UNIVERSITY OF GHANA

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ASSOCIATION BETWEEN SELECTED ANTHROPOMETRIC VARIABLES AND LUMBAR VERTEBRAL BODY MEASUREMENTS, DISC DEGENERATION, AND HERNIATION

BY

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DECLARATION

DECLARATION BY THE CANDIDATE

I hereby declare that this is the product of my own research undertaken under supervision and has not been presented either in whole or in part for another degree elsewhere. I am solely responsible for any residual flaws in the work.

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DECLARATION BY SUPERVISORS

We hereby declare that the principal work and presentation of this thesis were supervised by us in accordance with guidelines on supervision of thesis laid down by the University of Ghana.

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ABSTRACT

Background: A detailed understanding of lumbar vertebral body morphometry and disc degeneration among Ghanaians is relevant for clinical and research purposes. Studies exist on how age and sex affect lumbar vertebral morphometry and disc degeneration among Caucasians, but there is paucity of similar information in African populations including Ghana. Association of weight and height with lumbar vertebral morphometry and disc degeneration remains inadequately investigated in both populations.

Aim: This study investigated the association of age, sex, height, weight, and body mass index (BMI) with lumbar vertebral body morphometry and disc degeneration using archived radiologic data from the Korle-Bu Teaching Hospital in Accra, Ghana.

Method: Lumbar magnetic resonance imaging (MRI) of patients who had accessed services at the Radiology Unit of Korle-Bu Teaching Hospital from March, 2014 to February, 2015 were reviewed retrospectively. Patients' age, sex, weight and height, were collated from available MRI records together with mid-sagittal images of the lumbar spine. The anterior, middle, and posterior vertebral body heights as well as anteroposterior diameter were measured. Disc degeneration as well as herniation was classified by standard criteria. The obtained data were analysed to determine statistical association between variables studied.

Results: The study revealed that, vertebral body dimensions decreased with age but increased as an individual grew taller (P=0.001) and were greater in males than in females. BMI and body weight, however, showed no significant association with lumbar vertebral body dimensions. Lumbar disc degeneration (LDD) as well as herniation increased significantly with age (P=0.001) and were most prevalent among the elderly. Body weight and BMI were positively correlated with LDD at the caudal end of the lumbar spine. There was no significant correlation with disc herniation. Height, on the other hand, was negatively correlated with disc degeneration but not disc herniation. LDD and herniation were more frequent among males than females for the first 4 intervertebral discs but higher in females at the 5th intervertebral disc.

Conclusion: Vertebral body dimensions decreased with age but increased as an individual grew taller and were larger in males than in females. LDD increased with age, increasing body weight and BMI but decreased with increasing body length. LDD and herniation occurred more frequently in males than in females. Age and gender related findings observed in the present study were similar to those reported in literature.

DEDICATIONS

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LIST OF ABBREVIATIONS

ABBREVIATION	DEFINITION
BMI	Body Mass Index
D	Anteroposterior Diameter
E	Extrusion
Ha	Anterior Vertebral Body Height
Hm	Mid Vertebral body Height
Hp	Posterior Vertebral Body Height
IntVert	Intravertebral Herniation
LDD	Lumbar Disc Degeneration
MRI	Magnetic Resonance Imaging
P	Protrusion
PACS	Picture Archiving and Communication System
S	Sequestration
T1	Longitudinal relaxation time
T2	Transverse Relaxation Time
M	Migration

CHAPTER 1

INTRODUCTION

1.0 BACKGROUND

The human spine is a subject of great interest to clinicians and researchers due to its vital role in housing and protecting the spinal cord as well as providing a framework for supporting the trunk. It comprises the cervical, thoracic, lumbar, sacral and coccygeal regions. The lumbar segment of the vertebral column is of primary interest because it is the most weight-bearing part of the human spine and a considerable amount of movement also occurs in this region (Standring *et al*., 2008). Owing to its weight-bearing function, it is a common site for degenerative diseases (Eizenberg *et al*., 2008).

The lumbar spine has been studied extensively to determine the nature and pattern of disc degeneration as well as variations in lumbar vertebral morphometry (Yu *et al*., 2012; Perry *et al*., 2006; Pfirrmann *et al*., 2001; Cheng *et al*., 1998). Vertebral dimensions have been reported to increase linearly with age (Goh *et al*., 2000). According to Diacinti *et al*. (1995), vertebral heights are reduced with advancing age and menopause. The average dimensions of male vertebrae have been reported to be greater than those of females (Gocmen-Mass *et al*., 2010; Karabekir *et al*., 2011). Cheng *et al*. (1998), also confirm that vertebral body measurements vary significantly with sex and vertebral level. The authors further reported that anterior wedge (Ha/HP) and biconcavity (Hm/Hp) ratios are smaller in men than in women. Among females, vertebral heights and anterior wedge (Ha/Hp) have been found to be significantly lower in postmenopausal women compared to menopausal women (Diacinti *et al*., 1995). Variations in vertebral body shape apart from normal gender variations have also been attributed to vertebral deformities or fractures (Goh *et al*., 2000). Reference values for vertebral body measurements are also now available for a number of populations (Goh *et al*., 2000; Ismail *et al*., 1999; Cheng *et al*., 1998).

In many of these studies, the preferred methodology has been the use of Magnetic Resonance Imaging (MRI). MRI is used routinely to diagnose degenerative disc diseases using vertebral signal intensity changes (Yu *et al*., 2012). The manner of classification and identification of these deformities has progressed from qualitative descriptive methods to morphometric approaches.

A survey of available literature, however, reveals paucity of studies on vertebral body morphometry and lumbar disc degeneration in Sub-Saharan African populations. In Ghana, Jumah and Nyame (1994) have studied the relationship between load-carrying on the head and cervical spondylosis using plain radiographs. To our knowledge, no studies have been done to investigate the pattern and causes of lumbar disc degeneration among Ghanaians.

In Caucasian populations, disc degeneration has been reported to increase with age (Goh *et al*., 2000; Powell *et al*., 1986). It has been found to occur more frequently in males than females (Takatalo *et al*., 2009; Goh *et al*., 2000). Hulme et al. (2007), observed a negative linear relationship between disc health and vertebral strength. Lumbar disc degeneration is also known to be prevalent among working population (Evans *et al*., 1989). Night shift work was found to be a significant risk factor for the development of lumbar disc degeneration in a study conducted in Switzerland (Elfering *et al*., 2002).

Considering the variation in socio-economic conditions and cultural practices among Western populations and Ghanaian populations, one may wonder if these conditions predispose Ghanaians to lumbar disc degeneration more than their Caucasian counterparts. For example Ghanaians travel long journeys on poor roads with multiple deep potholes in vehicles that have poor suspension systems and hard seats that lack ergonomic designs. These conditions are expected to increase pressure on the lumbar vertebrae and exacerbate normal age-related degenerative changes. It is notable that Ghanaian cultural practices include many activities that require individuals to bend over. For example, the use of short hoes and cutlasses is still the predominant method among rural farmers and city labourers engaged in weeding. Most Ghanaians especially in their childhood years have been exposed to sweeping with short brooms either in school or as part of house chores. Ghanaian mothers are also fond of carrying babies on their backs which increases the load imposed on the spine. Other chores that may subject the spine to stress and increased load include, carrying load on the head, bending over to fetch water from wells and reservoirs as well as carrying bucket of water on the head.

Bearing in mind the differences in socio-economic factors among the Western and Ghanaian population, it is worth investigating age and sex related changes in lumbar disc degeneration among Ghanaians. There is a paucity of information in literature on this subject. The deficiency in available data explaining influence of age and sex variations in vertebral morphometry and disc degeneration among Negroid populations stimulates the need for this research.

Again, literature available has failed to explain how a person’s body stature (weight and height) as well as BMI ratio influences lumbar morphometry or how it predisposes an individual to lumbar disc degeneration. Do vertebral body dimensions increase with increasing height? Does increase in an individual’s weight predisposes him/her to lumbar disc degeneration? These were some of the questions that the present study sought to address.

1.1 PROBLEM STATEMENT

Vertebral morphometry and disc degeneration has been studied extensively by researchers with the aim of investigating the pattern of age and sex-related changes on vertebral body indices as well as disc degeneration (Yu *et al*., 2012; Kjaer *et al*., 2005; Elfering *et al*., 2002; Pfirrmann *et al*., 2001; Goh *et al*., 2000; Cheng *et al*., 1998). Despite extensive studies on the subject, there is little information on age and sex related changes on vertebral body shape and lumbar disc degeneration among Negroid populations.

Although age and sex related changes on lumbar vertebral morphometry and disc degeneration are known, there is paucity of information on the influence of body weight, height and BMI on vertebral body dimensions and disc degeneration. Even though disc degeneration has been reported to have high prevalence among obese individuals (Liuke *et al*., 2005), little work has been done to determine how body weight influences vertebral morphometry.

Load carrying on the head has been found to be positively correlated with cervical spondylosis among Ghanaians (Jumah and Nyame, 1994). Considering that similar stresses are imposed on the lumbar vertebrae due to the prevailing socio-cultural practices as well as poor ergonomic practices among Ghanaians, it becomes necessary to investigate the impact of these stresses on lumbar disc degeneration among Ghanaians.

1.2 JUSTIFICATION

Adequate morphometric knowledge about the lumbar vertebra and discs is relevant for clinical and research purposes. Inadequate baseline information on lumbar vertebral body morphometry among Ghanaians as well as the need to understand the pattern of disc degeneration among Ghanaians has necessitated the need for this study. Knowledge of the pattern of degeneration among age groups and BMI classes is relevant for planning of preventive and intervention models for the management of disc degenerative conditions. Morphometric data generated from this study will be useful in planning lumbar surgical interventions just as such data have been provided by Gocmen-Mas *et al*. (2010) and Karabekir *et al*. (2011) for other populations. Data generated from the proposed study will provide basic information upon which other studies may be conducted to explore aetiology of lumbar vertebral dysfunction among Ghanaians.

1.3 AIM

The aim of this study was to investigate the association of age, gender, weight, height and BMI with lumbar vertebral body morphometry and disc degeneration using archived radiologic data from the Korle-Bu Teaching Hospital in Accra, Ghana.

1.4 SPECIFIC OBJECTIVES

- To determine vertebral body dimensions among individuals as well as investigate the association of age, weight, height and BMI with these measurements.
- To determine the association of age, weight, height and BMI with lumbar intervertebral disc degeneration.

- To determine the prevalence of lumbar intervertebral disc degeneration among sexes, age groups and BMI classes.

CHAPTER 2

LITERATURE REVIEW

2.1 THE HUMAN SPINE

The human spine (vertebral column) is the central bony pillar of the body. It consists of 33 vertebrae in an adult. Each of the 33 vertebrae is unique but most of them demonstrate characteristic features that help in grouping them into one of the five regions of the vertebral column (Standring, 2008; Snell, 2008; Moore & Dalley, 2006). These regions are: cervical, thoracic, lumbar, sacral and coccygeal as illustrated in Figure 1. There are 7 cervical, 12 thoracic, 5 lumbar, 5 sacral and 4 coccygeal vertebrae. These numbers are however subject to frequent variations resulting in total numbers being reported between 32 and 35 bones (Standring, 2008). The four coccygeal vertebrae fuse to form the coccyx and this usually occurs at age 30 (Moore & Dalley, 2006).

When viewed laterally in a standing position, the adult vertebrae exhibit the following regional curves: the cervical region is posteriorly concave, the thoracic is posteriorly convex, the lumbar region is posteriorly concave and the sacral posteriorly convex. These curvatures are illustrated in Figure 1(B). In the fetus however, the vertebral column has one continuous anterior concavity (Snell, 2008).

The vertebral column measures approximately 70 cm in males and 60 cm in females. The cervical vertebrae constitute about 8% of the overall body length, 20% by the thoracic, 12% by the lumbar and 8% by the sacrococygeal regions (Standring, 2008). In the neutral upright posture, the spine is approximately one-third of the body height (Keller *et al*., 2005).

The size of the vertebrae (in the vertebral column) increases progressively from the cervical to the sacral level and then becomes progressively smaller toward the apex of the coccyx. As the column descends, successive vertebrae bear an increasing amount of the body's weight. This accounts for the changes in size of vertebrae in the vertebral column.

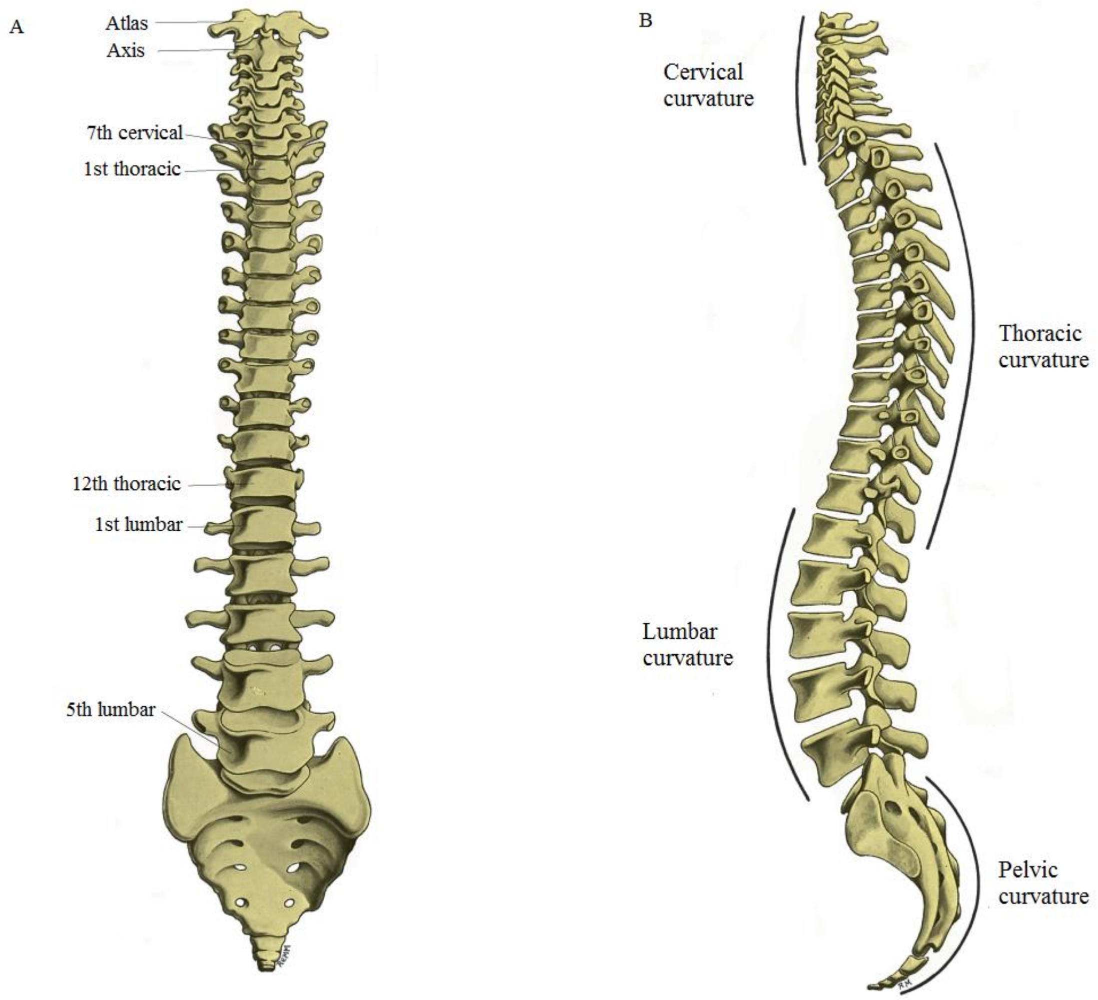

Figure 1: Diagram showing anterior view (A) and lateral view (B) of the vertebral column.

Source: Standring (2008), p 737.

According to Keller *et al*. (2005), compressive load on the intervertebral disc increases progressively from the cervical spine to the lumbar spine. Their study reported a compression load of 15.2%, 61.9% and 65.1% of body weight for the cervical, thoracic and lumbar segments of the spine, respectively. The body weight is further transmitted inferiorly to the sacrum through the sacroiliac joints to the pelvic girdles and then from there to the lower limbs (Snell, 2008; Moore & Dalley, 2006).

The individual vertebrae that make up the vertebral column are separated by resilient fibro-cartilaginous intervertebral discs which make the column flexible (Snell, 2008; Standring, 2008; Moore & Dalley, 2006). The intervertebral disc contributes to about a quarter of the length of the vertebral column in young adults. Very little movement occurs between two adjacent vertebrae. However, a combination of the individual movements between adjacent vertebrae and intervertebral discs provide appreciable movement in the spine (Moore & Dalley, 2006). Flexibility of the vertebral column is facilitated and controlled by the articulation of the cervical, thoracic, lumbar and first sacral vertebrae (first 25 vertebrae) at the zygapophysial joint. This is the synovial joints found between the superior and inferior articular processes (Moore & Dalley, 2006).

The vertebral column's morphology is influenced externally by mechanical and environmental factors. Internally, it is influenced by genetic, metabolic and hormonal factors. All these factors make the vertebrae able to withstand the dynamic forces of everyday life, which include compression, traction and shear forces (Standring, 2008). It is worth mentioning that, the magnitude of these forces may be influenced by occupation, locomotion and posture (Standring, 2008).

The functions of the vertebral column are to provide attachment for muscles, protect the spinal cord, nerves and the covering meninges (Snell, 2008), provide support to the trunk as well as serves as a site for haematopoiesis (Standring, 2008). Furthermore, it bears the body's weight and transmits it to the lower limbs (Snell, 2008).

2.1.1 STRUCTURE AND CHARACTERISTICS OF A TYPICAL VERTEBRA

Vertebrae show regional variations in size and other characteristics, that notwithstanding, their basic structure remains the same. As shown in Figure 2, a typical vertebra consists of a rounded body anteriorly and a vertebral arch posteriorly (Moore & Dalley, 2006). Enclosed by the vertebral arch and body, is a cavity called the vertebral foramen (Figure 2). Within the vertebral foramen lies the spinal cord, the roots of the spinal nerves and the covering meninges (Snell, 2008; Moore & Dalley, 2006).

The vertebral body is more massive, roughly cylindrical and gives strength to the vertebral column and supports the body weight. The size of the vertebral body increases as the column descends and this is clearly noticeable from the 4th thoracic vertebra and below (Moore & Dalley, 2006). The vertebral body is made up of an inner spongy or trabecular bone, which is vascularised, and a thin external layer of compact bone as shown in Figure 3. The spaces within the trabeculae are filled with red marrow which is involved in red blood cell formation. Large foramina exist in the posterior surface of the vertebral body. These foramina accommodate the basivertebral veins which drain the bone marrow. The superior and inferior surfaces of the vertebral body are covered with hyaline cartilage, which are remnants of the cartilaginous model from which the bone develops (Grieve, 1997).

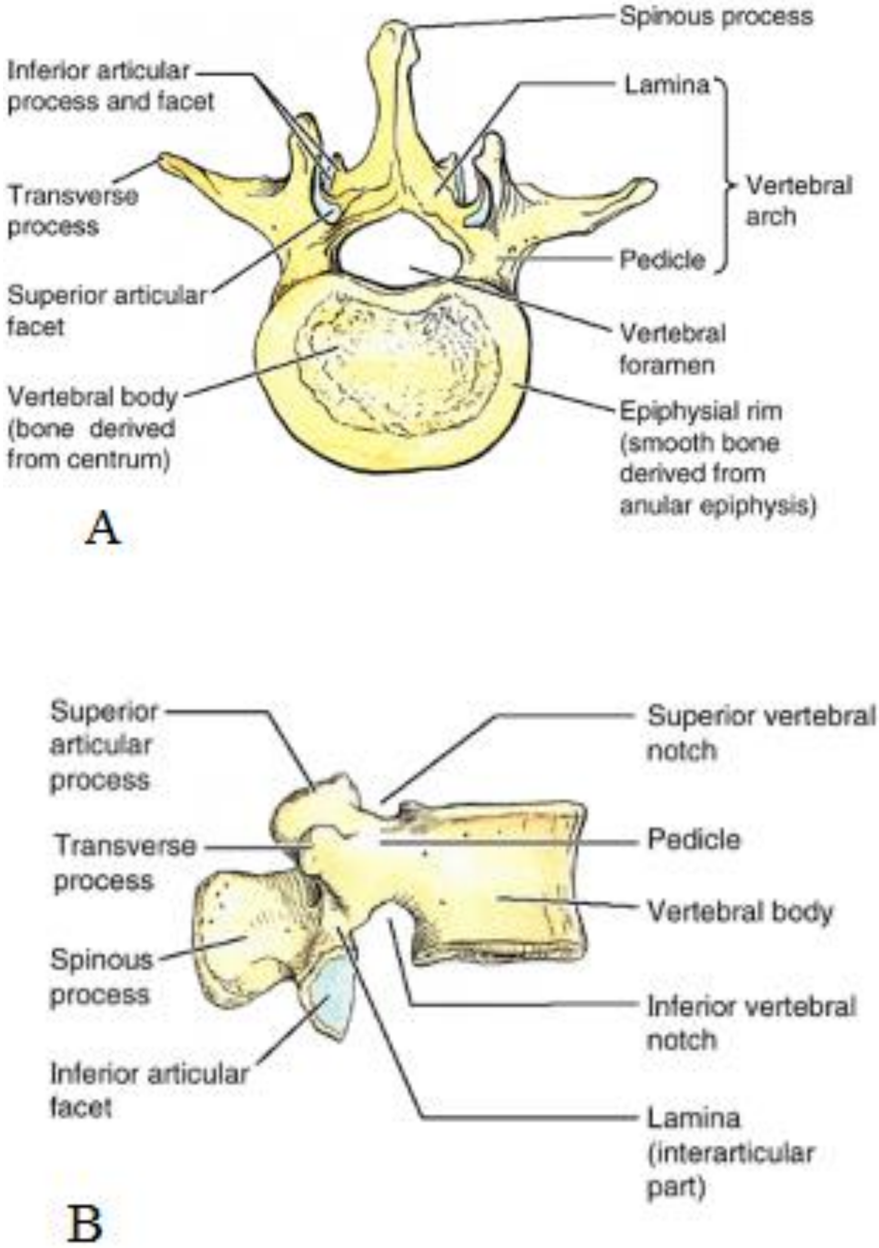

Figure 2: Diagram of superior view (A) and lateral view (B) of a typical vertebra.

