“I admit to have read this report and it has followed the scope and quality in Partial Fulfillment of Requirement for the Degree of Bachelor of Mechanical Engineering (Structure and Material)”

Signature : ....

Supervisor Name : Dr Mohd Juzaila bin Abd Latif

Date : June 2012

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MODELING AND STUDY OF VERTEBRA UNDER COMPRESSIVE LOADING

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ABSTRACT

Finite Element Analysis (FEA) technique is used to analyze the stress distribution of human lumbar spine (L4). The project describes the FEA method to investigate the biomechanical behavior of lumbar spine vertebral under compression loading and identify the critical region of the vertebral. The three-dimensional solid modeling of L4 vertebrae was developed by using SolidWorks software. The analysis was carried out in ABAQUS software. The finite element model was validated with solid mechanic theory. The stress and stress distribution that obtained from the finite element model could be useful to find the cause of low back pain.

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ABSTRAK

Teknik Analisis Unsur Terhingga (FEA) telah digunakan untuk mengkaji sebaran daya pada tulang pinggul manusia (L4). Projek ini menerangkan tentang teknik-teknik FEA dalam menganalisis ciri-ciri biomekanik pada tulang pinggul vetebra di bawah sebaran daya dan mengenal pasti kawasan-kawasan yang akan mengalami kritikal di tulang vetebra. Permodelan tiga dimensi pada L4 vetebra dijalankan dengan menggunakan perisian SolidWork. Analisis dilakukan dalam perisian ABAQUS. Untuk pengesahkan keputusan dari FEA, perbandingan dengan teori mekanik pepejal telah dijalankan. Keputusan diperolehi mungkin akan membantu untuk untuk mengkaji punca kesakitan pada tulang belakang.

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CHAPTER I

LITERATURE REVIEW

1.1 Introduction

Human spine is a complex structure that provides both mobility and stability, and also protects the spinal cord. The normal human spine consists of twenty four vertebras where intervertebral disc lies in the vertebral. From Figure 1.1, the spine forms three curves, named according to region and position:

1. Cervical: 7 vertebrae (C1-C7)
2. Thoracic: 12 vertebrae (T1-T12)
3. Lumbar: 5 vertebrae (L1-L5)

Each region has its own function to human body. The cervical spine support load from the weight of the head and allow for its rotation. The thoracic region is only experience little movement. The lumbar region withstands pressure from body weight and experience the most motion compare to other region of the spine.

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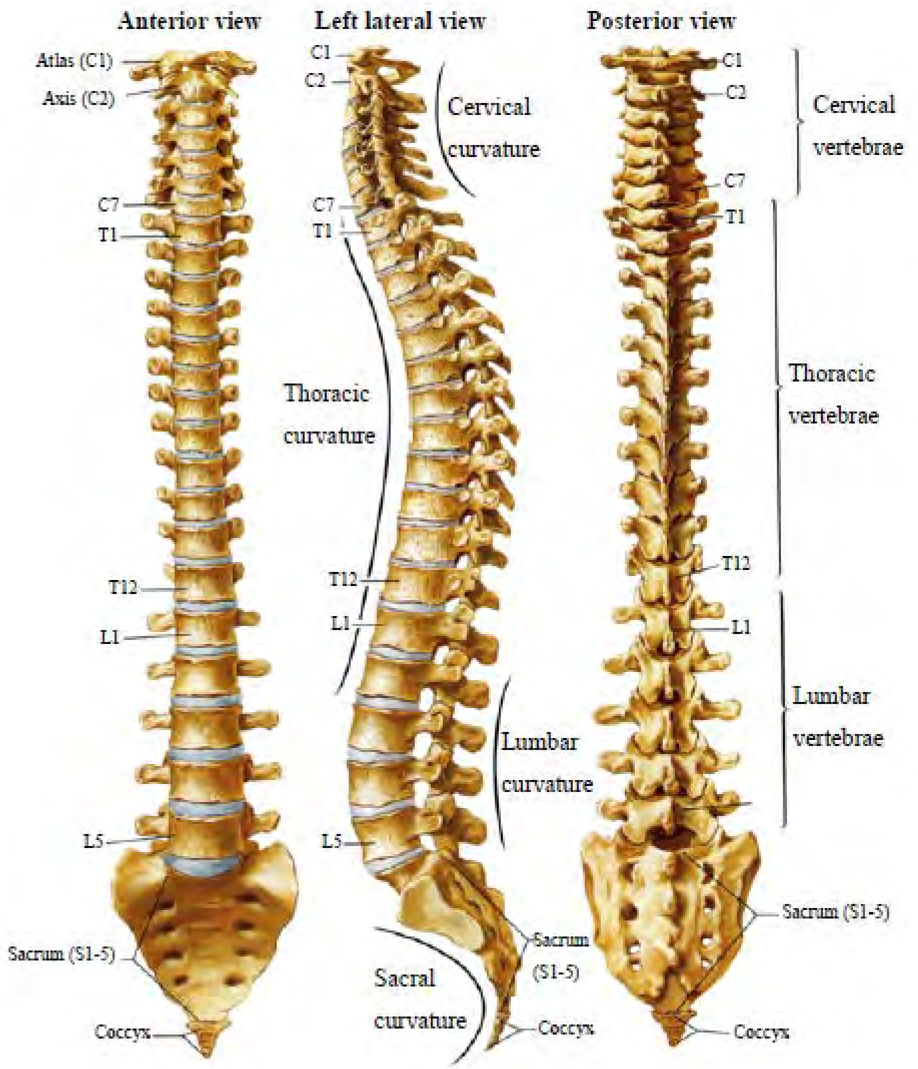

