and the selected anthropometric and demographic factors (with the exception of LS angle and previous pregnancy).

The Alternate Hypothesis (H_a) which stated that there would be a significant association between LS angle and previous pregnancy was set based on the study of Bryner and El Moussali (1992).

For objective **1.2.2** with respect to the IVD angle and IVD height:

The Null Hypothesis (H_o) which stated that there would be no significant association between IVD height and the different age groups was set based on the conflicting reports of Vernon-Roberts and Pirie (1977), Twomey and Taylor (1987), Miller *et al*. (1988), Amonoo-Kuofi (1991) and Shao *et al*. (2002).

With respect to the association between the IVD height and height of the subjects in this study, the Null Hypothesis (H_o) was set which stated that there would be no significant association between the IVD height and the height of the subjects in this study.

The Null Hypothesis (H_o) which stated that there would be no significant association between IVD height and the weight and body mass index was set based on the conflicting reports of Luoma *et al*. (1998), Pietilä *et al*. (2001) and Luike *et al*. (2005).

The Null Hypothesis (H_o) which stated that there would be no significant association between IVD height and smoking was set based on the conflicting reports of Luoma *et al*. (1998) Livshits *et al*. (2001) and Pye *et al*. (2007).

The Alternate Hypothesis (H_a) which stated that there would be a significant association between IVD height and occupation was set based on the study of Evans *et al*. (1989), Luoma *et al*. (1998), Videman *et al*. (2007)

With respect to the association between IVD height and previous pregnancy, the Null Hypothesis (H_o) was set which stated that there would be no significant association between IVD height and previous pregnancy.

With respect to the association between IVD height and LLI, the Null Hypothesis (H_o) was set which stated that there would be no significant association between IVD height and LLI.

The Null Hypothesis (Ho) was set which stated that there would be no significant association between IVD angle and the selected anthropometric and demographic factors.

For objective **1.2.2** with respect to the IPD, sagittal canal diameter and lumbar gravity line: The Null Hypothesis (H_o) was set which stated that there would be no significant association between IPD and the selected anthropometric and demographic factors.

The Null Hypothesis (H_o) was set which stated that there would be no significant association between sagittal canal diameter and the selected anthropometric and demographic factors.

The Null Hypothesis (H_o) was set which stated that there would be no significant association between lumbar gravity line and the selected anthropometric and demographic factors.

1.4 SCOPE OF THE STUDY

The results of 55 healthy, asymptomatic, young to middle aged Indian females who met all the inclusion criteria of this study are reported in this dissertation. The subjects were informed of the nature of this study and each one signed an informed consent form. All subjects underwent a case history and a physical examination. Erect posture radiographs of the lumbar spine (antero-posterior [AP] and lateral views) was taken for each subject. The selected radiographic parameters of the lumbar spine were then evaluated by the researcher.

CHAPTER TWO

LITERATURE REVIEW

2.1 INTRODUCTION

Plain film radiography remains the primary investigation of choice in clinical practice today (Kendrik *et al.,* 2001; Yochum and Rowe, 2005). Despite this, the normal values for some of the radiographic parameters have not yet been established or are in inconsistent (Farfan *et al*., 1972; Torgerson and Dotter, 1976; Chen and Lee, 1997; Saraste *et al*., 1985; Tibrewal and Pearcy, 1985; Brinckmann *et al*., 1998; Chernukha *et al*., 1998; Nourbakhsh *et al*., 2001; Shao *et al*., 2002; Yochum and Rowe, 2005; Kim *et al*., 2006). Although some studies have reported that some demographic and anthropometric factors are associated with certain radiographic parameters (Amonoo-Kuofi, 1992; Nourbakhsh *et al*., 1998; Livshits *et al*., 2001; Murrie *et al*., 2003) this is by no means conclusive.

2.2 AN OVERVIEW OF THE RELEVANT BONY ANATOMY OF THE LUMBAR SPINE AND SACRUM

The lumbar spine is situated in the lower back between the thoracic spine and the sacrum (Moore, 1999). It usually has five vertebrae (L1-L5) and each vertebra has two basic parts viz. a vertebral body (VB) and a neural arch. After birth, the lumbar vertebral bodies lose their rounded, ovoid appearance and become rectangular in profile (Bogduk, 2005). Posterior to the VB lies the neural arch, which consists of a pair of pedicles on the postero-lateral surface of the upper portion of the VB that joins with the posteriorly-located paired laminae (Ebraheim *et al*., 2004). The lumbar VB is wider transversely and resembles the shape of a kidney (Moore, 1999; Middleditch and Oliver, 2005). From birth–5 years, the lumbar vertebral bodies increase in height from 5 mm–18 mm. They then increase to 22 mm between 5–13 years of age and reach 25 mm by adulthood. Other studies have shown that the size of the vertebral body at age 13 is 26 mm and in adulthood it is 34 mm (Bogduk, 2005). The vertebral foramen which is either triangular or oval-shaped (Moore, 1999; Middleditch and Oliver, 2005) is most distinguishable at the L5 vertebra (Ebraheim *et al*., 2004). The spinal cord and the cauda equina lies within the vertebral canal.

The short pedicles tend to consistently incline medially from L1 to L5 (Middleditch and Oliver, 2005) and, furthermore, there is a gradual increase in pedicle length from L1 to L5 (Ebraheim *et al*., 2004). Embryologically, the pedicles contribute to the formation of the VB but are largely formed by the ossified centrum and the anterior ends of the neural arches (Bogduk, 2005). The lumbar spine laminae are thicker and vertically-oriented in the sagittal plane (Ebraheim *et al*., 2004). The laminae may be divided into superior and inferior portions. The superior portion is arched and has a smooth inner surface, whereas the inferior portion has a rough inner surface which serves as the site of attachment for the ligamentum flavum (Ebraheim *et al*., 2004).

The pars interarticularis, which is the portion of the lamina between the superior and inferior articular processes (SAPs and IAPs respectively) and lies just below the level of the pedicle, is a common site for stress fractures (Ebraheim *et al*., 2004). The inferior articular facet (IAF) is convex and faces anterolaterally while the superior articular facet (SAF) is concave and faces posteromedially (Moore, 1999). At the junction of the laminae, a quadrangular-shaped spinous process (Sp) arises posteriorly and almost horizontally and is thickened along its posterior and inferior borders (Moore, 1999; Middleditch and Oliver, 2005).

The transverse processes (TVPs) are long, thin and project laterally and slightly posteriorly from the junctions of the SAPs with the laminae (Middleditch and Oliver, 2005). Anteriorly, the vertebral bodies are separated by the intervertebral discs (IVDs) and are held together by the anterior and posterior longitudinal ligaments. The IVDs are formed from densely packed cells of sclerotomal origin (Moore and Persuad, 1998; Kaplan *et al*., 2005). Posteriorly, the articular processes form the zygapophsial (facet) joints, and consecutive vertebrae are stabilised by the supraspinous, interspinous and intertransverse ligaments. The lumbar gravity line or centre of gravity lies anterior to the vertebral column in 75% of individuals (Middleditch and Oliver, 2005). The activity of the erector spinae muscles increases to prevent the trunk from falling posteriorly thereby maintaining the LL (Middleditch and Oliver, 2005).

Five sacral vertebrae (S1-S5) fuse to form the triangular sacrum. The shape as well as the sides of the sacrum may, however, show differences in individuals (Middleditch and Oliver, 2005). The base of the sacrum (sacral promontory), is angled anteriorly and inferiorly, and is formed by the superior surface of the first sacral segment (S1) (Middleditch and Oliver, 2005). The spinous processes are fused in the midline to form the median sacral crest ((Middleditch and Oliver, 2005). The dorsal sacral foramina lie laterally to the fused spinous processes (Middleditch and Oliver, 2005, Moore and Dalley, 2006). According to Middleditch and Oliver (2005), the LS angle, which is the angle formed by the sacral base and the horizontal plane is 42º-45º which could increase by 8º in the erect position. In order for an individual to maintain an erect posture, it is necessary for the lumbar spine to develop the lordotic curve to compensate for the angulation of the sacrum (Bogduk, 1997; Middleditch and Oliver, 2005).

2.3 AN OVERVIEW OF THE ANATOMY OF THE INTERVERTEBRAL DISC

The IVDs are fibrocartilagenous structures enclosed by the endplates of adjacent vertebral bodies (Cassinelli *et al*., 2001). The peripheral portion of the IVD, the annulus fibrosus (AF) is composed of dense and orientated collagen fibres. The inner or central portion of the IVD, the nucleus pulposus (NP), is composed mainly of chondrocytes, collagen fibrils, proteoglycans (PGs) and hyaluronic acid. It is also avascular. Generally, the IVDs have little innervation (Cassinelli *et al*., 2001). The principal mechanism of nourishment is diffusion through the endplates. In the IVDs of young persons, the NP contains two types of cells i.e. the chondrocyte-type cells and the notochordal cells. The notochordal cells which are responsible for increased proteoglycan synthesis (Aguiar *et al*., 1999) disappear completely by adulthood (Buckwalter, 1982).

A protein core attached to the glycosaminoglycan (GAG) chain makes up the PGs. Chondroitin-6-sulphate and keratin sulfate are the predominant glycosaminoglycans in the IVDs (Cassinelli *et al*., 2001). PGs are distributed non-uniformly in the IVD and constitute a small percentage of the dry weight of the outer annulus and 50% of the dry weight of the NP in the young IVDs (Buckwalter, 1982). The larger PGs aggregate and their interaction with water has a major effect on the properties of the IVD (Cassinelli *et al*., 2001). The glycosaminoglycans have a hydrophilic nature and retain water in the IVD thereby absorbing much of the forces acting on the spine (Ohshima *et al*., 1995). The amount of PGs alters tissue permeability and diffusion thereby altering the passage of nutrients, chemical mediators and chemical waste products (Ohshima *et al*., 1995).

Collagen is one of the major structural components of the extracellular matrix. It gives the IVD its tensile strength and allows for stability between the vertebral bodies and also allows it to compensate in response to loads (Cassinelli *et al*., 2001). In the IVD of young individuals, 67% of the dry weight of the AF and 25% of the NP is collagen. There are two main types of collagen found in the IVDs (Cassinelli *et al*., 2001). Type I is predominantly found in the outer AF with no Type I in the NP while 80% of the Type II collagen is found in the NP. The other types of collagen are found in smaller quantities and play a role in collagen fibril organization.

2.4 CURVES OF THE VERTEBRAL COLUMN

The vertebral column has four curvatures: cervical, thoracic, lumbar and sacral (Moore, 1999). The primary curvatures that develop during the fetal period are the thoracic and sacral curvatures which are concave anteriorly (Moore, 1999). These are termed the “kyphotic” curves. The cervical and lumbar curves are concave posteriorly (“lordotic” curves) and are the secondary curves that commence during the fetal period but don’t become obvious until infancy. The lumbar curvature becomes obvious when an infant begins to walk and assumes the upright posture (Moore, 1999). This normally occurs around the ages of 9 -12 months (Lewis, 2007). The erect lumbar spine has a lordotic curve which is concave posteriorly when viewed laterally (Middleditch and Oliver, 2005). In the erect position, the sacrum is tilted inferiorly and anteriorly; therefore, the lumbar spine has to compensate for the angulation in the sacrum by forming the LL (Bogduk, 1997; Middleditch and Oliver, 2005).

2.5 RADIOGRAPHIC EVALUATION OF THE LUMBAR SPINE

Most patients requiring medical attention for low back pain have routine x-rays taken of the lumbosacral spine as part of their initial evaluation (Torgerson and Dotter, 1976; Chung *et al*., 1981). These radiographs may be evaluated utilizing the ABCS approach [Alignment (A), Bone (B), Cartilage (C), Soft tissue(S)] especially in the chiropractic profession (Yochum and Rowe, 2005). Measurement of the lumbar spine radiographic parameters may be useful in the investigation of low back pain (LBP) (Amonoo-Kuofi, 1992).

2.5.1 Radiographic Alignment and Measurement Parameters of the Lumbar Spine

With respect to the lumbar spine radiograph, the following alignment and measurement parameters are usually evaluated (Yochum and Rowe, 2005):

2.5.1.1 LL
2.5.1.2 LS angle, LSD angle, LSL angle
2.5.1.3 IVD angles and heights
2.5.1.4 Interpedicular distances and sagittal canal diameters
2.5.1.5 Lumbar gravity line

2.5.1.1 Lumbar Lordosis

A summary of the reported mean lumbar lordotic angle and methods of measurement in vivo and in cadavers is shown in **Table 2.1**.

Table 2.1 The mean lumbar lordotic angle and methods of measurement as reported in the literature

Reference	Sample	Method	Mean LL
Farfan *et al*. (1972)	182 lumbar spines obtained at autopsy	LL is measured using three angles from lateral radiographs: 1) The angle subtended by the planes of the L1 and L2 disc spaces and between the L3 and L4 vertebrae. 2) The angle subtended by the planes between L3 and L4 disc spaces and the L5 and S1 vertebrae. 3) The angle subtended by the plane between L5 and S1 and a line drawn at 90º to the axis of the sacrum is measured.	42˚
Torgerson and Dotter (1976)	217 individuals with no LBP 60 individuals with LBP	Angle measured from the top of L3 to the top of the sacrum with the pt lateral recumbent and pt's hips and knees flexed to 45˚.	N/A
Andersson *et al.* (1979)	8 patients	Angle from the top of L1 to the top of the sacrum with the pt in a standing position.	59.8˚
Pelker and Gage (1982)	N/A	Angle from the top of L1 to the top of the sacrum	67˚
Stagnara *et al*. (1982)	100 adults in the erect posture	From the sacrum to the superior surface of an intermediate vertebral body giving the largest lordotic angle	56˚
Fernand and Fox (1985)	973 randomly selected adults	The proximal boundary is a line parallel to L2 and the distal border is a line drawn through the inferior surface of L5.	RG: 45.05˚ PG: 32.33˚
Bryner and El Moussali (1992)	Retrospective survey of 124 erect lateral lumbar x-ray films of symptomatic and asymptomatic subjects	**Cobb method** – A line through and parallel to the superior endplate of L1 (line 1). A 2nd line drawn through the endplate of S1 (line 2). Perpendiculars are created and the angle at the intersection is measured. This was done in the erect and seated postures.	47.6º in both groups. M: 45.4º F: 49.6º
Lord *et al*. (1997)	109 patients with LBP	Cobb method	Erect: 49˚ Seated: 34˚
Chernukha *et al*. (1998)	199 individuals; bet. 1-30 y.o.a.	Cobb and the TRALL methods **TRALL method** - 1st, curved line was drawn along the anterior wall of the spinal canal in the lumbosacral segment. Next, the 1st 2 points needed for angle construction were located at the postero-superior margin of L1 (point A) and postero-inferior margin of S2 (point B). 3rd point (C) det by connecting A and B with a chord line and then finding the greatest perpendicular distance bet the arc line and chord line (D). Finally, points A and C and B and D were connected. The intersection lines of AC and BD provides the TRALL angle.	50˚ at maturity. 52˚: Cobb 47˚: TRALL
Nourbakhsh *et al*. (2001)	840 subjects; bet 20-65 y.o.a.	Multiple linear regression modeling	M: 32º F: 43º
Kamali *et al*. (2004)	100 asymptomatic individuals (54 males, 46 females) bet 20-70 y.o.a.	Cobb method	F: 57º M: 52.5º
Yochum and Rowe (2005)	N/A	Cobb method	N/A
Kim *et al*. (2006)	11 male and 20 female patients with LBP bet 13-61 y.o.a.	A permutation of the Cobb method – Lordotic angle was obtained between the inferior endplate of L5 and inferior endplate of L1	27.19 º

LL = Lumbar lordosis; LS = Lumbosacral angle; TRALL = Tangential radiologic assessment of lumbar lordosis; N/A = Not available; pt = patient; bet = between; det = determined; y.o.a = years of age; yrs = years; LBP = low back pain; M = Males; F = Females; RG = Retrospective group; PG = Prospective group

Despite there being no universally accepted method of measuring the LL (Fernand and Fox, 1985), the two methods most widely utilized for measuring the LL are the Cobb and tangential radiologic assessment of lumbar lordosis (TRALL) methods. Polly *et al*. (1996) evaluated the intraobserver, interobserver variability when measuring the LL from spinal radiographs. They found that if the measurement technique of the LL was specific and the interpreter of the radiograph accepted 10º as an acceptable variation, then the measurement of LL was reproducible and reliable. They also suggested that the reproducibility of the measurement of LL could be affected by the choice of the end vertebra and the endplate architecture. Although the method of Cobb was originally used to determine the degree of deformity of the spine in the coronal plane (scoliosis), it is deemed a reliable and reproducible method for determining the lumbar curvature in the sagittal contour (Kim *et al*., 2006).

The TRALL has, however, been shown to be more reproducible and reliable as it provides a smaller range (8º-16º) on normal values (Chernukha *et al*., 1998). This smaller range may allow the clinician to clarify the difference between "normal" and "abnormal" LL (Chernukha *et al*., 1998). Other reasons why the TRALL method is considered more useful are 1) there is a lack of agreement amongst some authors of the precise location of the reference lines in the Cobb method i.e. L1 or L2 for the superior lines and L5 or S1 for the inferior lines, 2) the wedge shape of the lumbar vertebrae which could lead to over/underestimating the LL using the Cobb method. The wedge shape may differ from one vertebra to the next as well as between individuals. Furthermore, the shape of the lumbar vertebra/e may also be influenced by spinal conditions such as spondylosis, osteoporosis and osteomalacia. Instead of utilizing the endplates as landmarks for the measurement of the LL, the TRALL method uses the posterior margins of the vertebral bodies as this is considered to be a more reliable landmark. The main factors that can significantly change the radiologic appearance of this landmark are VB fracture/dislocation, neoplastic/infectious destruction of the vertebra and spondylolisthesis (Chernukha *et al*., 1998).

There appears to be no standard acceptable mean LL as shown in **Table 2.1** and the reported range of the lumbar lordotic angle varies considerably amongst some of the authors as shown below:

- Farfan *et al*. (1972): Range: 10º – 67º
- Torgerson and Dotter (1976): Range: 40º – 95º
- Stagnara *et al*. (1982): Range: 33º - 79º

- Yochum and Rowe (2005): Range: 50º – 60º

The possible reasons for the discrepancy in the values of the mean LL include no standard sample size [e.g. Andersson *et al*. (1979) had 8 samples *vs*. Fernand and Fox (1985) having 973 samples], differences in the population (sample) profile and different methods of measurement **(Table 2.1)**. It is possible that the removal of the spines at autopsy could have been responsible for the large range reported by Farfan *et al*. (1972).

A) Factors Influencing the Lumbar Lordosis

i) Anatomical factors

The vertebral bodies of L1-L4 are inclined slightly posteriorly in relation to the L5 VB (Bogduk, 1997; Middleditch and Oliver, 2005) resulting in stretching of the anterior longitudinal ligament and the anterior part of the AF. Posteriorly, the IVDs are slightly compressed; the IAPs slide inferiorly and may impact on the SAPs or the pedicles below (Bogduk, 1997). The L5 VB is wedge-shaped with the anterior height about 3 mm greater than the posterior height. The superior surface of the L5 VB is, therefore, closer to the horizontal plane than the superior surface of the sacrum (Bogduk, 1997; Middleditch and Oliver, 2005). The L5-S1 IVD is wedge-shaped since the anterior height is 6-7 mm greater than its posterior height resulting in the inferior surface of the L5 VB not being parallel to the superior surface to the sacrum. The L5 VB is inclined anteriorly and inferiorly but not as steeply as the sacral base (Bogduk, 1997; Middleditch and Oliver, 2005).