Source: Moore & Dalley (2006), p 481

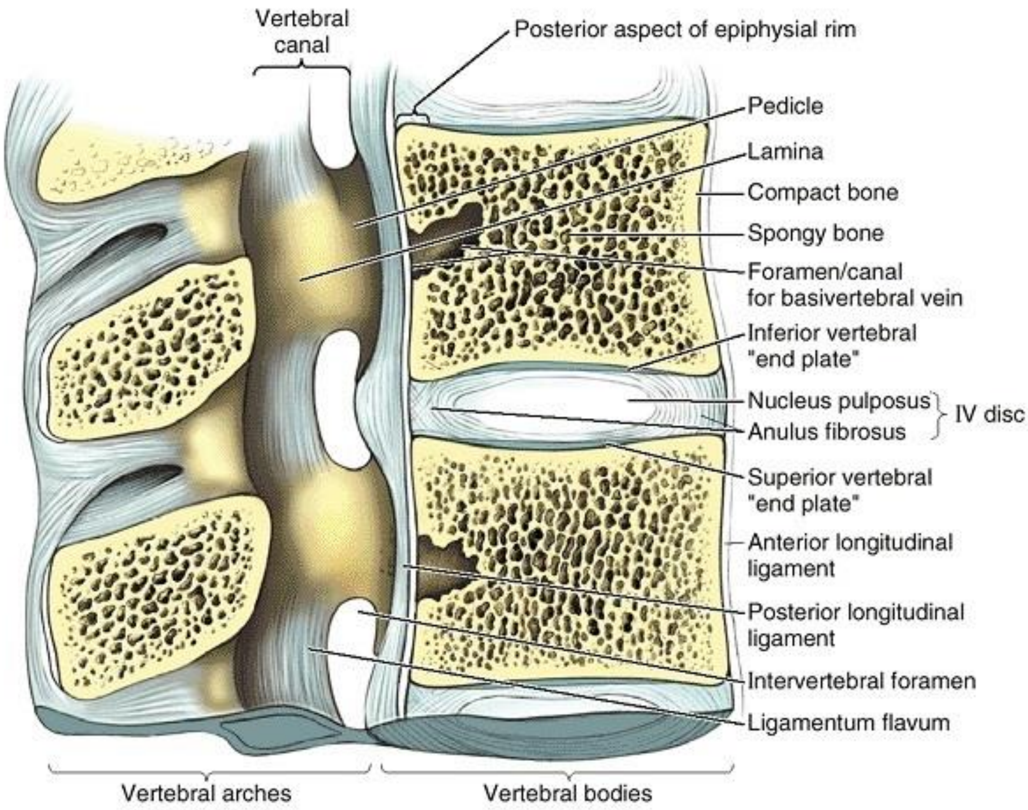

Figure 3: Diagram showing a medial view of left halves of two adjacent hemisected vertebrae.

Source: Moore & Dalley (2006), p 482

The vertebral arch consists of a pair of pedicles laterally and a pair of broad flat plates called laminae, which complete the arch posteriorly (Figure 2). The pedicles are short, stout and cylindrical and project posteriorly from the vertebral body (Moore & Dalley, 2006). Arising from the arch are seven processes. These are one spinous, two transverse and four articular processes. The spinous process arises from the junction between the two laminae and points posteriorly. Each transverse process arises from the junction between the laminae and the pedicles and point laterally as shown in Figure 2A. The transverse and spinous processes serve as a lever for attachment of muscles and ligaments (Snell, 2008). Also at the junction between the laminae and the pedicles are the articular processes. They are arranged vertically consisting of two superior and two inferior processes (Figure 3). The articular surfaces are lined by hyaline cartilage. The superior articular processes of one vertebra articulate with the inferior articular processes of the vertebra above forming a synovial joint which is referred to as zygapophysial joint. Present on the upper and lower borders of the pedicles are notches which form the superior and inferior vertebral notches, respectively. The superior notch of one vertebra and the inferior notch of an adjacent vertebra on each side together form an intervertebral foramen. The intervertebral foramina serve to transmit the spinal nerves and blood vessels (Snell, 2008).

Other vertebral segments have unique characteristics attributed to vertebrae in those segments. The segment of the vertebral column which is of primary interest to the present study is the lumbar region. The characteristics of the lumbar vertebrae are reviewed below.

2.1.2 THE LUMBAR VERTEBRAE

The lumbar part of the vertebral column is found between the thoracic and the sacral regions. There are five lumbar vertebrae usually designated as L1, L2, L3, L4 and L5 in descending order along the vertebral column with an articulating disc between adjacent vertebrae. They support the weight of the upper body which increases inferiorly within the vertebral column. The lumbar vertebrae have large bodies (Figure 4A) which bears the increasing weight imposed on them by the upper part of the body (Moore & Dalley, 2006). Most of the thickness observed in the lower vertebral column within the median plane of the human vertebrae is as a result of the massive bodies of the lumbar vertebrae. When viewed superiorly, the body of a lumbar vertebra appear kidney-shaped whiles the vertebral foramina maintains a triangular shape (Figure 4B).

Lumbar vertebrae have articular processes that are oriented vertically (Figure 4A). The L1 vertebra appears sagitally oriented but as the column descends, articular facets of subsequent vertebrae become more coronally oriented. The superior facet joints are more sagittally oriented and are arranged such that the inferior processes of the vertebra above are interlocked with the superior processes of the vertebra below. This arrangement facilitates flexion and extension, allows lateral flexion and restricts rotation (Moore & Dalley, 2006).

Lumbar vertebrae generally have triangular transverse processes which are long and slender. The transverse processes of the lumbar vertebrae are projected posterio-superiorly as well as laterally (Figure 4A). At the posterior surface of the base of each transverse process is a small accessory process, which provides attachment for the medial intertransverse lumborum muscle. Mammillary processes are present on the posterior surface of the superior articular processes as shown in Figure 4A.

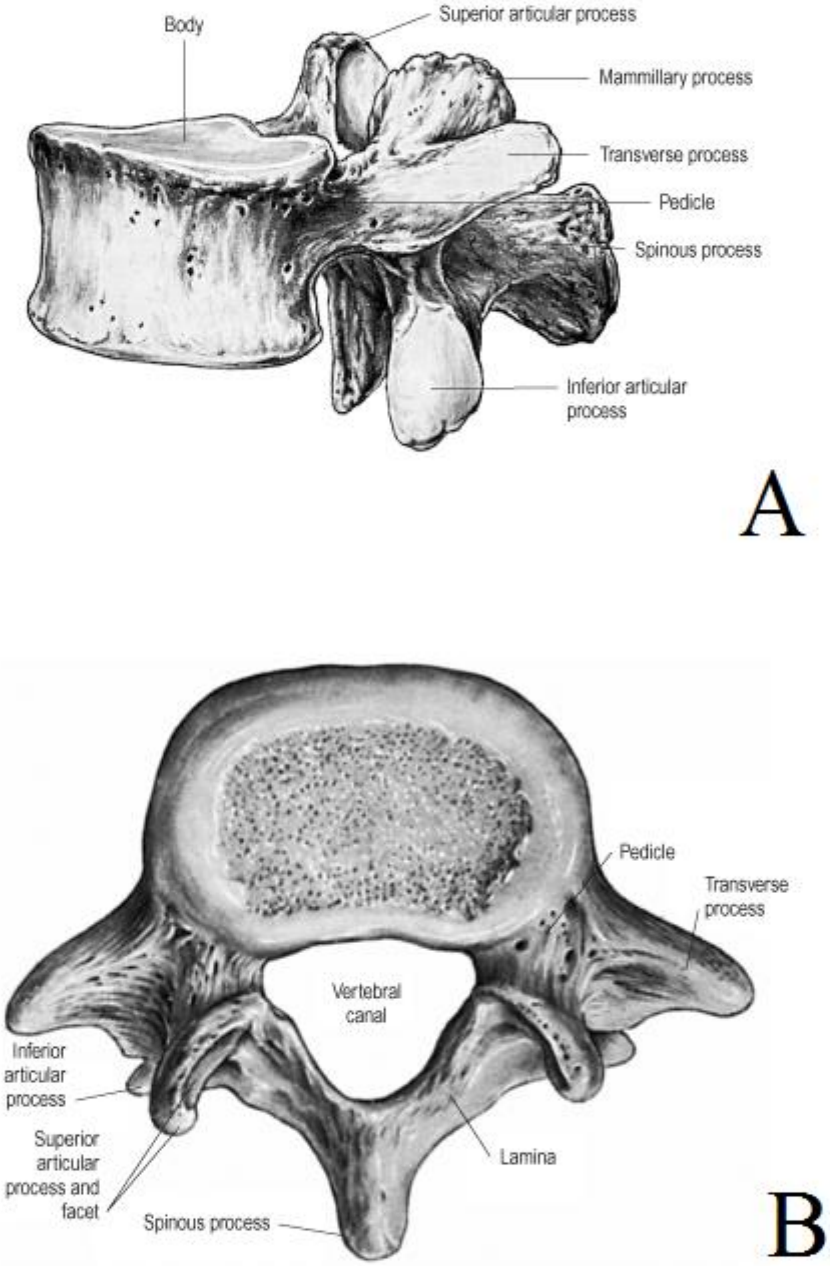

Figure 4 : Diagram showing lateral (A) and superior (B) views of a lumbar vertebra. Source: Standring (2008).

They provide surfaces for attachment of the back muscles (Moore & Dalley, 2006). They have thick, broad, hatched-shaped, short and sturdy spinous processes.

The L5 vertebra is the largest amongst all the moveable vertebrae in the vertebral column. It carries the weight of the whole upper body. It is characterised by a massive body and transverse processes. Its vertical body is deeper anteriorly thus contributing to the lumbosacral angle (Moore & Dalley, 2006).

The lumbar vertebra is the most mobile and weight bearing segment of the lumbar spine (Snell, 2008; Moore & Dalley, 2006). As one descends the vertebral column, successive vertebrae bear an increasing amount of the body's weight. This may tend to increase the load exerted on the lumbar intervertebral discs (Keller et al. 2005). Owing to its massive bodies and greater weight bearing capabilities, the lumbar spine tends to support most of the movement that occurs in the human spine. Thus, the lumbar spine may be more predisposed to degenerative changes. For this reason, the lumbar segment of the human spine was selected as the region of interest for this present study. The study seeks to investigate whether an individual’s body form (weight, height and BMI) as well as age contributes to further degeneration in the lumbar spine.

2.1.3 INTERVERTEBRAL DISCS

Intervertebral discs are found between the articulating surfaces of adjacent vertebrae (Figure 5A). They are usually located between the intervertebral spaces of the second cervical vertebra (C2) through to the first sacral vertebra (S1). They unite the vertebrae into a continuous semi-rigid column. Intervertebral discs account for 20-25 % of the length of the vertebral column (Snell, 2008; Moore & Dalley, 2006).

According to Urban et al. 2000, the intervertebral disc occupies about one-third of the entire length of the vertebral column. The three major compositions of the intervertebral discs are water, collagens and proteoglycan aggregations. The discs are semi-elastic and their elasticity allows the vertebrae to move over each other (Snell, 2008). They have a resilient nature that allows them to serve as shock absorbers. The resilience in the discs is, however, gradually lost with advancing age (Snell, 2008). Each intervertebral disc has an outer fibrous part referred to as the annulus fibrosus (Figure 5B), which has more collagen constituent compared to water and aggregating glycoproteins (Urban et al., 2000). The central portion of the intervertebral disc is gelatinous and is called the nucleus pulposus. It contains a greater proportion of water and proteoglycans than collagen.

The annulus fibrosus is a fibrous ring consisting of concentric lamellae of fibrocartilage. It forms the circumferential periphery of the intervertebral disc. The fibres insert into the epiphyseal rims on the outer margins of the articular surfaces of the vertebral bodies. The fibres forming each concentric lamella run obliquely between adjacent vertebral bodies and their inclination is reversed in alternate sheets (Snell, 2008). This arrangement allows movement between adjacent vertebrae as well as provide a strong bond between them (Moore & Dalley, 2006). The more peripheral fibres are strongly attached to the anterior and posterior longitudinal ligaments of the vertebral column (Snell, 2008).

The nucleus pulposus is the central core of the intervertebral disc as illustrated in Figure 5B and is made up of notochodal cells. It exhibits the most dramatic degenerative changes with advancing age (Urban et al., 2000). It is made up of about 88% water at birth and is more cartilaginous than fibrous (Moore & Dalley, 2006). In fetus and infants, the nucleus contains actively dividing as well as biosynthetically active notochordal cells.

As an individual ages, the density of notochodal cells decreases together with the proportion of living cells that may be found among them and is replaced by cell that are chondrocytic in appearance but are of unknown origin (Urban et al., 2000). These cells with chondrocytic appearance although they continue to synthesise proteoglycans also synthesises significant amounts of collagen. This results in the nucleus pulposus becoming firmer and less hydrated thereby losing its transparent appearance. Eventually, clefts and fissures begin to form within the disc. From this point, the nucleus may continue to degenerate until it can no longer fulfil its mechanical role (Urban et al., 2000).

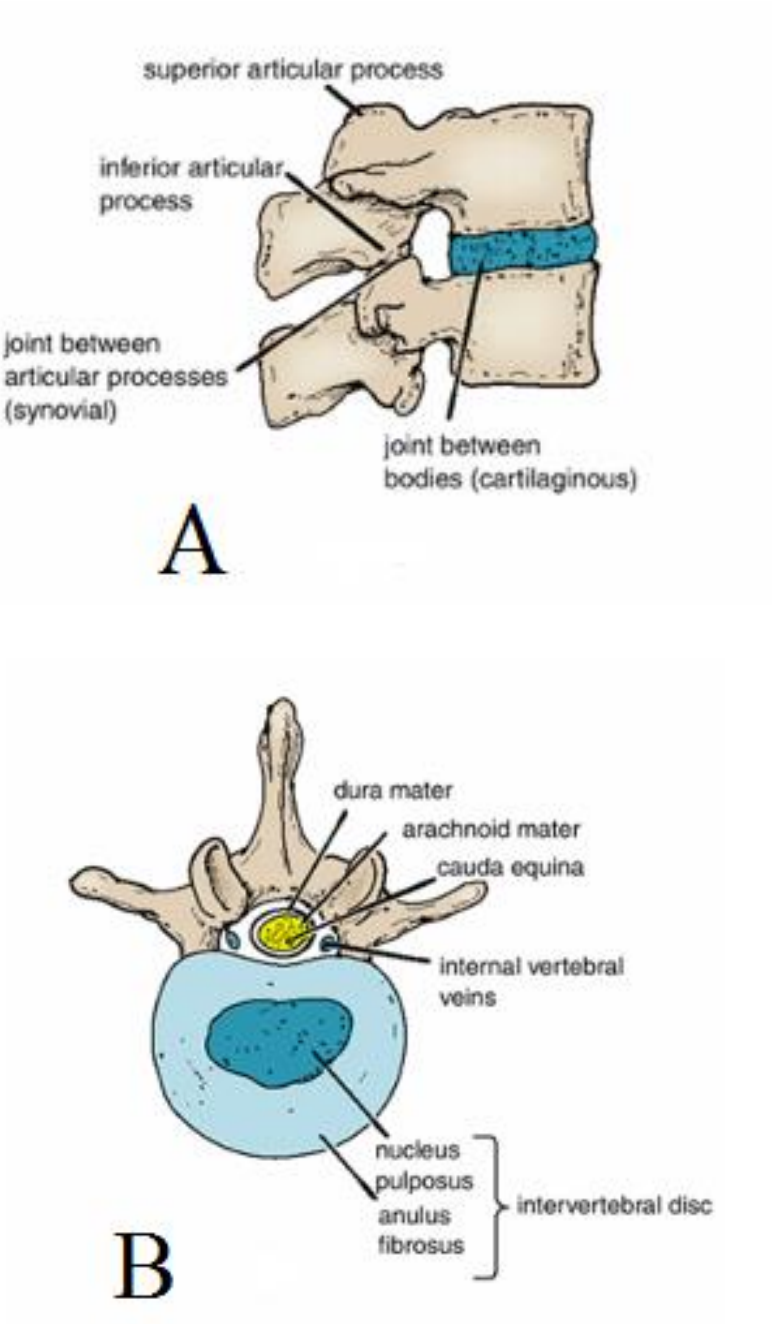

Figure 5: Diagram showing lateral view (A) of an intervertebral disc between two vertebrae and superior view (B) of an intervertebral disc.

Source: Snell (2008).

The nucleus pulposus is more posteriorly placed rather than centred. This is due to the fact that the lamellae of the annulus fibrosus are thinner and less numerous posteriorly compared to the anterior and lateral sides. The nucleus pulposus is avascular hence it receives its nourishment via diffusion from blood vessels in the annulus fibrosus and the vertebral body (Moore & Dalley, 2006).The semifluid nature of the nucleus pulposus makes it flexible and resilient. This allows the disc to change shape and also permits one vertebra to rock forward or backward on another during flexion and extension of the vertebral column (Snell, 2008).

The discs serve as shock absorbers against vertical forces exerted on them by the body. A sudden increase in the compression force on the vertebral column causes the semi-fluid nucleus pulposus to flatten out. The surrounding annulus fibrosus accommodates the outward thrust of the nucleus pulposus during compression. Sometimes, the outward thrust of the nucleus pulposus may be too great for the annulus fibrosus. When this occurs, the nucleus may herniate and protrude into the vertebral canal where it may compress spinal nerve roots or even the spinal cord (Snell, 2008). Disc herniation may be classified as protrusions, extrusions, and sequestrations (Fardon and Milette, 2001; Ohshima *et al*., 1993). When stretched or tensed as occurs during hanging and suspension of the body, the nucleus pulposus becomes thinner. During anterior flexion, lateral flexion and extension of the vertebral column, compression and tension occurs simultaneously in the same disc. When these movements are performed and also during rotational movements, the turgid nucleus pulposus acts as a semifluid fulcrum (Moore & Dalley, 2006).

The thickness of intervertebral discs varies at different regions of the vertebral column. The discs are relatively thicker in the cervical and lumbar regions but their thickness is more prominent in the lumbar region. In the cervical and lumbar regions, the discs are thicker anteriorly but are uniform throughout the thoracic region. The varying shapes of the intervertebral disc contribute to secondary curvatures of the vertebral column (Moore & Dalley, 2006).

The nucleus pulposus shows regressive changes quite early. With advanced age, the fluid content of the nucleus pulposus decreases and is replaced by fibrocartilage. There is also degeneration in the collagen fibre of the annulus fibrosus. As a result of this, the annulus cannot always contain the nucleus pulposus under stress. The discs are thin and less elastic during old age making it difficult to distinguish between the nucleus and the annulus (Snell, 2008; Friberg, 1948). These changes are considered to lie within the framework of normal physiologic changes rather than being pathologic.

2.2 IMAGING OF THE LUMBAR SPINE

Imaging of the vertebral column is essential for diagnosing spinal pathologies. Its use has been increasingly employed in the diagnosis of acute low-back pain and sciatica (Boden et al., 1990). Computed Tomography (CT) has improved radiological assessment of fractures of the vertebral column, particularly in determining the degree of compression of the spinal cord (McCormick *et al*., 2000). Magnetic Resonance Imaging provides improved resolution of soft tissue structures and as such facilitates more accurate diagnosis of degenerative disc disease (Heithoff, 1988). Conventional radiographs are usually used when visualising high contrast structures such as bone. Radiographic images of the vertebral column are usually taken in the anteroposterior and lateral views (McCormick *et al*., 2000).

Magnetic Resonance Image (MRI) is a computer assisted imaging procedure similar to CT. Unlike CT where x-rays are used in producing the desired images, MRI uses magnetic fields and pulses of radio wave energy to generate the images (Moore & Dalley, 2006). MRI produces extremely good images of the vertebral column, spinal cord and cerebrospinal fluid. The components of the intervertebral disc and their relationship to the vertebral bodies are well demonstrated on MRI (Edelman & Warach, 1993). Disc herniation as well as their relationship with the spinal nerve roots is also well defined. MRI also shows spinal cord or nerve root compression and indicates the extent of degenerative changes that occur within the intervertebral disc (Moore & Dalley, 2006). MRI is a very sensitive radiological technique for clinical assessment of intervertebral disc pathologies (Powell *et al*., 1986). It is sensitive enough to detect a partial or complete tear of the annulus fibrosus (Boden et al., 1990). It is extremely useful for evaluating degeneration of intervertebral discs (Pfirrmann *et al*., 2001). It provides biomechanical and pathological information without irradiation or invasive procedures. Due to its immense advantages, MRI is gradually replacing CT and myelography at most imaging centres and has become the choice of many researchers and clinicians (Edelman & Warach, 1993).

MRI creates images by picking up varying signal intensities from tissues based on their proton density. Longitudinal relaxation time (T1) MRI images are produced by longitudinal movement of protons and are usually used to visualise normal anatomical details. Transverse relaxation time (T2) MRI images are produced by transverse movement of protons and are usually used for viewing pathologies.

MRI clearly shows changes in signal intensity at the vertebral body endplates and this has been used in the diagnoses of degenerative disc diseases and spondylosis of the lumbar spine (Kjaer *et al*., 2005; Elfering *et al*., 2002; Savage *et al*., 1997; Evans *et al*., 1989). Proteoglycans, water content loss and collagen occurring in degenerated intervertebral discs are observed as hypointense signals on T2 weighted MRIs (Yu *et* *al*., 2012). T2 shows the structural integrity of intervertebral disc and is sensitive to the water content of the disc as well as the arrangement of the collagen network structure.

Healthy intervertebral disc shows high signal intensity for the nucleus pulposus on T2 images. The signal intensity, however, decreases with the decrease in water content which is usually associated with disc degeneration. In contrast, T2 for the annulus fibrosus shows low signal intensity in healthy intervertebral discs, and the intensity increases with increased water content as well as loss of collagen anisotropy (Chatani *et al*., 1993). As degeneration progresses, uniformity of T2 in both the nucleus pulposus and the annulus fibrosus decreases until eventually the distinction of signal intensity between the nucleus pulposus and the annulus fibrosus is lost (Thompson *et al*., 1990).

Due to the immense advantages of magnetic resonance imaging (MRI) as a modality for studying the vertebral column, it was employed in the present study.

2.3 VERTEBRAL MORPHOMETRY STUDIES AMONG DIFFERENT POPULATIONS

Morphometry refers to the quantitative analysis of form, a concept that encompasses size and shape. Morphometric analyses are usually performed on organisms, and are useful for analysing fossil records, the impact of mutations on shape, developmental changes in form, covariance between ecological factors and shape, as well as for estimating quantitative-genetic parameters of shape (Marcus, 1990). Morphometry is used to statistically test hypotheses about the factors that affect shape.

Morphometry has been used to study the vertebral column in an attempt to provide an understanding of variations in the vertebral column among individuals (Goh *et al*., 2000; Cheng *et al*., 1998; Diacinti *et al*., 1995). In these studies, age and sex related changes were also observed in relation to vertebral morphometry. The association between lumbar lordosis angle and vertebral body shape has also been studied (Cheng *et al*., 1998).

Goh *et al*., (2000), investigated age and sex related changes on the thoracic vertebral body and intervertebral disc. The study was a retrospective study involving 169 cases. For each vertebra, age and sex related changes were investigated on the anterior wedge (ratio of anterior height to posterior height), biconcavity (ratio of central height to posterior height), and compression index (ratio of posterior height to the transverse diameter of the vertebral body). From the study, a linear age related decline in the anterior height and biconcavity of the thoracic vertebrae was noted. The compression index increased during the first few decades of life and then decreased gradually afterwards.

Diacinti *et al*. (1995) also investigated age related changes on thoracic and lumbar vertebral morphometry in healthy postmenopausal and premenopausal Italian women between the ages of 39 and 74 years. The study revealed that vertebral heights as well as anterior wedge (anterior height/ posterior height ratio) were significantly decreased in postmenopausal compared with premenopausal women. Anterior vertebral heights decreased by 1.5 mm/year, while middle and posterior heights decreased by about 1.3 and 1.2 mm/year, respectively. Their study also proved that vertebral heights were lower with advancing age and menopause.

In Belgium, sex differences and their relationship with vertebral morphometry and lumbar lordosis have been studied by Cheng *et al*. (1998). The study was aimed at investigating sex related and vertebral-level-specific differences in vertebral shape as well as to determine the relationship between lumbar lordosis angle and vertebral morphology. Plain radiographs of 142 healthy men and 198 healthy women over 50 years of age were examined. Their anterior (Ha), posterior (Hp) and central (Hc) vertebral body heights were measured beginning from the 4th thoracic vertebra (T4) to the 4th lumbar vertebra (L4). The ratio of Ha/Hp (anterior wedge) and Hc/Hp (biconcavity) were calculated. Their lumbar lordosis angle was also measured. Ha/Hp (anterior wedge) and Hc/Hp (biconcavity) ratios were noticed to be smaller in men than in women. Significant correlation was also found between vertebral shape and lumbar lordosis angle. It was concluded from the study that, vertebral shape varied significantly with sex, vertebral level and lumbar lordosis angle.