Figure 1. 1: Human spine. Adapted from Netter (2006)

As an important human load-bearing structure, the lower back which is called lumbar spine region (Figure 1.2) is the most flexible and receives the most stress compare to other region. Due to this bone structure, the pain is more likely to occur at this area which is known as low back pain.

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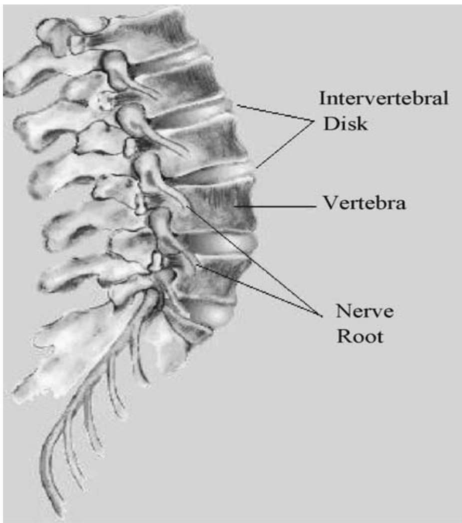

Figure 1. 2: The Lumbar Spine

Some researchers have clarified that intervertebral disc degeneration that resulting pain is determined by genetic inheritance (MacGregor et *al*., 2004) and all the aspect of back pain behavior is dominated by psychosocial characteristic (Waddell, 1998). However, mechanical load remains one of the most important aspects that can aggravate low back pain and disc degeneration.

1.2 Structural Anatomy of Lumbar Spine

Lumbar spine is the section of spinal column at the lower part of human spine. It consists of 5 vertebrae named L1-L5 connected to the top sacrum, a triangle bone at the bottom of the spine. The classification system is based on the "three-column" theory which is shown in Figure 1.3. Anterior at the front of low back, middle and posterior at the back. The Important parts of lumbar vertebral are facet joints, intervertebral discs, ligaments and muscles.

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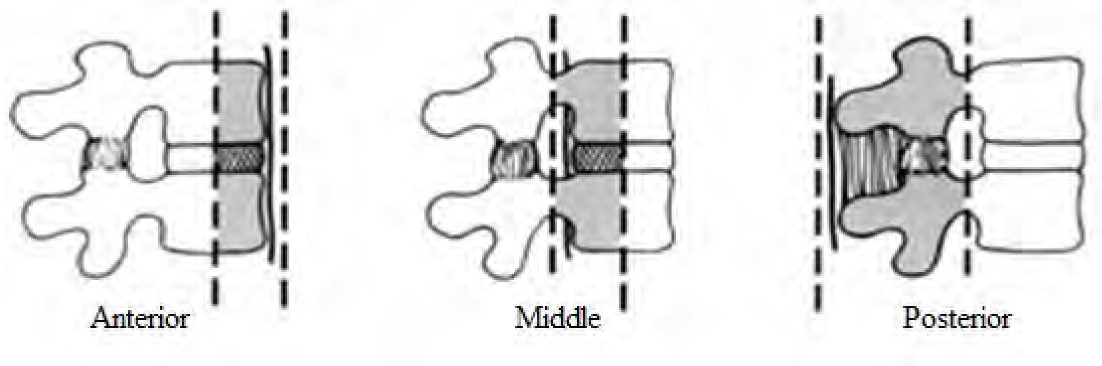

Figure 1. 3: Classification of spine

1.2.1 Vertebral Body

The vertebral body makes the front bony structure of the vertebra. From Figure 1.4, the vertebral body consists of cortical bone at the outer shell and cancellous bone at the inside. The cancellous bone is less compact compared to the cortical bone. The pedicle at the upper end of the posterior supporting the posterior elements.