Scoliosis is described as an abnormal lateral curvature of the spine that is often accompanied by rotation of the vertebrae (Cailliet, 1980; Moore and Dalley, 2006). Posterior rotation occurs on the convex side and anterior rotation on the concave side of the scoliosis (Cailliet, 1980). Ploumis *et al*. (2007) suggested that ageing may lead to degenerative changes of the bony structures and the IVDs which would result in wedging of the vertebral bodies and IVDs. This could then result in rotation and translation of the vertebrae leading to a degenerative scoliosis and a decrease in the lumbar lordotic curve.

ii) Biomechanical

A bilateral foot deformity may lead to compensatory hyperpronation of the feet which displaces the body weight anteriorly. This could increase the activity in the erector spinae muscles leading to an increase in the LL (Middleditch and Oliver, 2005). Moore and Dalley (2006) have, however, associated the increase in the lumbar lordotic curve with weakened trunk and abdominal musculature. Bilateral foot deformities that cause hypersupination may lead to hypolordosis of the lumbar spine (Middleditch and Oliver, 2005). In the weight bearing position, bilateral medially-rotated anteverted hips are associated with an increase in LL (Middleditch and Oliver, 2005; Moore and Dalley, 2006) while laterally-rotated retroverted hips are associated with a decrease in LL (Middleditch and Oliver, 2005).

A vertical spine is dependent on a horizontal pelvis (Cailliet, 1980). An oblique sacral promontory could result in a compensatory scoliosis. Pelvic obliquity could be caused by a muscle contracture superior or inferior to the pelvis or due to LLI (Cailliet, 1980). In 1955, Williams suggested that decreased strength of the abdominal muscles and shortening of the back extensor muscles were probably related to prolonged sitting and were sufficient contributors to a hyperlordotic lumbar spine. On the other hand, McKenzie (1981) suggested that prolonged sitting could lead to a hypolordotic lumbar spine.

Korovessis *et al*. (1998), in a study conducted to determine selected x-ray parameters of the standing sagittal profile of the lumbar spine in an asymptomatic Greek population, reported a strong correlation ($p < 0.007$) between pelvic tilting and LL. Youdas *et al*. (2000) reported that LL was associated univariately with lumbar extension range of motion (ROM) in a sample of 30 men and 30 women with chronic LBP. They also reported a weak positive correlation ($r = 0.31$ for women; $r = 0.37$ for men) between the angle of pelvic inclination and the magnitude of the LL in the standing position in these symptomatic individuals. The LL and pelvic inclination was not associated with the force of abdominal muscle contraction. Earlier, Walker *et al*. (1987) tried to determine if a relationship existed between LL, abdominal muscle performance and pelvic tilt but could not find any. Youdas *et al*. (1996) also could find no relationship between the LL and pelvic inclination. Kim *et al*. (2006) also found no relationship between the LL and pelvic inclination but they did find that an imbalance between the trunk muscles could lead to hyperlordosis. This finding was attributed to a lower extension/flexion ratio and reduced extensor muscle strength than flexor muscle strength in patients with LBP (Lee *et al*., 1999). Therefore, in the clinical setting, spinal health care practitioners could apply strengthening techniques of the trunk muscles to reduce LBP in individuals with a hyperlordotic lumbar spine.

iii) Age

The lumbar curve was found to be independent of age, in those over the age of 40 years (Farfan *et al*., 1972). The authors could not comment on the relationship between the lumbar curve and age less than 40 years as there were an insufficient number of specimens (Farfan *et al*., 1972). Milne and Lauder (1974) reported that there was no age effect on the lumbar curve in males aged 20–59 years and females aged 20–49 years. They did, however, report that there was a tendency of flattening of the LL with increasing age. This was probably related to an increased thoracic kyphosis which displaces the lumbar gravity line anteriorly and a subsequent compensatory flattening of the lumbar spine.

Earlier, Urist *et al*. (1970) had shown that ageing women with osteoporosis had an accentuated thoracic kyphosis and a reversed lumbar curve. The development rate of LL with age which was documented by Chernukha *et al*. (1998) using the Cobb and TRALL methods was found to have a nonlinear pattern with two peaks: one during infancy and the other during puberty. The lumbar lordotic angle reached a plateau of approximately 50˚ at maturity (Chernukha *et al*., 1998; **Table 2.1**). Later, Nourbakhsh *et al*. (2001) found that age was positively associated with the degree of LL. They found a significant decrease in LL in both males and females with age, specifically the age group of 50-60 years. In contrast to the findings of Milne and Lauder (1974) and Nourbakhsh *et al*. (2001), Korovessis *et al*. (1998) and, later, Murrie *et al*. (2003) were unable to demonstrate any significant association between LL and age.

iv) Gender and Ethnicity

The mean LL values in males and females at different ages as reported by Torgerson and Dotter (1976) is shown in **Table 2.2**:

Table 2.2 Differences in the mean LL according to age and gender

Age (decade)	Males (º)	Females (º)
Fifth	58	62
Sixth	63	64
Seventh	59	63

While Farfan *et al*. (1972), Torgerson and Dotter (1976) and Korovessis *et al*. (1998) found no gender differences in the LL, Fernand and Fox (1985), however, reported a significant difference of almost 5° between males and females. Bryner and El Moussali (1992) and Kamali *et al*. (2004) corroborated the findings of Fernand and Fox (1985) in later studies

(Table 2.1). Females had a greater degree of LL when compared to the male subjects in studies by Amonoo-Kuofi (1992), Nourbakhsh *et al*. (2001) **(Table 2.1)** and Murrie *et al*. (2003). Stagnara *et al*. (1982) suggested the reason that females had greater lumbar lordosis was due to a larger buttock size. Mosner *et al*. (1989) who conducted a study of actual and apparent LL in White and Black females agreed with Stagnara's view. Middleditch and Oliver (2005), however, report that after middle age there is no difference in the LL between the males and females. With respect to ethnicity, there appears to be no difference in the LL between Whites and Blacks (Fernand and Fox, 1985; Mosner *et al*., 1989).

v) Weight and Height

McIlwraith's (1996) study, which set out to determine the effect of the back support of a (Ford) car seat on LL on 20 members of a car club also reported that there was no correlation between the weight of the car drivers (range 55–111 kg; mean (± SD) 74.0 kg (± 15.9)) and loss of the LL. In 2001, Nourbakhsh *et al*. found a negative relationship between weight of the subjects and the degree of LL ($p = 0.04$) but found a positive relationship to height in the same subjects. An increase in height could result in increased loading on the lumbar spine (Pietilä *et al*., 2001). A Japanese study on young patients with LBP and the changes in the LL over a 10-year period reported that the average height and weight of young individuals have increased over the past 13 years (Murata *et al*., 2002). The authors also found that the strength of the back muscles have decreased over the past 12 years. Murrie *et al*. (2003), on the other hand, found the LL was significantly ($p < 0.04$) prominent in individuals with a high body mass index. These changes were presumed to influence the alignment of the lumbar spine with an increase in LL. Moore and Dalley (2006) suggested that a hyperlordotic lumbar spine may be found in obese individuals due a compensatory backward lean to improve balance.

vi) Pregnancy

An exaggerated increase in the LL occurs in the late stages of pregnancy (Moore and Dalley, 2006; Trupin, 2006). The center of gravity as a whole, shifts more posteriorly and inferiorly as the spine moves posterior to the center of gravity (Collitan, 1996) and as the pregnancy progresses there may be discogenic symptoms as well as facet impaction (Collitan,1996) due to the weight of the abdominal contents.

There is some supporting evidence in the literature that previous pregnancy and the number of pregnancies are associated with the degree of LL (Nourbakhsh *et al*., 2001). They suggested external forces and hormonal imbalances caused by being pregnant may be responsible for an increase in LL (Nourbakhsh *et al*., 2001). Relaxin, a hormone which is secreted in large quantities during pregnancy, causes the spinal ligaments, pubic symphysis and the sacroiliac joints to relax (Middleditch and Oliver, 2005). It is believed that relaxin may be responsible for increasing the LL in adolescent and middle aged women since before adolescence and after middle age there is no difference in the LL between the males and females (Middleditch and Oliver, 2005).

vii) An Individual's Posture and Position

In the supine position, the LL may vary from 20º-60º, with a mean LL of 50º (Bogduk, 1997). Fernand and Fox (1985) found that hip and knee joint flexion at 45º compared to full extension of the hip and knee joints did not significantly affect the LL. They postulated that when a patient is weight bearing (standing) or sitting the lumbar spine is loaded compared to the minimal loading that occurs in the lumbar spine during the recumbent position. In 2007, Andreasen *et al*. utilized magnetic resonance imaging (MRI) to determine if there was any difference in the LL on standing versus the supine position and found that the LL with the subject in the standing position was 3º greater than in the supine position.

On average, LL was found to be greater in the erect position than in the seated position (Lord *et al*., 1997; **Table 2.1**). Sitting in a confined space may also have an effect on the LL. To minimize the discomfort during sitting in a confined space, some car manufacturers have allowed for greater room for knee extension. The knee extension causes the LL to flatten due to an increased pull of the hamstring muscles which would create a posterior rotation of the pelvis (Keegan, 1953; Floyd and Roberts, 1958). By tilting the seat back support posteriorly, this effect can be minimized (McIlwraith, 1993). Although these studies suggest a relationship exists between the LL and pelvic tilt which is supported by the later studies of Korovessis *et al*. (1998) and Youdas *et al*. (2000), the correlation may, however, be poor (Gilliam *et al*., 1994) or non-existent (Walker *et al*., 1987; Youdas *et al*., 1996; Kim *et al*., 2006)

viii) Occupation

The relationship between lumbar extension ROM and LL (Youdas *et al*., 2000) was further demonstrated by Milosavljevic *et al*. (2005) in a study to determine the effects of occupation on sagittal spinal motion and posture. The sample consisted of 64 sheep shearers and 64 non-shearers who were matched by age and anthropometry findings. Their results showed that sheep shearers had a marked loss of extension ROM of the lumbar spine, hypolordosis of the lumbar spine and a flatter compensatory thoracic kyphotic curve compared to non-shearers. In a sample of 840 randomly selected Iranian subjects, Nourbakhsh *et al*. (2001), however, reported no significant difference in the degree of LL between subjects who 1) utilized tables and chairs instead of (living on) the floor, 2) worked in standing or sitting postures or 3) performed strenuous or light physical activity. Sarikaya *et al*. (2006) conducted a study to assess the incidence of LBP amongst Turkish coal (surface and underground) miners and to also investigate the relationship between the angles of the lumbar spine and LBP in these miners. They found that although the incidence of LBP was 70% in these miners, the degree of the LL was not found to be associated with LBP in this population group.

ix) Leg Length Inequality

LLI is defined as an absolute inequality in the length of the lower limbs i.e. greater than nine millimeters or more (Giles, 1989). It can be subdivided into two etiological groups: a structural or anatomical LLI which is associated with a shortening of bony structures and a functional LLI which occurs as a result of altered mechanics of the lower extremities (Gurney, 2002). LLI is a relatively common problem found in 40-70% of individuals (Gurney, 2002).

Giles and Taylor (1982) reported that patients with LLI of greater than nine millimeters demonstrated abnormal radiologic findings compared to the controls including wedging of the fifth lumbar vertebra, concavities of the vertebral end-plates in the lumbar spine, and traction spurs and osteophytes of the vertebral bodies. Specht and De Boer (1991) analysed the relationship between anatomical LLI, scoliosis and LL from the radiographs of 106 patients in a private chiropractic practice. A significant number of patients (70%) had an LLI of greater than 3 mm while 40% were found to have an LLI of greater than 6 mm. Although there was no strong correlation between scoliosis or hyper- or hypolordosis of the lumbar spine and anatomic LLI, of the patients who had an LLI of greater than 6 mm, 53% had a scoliosis or a hyper- or hypolordotic lumbar spine. This suggests that there is some degree of abnormal spinal adaptation that may occur in individuals with an LLI of greater than 6 mm.

B) Low Back Pain and Other Clinical Conditions and Lumbar Lordosis

Murata *et al*. (2002) and Yochum and Rowe (2005) have stated that several authors have looked at the relationship between LL and LBP. While Hansson *et al*. (1985) have stated that LBP may not be related to changes in the LL and Murrie *et al*. (2003) have suggested that a weak relationship may exist with respect to changes in the LL and the development of LBP, other authors (Drum, 1968; Banks, 1983; Bryner and El Moussali, 1992; Jackson and McManus, 1994; Taka, 1999) have suggested that there is a positive relationship between the loss of LL and the development of LBP.

A possible reason for this is the increase in intradiscal pressure which may follow the loss of LL. A large lumbar lordotic angle may, however, be responsible for the development of LBP due to poor posture and strain to the low back region (Williams, 1955). A contrasting finding was, however, reported by Nourbakhsh *et al*. (2001) that there was no significant difference in the degree of LL in subjects with and without LBP ($p = 0.28$). Furthermore, although there was no significant difference in the degree of LL in those who engaged in strenuous versus light physical activity, the incidence of LBP was higher in those who engaged in strenuous physical activity. In 2002, Ng *et al*. also reported that there was no significant difference in LL in 15 subjects with LBP and 15 age-, height-, obesity-, and physical activity-matched asymptomatic controls. These findings were corroborated by Murrie *et al*. (2003) in a study with 27 patients with LBP and 19 patients and 10 volunteers with no LBP. Kim *et al*. (2006) reported a considerably lower mean LL than other authors in a sample of 31 Korean patients with LBP **(Table 2.1)** which was in contrast with the reported mean LL of LBP patients reported by Lord *et al*. (1997) **(Table 2.1)** and Nourbakhsh *et al*. (2001) (mean LL of 37º [of subjects with LBP]).

Berlemann *et al*. (1999) reported that there was no significant difference in LL in 23 patients with degenerative spondylolisthesis and 40 age- and sex-matched controls. In a later Danish study where the data was obtained from the lumbar spine radiographs of 2618 females, an increased LL was, however, found to be associated with degenerative spondylolisthesis in females (Jacobsen *et al*., 2007). Trauma which would result in a vertebral fracture has been shown to decrease the LL (Sinaki *et al*., 1996). Briggs *et al*. (2004) have hypothesized that in osteoporotic vertebral fracture, intersegmental spinal stability may be compromised as a result of an influence by an increased thoracic kyphosis, decreased LL and change in sacral inclination on paraspinal muscle control. This hypothesis has, however, yet to be verified.

In conclusion, it is, therefore, a reasonable assumption to regard changes in the LL in individuals with LBP as a weak clinical sign (Murrie *et al*., 2003).

2.5.1.2 Lumbosacral Angle, Lumbosacral Disc Angle and the Lumbosacral Lordosis Angle

A summary of the studies that have investigated the measurement of the LS angle, the LSD angle and the LSL angle is presented in **Table 2.3**.

Table 2.3 A summary of the investigations done on LS angle and LSD angle and LSL angle measurements

Reference	Method	LS angle	LSD angle	LSL angle
Chung *et al*. (1981)	**Ferguson method:** LS: A line drawn parallel to the bottom edge of the film and a second oblique line is drawn parallel and through the sacral base. The posterior angle is measured.	Males: 32.4º Females: 31.5º	N/A	N/A
Fernand and Fox (1985)	LS: a line drawn parallel to L2 and another line drawn parallel to the top of the sacrum. The angle formed was measured.	Retrospective group: 29.96˚ ± 0.74˚: Prospective group: 46.51˚ ± 1.4˚:		
Saraste *et al*. (1985)	LS: the angle between the inferior border of L3 VB and the superior border of S1 segment. LSL: the angle between the midpoints of the L3, L5 and S1 VBs.	40º		Patients with spondylosis: 135º Control group: 145º
Bryner and El Moussali (1992)	LS: Ferguson method: LSD: Ferguson method: Line drawn parallel and through the inferior endplate of L5 and the superior endplate of S1.	40.6º	15.3º	
Chen and Lee (1997)	LS: the angle between the superior surface of L1 and S1 vertebrae.	Males in the upright posture: 46º± 6º		
Middleditch and Oliver (2005)	LS: the angle formed by the sacral base and the horizontal plane.	42º -45º. The value could increase by 8º in the erect position.		
Yochum and Rowe (2005)	LS: Ferguson method. LSD: Ferguson method. LSL: the centers of L3 and L5 VBs are found using the intersecting diagonals from the opposing corners for each of the vertebrae. A line is drawn connecting the midpoints of two VBs. The midpoint of S1 is also found and a second line is drawn between L5 and S1 midpoints. The angle formed posteriorly is measured.	The mean in the erect posture is 41˚. The value will increase from the recumbent to the upright position by 7-12˚.	Range: 10-15˚ [From Banks (1983) and Cox (1990)].	Range: 124º - 162º Average: 146º
Kim *et al*. (2006)	LS: the angle formed by the sacral base (superior endplate of S1) and the horizontal plane.	31.77˚		

LS = Lumbosacral angle; LSD = Lumbosacral disc angle; LSL = Lumbosacral lordosis angle; N/A = Not available; VB = vertebral body; VBs = vertebral bodies

Chen and Lee (1997) conducted a study on 16 healthy male subjects to develop a non-invasive method to predict the LS angle and vertebral angles compared to radiographic examination. The reasons provided for the use the non-invasive technique over the radiographic method included less expense, reduction in technical difficulties and decreased risk of exposure to x-rays. Their results showed that there was no significant difference between the calculated data (obtained from videographic measurements) and data obtained from the radiographs.

Chung *et al*. (1981) used a sample 132 Korean males and females that were treated and diagnosed surgically for lumbar IVD herniation. Males were found to have a slightly greater LS angle than females **(Table 2.3)**. Fernand and Fox (1985) had, however, found higher mean normal LS angles in males to be 43.25° and 47.19° in females. The L2 vertebra was used as a landmark since it was less variable than L1 (Fernand and Fox, 1985). Later, Yochum and Rowe (2005) reported a lower mean value of 41° for the LS angle which was similar to an earlier finding by Bryner and El Moussali (1992). Saraste *et al*. (1985) used the lumbosacral spines from 12 cadavers (six males and six females aged 41-90 years). Extreme cold was used to maintain the rigidity of the spines and to prevent mobility of the spine during radiographic examination. The LS angle ranged from 15º-60º while the LSL angle ranged from 124º-162º. Changing from the supine position to weight-bearing upright posture could increase the LS angle by at least 7° as reported by Chen and Lee (1997) and Yochum and Rowe (2005).

A) The Clinical Significance of the Lumbosacral Angle, the Lumbosacral Disc Angle and the Lumbosacral Lordosis Angle

Although Jessen (1971) and Bryner and El Moussali (1992) have not reached an agreement on the significance of the LS angle, Chen and Lee (1997) reported that it is important for determining the forces acting on the low back during lifting. Furthermore, Noh and Keum (2000) stated that although the LS joint is an unstable area anatomically because “it is an inflexion point in the spinal curvature”, in life, it is quite a mobile area. An increase in LS could be seen as a mechanical factor in leading to LBP according to Ferguson (1949) and Adams and Hutton (1980). The findings of Chung *et al*. (1981), however, suggest that there is a considerable decrease in the LS angle in symptomatic individuals with IVD herniation when compared to asymptomatic individuals **(Table 2.3)**. Kim *et al*. (2006) also reported similar findings in a sample of 31 patients with LBP. These findings, therefore, suggest that a lower

LS angle may be found in individuals with LBP (Chung *et al*., 1981; Noh and Keum, 2000; Kim *et al*., 2006). The LS angle was found to be greater in women who had a history of previous pregnancy (41.4º) than women who had no children (37.5º) (Bryner and El Moussali, 1992). According to Middleditch and Oliver (2005), the LS angle is greater in females during childbearing years than in males and the difference was presumed to be due to hormones.