Gocmen-Mas *et al*. (2010) investigated the vertebral morphometry of 25 healthy right-handed adult individuals in Turkey. Their aim was to provide standardised volumetric and morphometric data on the lumbar vertebrae and intervertebral discs. This was to facilitate surgical interventions using the anterior vertebral approach. Vertebral heights and diameters were measured from L1 to L5. Stereology was used to estimate disc and vertebral volumes. All volumetric and morphometric analysis were done using MRI images. Their study revealed that the average dimensions of male vertebrae were greater than females. Nonetheless, transverse and anteroposterior diameters as well as intervertebral disc height and volume displayed no sexual dimorphism. Also, concavity indexes for all lumbar vertebrae did not differ statistically among males and females.

These findings have been corroborated by Karabekir *et al*. (2011) who also studied lumbar vertebra morphometry using cadaveric specimen and radiographic data. Their findings were similar to those reported by Gocmen-Mas *et al*. (2010). The average dimensions of male vertebrae were greater than those of females although most of the differences were not statistically significant except the anterior height of L1. Posterior heights of vertebral bodies were smaller than anterior heights. Transverse and anteroposterior diameter of both vertebral body and foramen did not vary among males and females.

Vertebral morphometric measurements were found to decrease among individuals with osteogenesis imperfect in a study conducted by Land *et al*. (2006). Vertebral morphometry was used to assess changes in lumbar vertebral shape before and during pamidronate treatment for osteogenesis imperfecta. Before pamidronate treatment, vertebral body height ratios did not change significantly except for mean concavity index (Hc/Hp) which decreased by 22%. After pamidronate treatment, vertebral height ratios increased significantly with less vertebral compression. This comes to suggest that vertebral pathologies may also influence expected vertebral measurements.

Amonoo-Kuofi (1982) studied lumbar interpedicular distances in normal adult Nigerians using plain radiographs. He concluded from the study that, the width of the normal vertebral canal appear to be subject to individual and racial variations. In a subsequent study, the sagittal diameter of the lumbar vertebral canal was studied in the same population using osteological specimens (Amonoo-Kuofi, 1985). The author's conclusion was that, the midsagittal diameter of the vertebral canal is subject to racial variations, and is determined primarily by the thickness and orientation of the laminae and to a lesser extent by the height of the pedicles. No similar information is apparent, and data on lumbar vertebral morphometry among Ghanaians may be non-existent.

In summary, a survey of available literature reveals that vertebral body dimensions decrease with aging. Vertebral body dimensions are also known to be greater in males than females. Racial variations exist in the width and midsagittal diameter of vertebral canal measurements. Pathologic conditions such as oesteogenesis imperfecta are also known to affect vertebral body dimensions if not treated. There is paucity of information from available literature on the effect of weight and height of an individual on vertebral morphometry. This is one of the major deficiencies in vertebral morphometric studies that this research seeks to address.

2.4 INTERVERTEBRAL DISC DEGENERATION AND OTHER DISORDERS OF THE VERTEBRAL COLUMN

A clear cut distinction between normal physiologic changes due to aging and changes from pathologic origins has been difficult to demarcate (Urban, 2000). In a number of people, although they may show negative radiographic findings, it does not necessarily imply that they have an intact vertebral column (Friberg, 1948).

Disc degenerative changes have been reported to increase with age (Gocman-mas *et al*., 2010; Goh *et al*., 2000; Powell *et al*., 1986; Friberg, 1948). This was found to be very prominent in the mid and lower thoracic discs in a study conducted by Goh *et al*. (2000). Gocman-mas *et al*., (2010) also reported that deterioration in the intervertebral discs increased with age. In their study conducted to investigate intervertebral disc volumes using a stereological approach, disc space was found to decrease linearly with age. This decrease, however, was statistically significant with advanced age. Powell *et al*. (1986) investigated the prevalence of lumbar disc degeneration among symptomless women. Their study revealed that disc degeneration increases with age.

Though symptomless women were used, disc degeneration was already present in over one third of women between the ages of 21 to 40 years. Similarly, Boden et al. (1990) also reported disc degeneration in about one-third of symptomless individuals recruited for their study. Their aim was to study abnormal MRIs of asymptomatic subjects. Their study also revealed high occurrence of disc degeneration among participants 60 years or older with over 57% of scans sampled showing degenerations. Friberg (1948) also reported disc degeneration to be prominent among the 31-50 age group. Their study further revealed that almost half (47.6%) of disc degenerations were localised to the fourth lumbar disc while 75.2% involved both the fourth and fifth discs.

Disc degeneration has also been found to be more prevalent in males than females. This was reported by Goh *et al*. (2000) in a study involving the thoracic spine. Takatalo *et al*. (2009) also investigated the prevalence of lumbar disc degeneration among young adults. Their study equally showed disc degeneration to be more frequent in men than women (54% vs. 42%, with p=0.005). The prevalence of disc bulge, however, showed no difference among males and females. Herniation was significantly more common among males. Degenerative disc findings were more common at L5-S1 level. Friberg (1948) also reported disc degeneration to be higher in males than females. Their study involved 3,672 participants with back problems examined between 1936 and 1946. Out of this, 39% showed signs of disc degeneration. Of the male participants, 74% were classified as labourers (persons who, in the course of their work, have to lift and carry heavy objects).

A longitudinal MRI investigation of the lumbar spine was carried out in 41 asymptomatic individuals to investigate the risk factors for the development of lumbar disc degeneration (Elfering *et al*., 2002). Participants had an initial baseline MRI investigation of their lumbar spine carried out. A follow-up assessment was done in the same subjects five years after. From the study, 41% of participants exhibited deterioration in their lumbar intervertebral disc status after the five-year period. The study concluded that, the extent of disc herniation, the lack of sports activities and night shift work were significant risk factors for the development of lumbar disc degeneration.

Disorders of the vertebral column have also been associated with the heavy load imposed on the vertebral column (Jumah and Nyame, 1994). The authors investigated the relationship between load carrying on the head and cervical spondylosis among Ghanaian population. Three hundred and five participants between the ages of 29 and 78 were sampled for this study. From the study, 225 participants had carried load on their head out of which 63.6% were found to have developed cervical spondylosis. For participants who had not carried load on their heads, only 36% had cervical spondylosis. Participants who carried load on their head had done so over a period of 10 to 15 years and had carried an average load of 15 kg. Jumah and Nyame (1994) concluded from their study that, cervical spondylosis is not exclusively an ageing phenomenon. The heavy loads carried on the heads play a causative role in cervical spondylosis.

Disorders of the vertebral column have been found to be prevalent among sedentary workers (Evans *et al*., 1989). Though sedentary lifestyle has been associated with an increased risk of disc degeneration, Ong *et al*. (2003) reported an increased occurrence of lumbar disc degeneration among elite athletes compared with non-athlete population. Elite athletes at the 2000 Sydney Olympic Games who reported with low back pain at the Olympic Polyclinic were used for this study. Thirty one Olympic athletes were examined using MRI. Disc signal intensity, loss of disc height and presence of disc displacement were the criteria used for the examination. The study revealed that, disc signal intensity was mostly reduced towards the caudal part of the lumbar segment of the vertebral column. Thus, L5/S1 disc levels showed the most reduced signal intensity with 36% of participants showing degenerative changes in this region. Reduction in intervertebral disc height was also found to be most frequent at the same level. The prevalence of disc herniation was observed to increase towards the caudal end of the vertebral column. An element of disc displacement was observed at the L5/S1 disc level in 58% of participants. Over all, disc degeneration was found to be more severe in elite athletes compared with non-athlete population. This suggests that increased activity in the spine either through sports or work (occupation) predisposes an individual to spinal pathologies.

Evans *et al*. (1989) investigated the prevalence of lumbar disc degeneration in a working population by analysing MRI images of 38 ambulating and 21 sedentary employees. The study showed a significant association between occupation and lumbar disc degeneration. It further revealed that the L5/S1 level was the most common disc with degenerative changes. Ambulating females had no degenerative lumbar disc whiles sedentary females had an increased number of degenerative discs. Thus, though degeneration was prominent among the athlete population (Ong *et al*., 2003), a sedentary life style also predisposes an individual to disc degeneration (Evans *et al*., 1989). However, moderate activity is essential for reducing disc degeneration such as was observed among ambulating females in the study by Evans *et al*. (1989).

Savage *et al*. (1997) also carried out a study to determine the differences in the MRI appearances between various occupational groups. Their study involved a working population of men between the ages of 20 and 58, consisting of 5 occupational groups. The occupational groups included car production workers, ambulance men, office staff, hospital porters and brewery draymen. MRI of their lumbar spine was initially assessed. A follow-up assessment was done 12 months after. Their study showed no significant difference in the MRI appearance of the lumbar spine among five occupational groups. Despite the above findings, 45% of participants showed disc degeneration, disc bulge or protrusion, facet hypertrophy, or nerve root compression. Age related changes were also noted in the MRI appearances of the lumbar spine and these changes were most common at the L5/S1 disc level as have also been reported by Kjaer *et al*. (2005), Ong *et al*. (2003) and Evans *et al*. (1989).

Kjaer *et al*. (2005), also investigated abnormal lumbar spine MRI findings and their prevalence and associations with low back pain. Four hundred and twelve participants 40 years old were involved in the study. Abnormal MRI findings such as disc protrusions, endplate changes, nerve root compromise, modic changes and anterolisthesis were observed. Anterolisthesis and modic changes (these are irregularities found at the vertebral endplates) were found to be strongly associated with low back pain four times more likely than other findings. Hypointense disc signals and reduced disc heights were also found to be associated with low back pain. From the study, it was realized that disc herniation and nerve root compromises were not associated with low back pain. The study also revealed that, most abnormal findings were at the lowest lumbar levels as have been reported by Ong *et al*. (2003) and Evans *et al*. (1989).

The relationship between overweight and lumbar disc degeneration has been studied by Liuke *et al*. (2005). In this study, 129 middle aged men from three occupations (machine drivers, construction carpenters and office workers) were sampled. Their baseline MRI was taken and a follow up MRI was done 4 years after. Results from the study revealed that persistent overweight (BMI greater than or equal to 25 kg/m^2 was strongly associated with an increase in the number of lumbar discs that had decreased signal intensity of their nucleus pulposus at follow-up. It was concluded from the study that BMI above 25 kg/m^2 increased the risk of lumbar disc degeneration. It was further revealed from the study that participants who were overweight at younger age had an increased risk of lumbar disc degeneration.

Weiler *et al*. (2011) performed a histological analysis of surgical lumbar intervertebral disc tissue and investigated the association between disc degeneration and increased BMI. The study showed greater levels of degeneration in the nucleus pulposus than in the annulus fibrosus of discs examined. The study further revealed that increased BMI was a positive risk factor for the development of symptomatic clinically significant disc degeneration.

Keller *et al*. (2005) investigated the influence of spine morphology on intervertebral disc loads and stresses in asymptomatic adults. Digitalized lateral full-spine x-rays of 67 subjects were studied. Morphological measurements of sagittal curvature and balance were compared with intervertebral disc loads and stresses obtained using a quadrilateral element postural loading model. The study revealed that disc compressive stresses were greatest in the mid-thoracic region of the spine, whereas shear stresses were highest at L5-S1. In general, intervertebral disc stresses and loads were greatest in subjects with sagittal posture imbalance.

In summary, literature reveals that disc degeneration increases with age and is more prevalent among males than females. Greater levels of degeneration occur in the nucleus polposus than the annulus fibrosus. Laborious tasks as well as sedentary life styles have been found to increase the risk of developing disc degeneration. Despite these findings disc degeneration was significantly reduced among ambulating females. The literature further reveals that increased BMI is a positive risk factor to development of disc degeneration. Available literature, however, does not provide any information on the influence of height on disc degeneration.

2.4.1 CLASSIFICATION OF DISC DEGENERATION

Classification System by NASS, ASSR and ASNR

The North American Spine Society (NASS), American Society of Spine Radiology (ASSR) and American Society of Neuroradiology (ASNR) have jointly developed a nomenclature and classification system for lumbar disc pathologies (Fardon and Milette, 2001). This classification system is based purely on pathoanatomical findings and does not solely rely on relationship to symptoms, results from specific tests or the need for treatment. In this classification system, each lumbar disc can be classified in terms of one, and sometimes more than one, of the following categories: Normal; Congenital or Developmental Variation; Degenerative or Traumatic; Infectious or Inflammatory; Neoplastic; and or Morphologic Variant of Uncertain Significance. The categories can further be divided into subgroups based on the information available and the purpose for which it is intended.

According to the classification system, Annular Tear; Herniation; and Degeneration are further subgroups within which degenerative and traumatic changes can be categorised. Degeneration may include any or all of the following: an apparent desiccation, fibrosis, narrowing of the disc space, diffused bulging of the annulus beyond the disc space, numerous annular tears and mucinous degeneration of the annulus, defects and sclerosis of the endplates and osteophytes at the vertebral apophyses. If a disc demonstrates one or more of these changes, it may be classified as either a spondylosis deformans or an intervertebral osteochondrosis.

Disc herniation is a major subgroup under the degenerative and traumatic category. It is defined as a localised displacement of disc material beyond the limits of the intervertebral disc space. The displaced material may include the nucleus, cartilage, fragmented apophyseal bone, annular tissue, or a combination of these materials.

The vertebral body end plates define the intervertebral disc space cranially and caudally. Peripherally, the space is defined by the outer edges of the vertebral ring apophyses exclusive of osteophytic formations. Based on the shape of the displaced material, a herniated disc may be classified as a protrusion or an extrusion. A protrusion exists if the greater distance in any plane, between the edges of the disc material beyond the disc space is less than the distance between the edges of the base in the same plane. An extrusion exists when in at least one plane, any one distance between the edges of the disc material beyond the disc space is greater than the distance between the edges of the base, or if there is no continuity between the displaced material beyond the disc space and that within the disc space. If the displaced disc material has lost completely any continuity with the parent disc then extrusion may further be classified as a sequestration. The term migration describes displacement of disc material away from the site of extrusion irrespective of whether it is sequestrated or not. Discs that herniate cranio-caudally (vertically) through a break in the vertebral endplate are classified as intravertebral herniation.

According to the classification system, the base is defined as the cross-sectional area of the disc material at the outer margin of the disc space of origin, where disc material displaced beyond the disc space is continuous with disc material within the disc space.

The displacement of disc material in the axial plane beyond 50-100% of its circumference is a "bulge" and is not considered as a form of herniation.

For the purpose of the present study, the above classification system was employed in the classification of lumbar disc herniation.

Pfirrmann Classification of Disc Degeneration

A comprehensive grading system for lumbar disc degeneration was developed by Pfirrmann *et al*. (2001) details of which are outlined in Table 1 below. The classification was based on a five scale grading system using variations in signal intensity and structural morphology of the disc. Signal intensity and structural morphology of the nucleus pulposus on sagittal T2-weighted MRI images has been the focus for most classification systems for degenerative intervertebral discs. The Pfirrmann grading system is a non-invasive, simple and convenient MRI imaging method (Pfirrmann *et al*., 2001). It assesses degenerated intervertebral discs by identifying asymmetry in disc structure, distinction of the nucleus pulposus and annulus fibrosus, signal intensity of intervertebral discs and height of intervertebral discs and assigns grade I to V for the disc (Yu *et al*., 2012). Pfirrmann's classification system was used in the present study for assessing disc degeneration based on signal intensity changes.

Table 1. Pfirrmann grading system for classification of disc degeneration

Grade	Structure	Distinction of Nucleus and Annulus	Signal Intensity	Height of Intervertebral Disc
I	Homogeneous, bright white	Clear	Hyperintense, isointense to cerebrospinal fluid	Normal
II	Inhomogeneous with or without horizontal bands	Clear	Hyperintense, isointense to cerebrospinal fluid	Normal
III	Inhomogeneous, gray	Unclear	Intermediate	Normal to slightly decreased
IV	Inhomogeneous, gray to black	Lost	Intermediate to hypointense	Normal to moderately decreased
V	Inhomogeneous, black	Lost	Hypointense	Collapsed disc space

Source: Pfirrmann *et al*. (2001).

CHAPTER 3

MATERIALS AND METHODS

3.0 STUDY DESIGN

The study was a retrospective descriptive correlational study.

3.1 STUDY SITE

The study was conducted at the Radiology Unit of Korle-Bu Teaching Hospital in Accra, Ghana. The hospital is a major health facility in Ghana with over 2,000 bed capacity and a daily patient attendance of about 1,500. The hospital has an ultramodern Radiology Unit. Patients are referred to this unit from other health centres for lumbar spine imaging. The MRI unit averagely attends to about 12 patients a day out of which an average of 4 are lumbar cases.

3.2 STUDY POPULATION

The target populations were men and women whose MRI scans had been taken from March, 2014 to February, 2015. The specified time duration of one year was due to the fact that the MRI machine at the study site had a limited capacity with respect to how much patient data it could store. Periodically, old records of patients were deleted to make room for new data. Old images were then backed-up onto a Picture Archiving and Communication System (PACS). However, images stored on the PACS system did not have patients' weight and height information. This information was only available in the database of the MRI machine. Images belonging to Ghanaian patients were sorted out using the names and nationality information obtained from the records available.

3.2.1 INCLUSION CRITERIA

- MRI Images which stated Ghanaian nationality from the available records were considered for the study.
- Images whose indication for MRI scanning did not include any condition (such as tumours, trauma, fractures) that could potentially affect the shape and dimensions of the lumbar vertebrae.
- Images that were clear enough and had the required bony landmarks on T1 scans for morphometric measurements as well as clearly shown intervertebral disc features on T2 scans required for classification of disc degeneration.

3.2.2 EXCLUSION CRITERIA

Vertebral Morphometry

- Indications for MRI scanning that were due to trauma, malignancy or any other condition that could affect morphometric measurements.
- Images that demonstrate severe scoliosis were excluded from morphometric measurements. This is due to difficulty in determining a uniform mid sagittal point for all discs in a single slice of the image.
- Images with severe localised vertebrae deformation.
- Images with vertebral fractures, spinal metastases or evidence of spinal surgery.
- Images that were not clear which made it difficult to identify the landmarks for vertebral morphometry.

Disc Degeneration Classification

- Indications for MRI scanning that were due to trauma, malignancy or any condition that could affect classification of intervertebral disc.
- Images that showed evidence of spinal surgery.
- Images demonstrating severe scoliosis were excluded. This is due to difficulty in determining a uniform mid sagittal point for all discs in a single slice of the image.
- Images that were not clear which made it difficult to identify intervertebral disc features.

3.3 SAMPLE SIZE DETERMINATION

For a 5% precision and a confidence interval of 95%, a minimum sample size of 73 was required using the formula below (Daniel, 1999).

$$N = \frac{(Z)^2 (SD)(1-SD)}{E^2}$$

$$= \frac{1.96^2 (0.05)(0.95)}{0.05^2}$$

$$= 72.9904$$

Where N is minimum sample size

E is desired margin of error

Z is the critical Z score on the desired level of confidence (95%)

SD is the standard deviation

However, in order to enable generalisations of findings from this study to represent available data in Ghana, a larger sample size was used.

3.4 MATERIALS

A search through patient records for lumbar MRI, revealed two hundred and sixty-two (262) names on the MRI machine. Out of this, 40 images could not be retrieved from the PACS. Thus 222 images were retrieved, out of which only 143 were valid for morphometric measurements and 171 images were valid for classification of disc degeneration.

All images retrieved from the PACS were scanned with a Toshiba Vantage Titan MRI, 1.52Tesla which was manufactured by Toshiba America Medical Systems. Each image was copied onto a Compact Disk Recordable CD-R using the Clear Canvas Workstation Portable Edition, version 9.0.956.11723. The Clear Canvas Workstation is a Dicom Viewer software (an imaging application for viewing medical images), which is used at the study centre to manage images stored in the PACS. The images copied onto the CD-Rs had the Clear Canvas Workstation software automatically packaged with it to enable viewing of the images directly from the CD-Rs without having to install the software on the computer being used. The software had an in-built ruler with calibrations, which was used for all morphometric measurements. The software supported magnification of images without changing the dimensions measured with the ruler. Magnification was thus used to enable clear visualisation of vertebral landmarks and intervertebral disc features.

3.5 PROCEDURE USED

A search was done on the MRI machine at the Radiology Unit of Korle-Bu Teaching Hospital to obtain information on all patients that had taken an MRI at the centre. The search phrase used was “lumbar MRI”. The search returned 262 names of patients. These patients had undergone MRI scanning within March, 2014 and February, 2015. A snapshot of the MRI monitor displaying the search results was taken with a camera. From the snapshots, a list was compiled taking note of patient’s name, age, weight and height. The list was used to retrieve images from the PACS, which is an online database where all images taken at the Hospital are stored. Forty images out of the list compiled could not be retrieved from the PACS server. The images were missing from the database. In all, 222 images were retrieved. The images were transferred onto CD-Rs using the Clear Canvas Workstation software so they could be viewed at a convenient time on any available computer.

Patient images were grouped according to age, BMI and sex. Age classification was based on a modification of WHO’s age classification (World Health Organization, 2013). The present study combined WHO classification for infancy, childhood and adolescents and grouped them to collectively span the ages of 0-19. According to WHO, adulthood spans the ages of 20- 59 whiles ages 60 and above are classified as elderly. For the purpose of this study, adulthood was divided into early adulthood (20-39) and late adulthood (40-59). Ages 60 and above were maintained as elderly. BMI classification was adopted from Centre for Disease Control and Prevention (CDC, 2004). Sex was classified as male or female.

3.5.1 MORPHOMETRIC MEASUREMENTS

Morphometric measurements were performed on T1 weighted mid-sagittal digital images using the Clear Canvas Workstation software. The images were opened from the CD-Rs and the sagittal images were selected for morphometric measurements to be carried out. The mid-sagittal images were located by looking for the presence of a clear demarcation of the spinal cord and a clear view of the spinous processes posterior to the spinal cord (Figure 6). Six anatomical landmarks were marked on each vertebral body representing the four corners and midpoints of the superior and inferior end plates as shown by LM in Figure 6.

For each lumbar vertebra, the anterior height (Ha), mid height (Hm) and posterior height (Hp) were measured as shown in Figure 6. The mid height was defined by measuring a line drawn between the midpoints of the superior and inferior endplate. The distance between the midpoints of the lines used to determine Ha and Hp was measured as the anteroposterior diameter (D). Each measurement was done three times for each vertebra and the average recorded. Three indices of lumbar vertebral body shape defined as anterior wedge index (Ha/Hp), biconcavity index (Hm/Hp), and compression index (Hp/D) were then calculated from the recorded values. The Hp/D index was based on the specific compression index utilised by Nicholson *et al*. (1993).

During the measurements, where marked osteophytic formation was noticed, corner landmarks were selected to best represent the point at which the anterior vertebral border intersected with the vertebral end plate (Goh *et al*., 2000).

All measurements were carried out by me. I undertook series of training sessions with a qualified Radiologist until the Radiologist was satisfied I was competent to carry out all morphometric measurements accurately. Test for reliability of all measurements was, however, done by me, an MRI Radiographer and a Radiologist.