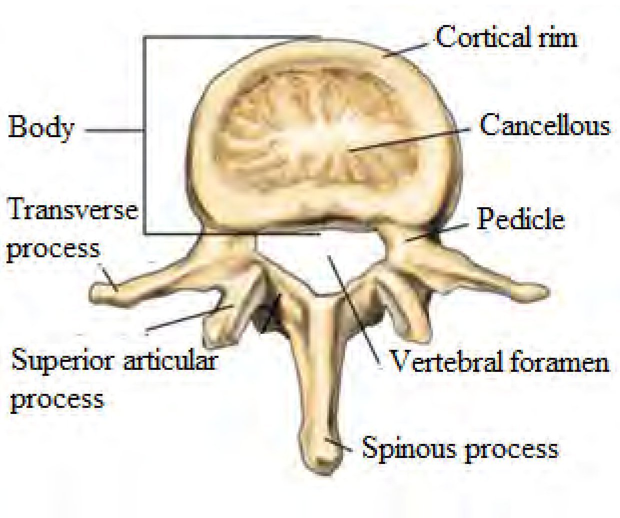

Figure 1. 4: Vertebral Body

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1.2.2 Facet Joints

Figure 1.5 and Figure 1.6 show the facet joints and articular cartilage in human spine. Facet joints are located at the back of the spine (posterior). The joint allows motion of the bone. The bone moves smoothly without friction because the end of most joints is covered by soft material that called articular cartilage.

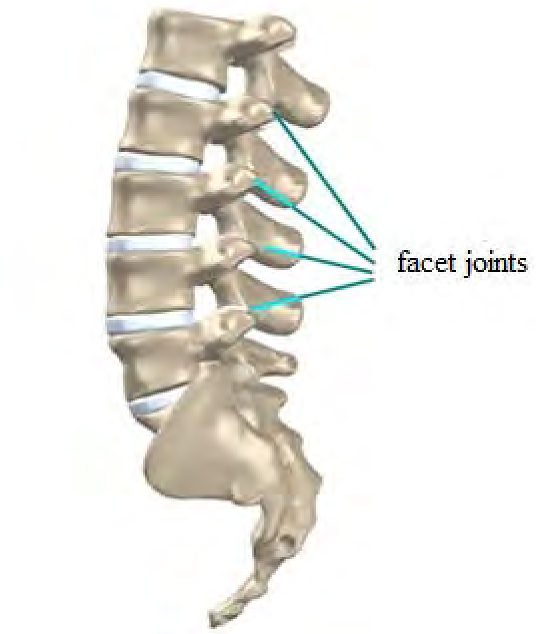

Figure 1. 5: Facet Joint

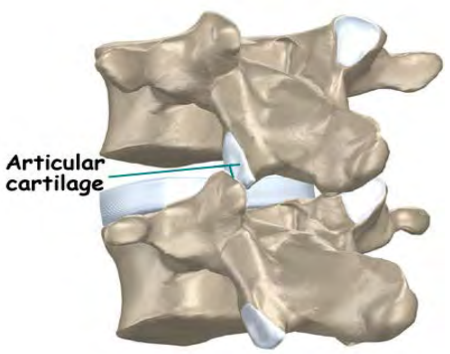

Figure 1. 6: Articular Cartilage

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1.2.3 Intervertebral Disc

From Figure 1.7, intervertebral disc lies between the vertebral. The intervertebral disc makes up 20-33% of the vertebra height and consists of three parts, nucleus pulposus, the annulus fibrosis and the cartilaginous end-plate. The functions of intervertebral disc are:

- Movement of fluid within the nucleus allows the vertebra to rock back and forth
- Provide flexibility to the vertebra
- The movement space of the 24 vertebra is maintain by intervertebral disc
- Absorb external loading that act like absorbers
- Allow flexion and extension