A review on the related literature showed that only Banks (1983) and Cox (1990) reported on LSD angle with a normal range of 10-15°. A LSD angle greater than 15º could lead to facet impaction which could lead to LBP (Cox, 1990). Bryner and El Moussali (1992) found no significant variation in the LSD angle in the presence of LBP. Peterson *et al*. (1990) found no association between an increased LS angle or LSD angle and the incidence of spondylolisthesis. The clinical significance of changes in the LSL angle has not yet been adequately assessed according to Yochum and Rowe (2005) although Saraste *et al*. (1985) found a lower LSL angle in patients with spondylosis compared to a control group **(Table 2.3)**. Furthermore, the LSL angle may be useful when the upper lumbar vertebral bodies are not included on the radiograph (Yochum and Rowe, 2005).

2.5.1.3 Intervertebral Disc Angle and Intervertebral Disc Height

A summary of the studies that have investigated the measurement of IVD heights and IVD angles is presented in **Table 2.4**.

Table 2.4 A summary of the methods of measurement of IVD height and IVD angle

Reference	Sample	IVD height	IVD angles
Tibrewal and Pearcy (1985)	11 normal male subjects bet 25-36 y.o.a, 10 male patients bet 27-38 y.o.a.	**Farfan's method:** the anterior and posterior disc heights are measured and are expressed as a ratio to disc diameter. The ratios are reduced to a ratio of each other.	N/A
Brinckmann *et al.* (1998)	627 lateral radiographs from a German database. 249 radiographs from a British database.	Anterior vertebral height* is the distance between the two anterior corners of the VB. The mean depth = (cranial depth: is the diameter of the superior surface of VB divided by the caudal depth: is the diameter of the inferior surface of VB). Anterior vertebral height / mean vertebral depth= vertebral height.	N/A
Shao *et al*. (2002)	607 women bet 20-87 y.o.a. 633 men bet 20-92 y.o.a.	Measurement of the disc height exclusively on the 4 corners of the adjacent vertebrae	N/A
Yochum and Rowe (2005)	N/A	**Hurxthal method:** The distance between the opposing endplates at the midpoint between the anterior and posterior vertebral margins is measured. Farfan's method	Lines drawn through & parallel to each lumbar body endplates; the lines are extended posteriorly until they intersect. The angles at each interspace are then measured.

IVD = Intervertebral disc height; N/A = Not available; VB = Vertebral body; bet = between; y.o.a. = years of age
***Anterior vertebral height is described as ventral disc height in the original article**

According to Frobin *et al*. (1997), published methods on measuring IVD height have often produced inaccurate results. The reasons put forth to explain their findings include subjective errors when interpreting radiographs, variation in exposure geometry and inadmissible simplifications on evaluating the radiographs. Tibrewal and Pearcy (1985) and, later, Pope *et al*. (1991), have however, reported that Farfan's method for measuring IVD heights from lateral radiographs was more reproducible and accurate. Tibrewal and Pearcy (1985) also reported on the mean anterior and posterior IVD heights **(Table 2.5)** and found no statistical significant differences in IVD heights between vertebral levels. At the L5-S1 IVD, the difference in the anterior and posterior height was 8.5 mm in normal patients compared to 7 mm in patients with IVD herniations **(Table 2.5)**. On the other hand, Middleditch and Oliver (2005) have reported slightly lower values of 6-7 mm for the difference of the anterior and posterior IVD heights. The frequency of IVD herniation of 132 spinal patients at Korean University Hospital was reported as follows (Chung *et al*., 1981):

- L3-L4: 25%
- L4-L5: 59.3%
- L5-S1: 50%

Despite several authors reporting on the measurement of IVD height **(Table 2.4)**, only Tibrewal and Pearcy (1985) have provided values **(Table 2.5)**. More information is, therefore, required to establish reference values for IVD height that would be suitable for quantitative comparison (Shao *et al*., 2002). With respect to the IVD angle, Yochum and Rowe (2005) reported that it increases from cephalic to caudal in the lumbar spine **(Table 2.6)**.

Table 2.5 The mean anterior and posterior IVD heights *

	11 Normal patients		10 Patients with IVD herniation	
Level	**Mean anterior IVD Ht (mm)**	**Mean posterior IVD Ht (mm)**	**Mean anterior IVD Ht (mm)**	**Mean posterior IVD Ht (mm)**
L1-L2	8	4	9.5	4
L2-L3	11	4.5	11	5
L3-L4	12.5	4.5	13	5.5
L4-L5	14	5.5	14	6
L5-S1	13	4.5	11.5	4.5

IVD = intervertebral disc height; Ht = height; mm = millimeters
*Data from Tibrewal and Pearcy (1985)

Table 2.6 The normal lumbar IVD angles*

IVD level	Mean angle (º)
L1-L2	8
L2-L3	10
L3-L4	12
L4-L5	14
L5-S1	14

* Data from Yochum and Rowe (2005)

A) Factors Affecting Intervertebral Disc Height

i) Growth factors

The cells of the AF and NP of the IVD are responsible for regulating the homeostasis of the IVD tissue by balancing the anabolic and catabolic reactions. An imbalance between the anabolic regulators, which include transforming growth factor β (TGF-β), insulin-like growth factor and bone morphogenic proteins (BMPs) (Thompson *et al*., 1991) and the catabolic regulators, which include matrix metalloproteases (Liu *et al*., 1991; Takaheshi *et al*., 1996; Fujita *et al*., 1993) and cytokines (Kang *et al*., 1997), may lead to IVD degeneration (Masuda and Howard, 2004).

ii) Age-related changes

Age-related changes in the spine are one of the key factors in determining IVD height although the literature is ambivalent with respect to the effect of aging on IVD height (Shao *et al*., 2002). The term "disc degeneration" has been subject to interpretation as it could refer to IVD thinning or desiccation or presence of osteophytic spurs at the joint margins (Shao *et al*., 2002).

Substantial biochemical and structural changes occur with ageing in the IVDs, which could be progressive and irreversible (Cassinelli *et al*., 2001). Alterations in the IVD composition occur before morphologic degeneration is visible. With ageing of the IVDs, the arterial supply to the endplates decreases, and finally disappears by the third decade of life. The number of functional cells in the inner parts of the IVD decrease, and the normal collagen fibril organization begins to disappear (Cassinelli *et al*., 2001). Changes in the biochemical composition of the IVDs are likely to play a role in altered mechanical properties of the disc (Cassinelli *et al*., 2001).

Anatomic changes of the IVD with age are grouped into stages (Kirkaldy-Willis *et al*., 1978; Adams and Hutton, 1981). With ageing the NP becomes dehydrated and fibrotic. Circumferential tears of the AF are visible which could progress to radial tears (Cassinelli *et al*., 2001). If this process continues unabated, there is a loss of IVD height and disc resorption.

Torgerson and Dotter (1976) had reported on significant IVD degenerative changes in symptomatic and asymptomatic individuals (age 60-69 years). Vernon-Roberts and Pirie (1977) reported that IVD height decreased with increasing age. They found that with moderate to advanced primary disc degeneration there is a decrease in the vertical IVD height and anterior tilting of the upper vertebral bodies. This resulted in the decrease of the anterior IVD height due to the herniation of the annulus antero-laterally. Increased forces are placed on the facet joints leading to changes to the bone structure which could then lead to altered mechanics of the vertebral column at the level of the affected disc. In contrast to the findings of Vernon-Roberts and Pirie (1977), Twomey and Taylor (1987) have suggested that the lumbar IVD height increased with age and that the decrease in the height of the spine was due to loss of the midvertebral height of the vertebral bodies with the increasing concavity of the vertebral end plates. Furthermore, measurement studies of cadaveric spines showed that the mean mid-sagittal height of most IVDs is usually maintained during ageing with a tendency to increase, while the peripheral disc heights tended to decrease (Twomey and Taylor, 1987; 1991). Amonoo-Kuofi (1991) had reported that the anterior and posterior IVD heights gradually increased till the fifth decade and decreased thereafter. Later, Shao *et al*. (2002) found that the IVD heights from T12-S1 of adults aged 20-69 years increased linearly with increasing age and the vertebral endplates became more concave with age.

Miller *et al*. (1988) reported that lumbar IVD degeneration was observed in the second decade of life in 600 cadaveric specimens. Furthermore, by age 49, 97% of the lumbar discs showed signs of degeneration. In 2004, Briggs *et al*. described the integrity of the disc with respect to age. There is a decrease in the discs water content with age thereby placing individuals at risk of vertebral injury. As the disc degenerates with age, it could result in increased mechanical loading on the VB.

iii) Gender

IVD degeneration was found to be as frequent in men as in women according to Torgerson and Dotter (1976). The IVDs of males tendered to degenerate at least a decade earlier than females and the degree of degeneration was considerably more in males than females (Miller *et al*., 1988). A few studies have, however, reported that lumbar IVD degeneration was more common in females under the age of 17 years than males of the same age category (Grobler *et al*., 1974; Silvers *et al*., 1994). This was presumably due to rapid spurts in height, weight and growth in females than males thus making their IVDs more susceptible to stress- and trauma-related damage. Pietilä *et al*. (2001), however, found no female preponderance in a study of 165 patients with a mean age of 21.2 years.

iv) Weight

In the literature it has been reported that the incidence of AF rupture is non-uniform at all levels in the lumbar spine and has a higher incidence of rupture at the lower lumbar intervertebral level. This was linked with the increase stress placed on the IVDs with weight bearing since the lower vertebral joints support most of the body weight (Farfan *et al*., 1972). Luoma *et al*. (1998), using MRI, found no association between overweight and IVD degeneration in a sample of 164 males. A conflicting finding, however, was reported by Pietilä *et al*. (2001) and Luike *et al*. (2005). Pietilä *et al*. (2001) found that males and females between ages of 14 and 25 years who were undergoing lumbar IVD surgery had a significantly higher body mass index. Luike *et al*. (2005) in a population-based four-year follow-up study of 1832 males aged 40–45 years, using multiple regression analysis, found that a body mass index greater than 25 $kg.m^{-2}$ increased the risk of IVD degeneration. Therefore, both the studies support the view of Videman *et al*. (2007) who mentioned that increased body weight was a contributing factor to IVD narrowing.

v) Smoking

Livshits *et al*. (2001) utilized computed tomography (CT) scans to evaluate IVD degeneration in 161 Arab individuals (male and female mean age of 34 years and 36 years respectively) and found that smoking was a significant risk factor in the development of IVD degeneration. In contrast, Luoma *et al*. (1998) found no association between smoking and IVD degeneration in a sample of 164 males. This finding was later supported by Pye *et al*. (2007) who found no association between smoking and IVD degeneration in a sample of a Caucasian population in north-eastern Scotland. The authors did mention that extrapolation of the data beyond this population should be done with caution.

Some of the factors put forth to explain IVD degeneration in smokers include abdominal aortic atherosclerosis causing discal ischaemia (Kauppila *et al*., 1994), disproportionate mix of IVD matrix proteases and their inhibitors (Goupille *et al*., 1998) and nicotine in cigarette smoke which appears to be dose-dependent (Frymoyer *et al*., 1983). Reduced blood flow to the vertebrae and impaired IVD metabolism may occur as a result of vasoconstriction caused by nicotine (Frymoyer *et al*., 1983; Kirkaldy-Willis and William, 1999; Cox, 1999; Uematsu *et* *al*., 2001). The other effects of nicotine include lowering of the central nervous system pain threshold (Brage and Bjerkedal, 1996) and the disturbance of the oxidative metabolism due to the carbon monoxide-haemoglobin content in the blood of smokers (Frymoyer *et al*., 1980). IVD degeneration may also occur from an increase in intradiscal pressure and tears that may occur as a result of frequent and sometimes severe cough in smokers (Fryomyer *et al*., 1980; Kirkaldy-Willis and William, 1999; Cox, 1999). Sackett *et al*. (1968), Rissanen *et al*. (1972) and Auerbach and Garfinkel (1980) have reported that aortic atherosclerosis and the subsequent stenosis of the arteries of the vertebrae may be indirectly related to smoking. The IVD relies heavily on the endplate for nutrition which mainly occurs through diffusion (Urban *et al*., 1977). By affecting the integrity of the endplates, cigarette smoke may also affect this diffusion process resulting in IVD degeneration (Masuda and Howard, 2004). Endplate sclerosis was found to be a contributor to IVD degeneration in an animal (sand rat) study conducted by Gruber *et al*. (2007).

vi) Occupation

Exposure to whole body vibration, heavy occupational and physical loading on the spine have been implicated in the aetiology of IVD degeneration (Battie *et al*., 1991; Battie *et al*., 1995).

Kelsey and Harding (1975) and McIlwraith (1996) reported that there is a high incidence of IVD herniation in both male and female drivers. A later study by Luoma *et al*. (1998) also found that car driving increased the risk of IVD degeneration. This was probably related to the increased intradiscal pressure during prolonged sitting and lack of proper lumbar support (Andersson *et al*., 1974). Evans *et al*. (1989) found that IVD degeneration was significantly more in the sedentary employees than in the ambulating employees. This was interesting since Porter *et al*. (1989) reported that IVD strength was greater in individuals who participated in greater physical activity.

Physical work overload could, however, lead to damage of the lumbar spine viz. fractures, a decrease of IVD height or a wedge shape of vertebral bodies and malalignment of the lumbar vertebrae due to ‘wear and tear’ of ligaments (Brinckmann *et al*.,1998). The IVDs at the levels of L1-L2, L2-L3 and L5-S1 showed a significant decrease in height in workers exposed to prolonged lifting and carrying (Brinckmann *et al*., 1998). In press operators and steelworkers the height of the vertebrae T12 and L1 was significantly reduced indicating a wedge-shape deformation (Brinckmann *et al*., 1998). Lifelong loading on the spine as a result of being in prolonged erect posture was found to be a more significant contributor to IVD degeneration than work and leisure physical activity (Videman *et al*., 2007). Luoma *et al*. (1998) in a study conducted on 53 machine drivers, 51 construction carpenters and 60 municipal office workers (age 40 – 45 years) found that occupational loading increases the risk of IVD degeneration in the lumbar spine. Carpenters were at risk of developing posterior IVD bulges while machine drivers were at risk of developing anterior IVD bulges.

vii) Leg Length Inequality and IVD Degeneration

Morscher (1977) reported that an LLI could lead to a compensatory scoliosis resulting in asymmetrical loading of the vertebral column. One of the consequences of this would be early degeneration of the IVDs resulting in a loss of IVD height.

B) Low Back Pain and Intervertebral Disc Degeneration

One of the factors implicated in the aetiology of LBP is lumbar IVD degeneration (Cassinelli *et al*., 2001). Torgerson and Dotter (1976) found that 22% of 217 asymptomatic individuals showed some evidence IVD narrowing at one or more levels in the lumbar spine while the figure increased to 56% in 387 symptomatic patients complaining of LBP. Between the ages 40-49 years, six percent of the asymptomatic patients showed evidence of IVD degeneration compared to 48% of symptomatic individuals (Torgerson and Dotter, 1976). Frymoyer *et al*. (1984) and Dabbs and Dabbs (1990) reported that there was a poor correlation between IVD narrowing and the development of LBP but Symmons *et al*. (1991) and Kauppila *et al*. (1997) have suggested that IVD degeneration in the lumbar spine may be responsible for LBP.

Interestingly, the IVDs of symptomatic and asymptomatic individuals show very little differences in chemical, structural and radiographic findings, but persons with LBP due to IVD degeneration often have more diffuse and severe degeneration (Paajanen *et al*., 1997; Salminen *et al*., 1999).

2.5.1.4 Interpedicular Distance and Sagittal Canal Diameter

A summary of the studies that have investigated the measurement of IPD and sagittal canal diameter is presented in **Table 2.7**.

Table 2.7 A summary of the investigations done on IPD and sagittal canal diameter

Reference	Sample	Method	IPD (mm)		Diameter of lumbar spinal canal (mm)	
Hinck *et al*. (1966)	353-children (under the age of 19yrs), 121-adults	IPD was considered the shortest distance between the medial surfaces of the pedicles of a given vertebra.	Adult male & female combined: L1: 25.0 L2: 25.5 L3: 26.0 L4: 26.9 L5: 29.7		N/A	
			Adult male L1: 25.9 L2: 26.5 L3: 26.8 L4: 27.6 L5: 30.7	Adult female L1: 24.3 L2: 24.9 L3: 25.4 L4: 26.4 L5: 29.0		
Eisenstein (1976)	275 skeletons, 113-Caucasian (78-male, 35-female) & 162 Black (108-males, 54 females)	From L1 to L4 the posterior limit of the spinal canal was found to coincide with a line connecting the apex of superior to the apex of the IAF. L5, the canal is limited posteriorly by a line placed 1-2 mm in front of the anterior border of a large radiolucent lake within the sp.	Caucasian* Male L1:23 L2:24 L3:23 L4:24 L5:26	Caucasian* Female L1:22 L2:22 L4:23 L3:23 L5:25	Caucasian* Male L1:18 L2:17 L3:16 L4:16 L5:18	Caucasian* Female L1:18 L2:17 L3:17 L4:16 L5:18
			Black* Male L1:21 L2:22 L3:22 L4:23 L5:26	Black* Female L1:20 L2:21 L3:21 L4:22 L5:24	Black* Male L1:16 L2:15 L3:15 L4:15 L5:16	Black* Female L1:17 L2:16 L3:15 L4:16 L5:16
Ebraheim *et al*. (1997)	9 male and 6 female cadavers age 42-75 at time of death	The distance between the pedicles at the same level.	L1: 23.5 ± 1.5 L3: 24.1 ± 1.9 L5: 24.4 ± 1.6		N/A	
Yochum and Rowe (2005)		IPD: The distance between the two pedicles of each vertebra. Eisenstein's method for sagittal canal diameter: Line drawn to connect tips of SAF and IAF at each level (Line 1). The midpoint of posterior vertebral body margin is found. The sagittal canal diameter is the distance bet. the posterior body margin and Line 1.	L1: 21-29, Av: 25 L2: 21-30, Av: 26 L3: 21-31, Av: 26 L4: 21-33, Av: 27 L5: 23-36, Av: 30		Less than 15 mm may indicate spinal stenosis.	

SAF = Superior articular facet; IAF = Inferior articular facet; IPD = Interpedicular distance; Av = average; sp= spinous process
***Eisenstein referred to his sample groups as Caucasoid and Negroid in the original article**

IPD refers to the shortest distance between the medial surfaces of the pedicles (Hinck *et al*., 1966). With respect to the IPD of the lumbar vertebrae, all researchers have reported an increase in the IPD from cephalic to caudal (Hinck *et al*., 1966; Eisenstein, 1976; Ebraheim *et al*., 1997; Yochum and Rowe, 2005) with values ranging from 21-26 mm (Eisenstein, 1976) and 25-30 mm (Hinck *et al*., 1966; Yochum and Rowe, 2005). Eisenstein's method for sagittal canal diameter is deemed to be the single most reliable measurement on plain radiographs in the assessment of spinal stenosis (Yochum and Rowe, 2005).