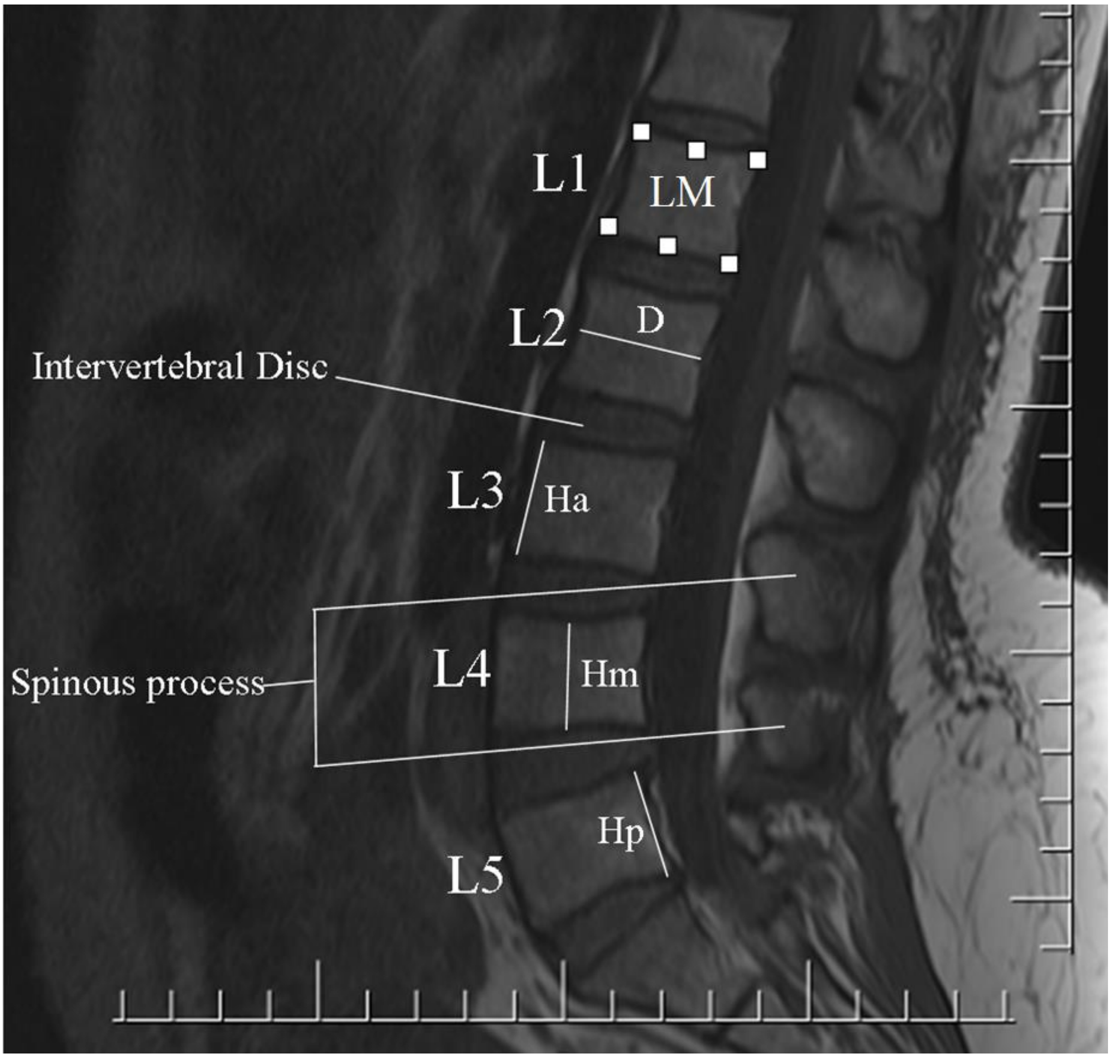

Figure 6: Mid sagittal MRI image of the lumbar spine showing D = anteroposterior diameter, Ha = anterior height, Hp = posterior height and Hm = mid height of the vertebral body. LM represents the six anatomical landmarks that will be used to determine the demarcations for all morphometric measurements. L1-L5 represents the various vertebral levels. **Magnification: 0.64 X**

3.5.2 DISC CLASSIFICATION

T2 weighted sagittal images were used for all disc classification. Disc classification included classification of disc degeneration using Pfirrmann's classification (Pfirrmann *et al*., 2001) and classification of disc herniation using a system developed by the combined task force of the North American Spine Society, American Society of Spine Radiology and American Society of Neuroradiology (Fardon and Milette, 2001).

MRI images were viewed using the Clear Canvas Workstation software portable edition, version 9.0.9561.11723. The mid-sagittal images were located by looking for the presence of a clear demarcation of the spinal cord and a clear view of the spinous processes posterior to the spinal cord. Disc degeneration was classified according to the five grade system developed by Pfirrmann *et al*. (2001), as follows:

Grade I: Homogenous disc, with bright hyperintense white signal intensity and a normal disc height as shown in Figure 7.

Grade II: Inhomogeneous disc, with a hyperintense white signal. The distinction between nucleus and annulus was clear, and the disc height normal, with or without horizontal grey bands as shown in Figure 7.

Grade III: Inhomogeneous disc, with an intermediate grey signal intensity. The distinction between nucleus and annulus was unclear, and the disc height was normal or slightly decreased. An illustration is shown in Figure 8.

Grade IV: Inhomogeneous disc, with hypointense dark grey signal intensity. The distinction between nucleus and annulus was lost, and the disc height was normal or moderately decreased. An illustration is shown in Figure 8.

Grade V: Inhomogeneous disc, with hypointense black signal intensity. The distinction between nucleus and annulus was lost, and the disc space was collapsed. An illustration is shown in Figure 8.

For the present study, grades I and II were classified as normal while grades III, IV and V were classified as degenerated as was done by Takatalo *et al*. (2009).

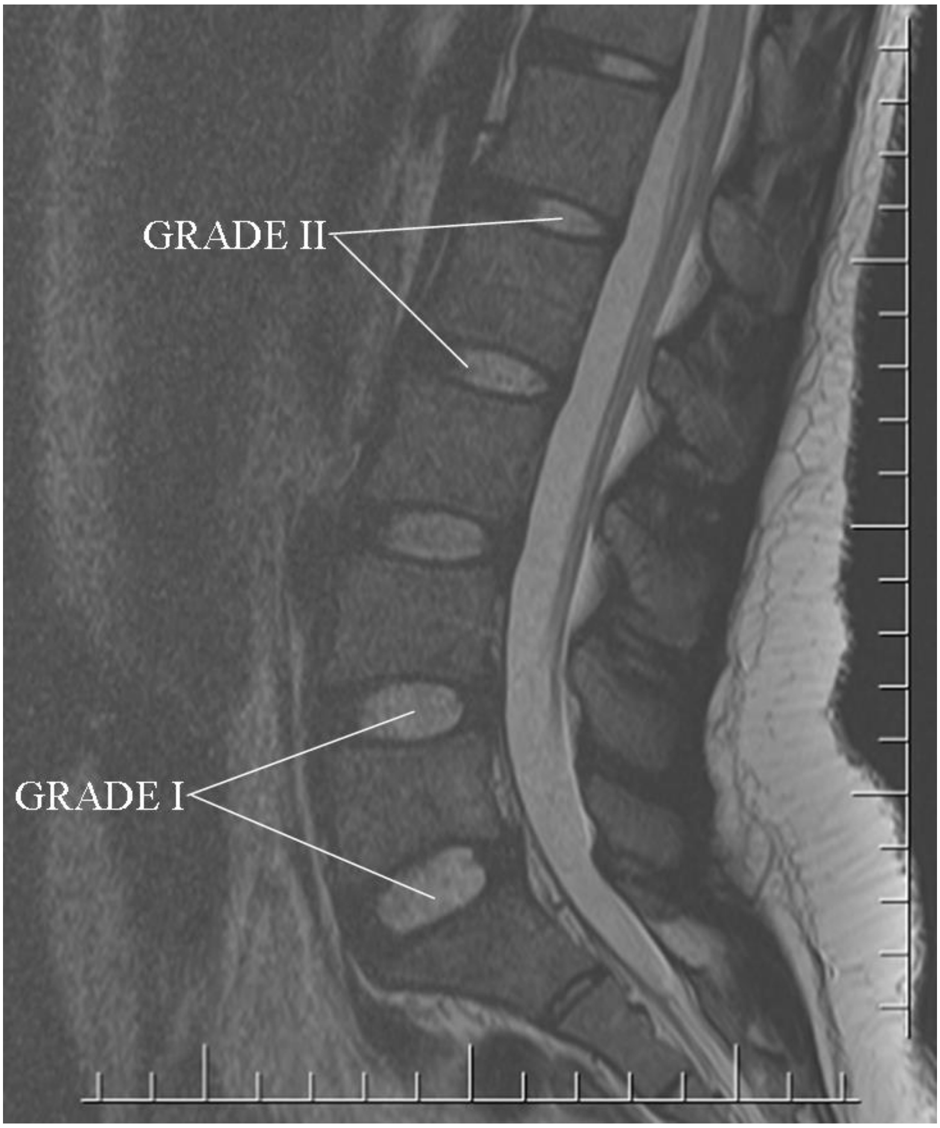

Figure 7: MRI image of lumbar spine showing Pfirrmmann's disc degeneration grade I (homogenous disc with bright hyperintense white signal intensity and normal disc heights) and grade II (inhomogeneous disc, hyperintense white signal with horizontal grey bands). **Magnification: 0.7 X**

Disc herniation was classified as follows according to Fardon and Milette, (2001):

Protrusion (Figure 9)**:** A protrusion existed if the greater distance in any plane, between the edges of the disc material beyond the disc space was less than the distance between the edges of the base in the same plane.

Extrusion (Figure 9)**:** An extrusion existed when in at least one plane, any one distance between the edges of the displaced disc material was greater than the distance between the edges of the base, or if there was no continuity between the displaced disc material and the parent disc.

Sequestration (Figure 10)**:** If the displaced disc material had lost completely any continuity with the parent disc, then extrusion was further classified as a sequestration.

Migration (Figure 10)**:** A disc was classified as migrated if the displaced disc material was away from the site of extrusion irrespective of whether it was sequestrated or not.

Intravertebral herniation (Figure 10)**:** Discs that herniate cranio-caudally (vertical) through a break in the vertebral endplate were classified as intravertebral herniation.

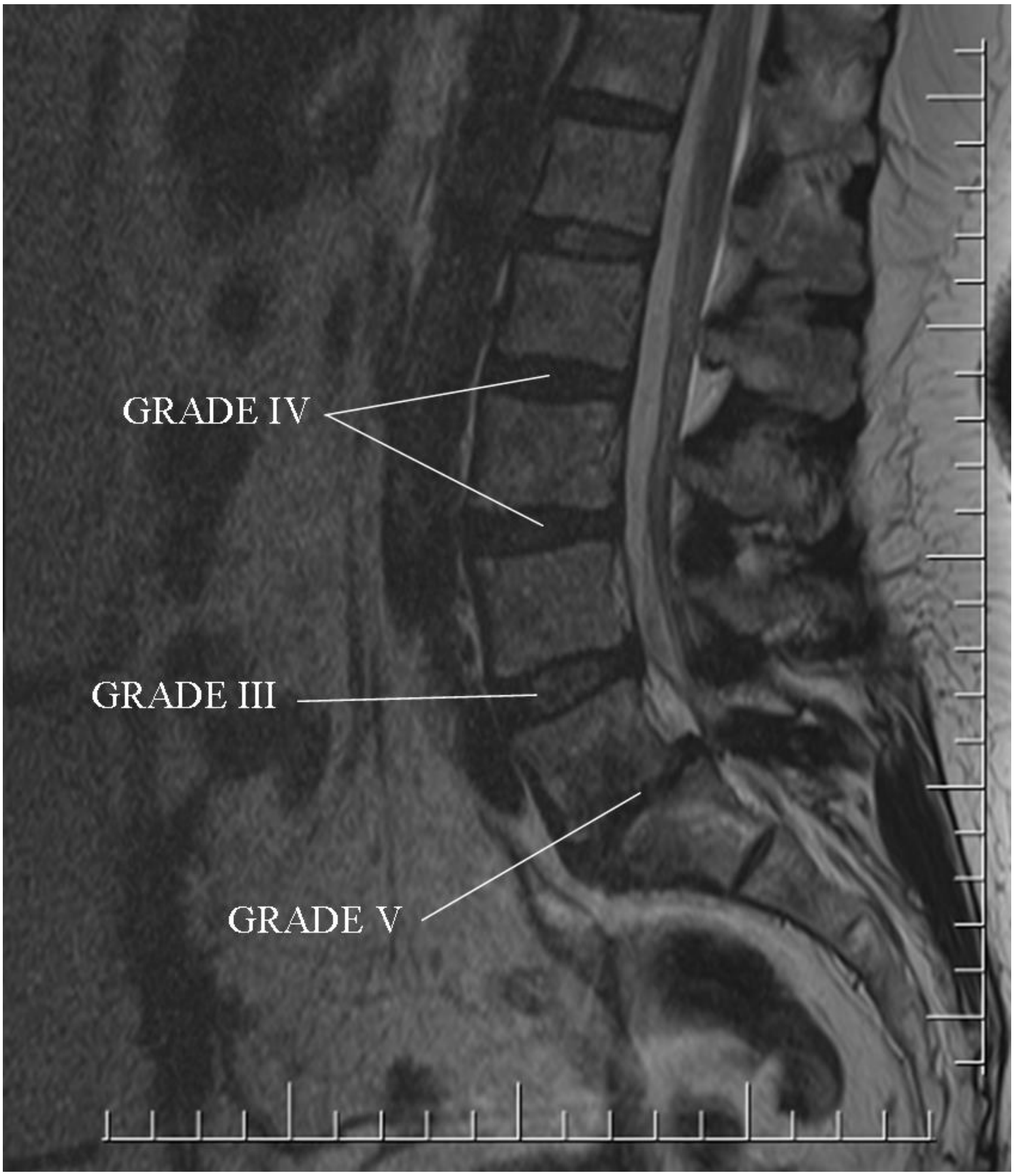

Figure 8: MRI of lumbar spine showing Pfirrmmann's disc degeneration grade III (inhomogeneous disc with intermediate grey signal intensity), grade IV (inhomogeneous disc with hypointense dark grey signal intensity) and grade V (inhomogeneous disc with hypointense black signal intensity and collapsed disc space). **Magnification: 0.65 X**

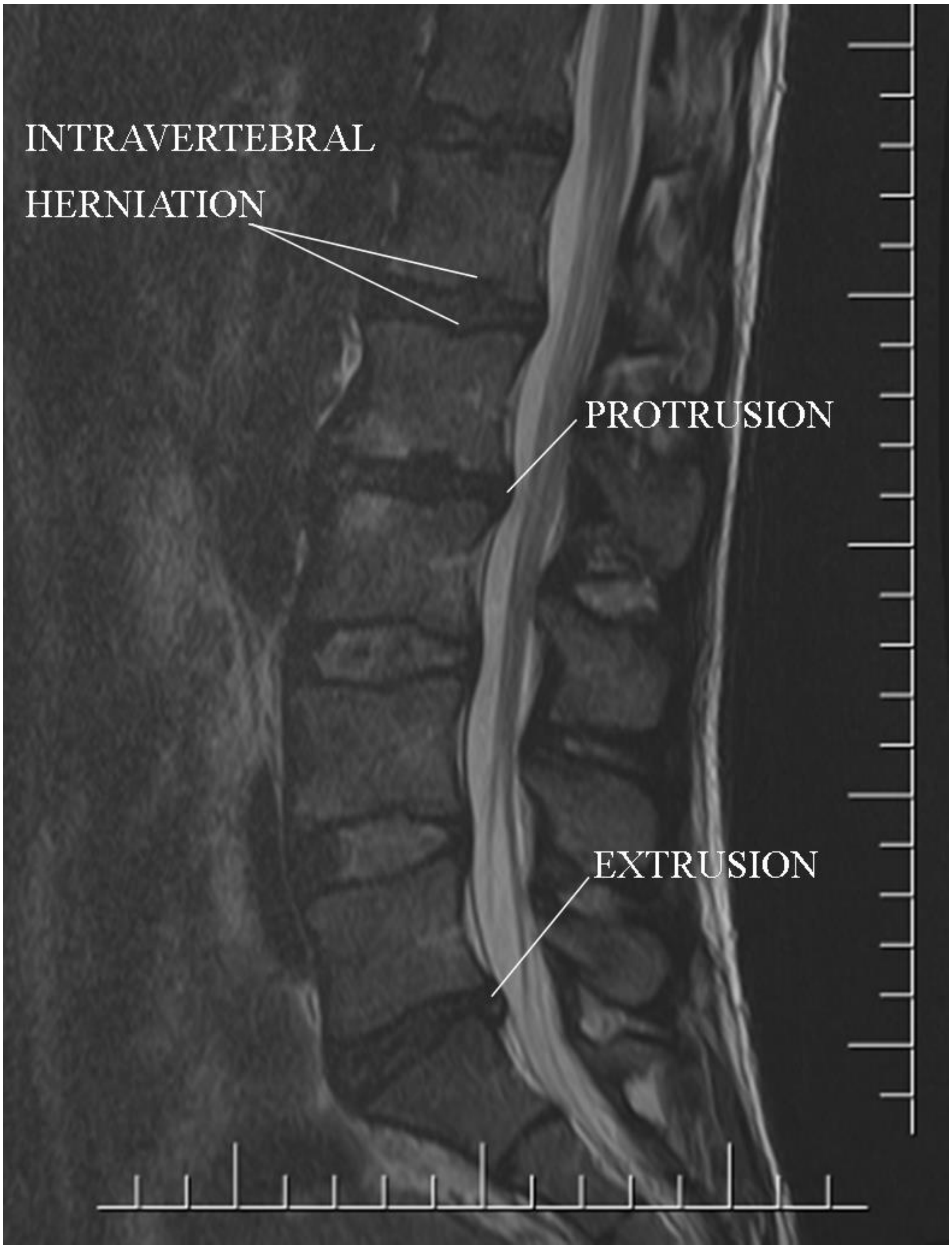

Figure 9: MRI image of the lumbar spine showing Protrusion (displaced disc material beyond the disc space with the edges of the disc material being less than the distance between the edges of the base in the same plane), Extrusion (displacement of disc material beyond the disc space with the edges of the displaced disc material being greater than the distance between the edges of the base) and Intravertebral Herniation (a cranio-caudal herniation of disc material through a break in the vertebral endplate). **Magnification: 0.65 X**

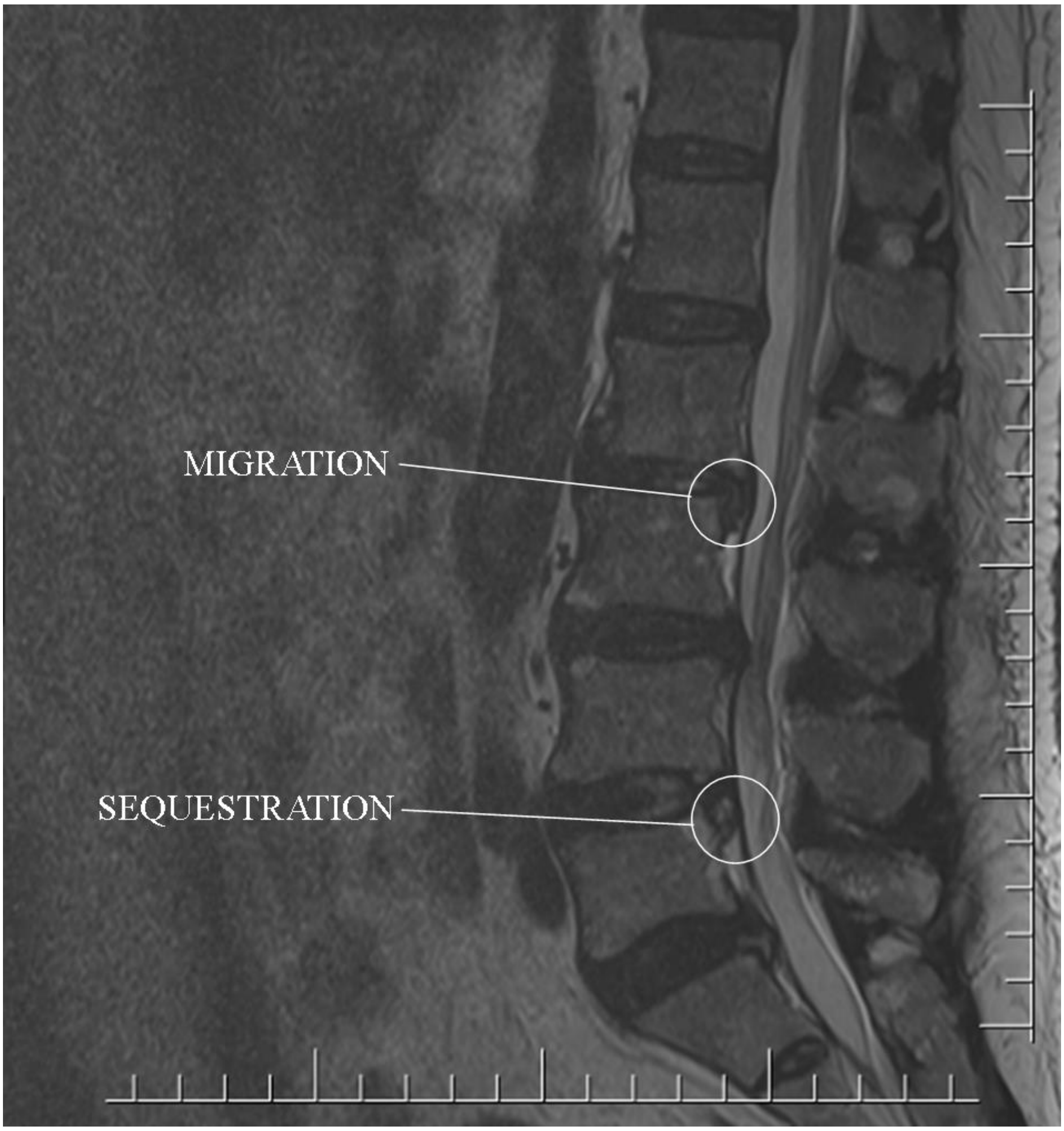

Figure 10: MRI of the lumbar spine showing Migration (displacement of disc material away from the site of extrusion) and Sequestration (displaced disc material that has lost completely any continuity with the parent disc). **Magnification: 0.6 X**

3.6 DATA HANDLING

Both raw and analysed data were kept on a password protected computer to safeguard the data from an authorised access. All images transferred onto CD-Rs were kept in a locked cabinet to ensure adequate safe-guarding of patient data. Confidentiality of patient information was ensured, by limiting access to patients' images as well as all confidential information pertaining to these images to only the principal researcher and the Radiologist who supervised the classification of these images.

3.7 STATISTICAL ANALYSIS

Results obtained from morphometric measurements and classification of disc degeneration were analysed using Microsoft Excel 2010, SPSS software version 20 and Minitab statistical software version 15.

Descriptive statistics of means, standard deviations, minimum and maximum values were used to summarise lumbar morphometric data. Frequencies and percentages were used to summarise disc degeneration grades and classification of disc herniation. Graphs and tables were used to summarize data where applicable. Each disc was considered as a single statistical unit.

A correlation matrix was used to determine if there was a correlation between vertebral body dimensions and age, weight, height and BMI variables. Sex differences in lumbar vertebral morphometry were analysed using independent T tests.

Non parametric analysis (Spearman's correlation) was used to determine associations between age, weight, height, BMI and disc degeneration grades. Chi-square was used to determine the association between gender and disc degeneration grades. Binary logistic regression was used to determine the correlation between age, weight, height, BMI as well as sex and disc herniation.

A statistical significance level was set at $P \leq 0.05$ for this study.

Age of individuals whose images were sampled for this study were grouped based on a modification of WHO's age classification (World Health Organization, 2013). The present study combined WHO classification for infancy, childhood and adolescents and grouped them collectively to span the ages of 0-19. According to WHO, adulthood spans the ages of 20- 59 whiles ages 60 and above are classified as elderly. For the purpose of this study, adulthood was divided into early adulthood (20-39) and late adulthood (40-59). Ages 60 and above were maintained as elderly.