Nucleus is at the centre and surrounded by annulus, a series of strong ligament. 25% of the areas of the disc are formed by nucleus. No clear boundary can be found between nucleus and annulus even though both parts are significantly difference in structure. Most of shocks of the spine are absorbed by the nucleus part. The pressure that acts to the disc will be distributed evenly across the disc. Together with lumbar vertebral body, 80% of compressive loading in standing position are resists by these parts (N, JB *et al*., 1988)

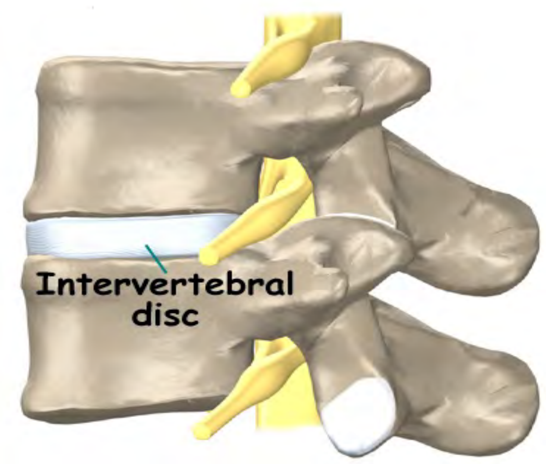

Figure 1. 7: Intervertebral disc that lies between vertebra

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The nucleus is located at the centre area of the disc. The nucleus is very stiff that consist of a collagen and proteoglycans. The water content of pulposus ranges from 70-90% which tends to reduce with age (Kalyanrao, 2002). Compare to cervical and thoracic region, the size of the disc larger in the lumbar region. The disc also is more posterior in lumbar region compare to thoracic region.

The annulus is composed of concentric ring of fibrous cartilage that surrounds and protects the soft material located in the centre of the disc. The fibers run on diagonal angle which is inclined at 30deg to the disc plane.

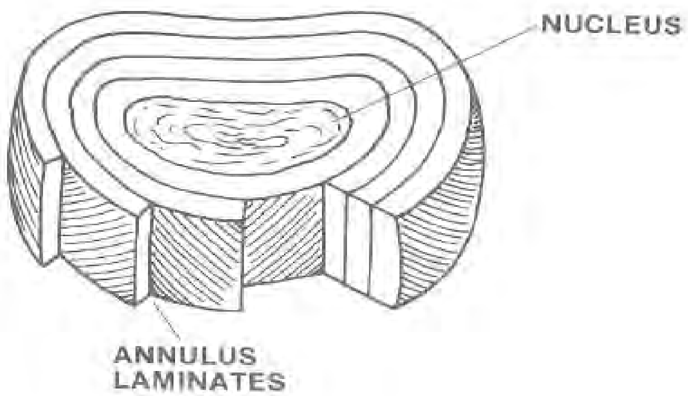

Figure 1. 8: Vertebral disc highlighting the annulus rings surrounding nucleus. Adapted from Kalyanrao (2002)

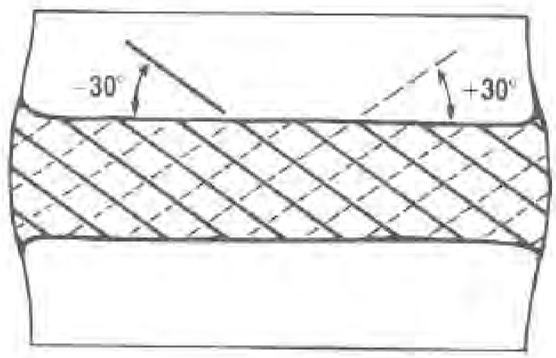

Figure 1. 9: Vertebral disc highlighting the annulus fibers at 30deg to the end-plate. Adapted from Kalyanrao (2002)

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1.2.4 Ligaments

Ligaments are strong connective tissue that attach to bone. Ligaments protect the spine from injury and help stabilize joints. It gives natural support to avoid injury to the spine from extreme movements. From Figure 1.10, there are seven types of ligaments in the lumbar spine which are connected to the front and back section of the vertebrae.