A) Factors affecting IPD and Sagittal Canal Diameter

i) The Relationship between Age and Interpedicular Distance

Hinck *et al*. (1976) reported two age extremes for IPD values during the 3rd, 4th, 5th years and adulthood. The IPD growth difference was 3-5 mm from ages 3-5 years to adulthood. In the lumbar spine there was an average increase of 3 mm from age groups 3-5 years to 9-10 years (Hinck *et al*., 1976).

ii) Gender Differences in the Interpedicular Distance

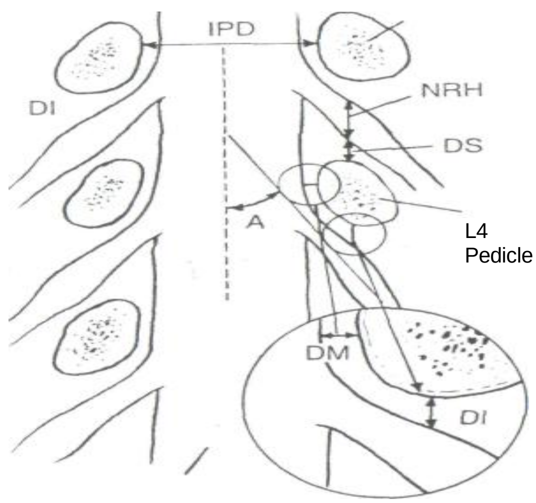
Hinck *et al*. (1966) found gender differences in the IPD measurements with the average male measurement for IPD consistently larger by 1 mm compared to that of females. This finding was later confirmed by Eisenstein (1976) **(Table 2.7)** and Vanharanta *et al*. (1985) who further reported that IPD increased significantly (p = 0.02) with age in males at L4 and L5 levels whereas in females the values were clearly smaller at all levels.

iii) Ethnic Differences in Interpedicular Distance and Sagittal Canal Diameter

Eisenstein (1976) reported differences between Whites and Blacks in IPD measurement **(Table 2.7)** with the spinal canal of the black population to be less capacious. No reasons were provided for this finding. Eisenstein (1976) also reported that the range of normal antero-posterior (AP) diameter in the whole lumbar spine in White males was 14-20 mm, White females 13-21 mm, Black males 12-20 mm and the Black females 13-19 mm. This finding suggests that there may be significant differences in the IPD and sagittal canal diameters in different ethnic groups.

B) The Clinical Significance of the Sagittal Canal Diameter and Interpedicular Distance

According to Eisenstein (1976), the AP diameter was found to be more significant than the transverse diameter of the spinal canal. Although a lower limit value (of the spinal canal) of 15 mm has been reported in the literature (Eisenstein, 1976; Yochum and Rowe, 2005), Eisenstein (1976) found that the lowest (normal) limit value of the spinal canal was 12 mm. Identification of stenosis on a plain film radiograph or MRI may increase the treating surgeon's awareness of the potential need for multilevel treatment (Singh *et al*., 2005). IPD is a useful method in the evaluation of spinal stenosis, congenital malformation and intraspinal neoplasms (Yochum and Rowe, 2005). An increased IPD could be due to pedicular erosion from expanding spinal cord tumors (Elseberg and Dyke, 1934). Knowledge of the IPD could also minimize the risk of neurological complications during pedicular screw placement surgery (Ebraheim *et al*., 1997). It was found that the distances between the medial pedicle surface and dural sac **(Figure 2.1)** were not more than 2 mm. If this distance were to decrease as a result of a decrease in IPD, neurological complications could arise (Ebraheim *et al*., 1997).



KEY:

DM - distance from the pedicle to the dural sac medially;

DS = distance from the pedicle to the nerve root superiorly;

DI = distance from the pedicle to the nerve root inferiorly;

IPD = interpedicular distance,

NRH = nerve root height;

A = angle between the midline and the axis of the nerve root in the frontal plane.

Figure 2.1 The relationship between IPD and the adjacent neural structures
(from Ebraheim *et al*., 1997)

2.5.1.5 Lumbar Gravity Line

According to Ferguson (1934; 1949) and Janelle *et al*. (1983) the lumbar gravity line is drawn through the center of the L3 VB which is located by intersecting diagonals from opposing vertebral body corners. A vertical line is then drawn through this point and the relationship to the upper sacrum is assessed. The lumbar gravity line should pass through midpoint of L3 and continue vertically to intersect the sacral promontory (Ferguson, 1934; 1949). Klaussen and Rasmussen (1968), on the other hand, used the intersection point at L5 VB as a reference point. MacThiong *et al*. (2004) investigated the relationship between sagittal alignment of the spine and pelvis and changes during growth. They found that pelvic tilt and LL increased with age to avoid the anterior shift of the body’s center of gravity.

A) The Clinical Significance of Measuring the Gravity Line

If the lumbar gravity line passed anteriorly to the sacral promontory by more than 10 mm, it could lead to an increase in anterior shearing forces between the lumbosacral facet joints (Ferguson, 1949), however, a posterior shift could lead to an increase in weight bearing forces on the lumbosacral facet joints which could result in LBP (Drum, 1968; Adams and Hutton, 1980; 1982). The position of the gravity line is the best estimate of the body's location (Engsberg *et al*., 2003). It is an important radiographic parameter to assist with surgical preparation as well as maintenance and restoration of the sagittal and coronal balance (Engsberg *et al*., 2003). In the advanced stages of pregnancy the lumbar gravity line is altered by moving posteriorly and inferiorly as the spine moves posterior to the center of gravity (Collitan, 1996). The lumbar gravity line is altered due to these women developing a temporary hyperlordosis (Moore and Dalley, 2006). In osteoporosis, vertebral fracture may lead to an increase in thoracic kyphosis resulting in the spine being in a position of greater flexion. This would lead to the line of gravity shifting anteriorly from the vertebral bodies. The consequence of this will be an increase in flexion moments leading to an increase in vertebral compression force (Briggs *et al*., 2004).

In 2004, the gravity line was measured in 25 individuals who had Harrington's rod surgery done 15-20 years previously. These adolescent idiopathic scoliosis patients showed a decrease in LL and thoracic kyphosis and a posterior shift of the gravity line (Kluba *et al*., 2004) while Ploumis *et al*. (2007) found that the sagittal gravity line passed anterior to S1 vertebra in individuals presenting with a scoliosis.

2.6 Conclusion

While several methods exist to measure the selected lumbar spine radiographic parameters, these have not always yielded consistent results. Some of the factors that have contributed to the differences in the results include differences in measurement technique, inconsistent sample sizes and differences in population or sample profile. A few studies measured the lumbar spine radiographic parameters in symptomatic individuals with no comparisons to asymptomatic individuals.

The literature is ambivalent with respect to the association between the selected demographic factors and the radiographic parameters. While some studies have provided evidence for a relationship between certain demographic factors and the lumbar spine radiographic parameters, other studies have provided conflicting or contrasting results. The study of Eisenstein (1976) found differences in IPD and sagittal canal diameter amongst South African White and Black males and females. No studies have yet been done to determine whether there are any significant differences in the lumbar spine radiographic parameters in the South African Indian female compared to the samples of other studies and whether any significant association exists between the selected anthropometric and demographic factors and lumbar spine radiographic parameters in this population group.

CHAPTER THREE

MATERIALS AND METHODS

3.1 STUDY DESIGN

This research study was designed in the form of a quantitative, non-interventional, cross-sectional study. The data was obtained from the lumbar spine radiographs and the selected anthropometric and demographic data of the subjects that presented to the Chiropractic Day Clinic (CDC) at the Durban University of Technology (DUT). Permission to conduct this study was obtained from the Durban University of Technology's Faculty of Health Sciences Research Committee **(Ethics Clearance Certificate No.: FHSEC 026/07 [Appendix J])**.

3.2 SUBJECT RECRUITMENT

Advertisements in the form of pamphlets **(Appendix G)** were posted in libraries, stores, surrounding campuses, CDC, Homeopathy Clinic and Student Wellness Clinic at the DUT.

3.3 SAMPLE

Convenience sampling was utilized in this study. The sample size consisted of 60 (n = 60) healthy, asymptomatic Indian females. This sample size was arrived at after discussions with an experienced biostatistician (Esterhuizen, 2007).

3.4 BRIEFING OF THE RADIOGRAPHERS

Prior to the commencement of this study a briefing session was held with the radiographers at the Radiography Clinic at the DUT. The researcher informed the radiographers about the purpose of the study, the study design and their role in the study. Each radiographer was given a letter of information **(Appendix I)** which explained their role in this study and an informed consent form **(Appendix B)**. The radiographers were given an opportunity to ask any questions that pertained to the study. All radiographers who agreed to participate in this study then signed the informed consent form.

3.5 INCLUSION CRITERIA

- All subjects were between the ages 18-40 years. Those younger than 18 years old would have needed parental consent while the possibility of degenerative changes to the lumbar spine would have been higher in those older than 40 years of age (Kirkaldy-Willis and William, 1999).
- Healthy, asymptomatic Indian females with no low back/hip pain for at least three months prior to this study were included in the study.

3.6 EXCLUSION CRITERIA

- Any subject with a history of trauma to the low back/hip and/or arthritic, inflammatory, endocrine diseases (e.g. Cushing's syndrome) was excluded from the study.
- Subjects who developed low back/hip pain or sustained any macrotrauma to the low back/hip region (e.g. motor vehicle accident/ fall from a height sustaining injury to the low back/hip) between the first consultation and the radiographic consultation were excluded.
- Females who were pregnant or suspected that they may be pregnant were excluded from the study.
- Refusal to sign the informed consent form **(Appendix B)**.
- Any subject with a clinical or radiographically detectable scoliosis and/or kyphosis of the lumbar spine was excluded.
- Subjects who had x-rays (of any region of the body) taken within a month prior to the commencement of this study were excluded. This was done to minimize the radiation dose to the subject.

3.7 RESEARCH PROCEDURES

3.7.1 Telephonic Respondents

The following screening questions were asked of any prospective subject who responded telephonically to the advertisements **(in 3.2)**:

1. "Are you between the ages 18-40 years old?"
2. "Do you have any low back/hip pain?"
3. "Do you have any history of trauma or arthritis or any other condition that affects your low back/hip?"
4. "Are you pregnant or suspect that you might be pregnant?"
5. "Have you had any x-rays done within last month of any region of the body?"

If the prospective subject answered “yes” to the first question and “no” to the rest of the questions, then an appointment was made for her at the CDC.

3.7.2 Phase One

When the prospective subjects arrived at the CDC for their appointment, they were given a letter of information **(Appendix A)** to read. The nature of the study was also verbally explained by the researcher. The prospective subjects were also given an opportunity to ask any questions and the researcher responded accordingly. Anyone who then expressed a willingness to participate in the study was then required to sign an informed consent form **(Appendix B)**. Thereafter, a case history **(Appendix E)** and physical examination **(Appendix F)** was done by the researcher. If the subject satisfied all the inclusion criteria then she proceeded through to **Phase Two** of the research. An appointment was made for these subjects to present at the Radiography Clinic for obtaining their x-rays. The following data were recorded at the first consultation in the Data Collection Sheet 1 **(Appendix D)**:

- Age
- Occupation
- Previous pregnancy/ies
- Smoking (current history)
- BMI (height and weight – these were measured using a stature measure and an electronic scale)
- Leg length was measured using a soft tape measure according to the technique described by Bickley and Szilagyi (2003) and Vizniak (2005).

3.7.3 Phase Two

Each subject arrived at Radiography Clinic at her stipulated appointment time. The researcher met the subject at the clinic and enquired if she had developed any low back/hip pain or sustained any trauma to the low back/hip region since the first consultation **(Phase one)**. If she had developed any LBP/hip pain or had sustained any trauma to the low back/hip region within that time she was excluded from the study. Thereafter, the radiographer prepared the subject according to the Radiography Clinic protocols (viz. changing into an appropriate gown, the use of the protective shields, etc). Each subject had an erect AP and right lateral view x-ray of the lumbar spine taken by a radiographer according to the Clinic’s protocols. To standardize the subject position for the x-ray, the radiographers were informed on the exact patient position **(Appendix C)** for each subject. The subject then changed into her clothes while the radiographer processed the x-rays. The subject's name on the x-ray was coded by the researcher and, therefore, did not appear on the x-ray. The researcher then thanked the subject for her participation in the study and she was allowed to leave. The radiographer handed the x-ray to the researcher once the processing was complete.

3.7.4 Phase Three

All the lumbar spine radiographs were evaluated using the **A**lignment, **B**one, **C**artilage and **S**oft tissue **(ABCS)** criteria (Yochum and Rowe, 2005). Any x-ray which showed a scoliosis or kyphosis of the lumbar spine was excluded. The following relevant radiographic parameters were measured and recorded on Data Collection Sheet 1 **(Appendix D)**:

- LL
- LS angle
- LSD angle
- LSL angle
- Lumbar IVD angles
- Lumbar IVD heights
- IPD
- Sagittal canal diameter
- Lumbar gravity line

The following instruments and measuring tools were utilized in this study:

- X-ray viewing box
- Divider (for accurate measurement between two points)
- T-square
- A 30 cm ruler
- Protractor (for measurement of angles)
- Stature measure (for the measurement of the subject's height)
- Electronic scale (for the measurement of the subject's weight)
- Dermatography liberty marking pen (this was used to mark the angles and lines on the x-ray)
- Soft tape measure (this was used to measure the subject's leg length).

The reference for the methods used for measuring the selected radiographic parameters is presented in **Table 3.1**:

Table 3.1 Methods utilized for assessing the radiographic parameters

Reference	Radiographic Parameter	Method Selected
Chernukha *et al*. (1998)	LL	**Trall method:** First, a curved line was drawn along the anterior wall of the spinal canal in the lumbosacral segment. Then the 1st 2 points needed for angle construction were located at the postero-superior margin of L1 (point A) and postero-inferior margin of S2 (point B). The 3rd point (C) was determined by connecting A and B with a chord line then finding the greatest perpendicular distance between the arc line and chord line (D). Finally, points A and C and B and D were connected. The intersection lines of AC and BD provided the TRALL angle **(Figure 3.1)**
Ferguson (1934, 1949)	LS angle	**Ferguson's method:** A horizontal line was made parallel to the bottom edge of the film. An oblique line was then drawn through and parallel to the sacral base and the angle was measured **(Figure 3.2 A)**.
Ferguson (1949)	LSD angle	**Ferguson's method:** A line was drawn parallel to and through the inferior endplate of L5 and the superior endplate of S1. The angle formed by these lines was then measured **(Figure 3.2 B)**.
Yochum and Rowe (2005)	LSL angle	The centers of the L3 and L5 vertebral bodies are found by intersecting diagonal lines from opposing corners for each of the two vertebrae. A line is then constructed joining the mid-points of these two bodies. The midpoint of the S1 segment is located similarly, and a second line is drawn between the L5 and S1 midpoints. The angle formed posteriorly is measured **(Figure 3.3)**.
Farfan *et al*. (1972)	IPD Sagittal canal diameter	**Farfan's method:** The anterior and posterior disc heights were measured and were expressed as a ratio to disc diameter. The ratios were then reduced to a ratio of each other **(Figure 3.4)**.
Yochum and Rowe (2005)		Lines were drawn through and parallel to each lumbar VB endplate, extending posteriorly until they intersected. The angles formed at each interspace were then measured **(Figure 3.5)**.
Eisenstein (1976)	IVD angles	A line was drawn to connect the tips of SAF and IAF at each level (Line 1).The midpoint of posterior VB margin was then found. The sagittal canal measurement is the distance between the posterior body margin and Line 1 **(Figure 3.6)**.
Ebraheim *et al*. (1997)		The distance between the most medial aspects of the two pedicles of each lumbar vertebra **(Figure 3.7)**.
Ferguson (1934; 1949)	Lumbar gravity line	**Ferguson's gravitational line method:** A line was drawn through the center of the L3 body located by intersecting diagonals from opposing body corners. A vertical line was then drawn through this point and the relationship to the upper sacrum was assessed **(Figure 3.8)**.

LL = Lumbar lordosis; LS = Lumbosacral; LSD = Lumbosacral disc; LSL = Lumbosacral lordosis; IPD = Interpedicular distance; IVD = Intervertebral disc; TRALL = Tangential radiographic assessment of lumbar lordosis; VB = vertebral body; L1, L3, L5 = corresponding lumbar vertebrae; S1, S2 = corresponding sacral vertebrae; SAF = Superior articular facet; IAF = Inferior articular facet

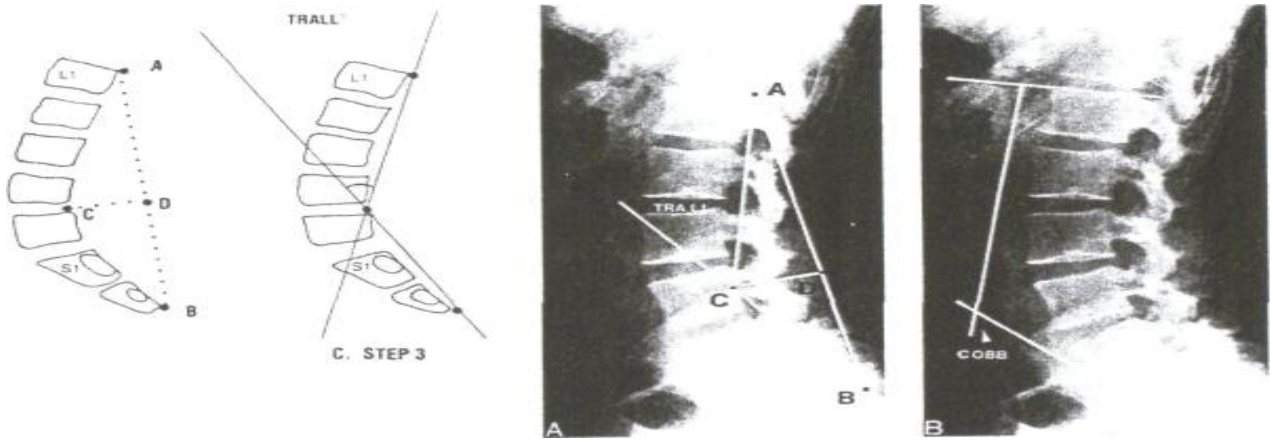
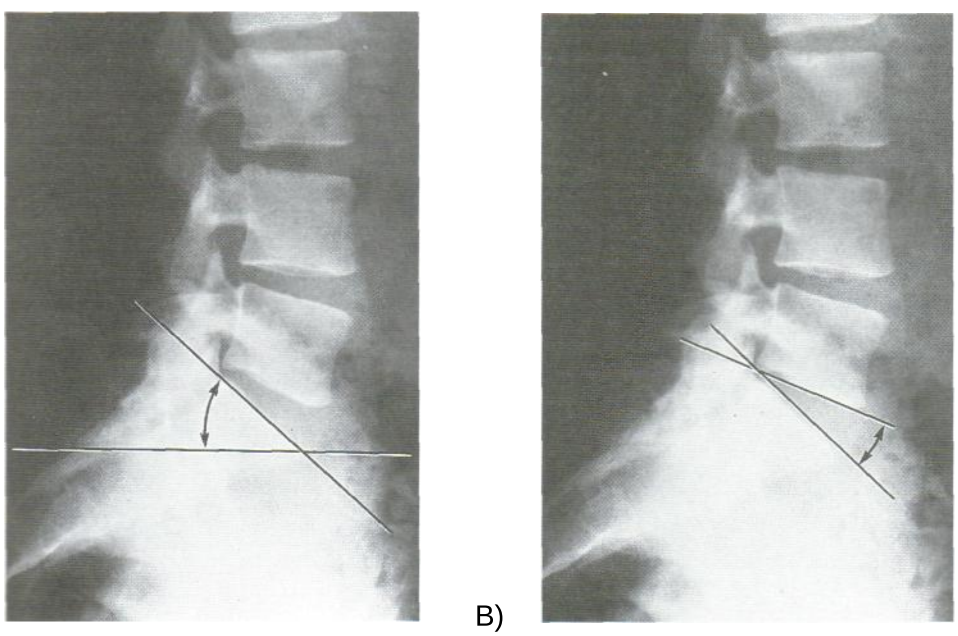