3.8 ETHICAL ISSUES

Ethical clearance was obtained from the Ethical and Protocol Review Committee, College of Health Sciences, University of Ghana. The protocol identification number was MS-Et/M.10-P3.4/2014-2015.

Permission was also obtained from the central administration of the Korle-Bu Teaching Hospital as well as the head of Radiology Unit at the hospital to allow collection of data from their facility. Confidentiality of patient information was ensured at all times by safe guarding patient information on a password protected computer.

CHAPTER 4

RESULTS

4.0 STATISTICS ON NUMBER OF IMAGES SAMPLED

Two hundred and sixty-two (262) names of patients who had taken an MRI examination between March, 2014 and February, 2015 were sampled from the database of the MRI machine at the Radiology Unit of Korle-Bu Teaching Hospital. The Radiology Unit periodically, transfers images from the MRI machine to a Picture Archiving and Communication System (PACS) for long term storage. Out of the 262 names sampled, 40 images could not be retrieved from the Picture Archiving and Communication System.

Out of the 222 images that were retrieved from PACS, only 143 were considered suitable for vertebral body morphometry. Seventy-seven (77) of these valid images were from females and 66 were from males. For the 79 that were considered not suitable, twenty-three (23) had been wrongly labelled. They were either brain, cervical or thoracic images. The remaining 56 images were excluded from the study either because of a fracture, metastasis, deformed vertebrae, scoliosis, spondylolisthesis or due to the images not being clear.

Again, out of the 222 images that were retrieved from PACS, only 171 were considered suitable for disc degeneration analysis. Ninety-three (93) of the valid images were from females while 78 were from males. For the 51 that were considered not suitable, 23 had been wrongly labelled. They were either brain, cervical or thoracic images. The remaining 28 images were excluded from the study either because of a metastasis, surgery, or due to the images not being clear.

Thus for the present study, 143 images were used for vertebral body morphometry and 171 images for disc degeneration analysis.

4.1 ANTHROPOMETRIC VARIABLES

4.1.0 AGE DISTRIBUTION

Age range of subjects whose images were sampled for vertebral morphometry was from 8 years to 82 years with a mean of 51.89 ± 16.26 years. Most of the images (44.1%) belonged to patients in the late adulthood group (40-59 years). The age group which was least represented was 0-19 years. Table 2 shows age group distribution with their corresponding frequencies and percentages. Mean age of females was 52.51 ± 17.76 years while that of males was 51.17 ± 14.42 years. There was no significant difference between the mean age of males and that of females.

For classification of disc degeneration, the age of patients' whose MRI images were used, ranged from 8 to 82 years. Their mean age was 53.24 ± 16.06 years. The age group that was most predominant (42%) was the late adulthood group (40-59 years). The age group which was least represented (2.9%) was 0-19 years. Frequency and percentage distributions for the various age groups are reported in Table 2. The mean age of females was 53.92 ± 16.93 years while that of males was 52.42 ± 15.02 years. The difference in the mean ages of males and that of females, however, was not statistically significant.

Table 2. Age Distribution of Patients

MORPHOMETRIC ANALYSIS (n=143)		
Age Group (Years)	Numbers	Percentage
0-19 (Infancy, Childhood, Adolescents)	4	2.8
20 – 39 (Early Adulthood)	29	20.3
40-59 (Late Adulthood)	63	44.1
60 and over (Elderly)	47	32.9
DISC DEGENERATION ANALYSIS (n= 171)		
0-19 (Infancy, Childhood, Adolescents)	5	2.9
20 – 39 (Early Adulthood)	30	17.5
40-59 (Late Adulthood)	72	42.1
60 and over (Elderly)	64	37.4

4.1.1 WEIGHT DISTRIBUTION

Weight distribution of patients whose images where sampled for vertebral morphometry was from 36 kg to 142 kg. The mean weight of patients was 77.56 ± 16.96 kg. Females had a mean weight of 78.40 ± 18.92 kg while males had a mean weight of 76.58 ±14.41 kg. There was a significant difference between the mean weight of males and that of females with a P- value of 0.011. Confidence interval for this difference is reported in Table 3.

Table 3. Age, Weight, Height and BMI Distribution of Male and Female Patients

Variable	Mean (Females)	Mean (Males)	95% Confidence Interval	t	P-Value
VERTEBRAL MORPHOMETRY					
Age (Years)	52.51 ± 17.76	51.17±14.42	-4.07 to 6.75	0.49	0.080
Weight (kg)	78.40 ± 18.92	76.58±14.41	-3.81 to 7.46	0.64	0.011
Height (cm)	162.53±7.87	170.20±7.57	-10.23 to -5.10	-5.91	0.961
BMI (kg/m^2)	29.67±6.93	26.39±4.32	1.33 to 5.23	3.33	0.001
DISC DEGEENRATION ANALYSIS					
Age (Years)	53.92±16.93	52.42±15.02	-3.375 to 6.38	0.608	0.343
Weight (kg)	79.17±18.95	77.49±15.19	-3.57 to 6.94	0.633	0.014
Height (cm)	162.38±7.67	170.33±7.35	-10.24 to -5.67	-6.882	0.965
BMI (kg/m^2)	30.01±6.92	26.67±4.63	1.53 to 5.15	3.635	0.001

For classification of disc degeneration, the weight of patients whose images where sampled ranged from 36 kg to 142 kg. The overall mean weight of patients was 78.40 ± 17.31 kg. The mean weight of females was 79.17 ± 18.95 kg while that of males was 77.49 ± 15.19 kg. There was a significant difference between the mean weight of males and that of females with a P-value of 0.014. Confidence interval and t-values are reported in Table 3.

4.1.2 HEIGHT DISTRIBUTION

The height of patients whose images were used for vertebral morphometry ranged from 130 cm to 190 cm with a mean height of 166.07 ± 8.61 cm. The mean height of females was 162.53 ± 7.87 cm while that of males was 170.20 ± 7.57 cm. There was no significant difference between mean height of males and that of females.

For classification of disc degeneration, patients' height ranged from 130 cm to 190 cm with a mean height of 166.01 ± 8.49 cm. The mean height of females was 162.38 ± 7.67 cm while that of males was 170.33 ± 7.35 cm. There was no significant difference between the mean heights of males and females. P-value and t-value are reported in Table 3.

4.1.3 BMI DISTRIBUTION

The BMI distributions of patients whose images were used for vertebral morphometry are reported in Table 4. Majority of images (36.4%) sampled for the study belonged to individuals who were overweight (25-29.5 kg/m^2). Only 3 (2.1%) of images sampled belonged to patients who were underweight (below 18.5 kg/m^2). The mean BMI of females was 29.67 ± 6.93 kg/m^2 while that of males was 26.39 ± 4.32 kg/m^2. As shown in Table 3, the difference between the mean BMI of males and that of females was statistically significant (P= 0.001).

For the classification of disc degeneration, BMI of patients whose images were sampled ranged from 16.96 to 53.45 kg/m^2. The mean BMI was 28.49 ± 6.20 kg/m^2. A greater proportion (33.9%) of the patients were overweight (BMI 25-29.9 kg/m^2). Only 3 out of 171 images belonged to persons who were underweight. Frequency and percentage distribution for the various BMI classes are reported in Table 4. Females had a mean BMI of 30.01 ± 6.92 kg/m^2 while that of males was 26.67 ± 4.63 kg/m^2. There was a significant difference between the mean BMI of males and that of females with a P-value of 0.001, as shown in Table 3. BMI classification was adopted from the CDC (2004).

Table 4. BMI of Patients

MORPHOMETRIC ANALYSIS (n=143)		
BMI in kg/m^2	Numbers	Percentage
Below 18.5 (Underweight)	3	2.1
18.5 – 24.9 (Normal)	44	30.8
25 – 29.9 (Overweight)	52	36.4
30 or Higher (Obese)	44	30.8

DISC DEGENERATION ANALYSIS (n=171)		
BMI in kg/m^2	Numbers	Percentage
Below 18.5 (Underweight)	3	1.8
18.5 – 24.9 (Normal)	54	31.6
25 – 29.9 (Overweight)	58	33.9
30 or Higher (Obese)	56	32.7

4.2 VERTEBRAL BODY MEASUREMENTS

The mean anterior height, mid height and posterior height of each lumbar vertebra for all images that met the inclusion criteria are reported in Table 5. Table 5 also reports the means for the anterior wedge (Ha\Hp), biconcavity (Hm\Hp) and compression indices (Hp\D).

The variables measured were compared between males and females. The results for this comparison are also reported in Table 5. Of all the means that were compared, the mid height of L2 vertebra, posterior height of L3 vertebrae, the biconcavity index of L3 vertebra and the compression index of L3 vertebra showed a significant difference between male and female measurements. The mid height of L2 vertebrae was 2.32 cm in females and 2.50 cm in males with a P-value of 0.031. The posterior height of L3 vertebra measured 2.54 cm in females and 2.70 cm in males with a P-value of 0.009. The biconcavity index (Hm\Hp) of L3 vertebra was 0.90 in females and 0.89 in males with a P-value of 0.001. The compression index (Hp\D) of L3 vertebra was 0.96 in females while males had a compression index of 0.93 with a P-value of 0.012.

Table 5 A. Summary of Measurements of Vertebral Bodies (L1 – L2)

Vertebrae	Variable	Mean (All n= 143)	Mean (Females n= 77)	Mean (Males n= 66)	95% Confidence Interval	t- test value	P-Value
	Ha (cm)	2.43±0.25	2.36±0.23	2.51±0.26	-0.23 to -0.07	-3.67	0.294
	Hm(cm)	2.36±0.24	2.26±0.23	2.48±0.20	-0.29 to -0.15	-6.07	0.849
	Hp (cm)	2.64±0.24	2.52±0.21	2.78±0.21	-0.33 to -0.19	-7.34	0.725
L1	D (cm)	2.46±0.28	2.33±0.24	2.63±0.23	-0.38 to -0.22	-7.55	0.828
	Ha/Hp	0.92±0.07	0.94±0.06	0.91±0.08	0.01 to 0.06	2.67	0.127
	Hm/Hp	0.89±0.06	0.89±0.06	0.89±0.06	-0.02 to 0.02	0.18	0.566
	Hp/D	1.08±0.11	1.09±0.12	1.06±0.10	-0.01 to 0.06	1.50	0.134
	Ha (cm)	2.50±0.26	2.43±0.24	2.59±0.25	-0.24 to -0.07	-3.78	0.559
	Hm(cm)	2.40±0.22	2.32±0.22	2.50±0.18	-0.24 to -0.11	-5.24	0.031
	Hp (cm)	2.69±0.26	2.58±0.25	2.81±0.20	-0.31 to -0.16	-6.07	0.384
L2	D (cm)	2.61±0.29	2.47±0.24	2.77±0.26	-0.38 to -0.22	-7.24	0.158
	Ha/Hp	0.93±0.07	0.94±0.06	0.92±0.07	0.00 to 0.05	2.01	0.320
	Hm/Hp	0.89±0.05	0.90±0.06	0.89±0.05	-0.01 to 0.03	1.28	0.442
	Hp/D	1.04±0.12	1.05±0.12	1.02±0.11	-0.01 to 0.07	1.48	0.498

Table 5 B. Summary of Measurements of Vertebral Bodies (L3 – L4)

Vertebrae	Variable	Mean (All n= 143)	Mean (Females n= 77)	Mean (Males n= 66)	95% Confidence Interval	t- test value	P-Value
	Ha (cm)	2.52±0.25	2.46±0.24	2.58±0.24	-0.20 to -0.04	-2.91	0.194
	Hm(cm)	2.34±0.21	2.29±0.23	2.40±0.18	-0.18 to -0.04	-3.15	2.044
	Hp (cm)	2.62±0.25	2.54±0.24	2.70±0.22	-0.24 to -0.08	-4.12	0.009
L3	D (cm)	2.77±0.29	2.65±0.25	2.92±0.26	-0.36 to -0.19	-6.42	1.751
	Ha/Hp	0.96±0.07	0.97±0.08	0.96±0.07	-0.01 to 0.04	1.28	0.505
	Hm/Hp	0.90±0.06	0.90±0.06	0.89±0.06	-0.01 to 0.03	1.25	0.001
	Hp/D	0.95±0.11	0.96±0.11	0.93±0.10	0.00 to 0.07	1.83	0.012
	Ha (cm)	2.48±0.27	2.46±0.26	2.51±0.28	-0.14 to 0.03	-1.21	0.958
	Hm(cm)	2.27±0.23	2.22±0.23	2.33±0.21	-0.18 to -0.03	-2.79	0.680
	Hp (cm)	2.46±0.24	2.39±0.21	2.54±0.25	-0.23 to -0.08	-4.01	2.165
L4	D (cm)	2.89±0.28	2.81±0.31	2.98±0.23	-0.26 to -0.08	-3.68	1.729
	Ha/Hp	1.01±0.09	1.03±0.08	0.99±0.10	0.01 to 0.07	2.51	2.598
	Hm/Hp	0.93±0.07	0.93±0.07	0.92±0.08	-0.01 to 0.04	1.11	1.416
	Hp/D	0.86±0.10	0.86±0.10	0.86±0.11	-0.04 to 0.03	-0.14	1.315

Table 5 C. Summary of Measurements of Vertebral Body (L5)

Vertebrae	Variable	Mean (All n= 143)	Mean (Females n= 77)	Mean (Males n= 66)	95% Confidence Interval	t- test value	P-Value
	Ha (cm)	2.59±0.26	2.52±0.25	2.67±0.26	-0.24 to -0.07	-3.63	0.700
	Hm(cm)	2.23±0.25	2.16±0.23	2.31±0.24	-0.23 to -0.07	-3.73	0.656
	Hp (cm)	2.29±0.26	2.23±0.23	2.36±0.27	-0.22 to -0.05	-3.18	0.224
L5	D (cm)	2.94±0.31	2.84±0.32	3.07±0.24	-0.33 to -0.14	-4.84	0.452
	Ha/Hp	1.14±0.10	1.14±0.10	1.14±0.11	-0.04 to 0.03	-0.14	0.471
	Hm/Hp	0.98±0.08	0.97±0.08	0.98±0.09	-0.04 to 0.02	-0.72	0.509
	Hp/D	0.79±0.10	0.79±0.10	0.77±0.10	-0.01 to 0.05	1.15	0.975

4.2.1 CORRELATION BETWEEN ANTHROPOMETRIC VARIABLES AND VERTEBRAL MEASUREMENTS

A stepwise regression was done to determine the correlation between all vertebral body measurements and age, weight, height as well as BMI values. The results of these analyses are shown in Table 6. Weight and BMI showed no correlation with any of the morphometric measurements for all vertebral levels analysed. Height showed a significant correlation with anterior height (Ha), posterior height (Hp), mid height (Hm) and anteroposterior diameter (D) across all lumbar vertebral levels. A P-value of 0.001 was obtained for all vertebral levels (Table 6). Age was positively correlated with the compression index of L2, L3, L4, and L5 vertebra. Linear equations were generated from variables that showed significant positive correlation with morphometric measurements. The correlation between age and other morphometric variables at various vertebral levels as well as their respective linear equations generated are shown in Table 6.

Table 6 A. Correlation between Vertebrae (L1 – L3) Measurements and Anthropometric Variables

Vertebrae	Morphometric Variable	Linear Equations of Anthropometric Variables that showed significant correlation
	Ha	Ha = - 0.300 + 0.0164 x Height(cm), P=0.001
L1	Hm	Hm = - 0.375 + 0.0164 x Height(cm), P=0.001
	Hp	Hp = - 0.477 + 0.0188 x Height(cm), P=0.001
	D	D = - 0.090 + 0.0154 x Height(cm), P=0.001
	Ha	Ha = - 0.233 + 0.0165 x Height(cm), P=0.001
	Hm	Hm = - 0.138 + 0.0153 x Height(cm), P=0.001
L2	Hp	Hp = - 0.715 + 0.0205 x Height(cm), P=0.001
	D	D = 0.068 + 0.0153 x Height(cm), P=0.001
	Hm/Hp	Hm/Hp = 1.11 - 0.00129 x Height(cm),P = 0.013
	Hp/D	Hp/D = 1.11 - 0.00145 x Age, P = 0.016
	Ha	Ha = - 0.284 + 0.0169 x Height(cm), P = 0.001
	Hm	Hm = 0.262 + 0.0125 x Height(cm), P = 0.001
L3	Hp	Hp = - 0.058 + 0.0161 x Height(cm), P = 0.001
	D	D = 0.097 + 0.0161 x Height(cm), P = 0.001
	Hp/D	Hp/D = 1.04 - 0.00179 x Age, P = 0.001

Table 6 B. Correlation between Vertebrae (L4 – L5) Measurements and Anthropometric Variables

Vertebrae	Morphometric Variable	Linear Equations of Anthropometric Variables that showed significant correlation
	Ha	Ha = 0.013 + 0.0149 x Height(cm), P = 0.001
	Hm	Hm = 0.026 + 0.0135 x Height(cm), P = 0.001
		Hm = 2.43 - 0.00312 x Age, P = 0.007
L4	Hp	Hp = - 0.347 + 0.0169 x Height(cm), P= 0.001
	D	D = 0.830 + 0.0124 x Height(cm), P= 0.001
		D = 2.68 + 0.00404 x Age, P = 0.006
	Hp/D	Hp/D = 0.965 - 0.00204 x Age, P = 0.001
	Ha	Ha = - 0.149 + 0.0165 x Height(cm), P = 0.001
		Ha = 2.78 - 0.00370 x Age, P = 0.006
	Hm	Hm = - 0.430 + 0.0160 x Height(cm), P = 0.001
		Hm = 2.40 - 0.00332 x Age, P = 0.009
	Hp	Hp = - 0.421 + 0.0163 x Height(cm), P = 0.001
		Hp = 2.48 - 0.00351 x Age, P = 0.008
L5	D	D = 0.292 + 0.0160 x Height(cm), P = 0.001
		D = 2.71 + 0.00459 x Age, P = 0.004
	Hp/D	Hp/D = 0.905 - 0.00232 x Age, P = 0.001

4.3 DISC DEGENERATION ANALYSIS

Intervertebral discs were examined and classified into degeneration grades using Pfirrmann's system. Disc 1, 2, 3, 4 and 5 represented the first to fifth lumbar intervertebral discs respectively. Disc degeneration grades I and II were classified as normal while grades III, IV and V were classified as degenerated as was done by Takatalo *et al*. (2009).

Frequencies of disc degeneration grades are reported for the various disc levels in Table 7 below. Disc degeneration grade III was most frequent (42.7%) among the first lumbar intervertebral discs. Grade IV was the most frequent grade observed among discs 2, 3, 4, and 5 with frequencies of 50.3%, 59.6%, 62.6% and 55.6%, respectively. Grade I was least observed at the second lumbar intervertebral disc level compared to the other disc levels. A grade I was most frequently observed at the 5th intervertebral disc level than at any other disc level as shown in Table 7. Similarly, a grade V was most frequently observed at the 4th intervertebral disc level. Over 80% of intervertebral discs showed degeneration at the various disc levels. Intervertebral disc 3 recorded the highest occurrence of disc degeneration (84.2%). Over all, disc degeneration increased for the first 3 intervertebral discs (disc 1= 81.3%, disc 2= 82.5% and disc 3= 84.2%) and subsequently decreased at disc 4 and 5 (81.9% and 81.4% respectively).

Table 7. Distribution of Disc Degeneration Grades

Disc Level		Normal Grades I	II	**Totals**	Degenerated Grades III	IV	V	**Totals**
Disc 1	Occurrence	4	28	**32**	73	61	5	**139**
	Percentage	2.3	16.4	**18.7**	42.7	35.7	2.9	**81.3**
Disc 2	Occurrence	3	27	**30**	46	86	9	**141**
	Percentage	1.8	15.8	**17.6**	26.9	50.3	5.3	**82.5**
Disc 3	Occurrence	5	22	**27**	33	102	9	**144**
	Percentage	2.9	12.9	**15.8**	19.3	59.6	5.3	**84.2**
Disc 4	Occurrence	4	27	**31**	21	107	12	**140**
	Percentage	2.3	15.8	**18.1**	12.3	62.6	7	**81.9**
Disc 5	Occurrence	8	24	**32**	36	95	8	**139**
	Percentage	4.7	14.0	**18.7**	21.1	55.6	4.7	**81.4**

Table 8. Distribution of Disc Herniation Types

		Type of Disc Herniation							
Disc Level		None	P	E	S	IntVert only	P + IV	E + IV	E + M
Disc 1	Occurrence	135	19	3	0	2	12	0	0
	Percentage	78.9	11.1	1.8	0	1.2	7	0	0
Disc 2	Occurrence	102	43	5	0	3	14	3	1
	Percentage	59.6	25.1	2.9	0	1.8	8.2	1.8	0.6
Disc 3	Occurrence	89	53	6	0	3	18	1	1
	Percentage	52	31	3.5	0	1.8	10.5	0.6	0.6
Disc 4	Occurrence	46	89	19	1	0	11	4	1
	Percentage	26.9	52.1	11.1	0.6	0	6.4	2.3	0.6
Disc 5	Occurrence	66	68	31	0	0	3	2	1
	Percentage	38.6	39.8	18.1	0	0	1.8	1.2	0.6

KEY P= Protrusion, E= Extrusion, S=Sequestration, IntVert= Intravertebral Herniation, M= Migration

Frequency and percentage distribution of disc herniation types are shown in Table 8. Protrusions were the most common type of herniation observed amongst the various disc levels as shown in Table 8. Sequestration was the least observed with a frequency of one. This frequency was only observed at the 4th intervertebral disc. A combination of different types of herniation were also noted, details of which are reported in Table 8. Extrusion with migration of disc material was observed at disc 2, 3, 4 and 5 with a frequency of one reported at each level.

4.3.0 DISC DEGENERATION AND AGE

The age group 0-19 showed no degeneration in the first four intervertebral discs (Figure 11). Degeneration was observed only at the 5th intervertebral disc and this occurred in only one individual. A degeneration grade of II occurred most frequently among this age group for all intervertebral disc levels (Table 9). Among the group, disc herniation was absent for intervertebral discs 1, 2 and 3. There was however one protrusion recorded in the 4th intervertebral disc and one extrusion recorded in the 5th intervertebral disc among the 0-19 age group.

For age group 20-39, fewer occurrences of disc degeneration were observed, with less than half the population showing degeneration at various disc levels (Table 9). Disc degeneration grade II was most frequent at all intervertebral disc levels. The age group 20-39 showed herniation trends that increased down the lumbar vertebral column and this is illustrated in Figure 12. Frequencies of herniation were 1, 2, 4, 10 and 11 respectively for discs 1-5 (Table 10). Protrusion was the most frequent type of herniation observed among the 20-39 age group.