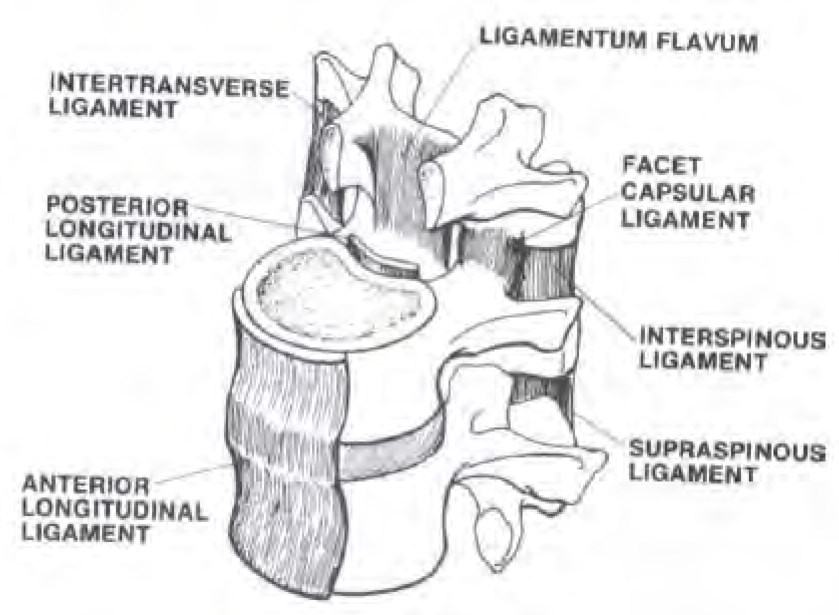

Figure 1. 10: Various ligament of the spine. Adapted from Kalyanrao (2002)

1.2.5 Muscles

Muscular system of the low back is complex. The role of muscle is very important by giving supports and stabilizes the human spine. Muscle in lumbar spine can be distinguished by their location around the spine: postvertebral and prevertebral muscles. Figure 1.11 bellow shows the support muscle of the lumbar spine.

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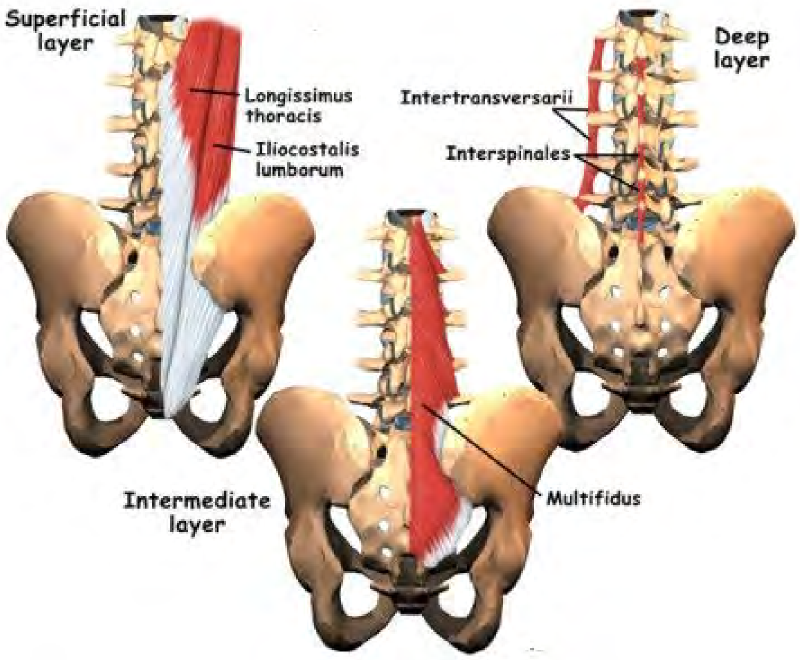

Figure 1. 11: Low back muscle

1.3 Biomechanics of Spine

Biomechanical in spine is related to the spine mechanical behavior as subjected to loads. There are three fundamental biomechanics of spinal column:

- Ensure that the load transfer steadily along the column.
- Prevent harmful to the spinal cord from damaging force.
- Give enough flexibility to the spinal column.

Lumbar spine has great role in these biomechanical functions. This is due to the lumbar spine experience the most forces and mobility (Kurutz, 2010).

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1.3.1 Compressive Strength of Vertebra

The compressive strength of the vertebra is very important issue. From Figure 1.13, several studies had been carried out to carry out a proper compressive strength of the vertebral body. It was found that the reason that the strength of vertebra different in each level is due to the size of vertebral body alone.

The load on the vertebra is transferred by the two structures of vertebral body which are the cortical bone and the cancellous bone which is shown in Figure 1.12. Cancellous bone is spongy bone and occupied a large area of vertebral body compare to cortical bone. Due to this bone structure, cancellous bone has good absorbing abilities.