Figure 3.1 Lumbar lordosis using the TRALL method
(From Chernukha *et al*., 1998)



A) B)

Figure 3.2 A) The lumbosacral angle and B) The lumbosacral disc angle
(From Yochum and Rowe, 2005)

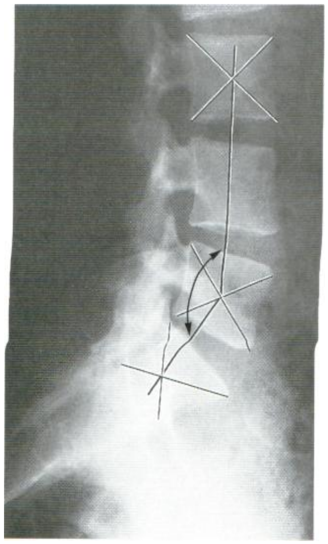
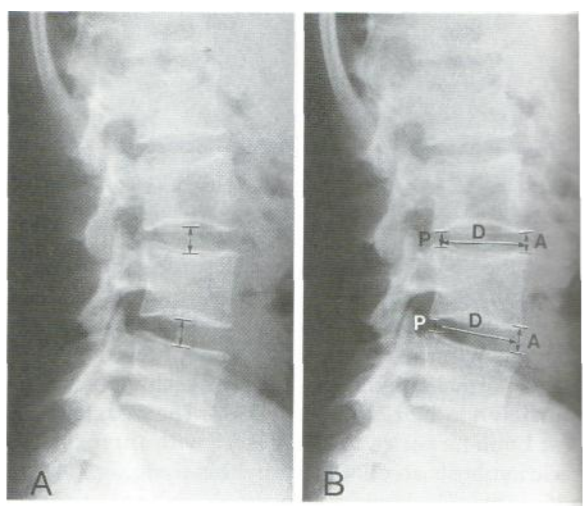
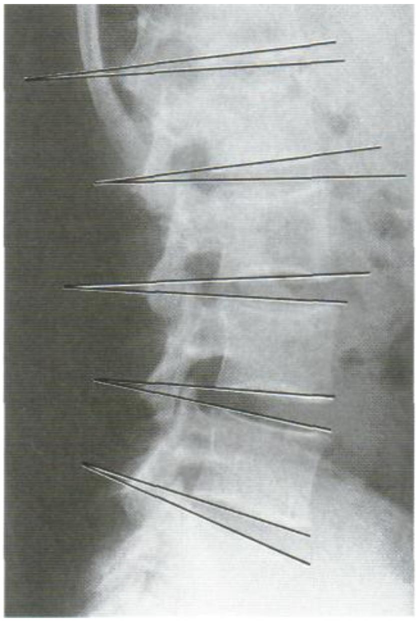
A)  B) 

Figure 3.3 A and B The lumbosacral lordosis angle
(Figure 3.3 A from Yochum and Rowe, 2005)



KEY:
A: anterior disc height
P: posterior disc height
D: diameter

Figure 3.4 A and B The anterior and posterior intervertebral disc heights
(From Yochum and Rowe, 2005)

A) 

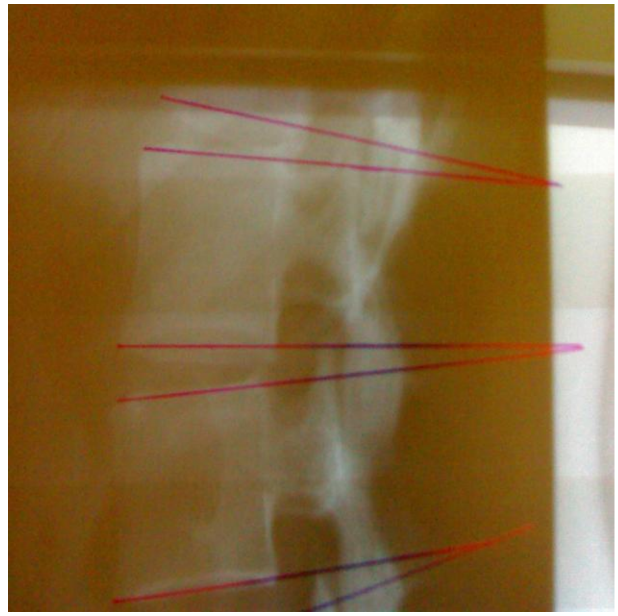
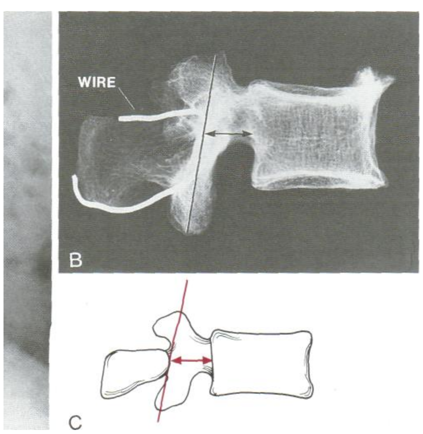
B) 

Figure 3.5 A and B The intervertebral disc angles
(Figure 3.5 A from Yochum and Rowe, 2005)



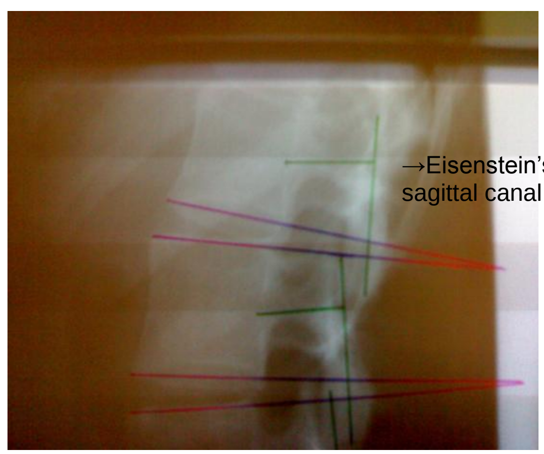


Figure 3.6 Sagittal canal diameter using Eisenstein's (1976) method
(Figures 3.6 B and C from Yochum and Rowe, 2005)

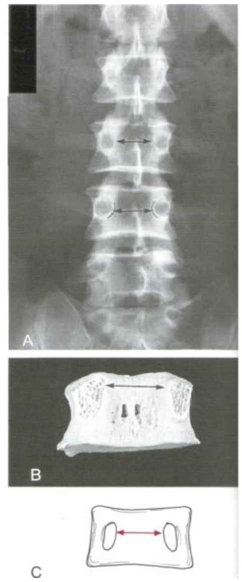


Figure 3.7 Interpedicular distance
(From Yochum and Rowe, 2005)

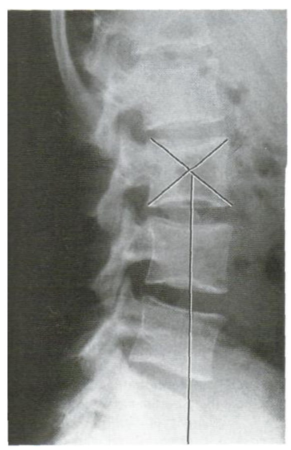


Figure 3.8 Lumbar gravity line
(From Yochum and Rowe, 2005)

3.8 STATISTICAL ANALYSIS

SPSS version 15.0 (SPSS Inc., Chicago, Ill, USA) was used to analyse the data. Descriptive analysis including mean and standard deviation was used to describe quantitatively the selected radiographic measurements by group. Comparison of quantitative radiographic measurements between demographic groups was achieved using t-tests (for two groups) and

ANOVA (for more than two groups) with Bonferroni *post-hoc* tests to identify the specific groups which differed. Categorical outcomes were compared between demographic groups using Pearson's chi square tests. A p value <0.05 was considered as statistically significant.

CHAPTER FOUR

RESULTS

4.1. Anthropometric and Demographic Characteristics of the Subjects that Participated in the Study

The selected anthropometric and demographic factors of 55 subjects that met all the inclusion criteria of this study are tabulated in **Table 4.1**. Five subjects were excluded from this study from the original 60 subjects recruited due to they fulfilling the inclusion criteria. The height (stature) ranged from 1.48-1.72 m, weight ranged from 35.3-103.4 kg while the body mass index ranged from 14.88 to 42.49 kg.m^{-2}. The majority of the subjects (*n* = 31) fell into the 1.56-1.60 m height category while 16 subjects fell into the 60-69 kg weight category. With respect to the body mass index, the majority of the subjects (*n* = 25) fell into the "normal" category i.e. 18.5-25 kg.m^{-2}. There were 52 non-smokers and 32 subjects had no history of a previous pregnancy.

Table 4.1 The selected anthropometric and demographic factors of the subjects (*n* = 55)

Variable	Mean ± SD	Percentage (%)
Stature (m)	1.60 ± 0.05	
Weight (kg)	62.50 ± 15.20	
Body Mass Index (kg.m^{-2})	24.55 ± 5.95	
Smokers		5.5%
Previous pregnancy		41.8%

The age group of subjects who participated in this study is depicted graphically in **Figure 4.1**. The maximum age recorded was 40 years and the minimum age was 18 years. The mean (± SD) age was 29 (± 8) years. The fewest number of subjects was in the 28-32 years group.

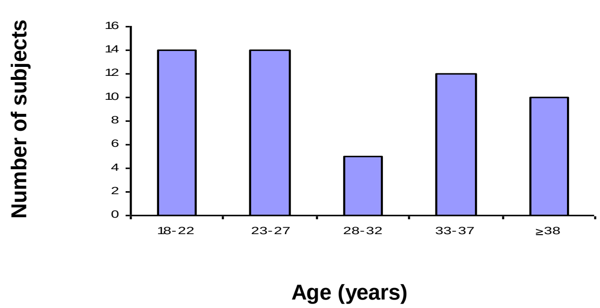


Figure 4.1 The age group of the subjects (*n* = 55) who participated in this study

The occupations of the subjects who participated in this study were relatively homogeneous (i.e. the vast majority were office-type jobs) and there were no “blue collar” jobs in the sample (**Figure 4.2**). All the subjects who were employed were permanent (full-time) staff. All the students were registered at the local universities and colleges.

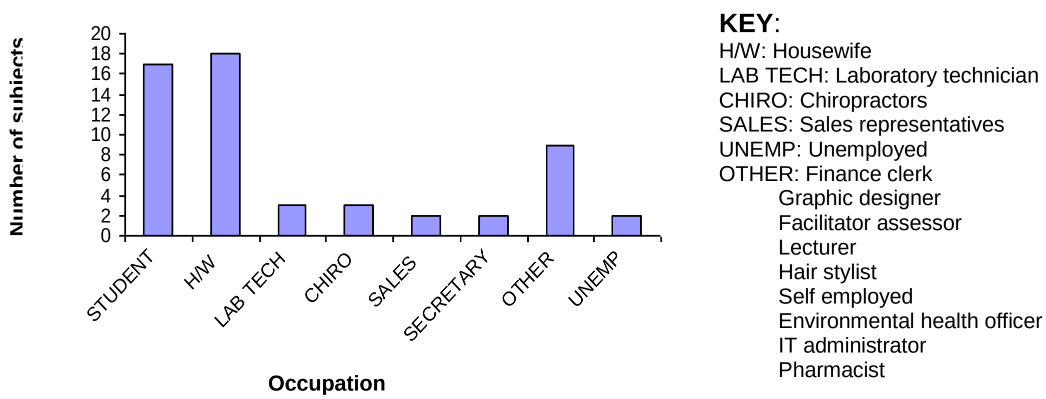


Figure 4.2 The occupation of the subjects (*n* = 55) who participated in this study

4.2. The Radiographic Parameters

4.2.1 Lumbar Lordosis

The mean LL was 49º ± 6º (range: 33º-60º). Only height showed significant association with lumbar lordosis (p = 0.004, Pearson’s chi square test) **(Table 4.2)**; specifically it was the 1.56-1.60 m and 1.61-1.65 m groups which were significantly different from each other (p = 0.002). There was no association of the LL to any of the other anthropometric and selected demographic factors as shown in **Table 4.2**.

Table 4.2 A comparison of the mean ± SD LL values between the selected anthropometric and demographic groups

Variable	Category	Mean ± SD LL (º)	*P*-value
Age (years)	18-22	50.4 ± 5.4	0.932
	23-27	49.2 ± 4.5	
	28-32	48.5 ± 1.7	
	33-37	49.2 ± 7.9	
	≥38	48.1 ± 5.0	
Height (m)	1.50-1.55	48.3 ± 5.4	0.004*
	1.56-1.60	51.5 ± 4.7	
	1.61-1.65	44.4 ± 5.5	
	≥1.66	49.5 ± 4.0	
Weight (kg)	<50	48.0 ± 4.0	0.716
	50-59	50.8 ± 5.5	
	60-69	48.2 ± 7.1	

	70-79	50.4 ± 4.2	
	≥80	49.7 ± 4.5	
BMI (kg.m^{-2})	Underweight (<18.5)	47.5 ± 5.0	0.719
	Normal (18.5-25)	49.4 ± 6.3	
	Overweight (26-30)	50.5 ± 5.2	
	Obese (>30)	48.3 ± 3.7	
Smoking	Yes	48.0 ± 5.7	0.740
	No	49.3 ± 5.6	
Previous pregnancy	Yes	47.9 ± 6.6	0.170
	No	50.2 ± 4.4	

*** *p* = 0.004; Pearson's chi square test**
LL = Lumbar lordosis; BMI = Body mass index; m = meters; kg = kilogram; kg.m^{-2} = kilogram per meter squared

4.2.2 Lumbosacral Angle

The mean (± SD) LS angle was 39˚ (± 8˚) while the range was 11º - 58º. There was no association between the LS angle and any of the selected demographic factors as shown in **Table 4.3**.

Table 4.3 A comparison of the mean ± SD LS angle values between the selected anthropometric and demographic groups

Variable	Category	Mean ± SD LS angle (º)	*P*-value
Age (years)	18-22	40.1 ± 8.6	0.898
	23-27	37.2 ± 8.9	
	28-32	41.0 ± 5.2	
	33-37	36.6 ± 10.3	
	≥38	41.8 ± 5.7	
Height (m)	1.50-1.55	40.3 ± 8.2	0.516
	1.56-1.60	40.1 ± 8.2	
	1.61-1.65	37.2 ± 5.1	
	≥1.66	35.3 ±14.0	
Weight (kg)	<50	36.4 ± 7.6	0.603
	50-59	40.5 ± 6.7	
	60-69	39.1 ± 7.7	
	70-79	39.2 ± 10.1	
	≥80	38.1 ± 13.3	
BMI (kg. m^{-2})	Underweight (<18.5)	34.0 ± 7.1	0.137
	Normal (18.5-25)	39.9 ± 7.6	
	Overweight (26-30)	37.1 ± 10.9	
	Obese (>30)	42.7 ± 5.8	
Smoking	Yes	38.0 ± 5.7	0.626
	No	38.9 ± 8.6	
Previous pregnancy	Yes	38.2 ± 9.1	0.898
	No	39.3 ± 8.1	

LS = Lumbosacral; **BMI = Body mass index; m = meters; kg = kilogram; kg.m^{-2} = kilogram per meter squared**

4.2.3 Lumbosacral Disc Angle

The mean (± SD) LSD angle was 12º (± 5º) while the range was 3º - 25º. There was no association between the LSD angle and any of the selected anthropometric and demographic factors as shown in **Table 4.4**.

Table 4.4 A comparison of the mean ± SD LSD angle values between the selected anthropometric and demographic groups

Variable	Category	Mean ± SD LSD angle (º)	*P*-value
Age (years)	18-22	12.2 ± 5.4	0.411
	23-27	9.8 ± 2.8	
	28-32	11.3 ± 3.8	
	33-37	16.2 ± 5.2	
	≥38	11.8 ± 4.7	
Height (m)	1.50-1.55	13.5 ± 2.1	0.592
	1.56-1.60	12.5 ± 5.8	
	1.61-1.65	12.4 ± 4.7	
	≥1.66	10.0 ± 2.5	
Weight (kg)	<50	11.3 ± 2.7	0.197
	50-59	14.7 ± 5.2	
	60-69	12.2 ± 5.6	
	70-79	9.0 ± 3.1	
	≥80	11.9 ± 5.3	
BMI (kg. m^{-2})	Underweight (<18.5)	11.3 ± 2.7	0.148
	Normal (18.5-25)	13.9 ± 5.1	
	Overweight (26-30)	10.7 ± 4.4	
	Obese (>30)	10.7 ± 5.6	
Smoking	Yes	5.0 ± 2.8	0.095
	No	12.6 ± 4.8	
Previous pregnancy	Yes	13.2 ± 4.8	0.411
	No	11.8 ± 5.0	

LSD = Lumbosacral disc; **m = meters; kg = kilogram; BMI = body mass index; kg.m^{-2} = kilogram per meter squared**

4.2.4 Lumbosacral Lordosis Angle

The mean (± SD) LSL angle was 143.2º (± 5º) while the range was 135º - 155º. There was no association between the LSL angle and any of the selected anthropometric and demographic factors as shown in **Table 4.5**.

Table 4.5 A comparison of the mean ± SD LSL angle between the selected anthropometric and demographic groups

Variable	Category	Mean ± SD LSL angle(º)	*P*-value
Age (years)	18-22	142.4 ± 5.5	0.080
	23-27	141.9 ± 3.9	
	28-32	144.5 ± 4.4	
	33-37	143.6 ± 5.0	
	≥38	145.3 ± 4.4	
Height (m)	1.50-1.55	143.5 ± 4.2	0.323
	1.56-1.60	142.4 ± 4.8	
	1.61-1.65	145.5 ± 4.5	
	≥1.66	142.2 ± 4.6	
Weight (kg)	<50	141.4 ± 4.4	0.786
	50-59	143.6 ± 4.2	
	60-69	143.6 ± 4.9	
	70-79	143.2 ± 5.4	
	≥80	144.3 ± 5.9	
BMI (kg. m^{-2})	Underweight (<18.5)	140.8 ± 5.2	0.192
	Normal (18.5-25)	143.5 ± 4.2	
	Overweight (26-30)	142.3 ± 4.4	
	Obese (>30)	146.3 ± 5.8	
Smoking	Yes	144.0 ± 1.4	0.816
	No	143.2 ± 4.8	
Previous pregnancy	Yes	144.7 ± 5.1	0.080
	No	142.3 ± 4.2	

LSD = Lumbosacral lordosis; BMI = Body mass index; m = meters; kg = kilogram; kg.m^{-2} = kilogram per meter squared

4.2.5 Lumbar Intervertebral Disc Angles and Heights

The mean (± SD) IVD angles at the respective vertebral levels are shown graphically in **Figure 4.3**. There was a linear increase in the mean (± SD) from L1-L2 level to the L3-L4 level and tapering at the L4-L5 level **(Figure 4.3)**. The range of the IVD angles at the respective vertebral levels is tabulated in **Table 4.6**.