Table 9. Synopsis of Disc Degeneration among Age Groups

Disc Level		Occurrence of Disc Degeneration Among Age Groups (in years) 0-19	20 - 39	40-59	60 and over
Disc 1	Grade I	2	2	0	0
	Grade II	3	16	8	1
	Grade III	**0**	**10**	**42**	**21**
	Grade IV	**0**	**2**	**20**	**39**
	Grade V	**0**	**0**	**2**	**3**
	TOTAL DEGENERATION	0/5	12/30	64/72	63/64
Disc 2	Grade I	1	2	0	0
	Grade II	4	14	8	1
	Grade III	**0**	**9**	**30**	**7**
	Grade IV	**0**	**5**	**32**	**49**
	Grade V	**0**	**0**	**2**	**7**
	TOTAL DEGENERATION	0/5	14/30	64/72	63/64
Disc 3	Grade I	1	4	0	0
	Grade II	4	12	5	1
	Grade III	**0**	**7**	**22**	**4**
	Grade IV	**0**	**7**	**41**	**54**
	Grade V	**0**	**0**	**4**	**5**
	TOTAL DEGENERATION	0/5	14/30	67/72	63/64
Disc 4	Grade I	1	3	0	0
	Grade II	4	17	5	1
	Grade III	**0**	**3**	**14**	**4**
	Grade IV	**0**	**6**	**47**	**54**
	Grade V	**0**	**1**	**6**	**5**
	TOTAL DEGENERATION	0/5	10/30	67/72	63/64
Disc 5	Grade I	1	5	2	0
	Grade II	3	11	9	1
	Grade III	**1**	**7**	**20**	**8**
	Grade IV	**0**	**7**	**37**	**51**
	Grade V	**0**	**0**	**4**	**4**
	TOTAL DEGENERATION	1/5	14/30	61/72	63/64

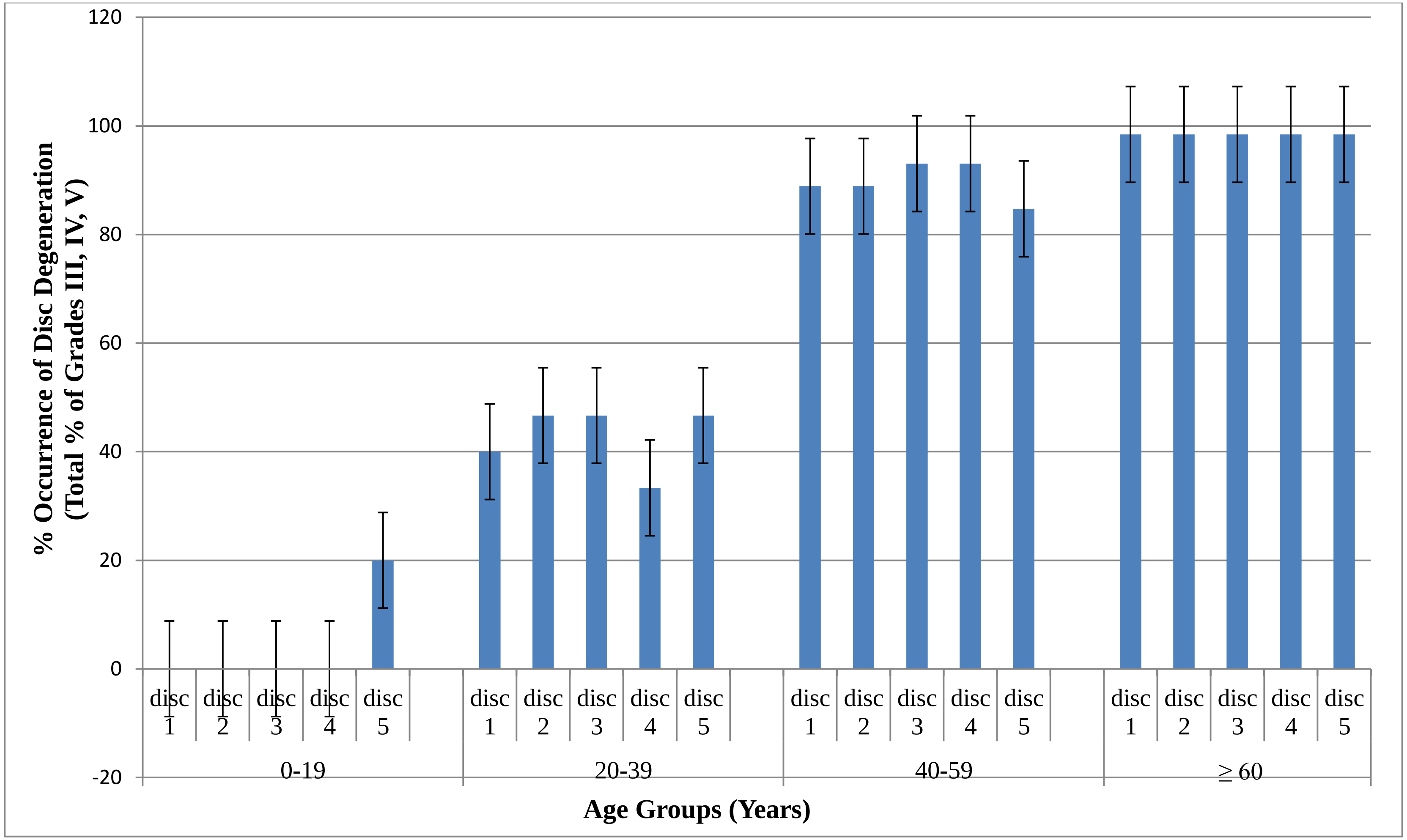

Figure 11: Bar Chart Showing Occurrence of Disc Degeneration among Age Groups

Among individuals 40-59 years, 64 images belonging to this group showed dis degeneration in the 1st and 2nd intervertebral discs. Sixty-seven out of the 72 discs were found to have degenerations at the 3rd and 4th intervertebral disc levels while 61 out of 72 discs showed degeneration at the 5th intervertebral disc level. A grade III was most frequent among the 40-59 age group for the first intervertebral disc level but grade IV was most frequent for all other levels. The frequency of disc herniation increased progressively from the first intervertebral disc level to the 4th and then decreased slightly at disc 5 among the late adults (40-59) as shown in Figure 12.

Degeneration was very high among the elderly (60 years and more) with disc degeneration occurring at all intervertebral disc levels in 63 out of 64 elderly persons. A disc degeneration grade of IV was most frequently observed among the elderly (Table 9). The frequency of disc herniation increased from disc 1 to disc 4 but decreased slightly at disc 5 (Figure 12). Protrusion was the most frequent type of disc herniation observed among the elderly (Table 10).

Figure 11 shows the trend of disc degeneration (grades III, IV, V) among the various age groups. From Figure 11, disc degeneration was most frequent among age groups 40-59 and ≥60 with over 98% of intervertebral discs of elderly persons showed degeneration at all disc levels. There was however no significant difference between the levels of degeneration among the 40-59 and ≥60 age groups when their error bars were compared. However, the level of degeneration was higher among late adulthood (40-59) than early adulthood (20-39) and this was statistically significant for all disc levels when their error bars were compared for both age groups as shown in Figure 11.

Table 10. Occurrence of Disc Herniation Types among Age Groups

Disc Level	Type of Herniation	AGE GROUPS (in years) 0-19	20-39	40-59	≥ 60
	None	5	29	55	46
	Extrusion	0	0	0	3
Disc 1	Intravertebral Herniation	0	0	2	0
	Protrusion	0	0	8	11
	Protrusion + Intravertebral Herniation	0	1	7	4
	TOTAL NUMBER OF HERNIATION (36)	**0**	**1**	**17**	**18**
	None	5	28	42	27
	Extrusion	0	0	2	3
	Extrusion + Intravertebral Herniation	0	0	0	3
Disc 2	Extrusion + Migration	0	0	0	1
	Intravertebral Herniation	0	0	2	1
	Protrusion	0	2	17	24
	Protrusion + Intravetebral Herniation	0	0	9	5
	TOTAL NUMBER OF HERNIATION (69)	**0**	**2**	**30**	**37**
	None	5	26	37	21
	Extrusion	0	0	2	4
	Extrusion + Intravertebral Herniation	0	0	1	0
Disc 3	Extrusion + Migration	0	0	0	1
	Intravertebral Herniation	0	0	0	3
	Protrusion	0	4	22	27
	Protrusion + Intravertebral Herniation	0	0	10	8
	TOTAL NUMBER OF HERNIATION (82)	**0**	**4**	**35**	**43**
	None	4	20	13	9
	Extrusion	0	1	8	10
	Extrusion + Intravertebral Herniation	0	0	3	1
Disc 4	Extrusion + Migration	0	1	0	0
	Protrusion	1	6	44	38
	Protrusion + Intravertebral Herniation	0	2	4	5
	Sequestration	0	0	0	1
	TOTAL NUMBER OF HERNIATION (125)	**1**	**10**	**59**	**55**
	None	4	19	26	17
	Extrusion	1	3	13	14
	Extrusion + Intravertebral Herniation	0	0	1	1
Disc 5	Extrusion + Migration	0	0	0	1
	Protrusion	0	8	32	28
	Protrusion + Intravertebral Herniation	0	0	0	3
	TOTAL NUMBER OF HERNIATION (105)	**1**	**11**	**46**	**47**

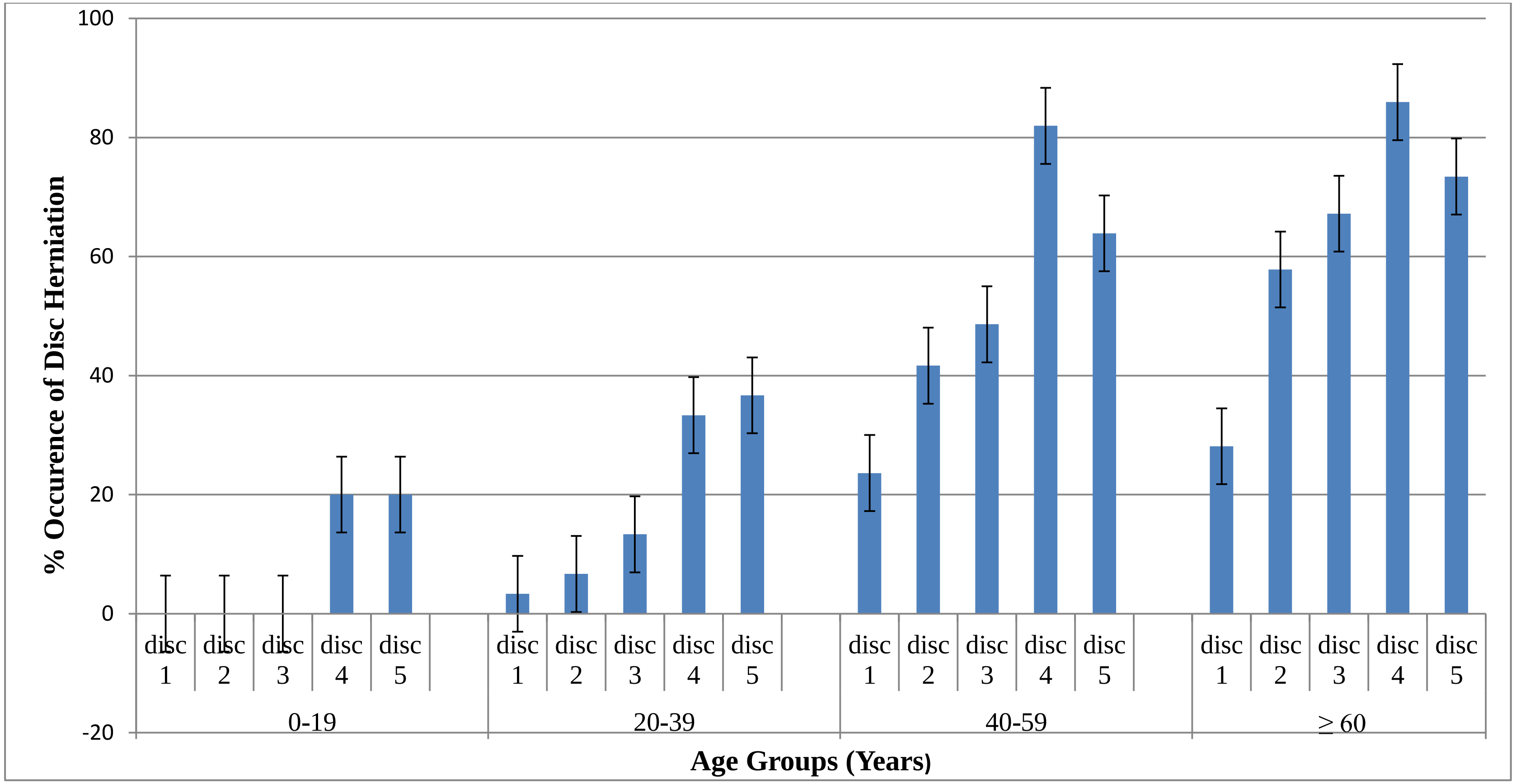

Figure 12: Bar Chart showing Occurrence of Disc Herniation among Age Groups

Further test to determine the correlation between age and disc degeneration showed a significant positive correlation with P-value of 0.001 for all disc levels. The respective correlation coefficients and P-values are reported in Table 15.

The trend of disc herniation among the various age groups is illustrated in Figure 12. The frequency of disc herniation was highest among the late adulthood (40-59 years) and elderly (60 or more) age groups. The proportion of herniation among these two groups was compared using the error bars from Figure 12. Herniation was found to be most prevalent among the elderly (60 or more) for all intervertebral discs levels but this was statistically significant only at the 2nd and 3rd disc levels (P= 0.028 and 0.013, respectively). For all age groups, protrusion was the most common type of disc herniation observed. A binary logistic regression was done to determine the association between age and disc herniation. For all disc levels, age was significantly correlated with disc herniation (Table 16).

4.3.1 DISC DEGENERATION AND BMI

Among underweight (BMI below 18.5 kg/m^2) individuals, only one occurrence of degeneration was observed at all intervertebral disc levels (Table 11). In addition, disc herniation occurred at disc 1, 2 and 5 with a frequency of one at each level. The highest occurrence of disc herniation (1/3) at the first intervertebral disc was observed among underweight individuals (Table 12).

Among individuals with normal BMI (18.5 - 24.9 $kg/m^{2)}$, 42 persons out of 54, showed degeneration in the first two intervertebral discs, while 44, 43 and 41 showed degeneration in the 3rd 4th and 5th intervertebral discs respectively (Table 11). Degeneration progressed from grade III in disc 1 to grade IV in discs 2, 3, 4 and 5 among normal individuals. Their respective frequencies are also reported in Table 11.

Table 11. Disc Degeneration among BMI Classes

Disc level		Occurrence of Disc Degeneration Grades (BMI Classes) <18.5	18.5 – 24.9	25 – 29.9	≥30
Disc 1	Grade I	0	2	1	1
	Grade II	2	10	12	4
	Grade III	**0**	**20**	**25**	**28**
	Grade IV	**1**	**21**	**19**	**20**
	Grade V	**0**	**1**	**1**	**3**
	TOTAL DEGENERATION	1/3	42/54	45/58	51/56
Disc 2	Grade I	0	2	1	0
	Grade II	2	10	11	4
	Grade III	**0**	**13**	**17**	**16**
	Grade IV	**1**	**26**	**27**	**32**
	Grade V	**0**	**3**	**2**	**4**
	TOTAL DEGENERATION	1/3	42/54	46/58	52/56
Disc 3	Grade I	2	1	1	1
	Grade II	0	9	9	4
	Grade III	**1**	**6**	**16**	**10**
	Grade IV	**0**	**35**	**30**	**37**
	Grade V	**0**	**3**	**2**	**4**
	TOTAL DEGENERATION	1/3	44/54	48/58	51/56
Disc 4	Grade I	1	1	1	1
	Grade II	1	10	12	4
	Grade III	**1**	**7**	**7**	**6**
	Grade IV	**0**	**33**	**34**	**40**
	Grade V	**0**	**3**	**4**	**5**
	TOTAL DEGENERATION	1/3	43/54	45/58	51/56
Disc 5	Grade I	1	3	2	2
	Grade II	1	10	12	1
	Grade III	**0**	**12**	**11**	**13**
	Grade IV	**1**	**26**	**31**	**37**
	Grade V	**0**	**3**	**2**	**3**
	TOTAL DEGENERATION	1/3	41/54	44/58	53/56

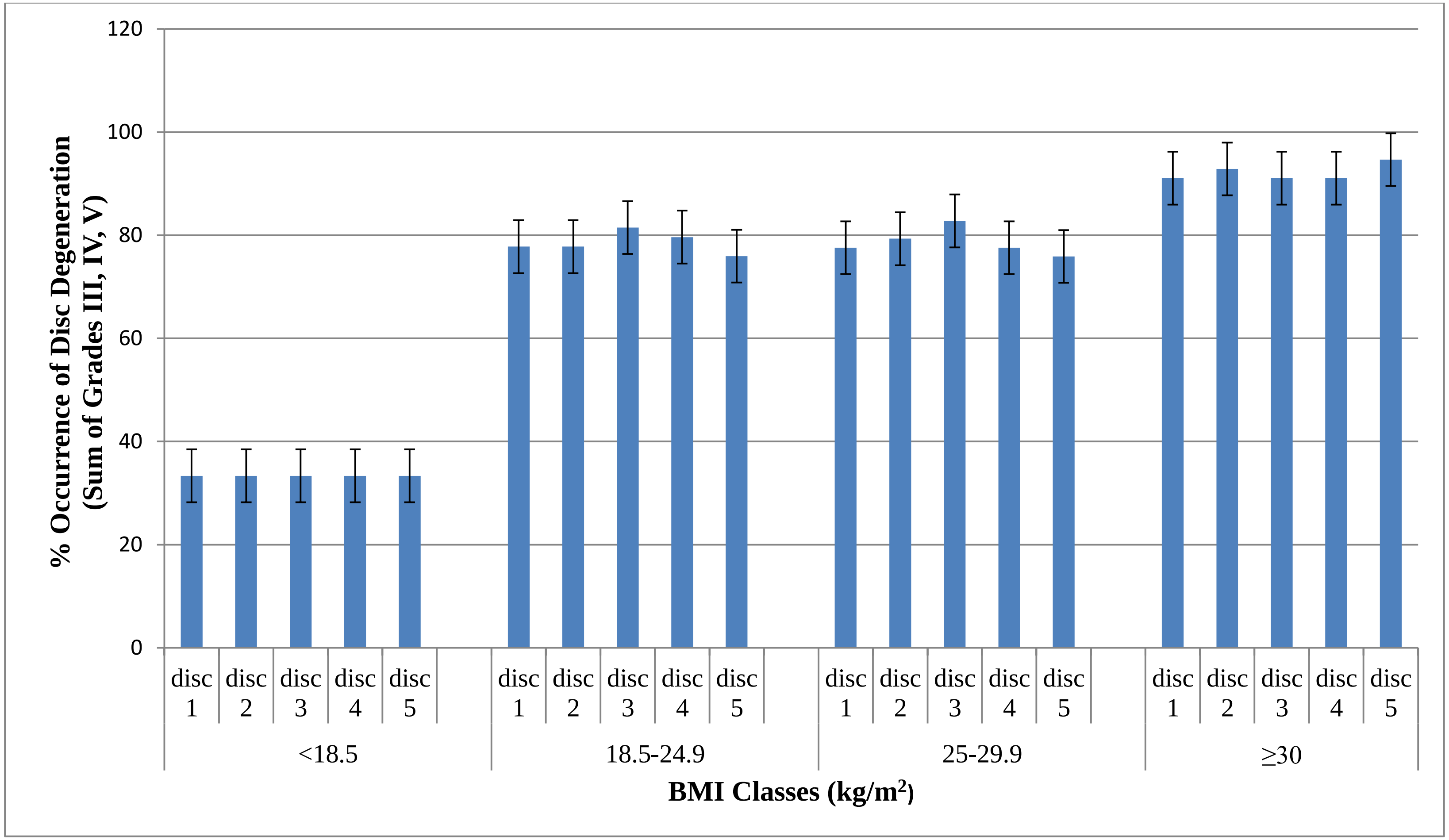

Figure 13: Bar Chart Showing Occurrence of Disc Degeneration among BMI Classes

Protrusion was the most frequent type of herniation observed among normal individuals (BMI 18.5-24.9 kg/m^2). The frequency of herniation for this group increased from disc 1 to 4 and decreased at disc 5 (Figure 14). Respective frequencies are reported in Table 12.

Overweight individuals, exhibited an increasing trend of disc degeneration from disc 1 to 3 and then a subsequent gradual decrease from disc 4 to 5 (Figure 13). The respective frequencies of degeneration for the various intervertebral disc levels are reported in Table 11. Also within the overweight BMI group (25-29.9 kg/m^2), protrusion with intravertebral herniation was most frequent (1 out of 3) at the first intervertebral disc level. Among intervertebral discs 2 to 5, protrusion was the most frequent type of herniation observed. As shown in Figure 14, the total frequency of herniation increased from discs 1 to 4 and decreased at disc 5 in overweight individuals.

Patients whose BMI was 30 kg/m^2 or more recorded the highest frequencies of disc degeneration as shown in Figure 13. A disc degeneration grade of III was most frequent at the first intervertebral disc level while a degeneration grade of IV was frequent among the other intervertebral discs of individuals within the obese BMI group (BMI 30 kg/m^2 and above) as shown in Table 11. Protrusion was also the most frequent type of herniation among the obese BMI group (30 kg/m^2 or higher). As was observed among normal and overweight individuals, the frequency of herniation for obese individuals increased from disc 1 to 4 and then decreased at disc 5 (Table 12).

Figure 13 shows the extent of disc degeneration (grades III, IV, V) among BMI classes. Degeneration was most prominent among obese individuals (BMI 30 kg/m^2 and above) with over 90% of intervertebral discs showing degeneration at all disc levels. Comparison of the proportions of disc degeneration among obese and overweight individuals showed a significant difference at the 1^{st}, 2^{nd}, 4^{th} and 5^{th} intervertebral discs with P-values of 0.022, 0.016, 0.022 and 0.002 respectively. There was, however, no significant difference between proportions of disc degeneration among normal and overweight individuals.

Further analysis was carried out to determine the correlation between BMI, weight, height and disc degeneration. The analysis revealed a significant positive correlation between weight and degeneration in the 5^{th} intervertebral disc (Table 15). Height showed a significant negative correlation with disc degeneration at the 1^{st} and 2^{nd} intervertebral discs levels. BMI was positively correlated with disc degeneration at the 4^{th} and 5^{th} intervertebral disc levels and this was statistically significant (Table 15). There was however no significant correlation between BMI, weight and height of individuals, with disc herniation for all intervertebral disc levels as observed in Table 16.