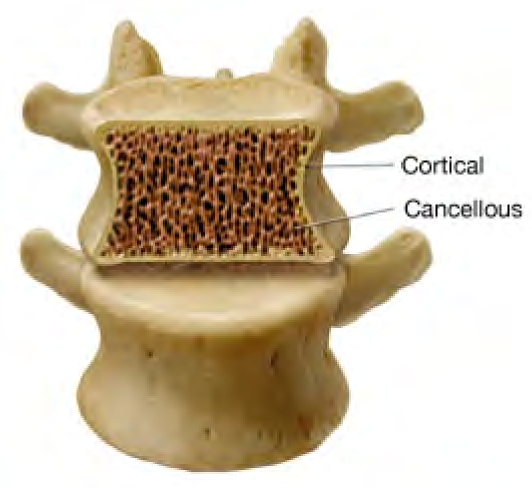

Figure 1. 12: Cortical bone and cancellous bone

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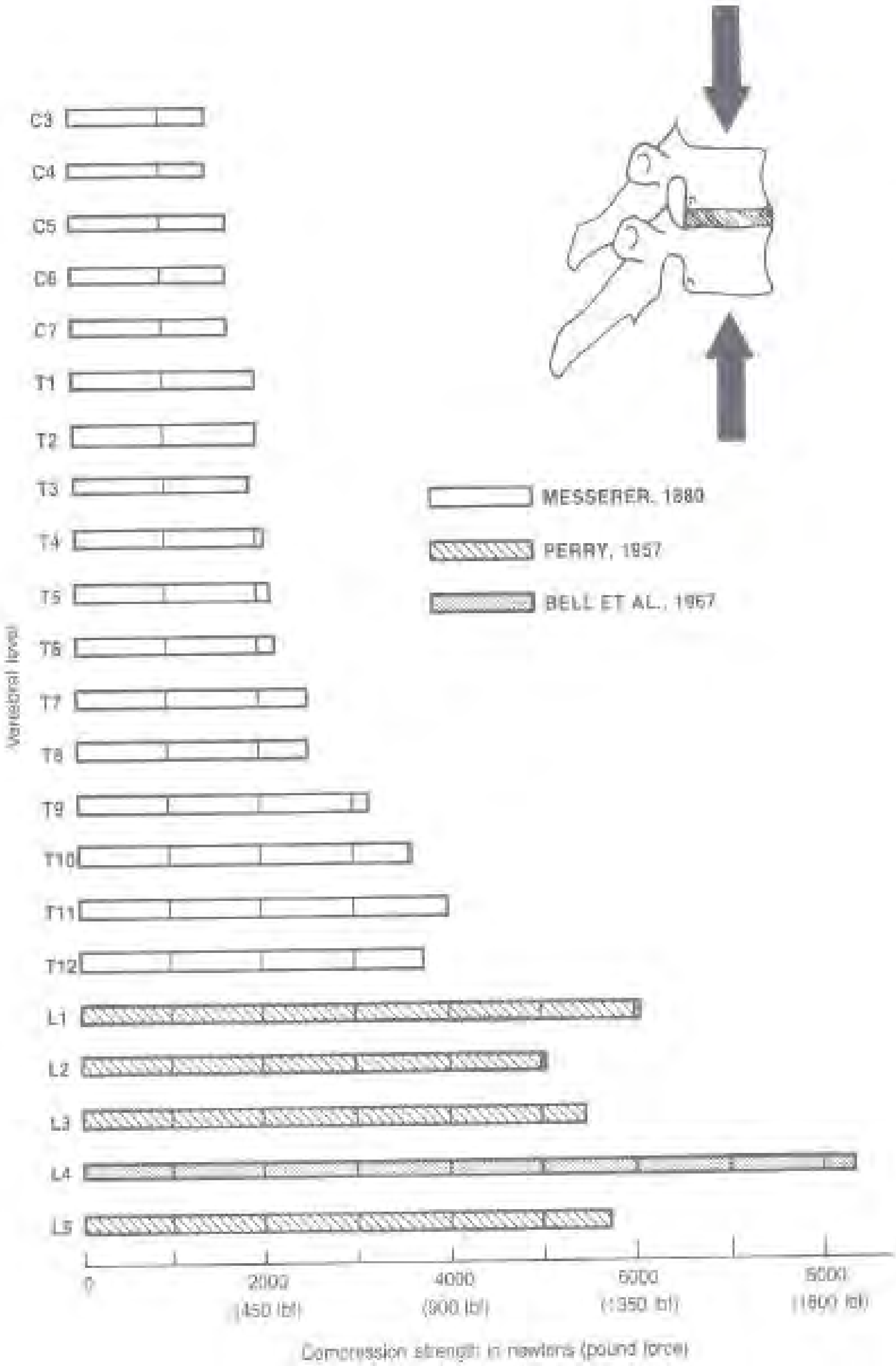