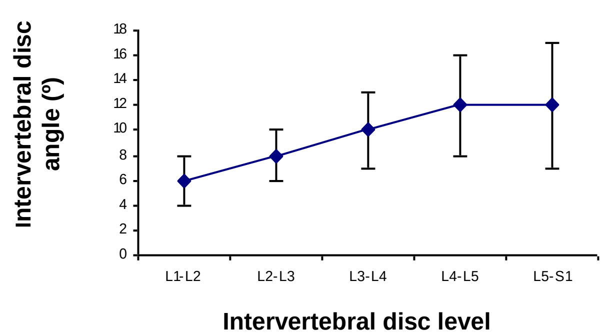


Figure 4.3 The mean (± SD) IVD angles at the respective vertebral levels

Table 4.6 The IVD angle range at the respective vertebral levels

IVD level	IVD angle range (º)
L1-L2	1-10
L2-L3	5-14
L3-L4	4-15
L4-L5	3-28
L5-S1	3-25

4.2.6 Intervertebral Disc Height and Ratio

The mean (± SD) IVD heights and ratios are shown in **Table 4.7**. From the L1-L2 to the L4-L5 levels, there was an incremental increase of 2 mm in the mean anterior IVD heights while there was no change in the mean posterior IVD heights **(Table 4.7)**. At the L5-S1 level, however, there was a slight decrease in the mean anterior IVD height but a corresponding increase in the mean posterior IVD height. The difference of the ratios of the mean anterior and posterior IVD heights at the different vertebral levels was not found to be statistically significant in this study.

Table 4.7 The mean ± SD IVD heights and ratio at the respective vertebral levels

Vertebral level	Mean anterior IVD Ht ± SD (mm)	Mean posterior IVD Ht ± SD (mm)	Mean IVD ratio* ± SD
L1-L2	8 ± 2	5 ± 2	2.00 ± 1.00
L2-L3	10 ± 2	5 ± 2	1.89 ± 0.64
L3-L4	12 ± 2	5 ± 2	2.06 ± 0.65
L4-L5	14 ± 3	5 ± 2	2.35 ± 0.55
L5-S1	13 ± 4	6 ± 2	2.32 ± 1.93

IVD = intervertebral disc height; Ht = height
*** Farfan's method - the anterior & posterior disc heights were measured & were expressed as a ratio to disc diameter. The ratios were then reduced to a ratio of each other.**

The following anthropometric and demographic factors were significantly associated with IVD angles and/or heights:

- Age, p = 0.007 (Pearson's chi square test); specifically it was the 23–27 years (mean ± SD: 9.8º ± 2.7º) and 33–37 years (mean ± SD: 16.5º ± 5.1º) groups who were significantly different from each other), p = 0.033 (Pearson's chi square test); L5-S1 IVD angle **(Table 4.8)**
- Body mass index [26–30 kg.m^{-2}] (at L3-L4, p = 0.028 and at L4-L5, p = 0.031 (Pearson's chi square test)); an increase in IVD angle was seen at these two vertebral levels **(Table 4.9)**
- Smoking (at L5-S1, p = 0.023, IVD angle and p = 0.005, IVD height (Pearson's chi square test)). A decrease in IVD was seen at this vertebral level.

- Previous pregnancy (at L3-L4, *p* = 0.016, IVD angle; at L4-L5, *p* = 0.032, IVD height (Pearson's chi square test)). An increase in the L3-L4 IVD angle was observed while a decrease in the L4-L5 IVD height was noted.

The mean IVD angles and IVD ratios within the five age categories are tabulated in **Table 4.8**.

Table 4.8 The influence of age on the mean IVD angles and ratio

	Mean IVD Angle (º)					Mean IVD Ratio				
Age (years)	**L1**	**L2**	**L3**	**L4**	**L5**	**L1**	**L2**	**L3**	**L4**	**L5**
18-22	6.5	7.7	10.0	13.5	12.2	1.5	1.8	1.8	2.4	2.1
23-27	6.2	8.0	10.1	13.0	9.8*	1.9	1.7	2.2	2.2	2.2
28-32	6.8	10.0	10.8	14.3	11.0	1.7	2.4	2.1	2.4	2.3
33-37	6.1	11.4	11.4	12.5	16.5*	1.7	1.9	2.1	2.2	2.7
≥38	6.9	11.6	11.6	12.0	11.8	1.8	2.0	2.2	2.6	2.3

*** *p* = 0.033; Pearson's chi square test**
IVD = Intervertebral disc

The mean IVD angles and IVD ratios in the four body mass index categories are tabulated in **Table 4.9**.

Table 4.9 The influence of body mass index on the mean IVD angles and ratio

	Mean IVD Angle (º)					Mean IVD Ratio				
BMI ($kg.m^{-2}$)	**L1**	**L2**	**L3**	**L4**	**L5**	**L1**	**L2**	**L3**	**L4**	**L5**
<18.5	6.3	7.2	10.3	11.5	11.3	1.3	1.4	1.7	2.1	2.2
18.6-25	6.4	8.3	9.9	12.4	13.8	1.7	1.8	2.0	2.4	2.3
26-30	6.0	8.5	12.0*	$15.1^{\#}$	10.9	1.5	2.1	2.2	2.5	2.5
>31	7.1	9.4	11.1	12.4	10.7	2.5	2.1	2.4	2.2	2.1

****p* = 0.028; $^{\#}p$ = 0.031; Pearson's chi square test**
IVD = Intervertebral disc; BMI = Body mass index

4.2.7 Interpedicular Distance

The IPD range at the different vertebral levels is tabulated below in **Table 4.10**. The minimum value found was 19 mm while the maximum value was 36 mm. The mean (± SD) IPD at the respective lumbar vertebral levels is shown graphically in **Figure 4.4**. There was an increase in the mean (± SD) IPD from L1 to L5. There was no significant association between IPD and the selected anthropometric and demographic factors.

Table 4.10 The IPD range at the respective vertebral levels

Vertebral level	IPD range (mm)
L1	19-27
L2	20-28
L3	21-29
L4	23-36
L5	25-36
Total	19-36

IPD = Interpedicular distance; mm = millimeter

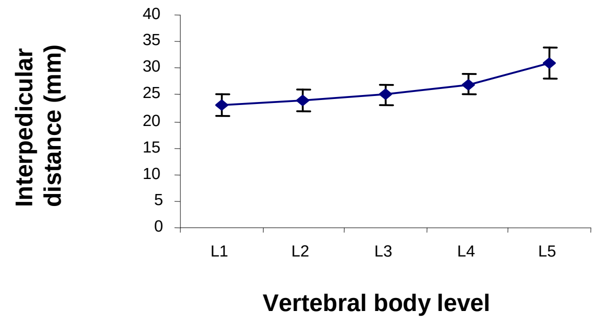


Figure 4.4 The mean (± SD) IPD at the respective vertebral levels

4.2.8 Sagittal Canal Diameter

The sagittal canal diameter range at the respective vertebral levels is tabulated in **Table 4.11**. The minimum value found was 11 mm while the maximum value was 31 mm. The mean (± SD) values for sagittal canal diameter are shown graphically in **Figure 4.5**. A rise in the mean (± SD) was seen at the L2 level, remaining unchanged at the L3 and L4 levels and decreasing at the L5 level **(Figure 4.5)**. There was no significant association between the sagittal canal diameter and the selected anthropometric and demographic factors.

Table 4.11 Sagittal canal diameter range at the respective vertebral levels

Vertebral level	Sagittal canal diameter (mm)
L1	13-27
L2	15-29
L3	14-28
L4	15-28
L5	11-31

mm= millimeter

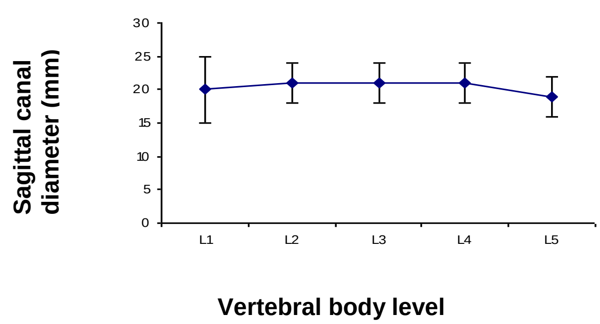


Figure 4.5 The mean (± SD) values for the sagittal canal diameter

4.2.9 Lumbar Gravity Line

The lumbar gravity line intersected the sacrum in 67.3% of the subjects and passed anterior to the sacrum in 29.1% of the subjects while in 3.6% of the subjects, it passed posterior to the sacrum.

None of the selected anthropometric demographic factors were significantly associated with lumbar gravity line as shown in **Table 4.12**.

Table 4.12 A comparison of the lumbar gravity line to the selected anthropometric and demographic groups

Variable		Lumbar gravity line						*p* - value
		Normal		Anterior to sacrum		Posterior to sacrum		
		Count	%	Count	%	Count	%	
Age (years)	18-22	9	64.3%	3	21.4%	2	14.3%	0.303
	23-27	10	71.4%	4	28.6%	0	.0%	
	28-32	3	60.0%	2	40.0%	0	.0%	
	33-37	10	83.3%	2	16.7%	0	.0%	
	≥38	5	50.0%	5	50.0%	0	.0%	
Height (m)	1.50-1.55	4	57.1%	3	42.9%	0	.0%	0.811
	1.56-1.60	20	64.5%	9	29.0%	2	6.5%	
	1.61-1.65	9	81.8%	2	18.2%	0	.0%	
	≥1.66	4	66.7%	2	33.3%	0	.0%	
Weight (kg)	<50	10	83.3%	1	8.3%	1	8.3%	0.684
	50-59	7	53.8%	5	38.5%	1	7.7%	
	60-69	11	68.8%	5	31.3%	0	.0%	
	70-79	4	66.7%	2	33.3%	0	.0%	
	≥80	5	62.5%	3	37.5%	0	.0%	
BMI ($kg.m^{-2}$)	Underweight (<18.5)	7	77.8%	1	11.1%	1	11.1%	0.678
	Normal (18.5-25)	17	68.0%	7	28.0%	1	4.0%	
	Overweight (25-30)	8	61.5%	5	38.5%	0	.0%	
	Obese (>35)	5	62.5%	3	37.5%	0	.0%	
Smoking	Yes	2	66.7%	1	33.3%	0	.0%	0.935
	No	35	67.3%	15	28.8%	2	3.8%	
Previous pregnancy	Yes	15	65.2%	8	34.8%	0	.0%	0.386
	No	22	68.8%	8	25.0%	2	6.3%	

m = meters; kg = kilogram; BMI = body mass index; $kg.m^{-2}$ = kilogram per meter squared

CHAPTER FIVE

DISCUSSION

5.1 ANTHROPOMETRIC AND DEMOGRAPHIC CHARACTERISTICS

The majority of the subjects in this study were young adults **(Figure 4.1)** as defined by Erikson (2001). The age range of the subjects in this study **(4.1)**, determined by the inclusion criteria, was dissimilar to those of Tibrewal and Pearcy (1985), Chernukha *et al*. (1998), Nourbakhsh *et al*. (2001), Shao *et al*. (2002), Kamali *et al*. (2004) and Kim *et al*. (2006) **(Tables 2.1 and 2.4)**. In terms of the key anthropometric measurements **(Table 4.1)**, the mean (± SD) of the height and weight of the subjects in this study was similar to those of the asymptomatic female subjects in the study of Nourbakhsh *et al*. (2001) while the body mass index of the majority of the subjects (n = 38) fell in the "normal" to "overweight" range for adults (adapted from the World Health Organisation Classification, utilized by Hanlon *et al*. (2006)). The majority of the subjects in this study were students, housewives or were involved in office-type jobs. There were no subjects with occupations involving excessive manual labour.

5.2 RADIOGRAPHIC PARAMETERS OF THE LUMBAR SPINE

5.2.1 Lumbar Lordosis

The mean LL found in this study **(4.2.1)** was similar to that of Chernukha *et al*. (1998) who also utilized the TRALL method **(Table 2.1)**. When the mean LL is compared to studies which utilized the Cobb method, with the exception of Bryner and El Moussali (1992), we find that there is a difference with generally higher values reported in those studies **(Table 2.1)**, but a lower mean LL value is provided by Farfan *et al*. (1972) who utilized a different method **(Table 2.1)**. The range of the LL in this study was dissimilar to what would be achieved when utilizing the TRALL method for determining the LL (Chernukha *et al*., 1998). The lower limit of the range of the LL in this study was the same as that of Stagnara *et al*. (1982) while the upper limit was the same as that of Yochum and Rowe (2005). The differences between the findings of this study and those that utilized the Cobb method could be explained by a lack of agreement on the precise location of the reference lines in the Cobb method, the intra- and inter-individual variability in the shape of the lumbar vertebrae (Chernukha *et al*., 1998) and the variability of the L1 vertebra (Fernand and Fox, 1985). Possible changes to the vertebral column during removal at autopsy could account for the difference between the mean and range of the LL of this study and that of Farfan *et al*'*s*. (1972). The difference in the sample size and sample profile of this study compared to those of the studies in **Table 2.1** is another possible contributory factor for the dissimilar results. With respect to the LL, the findings of this study, therefore, support the view of Chernukha *et al*. (1998). However, while the TRALL method is reproducible, future studies need to determine the appropriate range that this method provides when compared to other methods of determining the LL.

5.2.2 Lumbosacral angle

With respect to the mean LS angle found in this study **(4.2.2)**, the results were similar to those of Saraste *et al*. (1985), Bryner and El Moussali (1992) and Yochum and Rowe (2005) but are at odds with those of Chung *et al*. (1981), Fernand and Fox (1985), Chen and Lee (1997) and Kim *et al*. (2006) **(Table 2.3)**. A considerably large range of the LS angle **(4.2.2)** was found in the asymptomatic Indian females in this study. A similar range was previously reported by Saraste *et al*. (1985) in a sample of 12 cadavers. Of the studies that utilized the Ferguson method (which was used in this study) to determine the LS angle, the LS angle found in this study was similar to that reported by Yochum and Rowe (2005) but different to that found by Chung *et al*. (1981). The difference in this finding could be explained by the fact that the subjects in the study of Chung *et al*. (1981) were symptomatic individuals diagnosed with IVD herniation. Kim *et al*. (2006) also reported a lower LS angle in a sample of patients with LBP. The differences in the methods of measuring the LS angle could also account for the inconsistent results reported by several authors **(Table 2.3)**. Further studies are, therefore, required to establish the reproducibility and reliability of the Ferguson method of assessing the LS angle.

5.2.3 Lumbosacral Disc Angle

A slightly lower mean LSD angle **(4.2.3)** was found in this study compared to Bryner and El Moussali (1992) and Yochum and Rowe (2005) **(Table 2.3)**. The range of the LSD angle in this study was greater when compared to the range provided by Banks (1983) and Cox (1990).

5.2.4 Lumbosacral Lordosis Angle

The mean LSL angle **(4.2.4)** obtained in this study was not very dissimilar to those of Saraste *et al*. (1985) (for normal individuals) and Yochum and Rowe (2005) **(Table 2.3)**. The LSL angle was within the range reported by Yochum and Rowe (2005).

5.2.5 Intervertebral Disc Angle and Height

At each vertebral level the IVD angle was two degrees less than the values provided by Yochum and Rowe (2005) (**Table 2.6**). The IVD angles **(Figure 4.3)** increased from cephalic to caudal in the lumbar spine which was in keeping with the report of Yochum and Rowe (2005).

The anterior IVD heights **(Table 4.7)** found in this study concur with those of Tibrewal and Pearcy (1985) at the L1-L2, L4-L5 and L5-S1 levels of the 11 patients with no IVD herniation **(Table 2.5)**. With respect to the posterior IVD heights, the results of this study **(Table 4.7)** indicate slightly higher values than those of Tibrewal and Pearcy (1985) **(Table 2.5)**. There were also no statistically significant differences in the IVD heights between vertebral levels confirming the report of Tibrewal and Pearcy (1985). At the L5-S1 IVD, the difference between the anterior and posterior heights was 7 mm which was 1.5 mm greater than that reported by Tibrewal and Pearcy (1985) but in keeping with the value reported by Middleditch and Oliver **(2.5.1.3)** for normal individuals. The findings of this study show that Farfan's method of evaluating IVD heights is fairly reproducible and accurate thus supporting the views of Tibrewal and Pearcy (1985) and Pope *et al*. (1991). The differences in the IVD height values found in this study compared to Tibrewal and Pearcy (1985) could be due to inter-individual variance and possibly subjective errors when interpreting radiographs (Frobin *et al*., 1997).

5.2.6 Interpedicular Distance

The mean IPD and the range in this study are shown in **Figure 4.4 and Table 4.10**. IPD increased from cephalic to caudal thereby confirming the findings of Hinck *et al*. (1966), Eisenstein (1976), Ebraheim *et al*. (1997), Yochum and Rowe (2005) **(Table 2.7)**. When the mean results are compared to that of the general female population (Hinck *et al*., 1966), we note the following differences **(Table 5.1)**:

Table 5.1 A comparison of the mean IPD findings in the general female population

Vertebral level	Hinck *et al*. (1966) (mm)	This study's findings (mm)	Difference
L1	24.3	23.1	1.2
L2	24.9	24.1	0.8
L3	25.4	25.3	0.1
L4	26.4	27.5	-1.1
L5	29.0	30.6	-1.6

mm = millimeter

Therefore, the mean IPD found at the various vertebral levels in this study show smaller interpedicular distances (IPDs) at the L1 and L2 levels, almost equal at L3 and larger at the L4 and L5 levels than those reported in the literature **(Table 5.1)**. When the mean IPD levels are compared to those of the general combined-gender population in other studies we find the following **(Table 5.2)**:

Table 5.2 A comparison of the mean IPD in the general population

Vertebral level	A) Hinck *et al*. (1966) (mm)	B) Yochum and Rowe (2005)	C) This study's findings (mm)	Difference between A and C	Difference between B and C
L1	25	25	23.1	1. 9	1.9
L2	25.5	26	24.1	1.4	1.9
L3	26	26	25.3	0.7	0.7
L4	26.9	27	27.5	-0.6	-0.5
L5	29.7	30	30.6	-0.9	-0.6

mm = millimeter

A trend similar to that of the general female population **(Table 5.1)** is seen with the differences in the mean IPDs of the general combined-gender population **(Table 5.2)**. There is, however, a larger range in the difference of the mean of the L1 and L2 IPD and smaller range in the difference of the mean of the L4 and L5 IPDs. The range of the IPDs at all vertebral levels was within the range provided by Yochum and Rowe **(Table 2.7)** with the exception of the L4 vertebra where both the lower and upper limits were larger. Therefore, the results of the IPD measurements in this study indicate that the mean IPD is generally smaller at the L1 and L2 levels and larger at the L4 and L5 levels in the asymptomatic South African Indian female when compared to female and combined-gender population groups in other studies.

5.2.7 Sagittal Canal Diameter

The mean (± SD) and range of the sagittal canal diameter at each vertebral level are presented in **Figure 4.5** and **Table 4.11**. A surprising finding was that the lowest value for the sagittal canal diameter at L5 was 11 mm yet the subject was completely asymptomatic. We would have expected features of spinal stenosis as this value less than any value for normal subjects reported by Eisenstein (1976) **(2.5.1.4 B)**. The lower limit of the sagittal canal diameter at the L3 level was 14 mm which according to Yochum and Rowe (2005) may indicate spinal stenosis. Despite these findings indicating the possibility of spinal stenosis in some of our subjects, all subjects were asymptomatic. Further studies are, therefore, required to establish the clinical significance of these findings.

5.2.8 Lumbar Gravity Line

The lumbar gravity line intersected the sacrum in the majority of the subjects in this study. This is in keeping with the reports of Ferguson (1934; 1949) and Janelle *et al*. (1983).