Table 12 A. Occurrence of Disc Herniation among BMI Classes (Discs 1 – 2)

		Occurrence among BMI Classes			
Disc Level	Type of Herniation	<18.5	18.5– 24.9	25 –29.9	≥ 30
Disc 1	None	2	47	48	38
	Extrusion	0	0	0	3
	Intravertebral Herniation	0	0	1	1
	Protrusion	0	6	4	9
	Protrusion + Intravertebral Herniation	1	1	5	5
	TOTAL NUMBER OF HERNIATION	**1/3**	**7/54**	**10/58**	**18/56**
Disc 2	None	2	31	39	30
	Extrusion	0	2	1	2
	Extrusion + Intravertebral Herniation	0	0	0	3
	Extrusion + Migration	0	0	1	0
	Intravertebral Herniation	0	1	2	0
	Protrusion	0	17	12	14
	Protrusion + Intravetebral Herniation	1	3	3	7
	TOTAL NUMBER OF HERNIATION	**1/3**	**23/54**	**19/58**	**26/56**

Table 12 B. Occurrence of Disc Herniation among BMI Classes (Discs 3 – 4)

		Occurrence among BMI Classes			
Disc Level	Type of Herniation	<18.5	18.5– 24.9	25 –29.9	≥ 30
Disc 3	None	3	25	36	25
	Extrusion	0	3	0	3
	Extrusion + Intravertebral Herniation	0	0	0	1
	Extrusion + Migration	0	0	0	1
	Intravertebral Herniation	0	2	0	1
	Protrusion	0	20	16	17
	Protrusion + Intravertebral Herniation	0	4	6	8
	TOTAL NUMBER OF HERNIATION	**0/3**	**29/54**	**22/58**	**31/56**
Disc 4	None	3	17	14	12
	Extrusion	0	9	6	4
	Extrusion + Intravertebral Herniation	0	1	0	3
	Extrusion + Migration	0	0	1	0
	Protrusion	0	23	33	33
	Protrusion + Intravertebral Herniation	0	4	3	4
	Sequestration	0	0	1	0
	TOTAL NUMBER OF HERNIATION	**0/3**	**37/54**	**44/58**	**44/56**

Table 12 C. Occurrence of Disc Herniation among BMI Classes (Disc 5)

		Occurrence among BMI Classes			
Disc Level	Type of Herniation	<18.5	18.5– 24.9	25 –29.9	≥ 30
	None	2	26	22	16
	Extrusion	1	9	8	13
	Extrusion + Intravertebral Herniation	0	0	0	2
Disc 5	Extrusion + Migration	0	0	1	0
	Protrusion	0	18	26	24
	Protrusion + Intravertebral Herniation	0	1	1	1
	TOTAL NUMBER OF HERNIATION	**1/3**	**28/54**	**36/58**	**40/56**

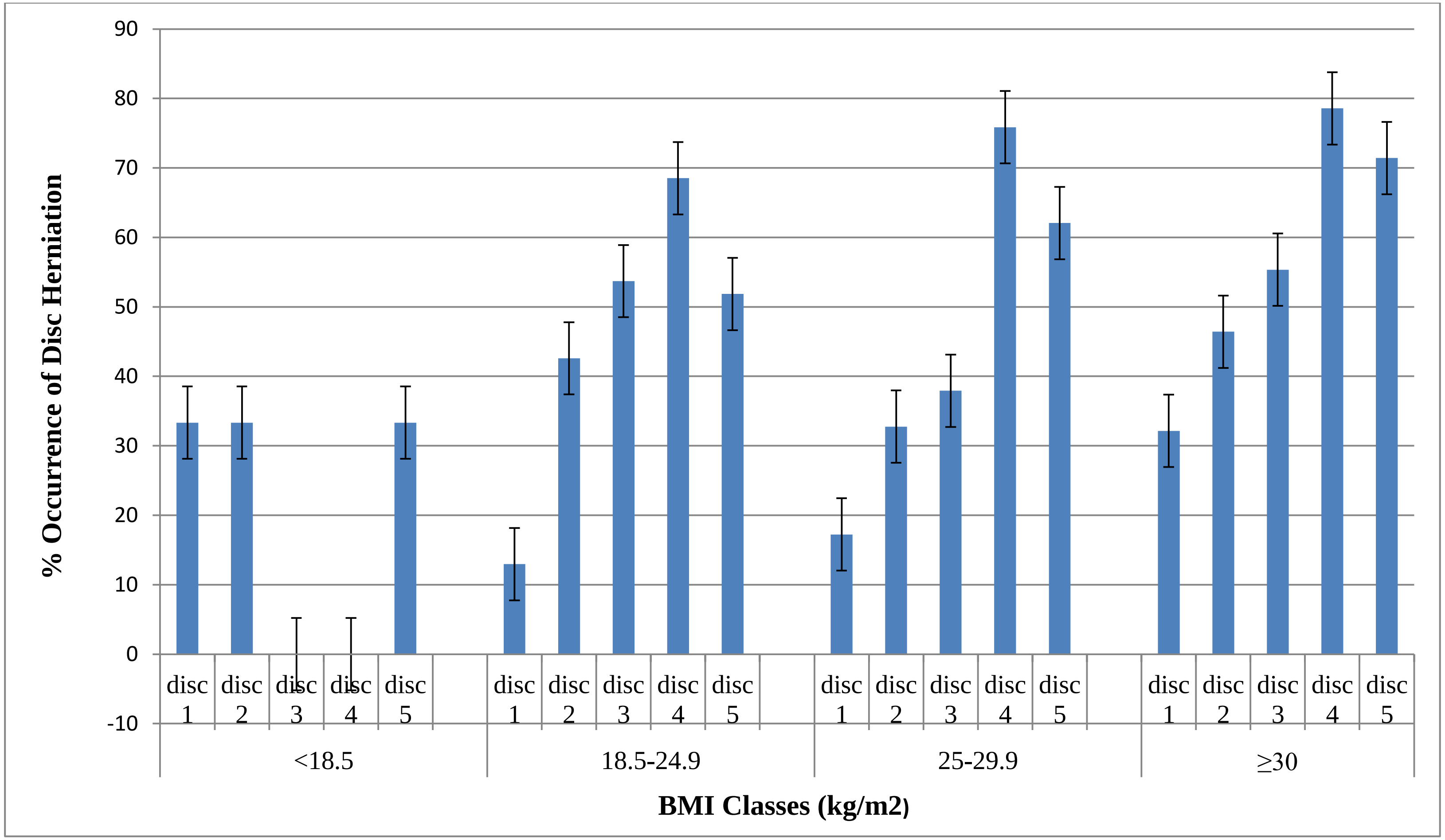

Figure 14: Bar Chart Showing Occurrence of Disc Herniation among BMI Groups

4.3.2 DISC DEGENERATION AND SEX

Among females, disc degeneration progressed from grade III at the first intervertebral disc to grade IV at discs 2, 3, 4 and 5. Respective frequencies of these grades are reported in Table 13. In males a degeneration grade of III was most frequent at the first intervertebral disc and grade IV was most frequent in the other disc.

Figure 15 shows the level of disc degeneration (grade III, IV, V) among males and that of females. Degeneration was more prominent in males for disc levels 1 to 4. However, disc 5 showed a higher level of degeneration in females than in males. The difference in proportion of degeneration among males and females was not statistically significant. A further analysis using chi-square showed no association between gender and disc degeneration (P-values are shown in Table 15).

As shown in Table 14, protrusion was the most frequent type of herniation that occurred among males and females across all disc levels. The total frequency of herniation for both sexes increased from disc 1 to 4 but decreased at disc 5 as shown in Figure 16. The total frequency of occurrence of disc herniation among females and males for each intervertebral disc level are reported in Table 14.

A binary logistic regression was performed to determine the association between gender and disc herniation. A significant positive correlation was observed only at the first intervertebral disc level (P- value 0.035).

Table 13. Disc Degeneration Grades and Sex

		Occurrence of Disc Degeneration Grades		
	SEX	Females	Males	
Disc 1	Grade I	3	1	Chi square
	Grade II	16	12	value=2.433
	Grade III	**39**	**34**	
	Grade IV	**31**	**30**	P-Value
	Grade V	**4**	**1**	0.657
	TOTAL DEGENERATION	74/93	65/78	
Disc 2	Grade I	1	2	Chi square
	Grade II	16	11	value=7.933
	Grade III	**18**	**28**	
	Grade IV	**51**	**35**	P-Value
	Grade V	**7**	**2**	0.094
	TOTAL DEGENERATION	76/93	65/78	
Disc 3	Grade I	5	0	Chi square
	Grade II	10	12	value=6.812
	Grade III	**15**	**18**	
	Grade IV	**59**	**43**	P-Value
	Grade V	**4**	**5**	0.146
	TOTAL DEGENERATION	78/93	66/78	
Disc 4	Grade I	3	1	Chi square
	Grade II	14	13	value=2.018
	Grade III	**13**	**8**	
	Grade IV	**58**	**49**	P-Value
	Grade V	**5**	**7**	0.733
	TOTAL DEGENERATION	76/93	64/78	
Disc 5	Grade I	3	5	Chi square
	Grade II	11	13	value=4.136
	Grade III	**17**	**19**	
	Grade IV	**58**	**37**	P-Value
	Grade V	**4**	**4**	0.388
	TOTAL DEGENERATION	79/93	60/78	

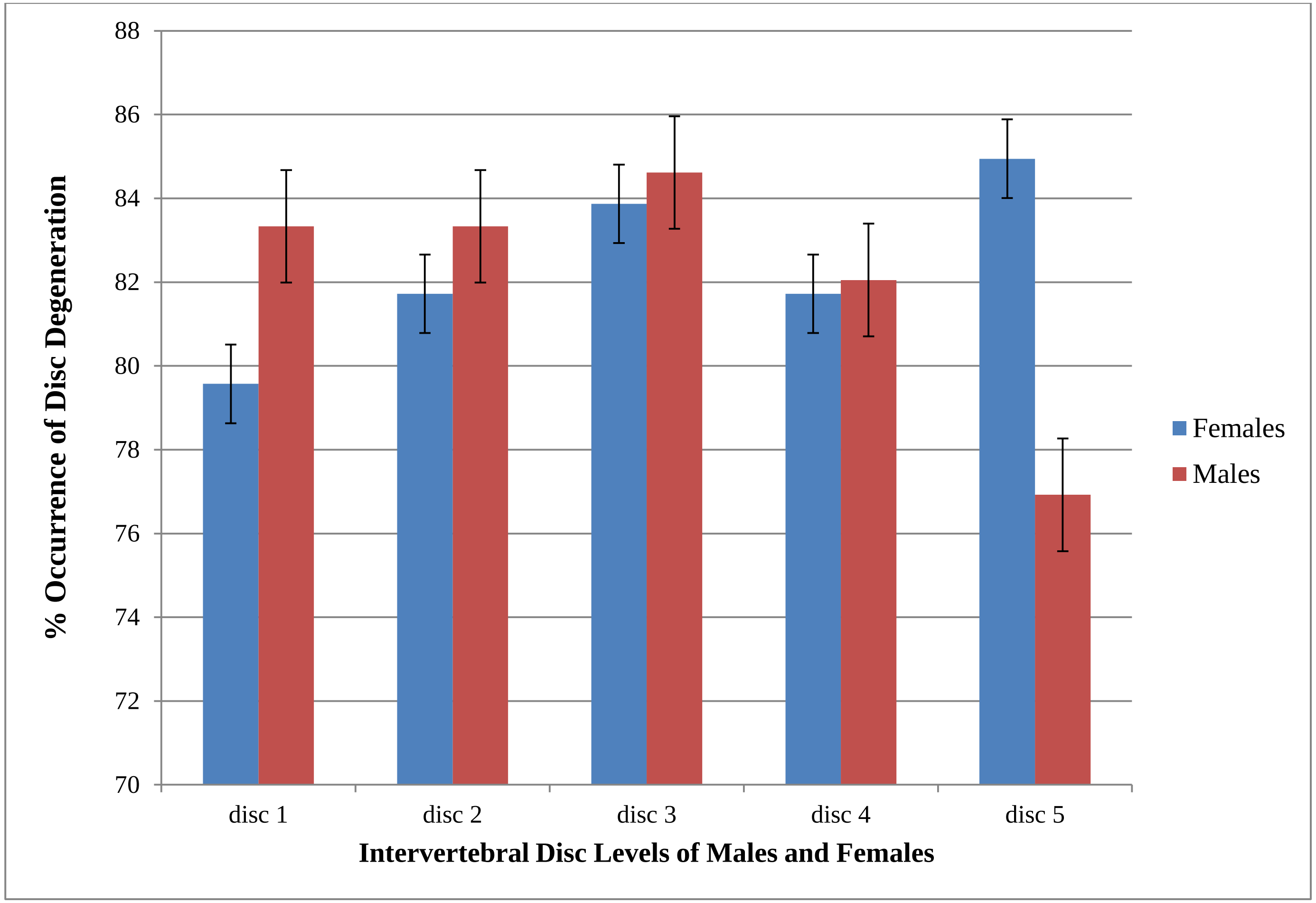

Figure 15: Bar Chart Showing Occurrence of Disc Degeneration among Males and Females

Table 14 A. Occurrence of Disc Herniation Types among Males and Females (Discs 1 – 3)

		SEX	
Disc Level	Type of Herniation	Females	Males
	None	79	56
	Extrusion	2	1
Disc 1	Intravertebral Herniation	0	2
	Protrusion	8	11
	Protrusion + Intravertebral Herniation	4	8
	TOTAL NUMBER OF HERNIATION (36)	**14**	**22**
	None	55	47
	Extrusion	3	2
	Extrusion + Intravertebral Herniation	3	0
Disc 2	Extrusion + Migration	0	1
	Intravertebral Herniation	0	3
	Protrusion	27	16
	Protrusion + Intravetebral Herniation	5	9
	TOTAL NUMBER OF HERNIATION (69)	**38**	**31**
	None	50	39
	Extrusion	4	2
	Extrusion + Intravertebral Herniation	0	1
Disc 3	Extrusion + Migration	0	1
	Intravertebral Herniation	2	1
	Protrusion	28	25
	Protrusion + Intravertebral Herniation	9	9
	TOTAL NUMBER OF HERNIATION (82)	**43**	**39**

Table 14 B. Occurrence of Disc Herniation Types among Males and Females (Discs 4 – 5)

Disc Level	Type of Herniation	SEX Females	Males
	None	26	20
	Extrusion	8	11
	Extrusion + Intravertebral Herniation	2	2
Disc 4	Extrusion + Migration	0	1
	Protrusion	50	39
	Protrusion + Intravertebral Herniation	7	4
	Sequestration	0	1
	TOTAL NUMBER OF HERNIATION (125)	**67**	**58**
	None	33	33
	Extrusion	21	10
	Extrusion + Intravertebral Herniation	0	2
Disc 5	Extrusion + Migration	0	1
	Protrusion	37	31
	Protrusion + Intravertebral Herniation	2	1
	TOTAL NUMBER OF HERNIATION (105)	**60**	**45**

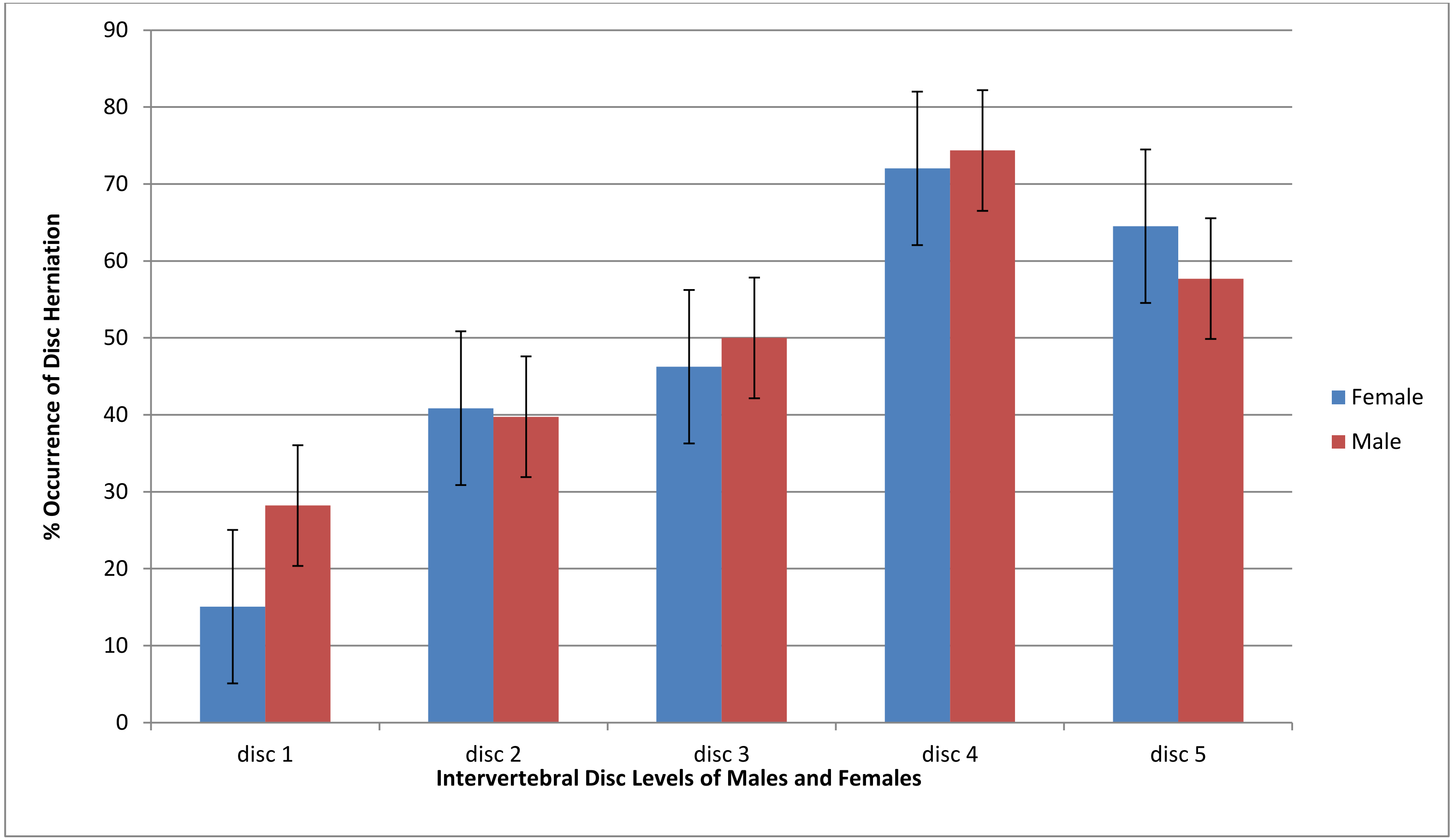

Figure 16: Bar Chart Showing Occurrence of Disc Herniation among Males and Females

Table 15. Spearman's Correlation between Anthropometric Variables and Disc Degeneration Grades

Variable	Disc 1	Disc 2	Disc 3	Disc 4	Disc 5
Age	r=0.603 P=0.001	r=0.594 P=0.001	r=0.607 P=0.001	r=0.557 P=0.001	r=0.560 P=0.001
Weight	r= -0.026 P=0.740	r= 0.022 P=0.780	r= 0.054 P=0.480	r= 0.140 P=0.068	r= 0.165 P=0.031
Height	r= -0.228 P=0.003	r= -0.202 P=0.008	r= -0.127 P=0.098	r= -0.149 P=0.052	r= -0.145 P=0.059
BMI	r=0.075 P=0.331	r=0.136 P=0.077	r=0.107 P=0.164	r=0.206 P=0.007	r=0.218 P=0.004

Table 16. Variables That Were Correlated With Disc Herniation

	Variable	B	Wald	P-value	Exp (B)
Disc 1	Age	-0.049	8.723	0.003	0.952
	Gender	1.022	4.434	0.035	2.779
Disc 2	Age	-0.052	16.524	0.001	0.950
Disc 3	Age	-0.070	26.147	0.001	0.932
Disc 4	Age	-0.061	21.622	0.001	0.941
Disc 5	Age	-0.046	15.214	0.001	0.955

CHAPTER 5

DISCUSSION, CONCLUSION AND RECOMMENDATION

5.1 AGE DISTRIBUTION OF THE STUDY POPULATION

Age distribution of patients for the study was from 8 years to 82 years. This age range was broad enough to cover all age groups from infancy to the elderly. Majority of images sampled for the study belonged to individuals who were in the late adulthood (40-59 years) and elderly age groups. This perhaps was because; the conditions for which lumbar MRI requests were necessary, were more in adult populations. This poses a challenge to retrospective studies of the lumbar spine among younger age groups.

Although a significant number of apparently normal individuals may show some degeneration in their lumbar spine, symptoms from this degeneration may usually not be apparent until a later age (Powell *et al*., 1986). As such, older people are more likely to show symptoms that will necessitate their visit to a doctor who may in turn request for an MRI scan. This accounts for the high number of adult and elderly patients observed in the present study.

The average age of females was higher in both morphometric and disc degeneration studies. In morphometric studies, the average age was 52.51 ± 17.76 years in females and 51.17 ± 14.42 in males. For disc degeneration studies, the average age was 53.92 ± 16.93 years in females and 52.42 ± 15.02 years in males. This could be attributed to higher longevity in females than in males (Austad, 2006). According to WHO's statistics, the life expectancy of Ghanaians in 2013 was 62 years in males and 64 years in females (World Health Organization, 2015). The difference in age observed between males and females in the present study however, was not statistically significant.

5.2 HEIGHT, WEIGHT AND BMI DISTRIBUTION OF THE STUDY POPULATION

As expected, males were taller than females. The present study reported an average height of 170.20 ± 7.57 cm in males and 162.53 ± 7.87 cm in females for morphometric studies as well as 170.33 ± 7.35 cm in males and 162.38 ± 7.67 cm in females for disc degeneration studies. The average height of females reported in the present study was higher than the 159.9 ± 6.5 cm reported by Benkeser *et al.* (2012), among urban Ghanaian women. The difference in female heights reported could be attributed to the present study sampling images belonging to individuals that had been referred from health centres all over Ghana which included people from both urban and rural areas. The higher average body heights observed in Males may be attributed to males having a longer vertebral column than females (Standring, 2008). Thus since the vertebral column contributes about 1/3rd of the body's height (Keller *et al.*, 2005), it is expected that males will be taller than females. The difference in the heights of males and females reported in the present study was, however, not statistically significant.

Females were significantly heavier than males for individuals sampled in both morphometric studies and disc degeneration analysis (p- value 0.011 and 0.014, respectively). This suggests that Ghanaian females who reported for lumbar MRI imaging were relatively heavier than their male counterparts. According to Adu and Adu (2015), who investigated anthropometric dimensions of Ghanaian public workers, 80% of Ghanaian female workers are either overweight or obese as opposed to 60% of Ghanaian male workers. The present study reported a larger female average weight of 78.40 ± 18.92 kg for morphometric studies and 79.17 ± 18.95 kg for disc degeneration studies compared to (72.5 ± 18.92 kg) reported by Benkeser *et al.* (2012) among urban Ghanaian females. This difference may have been due to the present study using archived images belonging to individuals from both urban and rural areas as well as larger sample size (2,813) used by Benkeser *et al.* (2012) compared to that of the present study (143 for morphometric studies and 171 for disc degeneration studies).

Sedentary life style pattern of Ghanaian females may be a significant contributing factor to females having a greater body weight than males. Ghanaian males are more involved in energy demanding occupations as compared to females. Ghanaian females are more likely to be involved in sedentary activities such as shop keeping, secretarial and office work. Some may even be housewives who spend most of the time at home cooking as well as caring for their children. These are usually tasks that expend less energy compared to activities of farmers, fishermen, construction workers and labourers which are usually occupations Ghanaian men are involved in. High levels of sedentary behaviour was reported to be associated with increase in BMI and poorer weight loss maintenance among African American Women (Taylor et al., 2015).

Abubakari *et al.* (2008) have shown from their study involving West African populations that, women are more likely to be obese than men. The present study reports similar findings with respect to BMI ratios of males and females. Results obtained from the present study indicated that, female patients sampled had a significantly higher BMI than males (P-value of 0.001 for both morphometric studies and disc degeneration analysis).

A greater proportion of images sampled for the present study belonged to individuals whose BMI fell within the overweight category (36% for morphometric studies and 34% for disc degeneration analysis). A study conducted by Benkeser *et al.* (2012) to investigate the prevalence of overweight and obesity among urban Ghanaian women revealed that 64.9% of women sampled were either overweight or obese. Obesity and overweight are reported to be on the rise in Africa and it is feared that in the near future, they may reach epidemic proportions (Ziraba *et al*., 2009). It was therefore not surprising to have majority of Ghanaians sampled for this study being heavier than normal. Obesity is known to be higher in urban residents than rural residents in West Africa (Abubakari *et al*., 2008). The high frequency of overweight individuals in the present study could be attributed to the risk of such persons developing symptomatic clinically significant disc degeneration (Weiler *et al*., 2011), that makes them more likely to report to the hospital compared to normal and underweight individuals.

5.3 VERTEBRAL BODY DIMENSIONS AMONG INDIVIDUALS

The present study sought to provide morphometric data for a Ghanaian population and compare them with those reported among other populations. Vertebral body dimensions have been reported among various populations (Karabekir *et al*., 2011; Gocmen-Mas *et al*., 2010; Goh *et al*., 2000; Diacinti *et al*., 1995). The available data on vertebral body dimensions have clearly shown that variations exist in vertebral morphometry among various populations. Vertebral body dimensions are known to increase down the vertebral column (Zhou *et al*., 2000; Kapandji *et al*., 1992).