Figure 1. 13: Vertebral compressive strength (A.White & M.Panjabi, 1990)

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There is a conflict between previous studies on the loads that shared between these two structures. An experiment was to resolve the conflict on which structure that support major load. The intact vertebral strength was compared with the experiment in which the loads were applied without the shell. It was found that under compressive load, the cancellous bone contributes 25-55% of the strength of lumbar vertebral body (Kalyanrao, 2002).

1.3.2 Biomechanics of Intervertebral Disc

The intervertebral disc is viscous in nature. The disc is a major load carrying in human spine especially in compressive load. Compressive load that act axial to the disc creates a hydrostatic pressure in the nucleus and tensile stresses in the annulus. Intervertebral disc withstand most of the compressive loading that act on the plane.

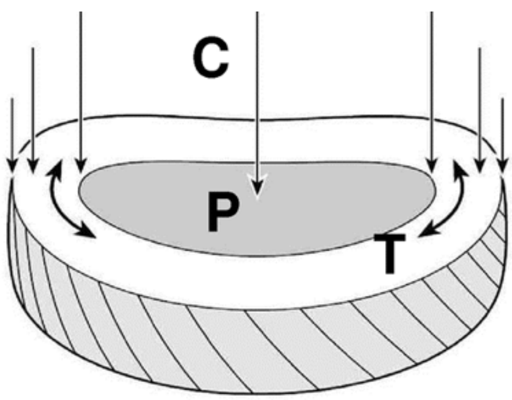

Figure 1. 14: Compressive loading of intervertebral disc. Adapted from Pollintine *et al.* (2004)[1]

Intervertebral disc degeneration affects the loads that distribute across the disc. In normal disc, most of the load spread evenly anterior and posterior of the vertebral body. Only 8% of the applied forces resisted by the neural arch. However, about 40% of compressive load resisted by neural arch in degeneration disc while the anterior region resists only 19%.

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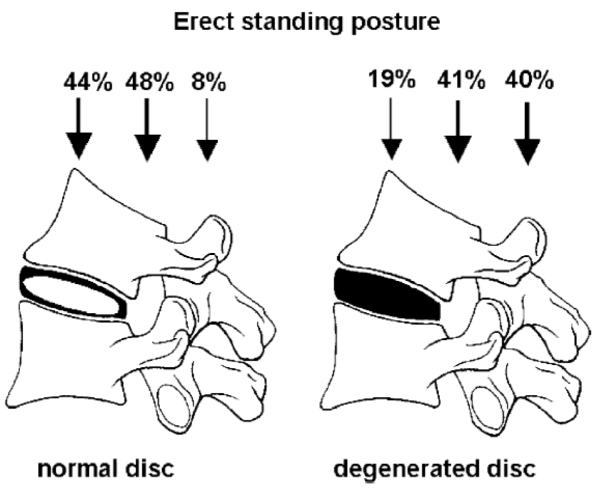

Figure 1. 15: : Load sharing in lumbar spine in normal and degeneration disc. Adapted from Pollintine *et al.* (2004)[2]

Many tests have been carried out to study disc on the disc at constant compressive loads. It was found that there is no disc herniation even when long incision was made on the annulus fibrosis. Another test was carried out by Brown and found that vertebral body is the first element to fracture when subjected to compressive load. There is no failure of disc due to herniation (Kalyanrao, 2002).

1.4 Low Back Pain

As an important human load-bearing structure, the lower back which is called lumbar spine region is the most flexible and receives the most stress compare to other region. Due to this bone structure which supports the weight from upper body, most pain is felt at this area which is known as low back pain. Anatomy structure of lumbar spine plays role that contribute to lower back pain.

L4-L5 intervertebral disc encounter 80-90% of lumbar flexion/extension in lumbar spine biomechanical motion. The occurrence of low back pain are high when the lumbar region experience forward bending, rotation or when trying to pick up

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