5.3 THE ASSOCIATION BETWEEN THE RADIOGRAPHIC PARAMETERS AND SELECTED ANTHROPOMETRIC AND DEMOGRAPHIC FACTORS

5.3.1 Lumbar Lordosis

With respect to the association between the LL and age, the findings of this study support those of Milne and Lauder (1974) (for females aged 20–49 years), Korovessis *et al*. (1998), Nourbakhsh *et al*. (2001) (for females below the age group of 50–60 years) and Murrie *et al*. (2003) who were unable to demonstrate any significant association between LL and age. It is, however, possible that there might be a significant association between LL and increasing age as reported by Nourbakhsh *et al*. (2001) who found that the LL was decreased in females (and males) between ages of 50–60 years. Earlier Milne and Lauder (1974) had also reported that the LL flattens with increasing age. More studies are, therefore, required to establish whether this association may exist in elderly Indian females.

The findings of this study could not be compared to those of previous studies (Farfan *et al*. 1972; Torgerson and Dotter, 1976; Stagnara *et al*., 1982; Fernand and Fox, 1985; Mosner *et al*., 1989; Amonoo-Kuofi, 1992; Korovessis *et al*., 1998; Nourbakhsh *et al*., 2001; Murrie *et al*., 2003) with respect to ethnic and gender differences since no males were included in this study and also due to the differences in the methods of measurement of the LL in those studies.

Our findings were similar to those of McIlwraith (1996) who reported no correlation between the weight of car drivers and LL, but were in contrast to those of Nourbakhsh *et al*. (2001) with respect to the association between weight, previous pregnancies and LL. We did, however, find a significant association ($p = 0.004$) between the height of the subjects and LL which is in keeping with the findings of Nourbakhsh *et al*. (2001). This may possibly be due to an increase in the loading of the lumbar as a result of an increase in height (Pietilä *et al*., 2001). Furthermore, there was no association between body mass index and LL in contrast to the findings of Murrie *et al*. (2003). There were no significant differences in the LL of smokers and non-smokers **(Table 4.2)**.

Since there were many subjects with unique occupations and they were all relatively homogeneous, no association could be made between occupation of the subjects and any of the radiographic parameters investigated in this study. Specht and De Boer (1991) had reported that 70% of their patients presented with an LLI of greater than three millimeters while 40% had an LLI of greater than six millimeters. In contrast, only one subject (0.02%) presented with an LLI of half a centimeter. Therefore, no statistical analyses were made to determine the association between LLI and any of the radiographic parameters evaluated in this study. Further studies involving subjects with heterogeneous occupations and significant LLI, therefore, need to be done to determine if an association exists between these variables and the radiographic parameters of the lumbar spine.

5.3.2 Lumbosacral Angle, Lumbosacral Disc Angle and Lumbosacral Lordosis Angle

The LS angle found in this study was higher than that reported by Chung *et al*. (1981) in symptomatic female (and male) patients. This suggests that the LS angle in individuals with lumbar IVD disease is likely to be reduced and highlights the need for further studies to either confirm or refute this comment. According to Cox (1990), an LSD greater than 15° could lead to facet impaction and the subsequent development of LBP. The findings of this study (range 3° -25°), however, suggests that an LSD angle less than 10° or greater than 15° may not necessarily lead to the development of LBP since all our subjects were asymptomatic. The lack of an association between the LS angle, LSD angle and LSL angle and the selected anthropometric and demographic factors suggest that these factors do not play a key role in influencing the LS, LSD and LSL angles.

5.3.3 Intervertebral Disc Angles and Heights

The IVD heights and angles increased from cephalic to caudal which is accordance with the reports of Tibrewal and Pearcy (1985) **(Table 2.5)** and Yochum and Rowe (2005) **(Table 2.6)**. With respect to the IVD angle and age, a significant difference in IVD angle was observed in the 23–27 years and 33–37 years age group (p = 0.033) **(Table 4.8)**. Banks (1983) had reported that the IVD angles increased in facet syndromes. The finding of this study, however, suggests that an increase in IVD angle could also occur in asymptomatic individuals. Interestingly, no significant association was found between IVD heights and age. This was in contrast to the findings of Vernon-Roberts and Pirie (1977), Twomey and Taylor (1987), Miller *et al*. (1988), Amonoo-Kuofi (1992) and Shao *et al*. (2002). It is possible that the age range (18–40 years) of the subjects in this study was not wide enough to show any significant age-related changes to the IVD heights since minimal degenerative changes would have occurred in this age range (Kirkaldy-Willis and William, 1999). There was an associated increase in IVD angles at L3-L4 (p = 0.028) and L4-L5 (p = 0.031) levels in the overweight (26–30 kg.m^{-2}) body mass index group but there were no significant changes to the IVD heights across all the body mass index categories. These findings are similar to the report of Lumoa *et al*. (1998) but are in contrast to the findings of Pietilä *et al*. (2001) and later Luike *et al*. (2005). This finding suggests that despite a high body mass index, the likelihood of developing IVD changes which may significantly affect the IVD height, is low in the South African Indian female between the ages of 18 and 40 years. Further studies using advanced imaging tools (e.g. MRI) and a larger age spectrum and sample size need to be done to confirm or refute these findings.

Smoking was significantly associated with a decrease in IVD angle (p = 0.023) and IVD height (p = 0.005) at the L5-S1 level which is in accordance with the findings of Livshits *et al*. (2001) who found that smoking is a significant risk factor for IVD degeneration. Our findings were, however, at odds with those of Luoma *et al*. (1998) and Pye *et al*. (2007). This may suggest that certain population or ethnic groups who smoke are more at risk of developing IVD degeneration than others especially at the L5-S1 IVD. Previous pregnancy was found to be associated with an increase in L3-L4 IVD angle (p = 0.016) and a decrease in IVD height at L4-L5 (p = 0.032). The significance of this finding needs to be investigated further as it is possible that this group of individuals may be predisposed to developing symptomatic IVD degeneration at a later stage.

5.3.4 Interpedicular Distance and Sagittal Canal Diameter

The results of this study show that mean IPD measurements were smaller at the L1-L4 levels and larger at the L5 level **(Figure 4.4)** than those of the adult male subjects in the study of Hinck *et al*. (1966) **(Table 2.7)**. This is also contrary to the findings Vanharanta *et al*. (1985). Furthermore, the mean IPD decreased at the L4 level but increased at the L5 level (non-significantly) which is also contrary to the findings of Vanharanta *et al*. (1985). There were differences in the mean IPD and sagittal canal diameter values found in this study and those of Eisenstein (1976) **(Table 2.7)** as shown in **Table 5.3**:

Table 5.3 The difference in the mean IPD and sagittal canal diameter in Indian females to the White and Black population

Vertebral level	Mean IPD (mm)	Whites *		Blacks *	
		Males	Females	Males	Females
L1	23	=	↑ (1) #	↑ (2) #	↑ (3) #
L2	24	=	↑ (2)	↑ (2)	↑ (3)
L3	25	↑ (2) #	↑ (2)	↑ (3)	↑ (4)
L4	27	↑ (3)	↑ (3)	↑ (4)	↑ (5)
L5	31	↑ (5)	↑ (6)	↑ (5)	↑ (5)
Vertebral level	**Sagittal canal diameter (mm)**	**Whites ***		**Blacks ***	
		Males	**Females**	**Males**	**Females**
L1	19	↑ (1) #	↑ (1) #	↑ (3) #	↑ (2) #
L2	21	↑ (4)	↑ (4)	↑ (6)	↑ (5)
L3	21	↑ (5)	↑ (4)	↑ (6)	↑ (6)
L4	21	↑ (5)	↑ (5)	↑ (6)	↑ (5)
L5	19	↑ (1)	↑ (1)	↑ (3)	↑ (3)

IPD = Interpedicular distance; mm = millimeters; ↑ = Increase
*** = Data from Eisenstein (1976)**
 # The number in the brackets indicate the difference in mm between the mean IPD and sagittal canal diameter in this study and those in Eisenstein's study

The results show that the IPD measurements were larger at all vertebral levels when compared to White and Black females and Black males **(Table 5.3)**. When the results are compared to those of White males, we find a similar trend at the L3-L5 levels. Sagittal canal diameter values were larger at all vertebral levels compared to the cadaveric specimens of Eisenstein (1976). The range of the AP diameter in the whole lumbar spine **(Table 4.10)** was larger than those reported by Eisenstein for the two gender and ethnic groups **(2.5.1.4 iii)**. This, therefore, suggests that the spinal canal of the South African Indian female is more capacious than those of South African White and Black (male and female) population groups. These values, however, do need to be confirmed by MRI studies as the clinical significance of these values lie in the evaluation of spinal stenosis, spinal malformation and intraspinal neoplasms (Yochum and Rowe, 2005). Knowledge of the IPD and sagittal canal diameters would also benefit the spinal surgeon by reducing the risk of neurological complications during pedicular screw placement surgery (Ebraheim *et al*., 1997).

5.3.5 Lumbar Gravity Line

In approximately 29% of the subjects, the lumbar gravity line passed between 3 mm and 39 mm (mean 13.8 mm) anterior to the sacrum while in approximately 4% of the subjects it passed between 1 mm and 14 mm (mean 7.5 mm) posterior to the sacrum. Ferguson (1949) reported that the passing of the lumbar gravity line anterior to the sacrum would result in anterior shearing forces between the lumbosacral facet joints while Drum (1968), Adams and Hutton (1980; 1982) reported that a posterior shift would result in an increase in weight bearing forces on the lumbosacral facet joints. Although both these shifts in the lumbar gravity line are predisposing factors in the development of LBP, our subjects were asymptomatic. This, however, does not rule out the possibility that these patients are at risk for developing LBP at a later stage.

CHAPTER SIX

CONCLUSIONS

The primary aim of this study was:

- To evaluate the normal radiographic measurements of the lumbar spine in young to middle aged Indian females in Durban.

With regards to the primary aim of the study and objective **1.2.1** of the study, the following mean (± SD) and ranges were noted:

- LL: 49º (± 6º); 33º – 60º
- LS angle: 39º (± 8º); 11º – 58º
- LSD angle: 12º (± 5º); 3º – 25º
- LSL angle: 143.2º (± 5º); 135º – 155º
- Lumbar IVD angles:
  - L1-L2: 6º (± 2º); 1º - 10º
  - L2-L3: 8º (± 2º); 5º - 14º
  - L3-L4: 10º (± 3º): 4º - 15º
  - L4-L5: 12º (± 4º); 3º - 28º
  - L5-S1: 12º (± 5º); 3º - 25º
- Lumbar IVD height:
  - L1-L2: anterior: 8 mm (± 2); posterior 5 mm (± 2)
  - L2-L3: anterior: 10 mm (± 2); posterior 5 mm (± 2)
  - L3-L4: anterior: 12 mm (± 2); posterior 5 mm (± 2)
  - L4-L5: anterior: 14 mm (± 3); posterior 5 mm (± 2)
  - L5-S1: anterior: 13 mm (± 4); posterior 6 mm (± 2)
- IPD:
  - L1: 23 mm (± 2); 19 – 27 mm
  - L2: 24 mm (± 2); 20 – 28 mm
  - L3: 25 mm (± 2); 21 – 29 mm
  - L4: 27 mm (± 2); 23 – 36 mm

  - L5: 31 mm (± 3); 25 – 36 mm
- Sagittal canal diameter:
  - L1: 20 mm (± 5); 13 – 27 mm
  - L2: 21 mm (± 3); 15 – 29 mm
  - L3: 21 mm (± 3); 14 – 28 mm
  - L4: 21 mm (± 3); 15 – 28 mm
  - L5: 19 mm (± 3); 11 – 31 mm

The lumbar gravity line intersected the sacrum in 67.3% of the subjects. In 29.1% of the subjects, the lumbar gravity line passed anterior to the sacrum while in 3.6% of the subjects, it passed posterior to the sacrum.

In terms of objective **1.2.2** and the associated hypotheses that were set at the onset of the study:

It was not possible to determine an association between occupation and the selected radiographic parameters due to homogeneity in the occupation descriptions of the subjects. It was also not possible to determine an association between LLI and the selected radiographic parameters as there was only one subject with an LLI of 0.5 mm.

The Null Hypothesis which stated that there would be no significant association between LL and the different age groups in this study was accepted.

The Alternate Hypothesis which stated that there would be a significant association between LL and weight, height and body mass index was partially accepted with respect to the height of the subjects.

The Alternate Hypothesis which stated that there would be a significant association between LL and previous pregnancies was not accepted.

The Null Hypothesis which stated that there would be no significant association between smoking and LL was accepted.

The Null Hypothesis which stated that there would be no significant association between LS angle (with the exception of LS angle and previous pregnancy), LSD angle and LSL angle and the selected anthropometric and demographic factors was accepted.

The Alternate Hypothesis which stated that there would be a significant association between LS angle and previous pregnancy was not accepted.

The Null Hypothesis which stated that there would be no significant association between IVD height and the different age groups was accepted.

The Null Hypothesis which stated that there would be no significant association between IVD height and the height of the subjects in the study was accepted.

The Null Hypothesis which stated that there would be no significant association between IVD height and the weight and body mass index was accepted.

The Null Hypothesis which stated that there would be no significant association between IVD height and smoking was not accepted.

The Null Hypothesis which stated that there would be no significant association between IVD height and previous pregnancy was not accepted.

The Null Hypothesis which stated that there would be no significant association between IVD angle and the selected anthropometric and demographic factors was partially accepted.

The Null Hypothesis which stated that there would be no significant association between IPD and the selected anthropometric and demographic factors was accepted.

The Null Hypothesis which stated that there would be no significant association between sagittal canal diameter and the selected anthropometric and demographic factors was accepted.

The Null Hypothesis which stated that there would be no significant association between the lumbar gravity line and the selected anthropometric and demographic factors was accepted.

CHAPTER SEVEN

RECOMMENDATIONS

Recommendations for future studies include the following investigations:

- A study utilizing advanced imaging techniques e.g. MRI and/or cadaveric specimens to confirm or refute the results of this study.
- A comparison study with symptomatic subjects (i.e. suffering from LBP) in order to determine possible differences between asymptomatic and symptomatic groups in the South African Indian female and to establish the clinical significance of our findings.
- A similar study on Indian males in order to determine possible gender differences in the values of the radiographic parameters.
- A similar study conducted on other ethnic groups in South Africa (e.g. Coloured [mixed-race] community) in order to determine possible ethnic differences in the values of the radiographic parameters.
- A similar study on subjects with heterogeneous occupations and significant LLI in order to determine the impact of these factors on the radiographic parameters of the lumbar spine.

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APPENDIX A
LETTER OF INFORMATION

TITLE OF RESEARCH:
The evaluation of normal radiographic measurements of the lumbar spine in young to middle aged Indian females in Durban.

Principal investigator : Melanee Naidoo (031 – 3732205)

Supervisor : Dr. J. Shaik (M.Tech.Chiro; M.Med.Sci.(SM), MCASA
(031 – 3732588

DEAR MADAM,
Welcome to my research project. You have been selected to take part in an evaluation for normal radiographic measurements of the lumbar spine in young to middle aged Indian females in Durban.

Purpose: A profile on the normal x-ray measurements of the lumbar spine would enable spinal health care professionals' (e.g. spinal surgeons and chiropractors) to make a proper diagnosis of low back complaints. Some of the factors that could influence these x-ray measurements include: age, body weight, height, occupation, smoking and differences in the length of a person's legs. One of the aims of this study would be to determine if there is a strong link (association) between these factors and the x-ray measurements.

You will be given a letter of information to read and should you agree to participate in this study you will have to sign the consent form. You will then have a case history and physical examination done once off (Phase one). All the information gathered will be strictly confidential. This examination should take no more than 1hr.

If all of the inclusion criteria have been met then only will you go through to Phase two of the research. You will have an appointment made for you by the researcher at the Radiographic Clinic. You will have an erect A-P and (right) lateral view of the lumbar spine done by a radiographer according to the Clinic's protocol. This concludes your participation in the study.

Risks/discomforts: You will be exposed to standard doses of radiation. According to various studies the risk to radiation is very minimal in keeping with the accepted exposure dosage.

Benefits: The results from this study will help spinal health care professionals to make a more accurate evaluation and diagnosis from the lumbar spine radiographs.
The results of the study will be made available at the Steve Biko library (DUT) in the form of a mini-dissertation.

You may be removed from the study without your consent for the following reasons:
- If you have any history of trauma to the low back/hip and/or arthritic changes (e.g. ankylosing spondylitis), metabolic diseases (e.g. Cushing's syndrome).

-If you develop back/hip pain or sustain macrotrauma to the low back/hip region (e.g. motor vehicle accident/ fall from a height sustaining injury to the low back/hip) between the first consultation and the radiographic consultation.
- Pregnant females or females who suspect that they may be pregnant.
-You will be excluded from the study if they do not sign the informed consent form (Appendix B).
-If you had x-rays (of any region of the body) within one month prior to the commencement of this study.

You will not be awarded any remuneration for taking part in this study.

Your participation in this research is free of charge.
Your participation in this study is voluntary and refusal to participate will not result in any adverse consequences.

Please don't hesitate to ask questions. Your full co-operation will assist the chiropractic profession in expanding its knowledge of the lumbar spine.

You are free to withdraw from the study at any time.

Any queries or questions about the study please feel free to contact my supervisor. Do not sign the consent form, unless all your questions have been answered to your satisfaction.

I have read and understood the contents of this informed consent form and I have also been given a verbal explanation of this study by the researcher/ supervisor. The researcher has answered my questions to my satisfaction. By signing the consent form, I agree to participate in this study.

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Volunteer's Name	**Volunteer's signature**
Date: ------------------	
------------------------------------	-----------------------------------
Witness Name (Print)	**Witness Signature**
Date: -------------------	

Researcher's Signature

APPENDIX B
INFORMED CONSENT FORM

TITLE OF THE RESEARCH:
The evaluation of normal radiographic measurements of the lumbar spine in young to middle aged Indian females in Durban.

Principal investigator : Melanee Naidoo (031 – 3732205)

Supervisor : Dr. J. Shaik (M.Tech.Chiro; M.Med.Sci.(SM), MCASA
(031 – 3732588)

Please CIRCLE the appropriate answer:

1. Have you read the research information sheet?
YES/NO

2. Have you had an opportunity to ask questions regarding the study?
YES/NO

3. Have you received satisfactory answers to your questions?
YES/NO

4. Have you had an opportunity to discuss this study?
YES/NO

5. Have you received enough information about this study?
YES/NO

6. Do you understand the implications of your involvement in this study?
YES/NO

7. Do you understand that you are free to withdraw from this study?
YES/NO

At any time
Without having to give any reason for withdrawing
And without affecting you future health

8. Do you agree to voluntarily participate in this study?
YES/NO

9. Who have you spoken to?

Please ensure that the researcher completes each section with you.

IF YOU HAVE ANSWERED NO TO ANY QUESTIONS, PLEASE OBTAIN THE NECESSARY INFORMATION FROM THE RESEARCHER BEFORE SIGNING.
THANK YOU.

Subjects Name: ----------------------- **Signature:** ---------------------

Witness Name: ----------------------- **Signature:** ----------------------

Researcher Name: ---------------------- **Signature:** ----------------------

APPENDIX C

Patient Position

AP View:

Each subject will stand in front of the x-ray bucky facing the x-ray tube with the heels 10 cm apart and the feet are within the normal fick angle of 12-15° (Diagram B). The subject must look straight ahead, shoulders in line with each other, bilateral ASIS must be in line with each other (to avoid pelvic obliquity), the knees extended between 0-5° (Diagram A).