Vertebral bodies become progressively larger from the cervical through to the lumbar region and then becomes smaller towards the apex of the coccyx (Standring, 2008; Moore & Dalley, 2006). Other researchers have reported diverse trends in vertebral body dimensions at the various vertebral levels (Mavrych *et al*., 2014; Karabekir *et al*., 2011; Goh *et al*., 2000). These trends are compared below in line with findings from the present study.

The present study showed variations in vertebral body dimensions at various vertebral levels. There was an increase in anterior vertebral body height (Ha) from L1 to L3 and then a subsequent decreased at L4 and then an increase again at L5 which was greater than all the other vertebral levels. Mavrych *et al*. (2014) also observed an increase in vertebral body measurements from L1 to L3. Contrary to findings from the present study, Mavrych *et al*. (2014) reported a decrease in L5 vertebral body dimensions for some age groups. The present study on the other hand, only observed an increase in the anterior height (Ha) of L5 vertebra.

For mid and posterior vertebral body heights (Hm and Hp), there was an increase at the first two lumbar vertebral levels (L1, L2) and then a subsequent decrease down the vertebral column.

Unlike vertebral body heights, anteroposterior diameter (D) of the lumbar vertebral bodies increased from L1 to L5. This supports the concept about vertebral body dimensions continually increasing down the lumbar spine (Zhou *et al*., 2000; Kapandji *et al*., 1992). Available vertebral morphometric data also showed an increase in anteroposterior diameter of vertebral bodies among Nigerian females (Amonoo-Kuofi, 1985). Compared to the present study, anteroposterior diameter of vertebral bodies L1-L5 reported among the Nigerian population was greater than those reported for the Ghanaian population. Findings from the present study, has shown that increase in vertebral body size down the vertebral column is primarily due to an increase in anteroposterior diameter of the vertebral bodies rather than a corresponding increase in vertebral body heights.

The current study further compared the three vertebral body heights (Ha, Hm, Hp). The results revealed a lower anterior vertebral body height (Ha) than posterior (Hp) at the first three lumbar vertebral levels (L1, L2 and L3). This was indicative of anterior wedging at these levels. The findings were contrary to those from Karabekir *et al*. (2011), who observed higher anterior vertebral body heights than posterior among a Turkish population. Results from Diacinti *et al*. (1995) in a study involving Italian population, showed a lower anterior height (Ha) than posterior (Hp) at the 1st and 2nd lumbar vertebral levels and subsequently, higher posterior heights than anterior for the 3rd, 4th and 5th lumbar vertebrae. In the present study, the 4th and 5th lumbar vertebrae rather showed a higher posterior height than anterior. This is indicative of a posterior wedge at the caudal end of the lumbar vertebrae.

The variations in vertebral body heights observed may be as a result of the functional load imposed on the lumbar vertebral column. Increase in biomechanical activities that involve flexion of the lumbar spine may also have contributed to the gradual anterior wedge shape adaptation of the upper lumbar spine observed in the present study.

Activities such as bending over to sweep with short brooms, weeding with cutlasses and hoes, bending over to fetch water from drums, boreholes and rivers are common among Ghanaians. Owing to this, it may be suggested that these mechanical activities were contributory factors to an increase in the anterior functional load imposed on the lumbar spine. This may have contributed to wedging of the lumbar spine over time.

However, the study by Mavrych *et al*. (2014) involving a Caucasian population rather reported a posterior wedge at L2 to L5 vertebrae. Compared to the Ghanaian population, the Caucasian population have modified ergonomic tools that help reduce excessive flexion of the lumbar spine. For example, vacuum cleaners would be used in place of short brooms, mowers and tractors would be used in place of cutlasses and hoes. There would be no need to bend over wells and rivers to fetch water due to constant running water from taps and showers.

This comes to suggest that Caucasians may have less flexion imposed stress on their lumbar spine. The posterior wedge in the Caucasian population may be explained by a less compromised physiologic lordotic curve of the lumbar spine. This in the Ghanaian population may have been compromised as a result of the anterior wedging of the lumbar vertebral bodies observed in the present study. In a normal physiologic lordotic curve, the posterior concave end is expected to experience relatively more compression forces than the anterior end. This may possibly leave a posterior wedging effect over time.

A comparison of mid-height and posterior height of lumbar vertebral bodies revealed that the ratio of Hm/Hp (biconcavity index) increased down the lumbar vertebral column. This implies that the vertebral body endplates becomes more flattened than concave down the vertebral column. This is in accord with the findings of He *et al*. (2012), who similarly, reported a decrease in the concavity of the vertebral body endplate down the vertebral column. According to the authors, the decrease was moderately associated with lumbar disc degeneration. The degree of flattening of the vertebral endplate was also related to the severity of degeneration. Thus, as disc degeneration increases, the vertebral endplate becomes more flattened and vice versa. In the present study, the level of disc degeneration increased down the vertebral column. This implies that to some extent, the high levels of disc degeneration observed in the present study may have contributed to the increase in biconcavity index down the vertebral column as suggested by He *et al*. (2012). Compared to biconcavity index, compression index (ratio of posterior vertebral height to anteroposterior diameter) for the present study was observed to decrease down the lumbar vertebral column.

As expected, and similar to findings reported by Karabekir *et al*. (2011), Gocmen-Mas *et al*. (2010) and Cheng *et al*. (1998), the present study showed that males have larger vertebral body dimensions than females. Males are known to be taller than females and their vertebral columns are longer (70 cm vs. 60 cm) than that of females (Standring, 2008). In like manner, the present study showed males to have a higher mean height (170.20±7.57 cm) than females (162.53±7.87 cm). The higher height of males reflected in a corresponding increase in their vertebral body dimensions. The spine is known to contribute about 1/3rd of the body's height (Keller *et al*., 2005). Thus, it was not surprising that vertebral body dimensions of males were greater owing to a heigher body height in males than females.

Although Karabekir *et al*. (2011) and Gocmen-Mas *et al*. (2010) reported higher vertebral dimension in males than in females, their study showed no sexual dimorphism for transverse and anteroposterior vertebral diameters as well as biconcavity index. In the present study however, anteroposterior diameter of vertebral bodies in males were observed to be higher than in females just as was observed for all other vertebral body measurements.

Among the Ghanaian population, the present study revealed vertebral body dimension to be greater in males than in females although the difference in measurements were statistically significant for only the mid-height of L2 , posterior height of L3, biconcavity index (Hm/Hp) of L3 and compression index (Hp/D) of L3 vertebrae. As a result of greater vertebral body dimensions in males than in females, anterior wedge, biconcavity and compression indices were smaller in males than in females. Cheng *et al*. (1998), reported significant variations in vertebral body dimensions among males and females which is in line with findings from the present study. On the other hand, Mavrych *et al.* (2014) in their study involving a Ukrainian population noticed vertebral body dimensions were independent of sex.

5.4 INFLUENCE OF AGE, WEIGHT, HEIGHT AND BMI ON LUMBAR VERTEBRAL BODY MEASUREMENTS

5.4.1 AGE AND VERTEBRAL MORPHOMETRY

The present study sought to investigate the influence of age on vertebral body dimensions among Ghanaians. The study revealed an age related decline in vertebral body morphometry and this was significantly correlated with all morphometric measurements for the 5^{th} lumbar vertebrae as well as compression indices of L2, L3, L4, L5 vertebrae. Similar to findings from the present study, Mavrych *et al*. (2014), Goh *et al*. (2000) and Diacinti *et al*. (1995) also reported an age related decline in vertebral body morphometry among Caucasian populations.

The present study provided equations (Table 6) for estimating vertebral body dimensions of the 5th lumbar vertebra using an individual's age. In the same vein, equations are provided in Table 6 for estimation of compression index using age. These equations were derived from a stepwise regression done between age and the various lumbar vertebral body morphometric variables. In the linear equations generated (Table 6), the lumbar vertebral body morphometric variable being predicted is the dependent variable while age is the independent variable. The equations are relevant for estimating the dimension of the 5th lumbar vertebral body in the absence of radiographic scanning provided the individual's age is known.

Decrease in vertebral body dimensions with age has been attributed to osteopenia (Mavrych *et al*., 2014), which is advanced by aging. Again, decrease in vertebral body dimensions have also been attributed to the functional load imposed on the spine resulting in gradual shape adaptation (Goh *et al*., 2000). The factors mentioned above may also have played a role in the age related decline in vertebral body dimensions observed in the present study.

5.4.2 WEIGHT & BMI AND VERTEBRAL MORPHOMETRY

Findings from the present study revealed that, body weight and BMI had no influence on vertebral body morphometry. An increase in body weight and BMI was rather found to increase the occurrence of lumbar disc degeneration. According to literature, body weight is transmitted through the vertebral column and its effect increases down the column (Moore & Dalley, 2006; Keller *et al*., 2005). Results from the present study however suggests that, though an increase in an individual's weight or BMI transmit weight down the vertebral column, its effect is rather on the intervertebral disc rather than the vertebral bodies. Perhaps, this may be because the vertebral body is made up of an external layer of compact bone which is tougher than the fibrocartilagenous intervertebral disc. Thus the bonny vertebral bodies are able to withstand the load imposed on it by the body's weight better than the intervertebral discs do.

5.4.3 HEIGHT AND VERTEBRAL MORPHOMETRY

The effect of body height on vertebral body morphometry was also investigated. Results from this study revealed that vertebral body dimensions at all vertebral levels increased with increasing body height (with a significance value of 0.001 for all measurements at all vertebral levels). The above finding was expected since the vertebral column is known to contribute about 1/3rd of an individual's body height. Thus as body height increases, a corresponding increase in vertebral body dimensions is expected. The present study however did not investigate the extent of increase in vertebral body dimension at various ages. All the same, the present study provided equations (Table 6) for predicting lumbar vertebral body dimensions at all vertebral levels using body height. These equations were derived from a stepwise regression done between height and the various lumbar vertebral body morphometric variables. In the linear equations generated (Table 6), the lumbar vertebral body morphometric variable being predicted is the dependent variable while height is the independent variable. With these equations, surgeons and other health professionals can estimate vertebral body dimensions in the absence of radiographs and other imaging modalities. This will assist in the choice of implants with appropriate dimensions for spinal surgical interventions.

5.5 PATTERN OF LUMBAR DISC DEGENERATION

Lumbar disc degeneration was prominent among the sampled population. Over 80% of lumbar intervertebral discs in this study showed degeneration at all disc levels. Although majority of images sampled for this study belonged to symptomatic individuals that had been referred for an MRI, the results still suggest a high occurrence of disc degeneration among the Ghanaian population. A study involving asymptomatic individuals among the same population may be required to justify this finding further.

Additionally, disc degeneration was most frequently observed at the 3rd intervertebral disc among the Ghanaian population sampled. On the contrary, Takatalo *et al*. (2009), Kjaer *et al*. (2005), Ong *et al*. (2003), Savage *et al*. (1997) and Evans *et al*. (1989), reported disc degeneration to be most prevalent at the 5th intervertebral disc in studies involving Caucasian populations. Friberg (1948), on the other hand in a study involving 3,672 participants noticed almost half of degenerations were localised at the 4th intervertebral disc with 75.2% of overall degeneration occurring in both the 4th and 5th intervertebral discs.

Again, in the present study, frequency of disc herniation increased down the vertebral column (from L1-L5). This was similar to findings by Ong *et al*. (2003) who also observed an increase in the prevalence of disc herniation towards the caudal end of the vertebral column. In their study, 55% of disc displacement occurred at the 5th intervertebral disc. In the present study however, about 55% of total herniation was observed at the 4th and 5th intervertebral disc with herniation occurring most frequently at the 4th intervertebral disc. Protrusion was the most frequent type of disc herniation observed and was most frequent at the 4th intervertebral disc.

The prevalence of disc degeneration has been attributed to the following: sedentary lifestyle, increase in the load imposed on the spine as well as increase in activities of the spine from occupation and sports activities (Ong *et al*., 2003; Jumah and Nyame, 1994 and Evans *et al*., 1989). These factors mentioned above are very prevalent among Ghanaians and as such may be suggested as the possible causes of disc degeneration in this population. That notwithstanding, the present study was unable to investigate the influence of these causative factors on disc degeneration.

5.6 ASSOCIATION OF AGE, WEIGHT, HEIGHT AND BMI WITH LUMBAR DISC DEGENERATION

5.6.1 DISC DEGENERATION AND AGE

As expected, findings from the present study revealed a positive correlation between age and lumbar disc degeneration with a significance value of 0.001 at all disc levels. Disc herniation was also positively correlated with age. Thus, lumbar disc degeneration as well as disc herniation increased with advanced age among the Ghanaian population sampled. This is consistent with findings reported among Caucasian populations (Gocman-mas *et al*., 2010; Goh *et al*., 2000; Powell *et al*., 1986; Friberg, 1948). Although disc degeneration and herniation recorded in the present study were observed among symptomatic individuals, symptomless individuals also showed an increase in disc degeneration in a study by Powell *et al*. (1986). A study in the Ghanaian population involving asymptomatic individuals may be required to enable generalization of this finding.

Results from the present study further revealed disc degeneration to be most frequent among individuals 60 years and above with 98% of discs belonging to elderly persons showing degeneration in all 5 intervertebral discs. The occurrence of lumbar disc degeneration was also high among the late adulthood group (40 to 59 years) with between 84% - 93% of discs showing degeneration at various levels. Friberg (1948), on the other hand reported disc degeneration to be most frequent in the 31-50 years age group.

The high frequency of disc degeneration among elderly Ghanaians may be attributed to the physiologic effects of aging. With increasing age, the proportion of proteoglycans and water in the nucleus pulposus of the disc decreases significantly (Urban et al., 2000). As a result, the relative proportion of collagen increases. Antoniou et al. 1996, argues that the increase in collagen content of the intervertebral disc during advanced age is not as a result of an increase in collagen production but rather, a loss of aggregating proteoglycans within the disc. This results in the nucleus pulposus becoming less hydrated, more collagenous and discoloured.

Again, the intervertebral disc contains enzymes which break down its matrix (Melrose and Ghosh, 1988 as cited by Urban *et al*., 2000). These enzymes increase with advanced age and as a result, accelerate the rate of degeneration in the intervertebral disc (Crean *et al*., 1997). The resilient nature of intervertebral discs that allow the discs to serve as shock absorbers is also lost with advanced age (Snell, 2008).

Furthermore, occupational stresses, increased load imposed on the lumbar spine as well as sedentary lifestyle are also known to be predisposing factors to disc degeneration (Ong *et al*., 2003; Jumah and Nyame, 1994 as well as Evans *et al*., 1989). Cumulative effects of these factors among Ghanaians may contribute to the high prevalence of disc degeneration during advanced age. A study on the causative factors of disc degeneration among Ghanaians may be helpful in adequately explaining these findings.

5.6.2 DISC DEGENERATION VERSUS HEIGHT, WEIGHT AND BMI

Body height was found to be negatively correlated with disc degeneration. This was significant at the 1^{st}, 2^{nd} and 4^{th} intervertebral discs. Thus relatively shorter individuals are more predisposed to intervertebral disc degeneration compared to their taller counterparts. This finding may be quite challenging to explain. Perhaps, since height contributes twice as much as weight in estimating BMI, it presupposes that shorter individuals are likely to have a higher BMI compared to their taller counterparts of the same weight. It is possible that the corresponding higher BMI in shorter individuals may account for the increase in disc degeneration among shorter individuals. Despite its negative correlation with disc degeneration, body height had no influence on disc herniation.

Weight showed a significant positive correlation with disc degeneration at the 5^{th} intervertebral disc level. BMI on the other hand was positively correlated with disc degeneration at both the 4^{th} and 5^{th} intervertebral disc levels. This comes to suggest that the contribution of weight and BMI to lumbar disc degeneration is significant at the caudal end of the lumbar spine. Although weight and BMI were positively correlated with disc degeneration, they showed no association with lumbar disc herniation. Disc herniation, however, was most prominent among obese individuals at all disc levels among BMI classes except the 1^{st} intervertebral disc of the underweight BMI class. This suggests that underweight individuals may stand equal risk of developing disc herniation at the first intervertebral disc as would obese individuals. The first intervertebral disc of the underweight BMI class had a relatively higher frequency of disc herniation than the obese group (33.3% versus 32.1%). This deference may have been due to the small population of underweight patients (3) among the sample population. Thus a single herniation forms a significantly high proportion among the small sample size.

Persistent overweight has been reported to be a significant contributing factor to the increase in development of lumbar disc degeneration (Luike *et al*., 2005). In the present study, obese individuals (BMI $\geq$ 30 kg/m^2) had the highest occurrence of disc degeneration. About 91%- 95% of intervertebral discs of obese individuals showed degeneration at various disc levels. This comes to suggest that obesity predisposes Ghanaians to developing lumbar disc degeneration. According to Weiler *et al*. (2011), increased BMI is a possible risk factor for the development of symptomatic clinically significant disc degeneration. Results from the present study indicated that most of the images sampled for disc degeneration analysis (66.6%) belonged to individuals who were either overweight (BMI 25-29.5 kg/m^2) or obese (BMI 30 kg/m^2 or higher). This explains the high occurrence of disc degeneration and herniation observed among the Ghanaian population in this study. Implementation of stringent measures to encourage overweight and obese individuals to participate in weight management activities hold the potential to significantly reduce the rate of occurrence of disc degeneration in such persons.

5.6.3 DISC DEGENERATION AND GENDER

From the present study, disc degeneration was more frequent among males than females in the first four intervertebral discs. The difference in the proportion of male and females with disc degeneration however was statistically significant only at the first intervertebral disc. The 5th intervertebral disc showed higher occurrence of degeneration in females than in males. Similarly, disc degeneration has been reported to be higher in males than in females in Caucasian populations by Takatalo *et al*. (2009), Goh *et al*. (2000) and Friberg, (1948). Despite the higher proportion of degeneration observed in males in all these studies, the chi-square analysis carried out in the present study to determine the association between gender and disc degeneration revealed no association between the two variables.

In a study by Friberg (1948), the high prevalence of disc degeneration among males was attributed to males commonly involved more in laborious tasks (74% of males in that study) than females. In the Ghanaian population also, physically demanding tasks are usually done by men and this could equally contribute to the high prevalence of disc degeneration among men. The present study however did not acquire data on occupation of patients and as such would not be able to fully justify the effect of occupation on disc degeneration.

Disc herniation was also observed to be more prevalent in males than in females for disc levels 1, 3 and 4. Takatalo *et al*. (2009) also reported disc herniation to be significantly more frequent among males than females. Although disc herniation was prevalent in males than females in the present study, the differences in proportion of degeneration among males and that of females were significant only at the first intervertebral disc. That notwithstanding, a binary logistic regression which was done to determine the correlation between gender and disc herniation revealed a positive correlation between the two variables at the first intervertebral disc. This implies that chances of developing a herniation at the first intervertebral disc are determined by an individual being male or female. From the results (Table 16) the odds of a female developing a herniation at the first intervertebral disc level is 2.779 times the odds of a male developing disc herniation at the first intervertebral disc level.

5.7 CONCLUSION

The present study has provided a comprehensive understanding of the pattern of vertebral body morphometry and disc degeneration among a Ghanaian population. It has also answered question with respect to the association of age, weight, height, BMI and gender with lumbar vertebral body morphometry and disc degeneration among this population.

From the present study, it was concluded that increase in lumbar vertebral body size down the vertebral column is primarily as a result of an increase in anteroposterior diameter of the vertebral bodies rather than a corresponding increase in vertebral body heights.

Again, vertebral body dimensions declined with age but increased significantly with increasing body height for all lumbar vertebrae. This study went further to provide equations for predicting vertebral body dimensions using an individual's body height. BMI and body weight, however, had no significant influence on lumbar vertebral body morphometry. Vertebral body dimensions were also found to be greater in males than in females although this was statistically significant for only the mid height (Hm) of L2 and posterior height (Hp) of L3 vertebrae.

From the study, lumbar disc degeneration was shown to be high among Ghanaians with over 80% of all lumbar intervertebral discs sampled showing degenerations. Degeneration was found to be most prevalent among the 3rd intervertebral disc which was contrary to findings reported among Caucasian populations. Disc herniation however, was most frequent at the 4th intervertebral disc. Protrusions were the most common type of disc herniation.

Lumbar disc degeneration increased with age. Disc degeneration was observed to be most prevalent among the elderly (60 years and more) although late adulthood (40-59 years) also had a high occurrence of disc degeneration.

Disc degeneration and herniation were highest among obese individuals. Body weight and BMI were positively correlated with lumbar disc degeneration and this was significant at the caudal end of the lumbar spine. Although weight and BMI were associated with disc degeneration, they showed no association with disc herniation.

Height was negatively correlated with disc degeneration. As such, shorter individuals were more likely to develop disc degeneration at the 1st, 2nd and 4th intervertebral disc than their taller counterparts.

Lumbar disc degeneration and herniation were more frequent among males than females for the first four intervertebral discs. The 5th intervertebral disc, however, showed a higher occurrence of disc degeneration and herniation in females compared to males. The difference in proportion of degeneration and herniation among males and that of females was significant only at the first intervertebral disc. The present study showed no association between lumbar disc degeneration and gender. Disc herniation on the other hand showed a significant positive correlation with gender at the first intervertebral disc level.

Results provided by this study will serve as baseline morphometric data for the Ghanaian population. The study also provided equations for estimating vertebral body dimensions using an individual's height. This will significantly assist medical professionals especially surgeons to estimate lumbar vertebral body size in the absence of radiographs. This study has revealed the high prevalence of disc degeneration among the sampled Ghanaian population especially among obese individuals and the aged. There is the need for implementation of stringent measures to help reduce the rate of degeneration among the aged and obese individuals. Appropriate life style modification may be the lasting solution to this problem. This study has no doubt added significant knowledge to the scientific community which will go a long way to promote national development.

Below are recommendations made based on the findings from the present study. The limitations encountered during this study are also outlined below.

5.8 RECOMMENDATIONS

1. This study should be extended to other imaging centres in other regions of Ghana. This will provide a broader view on vertebral morphometry and disc degeneration among Ghanaians.
2. Findings from this study reveal disc degeneration to be prominent among Ghanaians but did not address the causative factors of lumbar disc degeneration among this population. Further studies should be carried out to investigate the causative factors of disc degeneration among the Ghanaian population.
3. Since symptomatic individuals were sampled for this study, further studies should be carried out using asymptomatic Ghanaians so as to provide enough comparison and confirm the findings on vertebral morphometry and disc degeneration among the Ghanaians.

4. Disc degeneration was prominent among overweight and obese individuals. Thus weight reduction programmes should be promoted and made easily accessible to overweight and obese individuals

5.9 LIMITATIONS

1. There is paucity of information on lumbar vertebral morphometry and disc degeneration in this country to compare with the present study.
2. Since the study was retrospective, accuracy of weight and height information obtained could not be verified
3. Choice of variables to be included in the study was limited. The Korle-Bu Teaching Hospital was the only imaging centre that takes patients height information before MRI scans were taken. Other variables such as occupation and social information could not be obtained since the presence of the patients was required in order to obtain such information.
4. The study focused on the use of archived radiologic data for its investigations. As such, the present study could not selectively sample images of normal (asymptomatic) individuals so as to compare them with images sampled from symptomatic individuals from this study.
5. It was very challenging determining the nationality of some patients. According to the radiographers, patients lied about their nationality (being Ghanaians when they were not) to enable them pay less charges on imaging procedures since foreigners pay twice as much as Ghanaians.

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