Lateral View:
To standardize this position the ear, shoulder, and ASIS (Diagram A) must be line with each other. Again, the heels will be 10 cm apart and the feet within the normal fick angle of 12-15° (Diagram B).

Diagram A

AP VIEW LATERAL VIEW

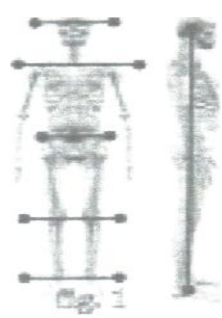
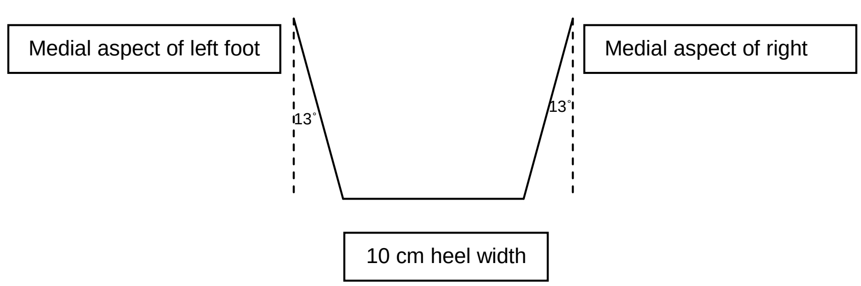


Diagram B

The radiographers at the Radiographic Clinic will be given a cardboard with the exact cut-out for the feet placement within the normal fick angle (13°) and 10 cm width between the heels for correct and convenient patient positioning i.e. the diagram below.

The diagram has been scaled down.



APPENDIX D

Data Collection Sheet 1

Demographic Data

Age		Occupation	
Smoking	YES	Previous Pregnancy	YES
	NO		NO

Clinical Data

Height (m)	
Weight (Kg)	
Leg Length (cm)	
Apparent Leg Length	
Actual Leg Length	

Radiographic Data

	L1	L2	L3	L4	L5
Interpedicular Distance (mm)					
Intervertebral Disc Height (˚)					
Intervertebral Disc Angles (˚)					
Eisenstein's method for sagittal canal measurement (mm)					

Lumbar Lordosis (˚)		Lumbosacral Angle (˚)	
Lumbosacral Disc Angle (˚)		Lumbosacral Lordosis Angle (˚)	
Lumbar Gravity Line			

APPENDIX E
DURBAN UNIVERSITY OF TECHNOLOGY
CHIROPRACTIC DAY CLINIC
CASE HISTORY

Patient: ____________________ File#: ________

Clinician; ____________________ Signature: ____________________

Student: ____________________ Signature: ____________________

FOR CLINICIANS USE ONLY:
Initial visit
Clinician: Signature :

Case History:

Examination:
Previous:
Current:

X-Ray Studies:
Previous:
Current:

Clinical Path. lab:
Previous:
Current:

CASE STATUS:

PTT:	Signature:	Date:

CONDITIONAL:
Reason for Conditional:

Signature: Date:

Conditions met in Visit No:	Signed into PTT:	Date:

Case Summary signed off:	Date:

Intern’s Case History:

1. **Source of History:**

2. **Chief Complaint : (patient’s own words):**

3. **Present Illness:**

	Complaint 1	**Complaint 2**
< Location		
< Onset : Initial:		
Recent:		
< Cause:		
< Duration		
< Frequency		
< Pain (Character)		
< Progression		
< Aggravating Factors		
< Relieving Factors		
< Associated S & S		
< Previous Occurrences		
< Past Treatment		
< Outcome:		

4. **Other Complaints:**

5. **Past Medical History:**

< General Health Status

< Childhood Illnesses

< Adult Illnesses

< Psychiatric Illnesses

< Accidents/Injuries

< Surgery

< Hospitalizations

6. Current health status and life-style:

< Allergies

< Immunizations

< Screening Tests incl. x-rays

< Environmental Hazards (Home, School, Work)

< Exercise and Leisure

< Sleep Patterns

< Diet

< Current Medication
Analgesics/week:

< Tobacco

< Alcohol

< Social Drugs

7. Immediate Family Medical History:

< Age
< Health
< Cause of Death
< DM
< Heart Disease
< TB
< Stroke
< Kidney Disease
< CA
< Arthritis
< Anaemia
< Headaches
< Thyroid Disease
< Epilepsy
< Mental Illness
< Alcoholism
< Drug Addiction
< Other

8. Psychosocial history:

< Home Situation and daily life
< Important experiences
< Religious Beliefs

9. Review of Systems:

< General

< Skin

< Head

< Eyes

< Ears

< Nose/Sinuses

< Mouth/Throat

< Neck

< Breasts

< Respiratory

< Cardiac

< Gastro-intestinal

< Urinary

< Genital

< Vascular

< Musculoskeletal

< Neurologic

< Haematologic

< Endocrine

< Psychiatric

APPENDIX F
DURBAN UNIVERSITY OF TECHNOLOGY
CHIROPRACTIC DAY CLINIC
PHYSICAL EXAMINATION

Patient:________________________________ File#:______________ Date:______

Clinician:______________________________ Signature:______________________

Student:________________________________ Signature:______________________

1. VITALS

Pulse rate:
Respiratory rate:
Blood pressure: R L Medication if hypertensive
Temperature:
Height:
Weight: Any change Y/N If Yes: how much gain/loss
Over what period

2. GENERAL EXAMINATION

General Impression:
Skin:
Jaundice:
Pallor:
Clubbing:
Cyanosis (Central/ Peripheral):
Oedema:
Lymph nodes – Head and neck:
- Axillary:
-Epitrochlear:
-Inguinal:

Urinalysis:

3. CARDIOVASCULAR EXAMINATION

1) Is the patient in **Cardiac Failure**?
2) Does this patient have signs of **Infective Endocarditis**?
3) Does this patient have **Rheumatic Heart Disease**?

Inspection
- Scars:
- Chest Deformity:
- Precordial bulge:
- Neck-JVP:

Palpation
- Apex beat (character + location):
- Right or left ventricular heave:
- Epigastric Pulsations:
- Palpable P2:
- Palpable A2:

Pulses -General Impression:
- Radio-femoral delay:
- Carotid:
- Radial:
- Dorsalis Pedis:
- Posterior tibial:
- Popliteal:
- Femoral:

Percussion - borders of heart

Auscultation: - heart valves (mitral, aortic, tricuspid, pulmonary)
- Murmurs (timing, systolic, diastolic, site, radiation, grade)

4. <u>RESPIRATORY EXAMINATION</u>

1) Is the patient in **Respiratory distress**?

Inspection
- Barrel chest:
- Pectus carinatum and cavinatum:
- Left precordial bulge:
- Symmetry of movement:
- Scars:

Palpation
- Tracheal symmetry:
- Tracheal tug:
- Thyroid gland:
- Symmetry of movement (ant + post)
- Tactile fremitus:

Percussion
- Percussion note:
- Cardiac dullness:
- Liver dullness

Auscultation
- Normal breath sounds bilat:
- Adventitious sounds (crackles, wheezes, crepitations)
- Pleural frictional rub:
- Vocal resonance
  - Whispering Pectoriloquy
  - Bronchophony
  - Egophony

5. <u>ABDOMINAL EXAMINATION</u>

1) Is the patient in **Liver Failure**?

Inspection
- Shape:
- Scars:
- Hernias:

Palpation
- Superficial:
- Deep = Organomegally
- Masses (intra-or extramural)
- Aorta:

Percussion
- Rebound tenderness:
- Ascites:
- Masses:

Auscultation
- Bowel sounds:
- Arteries (aortic, renal, iliac, femoral, hepatic)

Rectal Examination
- Perianal skin
- Sphincter tone and S4 Dermatome
- Obvious masses:
- Prostate:
- Appendix:

6. G.U.T EXAMINATION

External genitalia:
Hernias:
Masses:
Discharges:

7. NEUROLOGICAL EXAMINATION

Gait and Posture - Abnormalites in gait
- Walking on heels
- Walking on toes
- Rombergs test (Pronator Drift)

Higher Mental Function - Information calculation:
- Calculating ability:
- Abstract thinking:

G.C.S. - Eyes
-Motor
- Verbal

Evidence of head trauma:

Evidence of Meningism: - Neck mobility and Brudzinski's sign:
- Kernigs sign:

Cranial Nerves

I Any loss of smell/taste:
Nose examination:
II External examination of eye: - Visual Acuity
- Visual fields by confrontation
- Pupillary light reflexes = Direct:
= Consensual:
- Fundoscopy findings:
III Ocular Muscles:
Eye opening strength:
IV Inferior and Medial movement of eye:
V a. Sensory - Ophthalmic
- Maxillary:
- Mandibular:
b. Motor - Masseter
- Jaw lateral movement:
c. Reflexes - Corneal reflex
- Jaw jerk
VI Lateral movement of eyes

VII a. Motor - Raise eyebrows:
- Frown:
- Close eyes against resistance:
- Show teeth:
- Blow out cheeks:
b. Taste - Anterior two-thirds of tongue:

VIII General Hearing:

Rinnes = L: R:
Webers lateralization:
Vestibular function: - Nystagmus:
- Rombergs:
- Wallenbergs:
Otoscope examination:

IX & X Gag reflex:
Uvula deviation:
Speech quality:

XI Shoulder lift:
S.C.M. strength:

XII Inspection of tongur (deviation):

Motor system:

a. Power
- Shoulder = Abduction and adduction:
= Flexion and Extension:
- Elbow = Flexion and Extension:
- Wrist = Flexion and Extension:
-Forearm = Supination and Pronation
- Fingers = Extension (Interphalangeals & M.C.P's):
- Thumb = Opposition
- Hip = Flexion and Extension:
= Abduction and adduction:
-Knee = Flexion and Extension:
- Foot = Dorsiflexion and Plantarflexion:
= Inversion & Eversion:
= Toe (Dorsiflexion and Plantarflexion):

b. Tone - Shoulder:
- Elbow:
- Wrist:
- Lower limb – Int. and Ext. rotation:
- Knee clonus:
- ankle clonus:

c. Reflexes - Biceps:
- Triceps:
- Supinator:
- Knee:
- Ankle:
- Abdominal:
- Plantar:

Sensory System

a. Dermatomes - Light touch:
- Crude touch:
- Pain:
- Temperature
- Two point discrimination:

b. Joint position sense - Finger:
- Toe:

c. Vibration -Big Toe:
- Tibial tuberosity
- ASIS:

- Interphalaneal Joint:
- Sternum:

Cerebellar function:

Obvious signs of cerebellar dysfunction:
= Intention Tremor
= Nystagmus
= Truncal Ataxia
Finger-nose test (Dysmetria):
Rapid alternating movements (Dysdiadochokinesia):
Heel-shin test:
Heel-Toe gait:
Reflexes:
Signs of Parkinsons:

8. <u>SPINAL EXAMINATION</u>

Obvious Abnormalities:
Spinous Percussion:
R.O.M:
Other:

9. **<u>BREAST EXAMINATION</u>**

Summon female chaperon

Inspection - Hands rested in lap:
- Hands presses on hips:
- Arms above head:
- Leaning forward:

Palpation -masses:
- tenderness:
- axillary tail:
- nipple:
-regional lymph nodes:

APPENDIX G

ARE YOU BETWEEN THE AGES 18 – 45 YEARS

FREE LOW BACK X-RAYS

FOR INDIAN FEMALES ONLY

ARE BEING DONE AT THE CHIROPRACTIC DAY CLINIC SITUATED AT THE DURBAN UNIVERSITY OF TECHNOLOGY

IF YOU ARE INTERESTED AND WANT TO FIND OUT MORE

CONTACT: MELANEE

0728037619/ 031 – 3732205

APPENDIX H
LETTER OF INFORMATION

TITLE OF RESEARCH:
The evaluation of normal radiographic measurements of the lumbar spine in young to middle aged Indian females in Durban.

Principal investigator : Melanee Naidoo (031 – 3732205)

Supervisor : Dr. J. Shaik (M.Tech.Chiro; M.Med.Sci.(SM), MCASA
(031 – 3732588)

DEAR SIR/ MADAM,
Welcome to my research project. You have been selected to play an important part in this study for the evaluation for normal radiographic measurements of the lumbar spine in young to middle aged Indian females in Durban.

Purpose: A profile on the normal x-ray measurements of the lumbar spine would enable spinal health care professionals' (e.g. spinal surgeons and chiropractors) to make a proper diagnosis of low back complaints. Some of the factors that could influence these x-ray measurements include: age, body weight, height, occupation, smoking and differences in the length of a person's legs. One of the aims of this study would be to determine if there is a strong link (association) between these factors and the x-ray measurements.

You will be given a letter of information to read and should you agree to participate in this study you will have to sign the informed consent form.

As a student intern in the Chiropractic Day Clinic (CDC) at Durban University of Technology (DUT) you can participate in this research by introducing prospective subjects presenting to the CDC for any complaint other than low back/hip pain to this study.

Your role in his study is described in the table below:

Table 3 Student Interns' Procedures in this Study

	Subject presents to the Student Intern
Subjects' reason to visit the Chiropractic Day Clinic (CDC).	Any complaint other than low back pain and/ or hip pain.
Step 1	The subject will have a case history **(Appendix E)**, physical examination **(Appendix F)**, the specific regional examination, and treatment for the specific condition will be done by student intern.
Step 2	At the end of the consult, the Student Intern will inform the prospective subject of the nature of this study.

Step 3	If the prospective subject expresses a willingness to participate in the study, then the researcher will be called in to give a verbal explanation of the study to the prospective subject. The student intern's participation ends here.

Risks/ discomforts: There is no risk to you with your involvement in this study.

The results of the study will be made available at the Steve Biko Library (DUT) in the form of a mini-dissertation.

You will not be awarded any remuneration for taking part in this study.

Your participation in this research will benefit the researcher in terms of prospective subject recruitment.

Your participation in this study is voluntary and refusal to participate will not result in any adverse consequences.

You are free to withdrawn from the study at any time.

Any queries or questions about the study please feel free to contact my supervisor. Do not sign the consent form, unless all your questions have been answered to your satisfaction.

I have read and understood the contents of this informed consent form and I have also been given a verbal explanation of this study by the researcher/ supervisor. The researcher has answered my questions to my satisfaction. By signing the consent form, I agree to participate in this study

------------------------------ ------------------------

Student Intern's Name **Student Intern Signature**

Date: -----------------

----------------------------------- ---

Witness Name (Print) **Witness Signature**

Date: ----------------

Researcher Signature

APPENDIX I
LETTER OF INFORMATION

TITLE OF RESEARCH:
The evaluation of normal radiographic measurements of the lumbar spine in young to middle aged Indian females in Durban.

Principal investigator : Melanee Naidoo (031 – 3732205)

Supervisor : Dr. J. Shaik (M.Tech.Chiro; M.Med.Sci.(SM), MCASA (031 – 3732588)

DEAR SIR/ MADAM,
Welcome to my research project. You have been selected to play an important part in this study for the evaluation for normal radiographic measurements of the lumbar spine in young to middle aged adults in Durban.

Purpose: A profile on the normal x-ray measurements of the lumbar spine would enable spinal health care professionals' (e.g. spinal surgeons and chiropractors) to make a proper diagnosis of low back complaints. Some of the factors that could influence these x-ray measurements include: age, body weight, height, occupation, smoking and differences in the length of a person's legs. One of the aims of this study would be to determine if there is a strong link (association) between these factors and the x-ray measurements.

You will be given a letter of information to read and should you agree to participate in this study you will have to sign the informed consent form.

As a qualified radiographer at the Radiography Clinic at Durban University of Technology (DUT) you can participate in this research by x-raying the subjects chosen to participate in this research by the researcher.

Your role in my study is described in the table below:

Procedure at the Radiography Clinic at DUT

Step 1	An appointment would be scheduled at the Radiography Clinic already by the researcher.
Step 2	Subjects and researcher will meet at the Radiography Clinic and will proceed to Radiography Clinic reception.
Step 3	The researcher will ask the subjects if they have any low back pain, if they have developed any low back pain since the first consult, they will be excluded from the study.
Step 4	If the subject has not developed any low back pain then the subject will hand the radiographer the x-ray requisition form.
Step 5	Subjects will be prepared by the radiographer according to the Radiography Clinic protocols (i.e. change into a gown, protective shields)

Step 6	Subjects will be positioned for the x-rays (AP and lateral views) according to the researcher's patient position protocol **(Appendix C)**.
Step 7	The radiographer will then radiograph the subjects. An erect AP and lateral view of the lumbar spine will be done.
Step 8	Subjects will be allowed to change into their clothes while the radiographer is processing the x-rays. All the x-rays will be coded thereby omitting the subject's name.
Step 9	Subjects will be thanked for their participation in the study and this concludes the subjects' participation in the study.
Step 10	Radiographer will hand the x-rays over to the researcher.

The results of the study will be made available at the Steve Biko Library (DUT) in the form of a mini-dissertation.

You will not be awarded any remuneration for taking part in this study.

Your participation in this study is voluntary and refusal to participate will not result in any adverse consequences.

You are free to withdrawn from the study at any time.

Any queries or questions about the study please feel free to contact my supervisor. Do not sign the consent form, unless all your questions have been answered to your satisfaction.

I have read and understood the contents of this informed consent form and I have also been given a verbal explanation of this study by the researcher/ supervisor. The researcher has answered my questions to my satisfaction. By signing the consent form, I agree to participate in this study.

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Name of Radiographer **Radiographer's Signature**

Date: ------------------

------------------------------------ ---

Witness Name (Print) **Witness Signature**

Date: -------------------

Researcher Signature

!> L R H A \

APPENDIX J

ETHICS CLEARANCE CERTIFICATE

Student Name	Melanee Naidoo	Student No	20100661
> Ethics Reference Number	FHSEC 026/07	Date of FRC Approval	10/09/2007

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The evaluation of normal radiographic measurements of the lumbar spine ! in young to middle aged Indian females in Durban.

In terms of the ethical considerations for the conduct of research in the Faculty of Health Sciences, Durban University of Technology, this proposal meets with Institutional requirements and confirms the following ethical obligations:

1. The researcher has read and understood the research ethics policy and procedures as endorsed by the Durban University of Technology, has sufficiently answered all questions pertaining to ethics in the OUT 186 and agrees to comply with them.
2. The researcher will report any serious adverse events pertaining to the research to the Faculty of Health Sciences Research Ethics Committee.
3. The researcher will submit any major additions or changes to the research proposal after approval has been granted to the Faculty of Health Sciences Research Committee for consideration.
4. The researcher, with the supervisor and co-researchers will take full responsibility in ensuring that the protocol is adhered to.
5. ***The following section must be completed if the research involves human*** *participants:*

	YES	NO N/A
•J* Provision has been made to obtain informed consent of the participants	^	
* Potential psychological and physical risks have been considered and minimised	/ tX	
* Provision has been made to avoid undue intrusion with regard to participants and community	•^/	
* Rights of participants will be safe-guarded in relation to: Measures for the protection of anonymity and the maintenance of Confidentiality.	/ VX	
Access to research information and findings.	•«/	
Termination of involvement without compromise	iZ /	
Misleading promises regarding benefits of the research		

SIGNATURE OF STUDENT/RESEARCHER DATE

SIGN^ftJRE OF SUPERVISOR/S DATE

DATE

'S I'/?

SIGNATURE OF HEAD OF DEPARTMENT

DATE

SIGNATURE: GHAIRPERSON OF RESEARCH ETHICS COMMITTEE