EFFECT OF GRADED LAMINECTOMY AND FACETECTOMY ON BIOMECHANICAL PROPERTIES OF NORMAL LUMBAR SPINE

-A FINITE ELEMENT STUDY-

DR FARID FIKRI BIN SHUKRI

Dissertation Submitted In Partial Fullfillment Of The Requirements For The Degree Of Master Of Medicine

(ORTHOPEDICS)

UNIVERSITI SAINS MALAYSIA

2018

EFFECT OF GRADED LAMINECTOMY AND FACETECTOMY ON BIOMECHANICAL PROPERTIES OF NORMAL LUMBAR SPINE

-A FINITE ELEMENT STUDY-

DR. FARID FIKRI BIN SHUKRI

Supervisor

ASSOC. PROF. DATO' DR. ABDUL HALIM YUSOF

Dissertation Submitted In Partial Fullfillment Of The Requirements For The Degree Of Master Of Medicine

(ORTHOPEDICS)

UNIVERSITI SAINS MALAYSIA

2018

ACKNOWLEDGEMENT

Bismillahirrahmaanirrahim. Lots of syukr and praises to Al-mighty Allah whom without Him, none of this would have been achieved

I would like to express my gratitude to my supervisor Assoc. Prof. Dato' Dr. Abdul Halim Yusof for his invaluable guidance, effort and advice throughout my study period and assisting me in completion of my dissertion. Thank you for always looking at the bright side.

I am also would like to extend my appreciation to my co-supervisor Prof. Dato' Ir. Dr. Mohammed Rafiq Dato' Abdul Kadir, Head of Department of Faculty of Bioscience and Medical Engineering UTM, whose giving suggestion and encouragement in time of my research.

I am deeply indebted to my co-researcher Abdul Hadi, PhD's student in Faculty of Bioscience and Medical engineering UTM, for his assistance in guiding me to conduct the bioengineering research of finite element study

Not to forget, Assoc. Prof Sarimah, USM statician's lecturer for assisting me in resolving my concern regarding the statistical analysis

Most prominently, I would like to extend my gratitude to my beloved wife, daughters, parents, siblings and in laws for the never ending support, encouragement and patience throughout my study.

Lastly, I would like to express my appreciation to those who directly or indirectly involved in completing my dissertion especially to my friends and USM staffs, whom are really willing to help in times of need.

Thank you very much.

LIST OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF GRAPHS

LIST OF ABBREVIATIONS

L1, 2, 3, 4, 5 : Lumbar 1, 2, 3, 4, 5

S1 : Sacral 1

ROM : Range of Motion

STL : Standard Tensellation Language

CT : Computer Tomography

FE : Finite Element

CTL : Christmas Tree Laminectomy

EMG : Electromyography

N : Newton

Nm : Newton meter

NZ : Neutral Zone

VLe : Ventral-Lateral external

VLi : Ventral-Lateral internal

De : Dorsal external

Di : Dorsal internal

MPa : Mega Pascal

ABSTRACT

EFFECT OF GRADED LAMINECTOMY AND FACETECTOMY ON BIOMECHANICAL PROPERTIES OF NORMAL LUMBAR SPINE

-A FINITE ELEMENT STUDY-

INTRODUCTION

Graded laminectomy and facetectomy are techniques for decompressing neural structure in the lumbar spine. However this resection techniques normally lead to a decrease in spinal stability. Previous experimental studies were based on in vitro human cadaver model to determine the instability of lumbar spine following graded decompression surgery. However, there are some major limitations in these experimental studies in which the inability to determine the intrinsic parameters such as loads, stresses and strains over the intervertebral disc and vertebra bodies after the surgery. In order to investigate spinal stability and the intrinsic parameters after decompression spinal surgery, a finite element analysis of the lumbar spine was performed. Intersegmental motions of lumbar vertebrae, stresses of intervertebral disc and vertebra bodies were calculated while simulating an intact spine as well as different extents of resection (hemilaminectomy, hemifacetectomy, total laminectomy and total facetectomy).

METHODOLOGY

A three-dimensional, non-linear finite element model of the lumbar spine was created using Mimic 10.01 software and meshed using 3-Matic 11.0 software . Only one model of lumbar finite element L1-L5 was constructed from a normal lumbar CT images, and this finite element model was extrapolated to represent the human population with normal lumbar spine. Since no in vitro experiment is done in our study, the validation of our finite element model is based on previous experimental study. Then, spinal decompression procedures are simulated on the lumbar model using Marc Mentat 2010 software. There is no statistical analysis as the result is analysed directly from decompression surgery of one normal lumbar model, hence, there is no hypothesis in our study.

RESULT

For surgery that preserved the spinous process (hemilaminectomy, hemifacetectomy and total facetectomy), the displacement of the spine are 1.31^o, 1.20^o, 1.37^o. However, when the spinous process is resected (laminectomy), the displacement of the spine in flexion rise up to 3.43^o which was increased 4.53% compared to intact model. The displacement of lumbar spine in extension post decompression surgery are 1.85^o, 1.87^o, 1.91^o and 1.95^o. The result showed near equal displacement of lumbar spine in extension after each simulation surgery. There is high stress concentration post decompression surgery over anterior aspect of the intervertebral disc L3/L4 in flexion group otherwise low in extension group. The increased , stress concentration on vertebra bodies also produce different pattern in each decompression surgery during flexion and extension.

CONCLUSION

Graded laminectomy and facetectomy of lumbar spine in finite element analysis shows increase in intersegmental motion that lead to spinal instability. In our study, total laminectomy affect stability the most by having more intersegmental mobility and most intervertebral disc stress in flexion. Total facetectomy affect the intervertebral disc stress more in flexion but only have slight increase of intersegmental motion in flexion. This shows that total laminectomy produce the most instability compared to total facetectomy.

ABSTRAK

EFEK LAMINEKTOMI DAN FASETEKTOMI BERPERINGKAT KE ATAS SIFAT BIOMEKANIKAL TULANG LUMBAR YANG NORMAL

-KAEDAH ELEMEN FINIT-

PENGENALAN

Laminektomi dan facetectomi berperingkat adalah teknik untuk membebaskan struktur saraf pada tulang belakang lumbar. Walau bagaimanapun teknik reseksi ini biasanya membawa kepada penurunan kestabilan tulang belakang. Kajian eksperimen sebelum ini adalah berdasarkan kepada model cadaver manusia in vitro untuk menentukan ketidakstabilan tulang belakang lumbar selepas pembedahan dekompresi berperingkat. Walau bagaimanapun ada beberapa batasan utama dalam kajian eksperimental ini di mana ketidakupayaan untuk menentukan parameter intrinsik seperti beban tekanan, stres dan strain ke atas cakera intervertebral dan tulang vertebra selepas pembedahan. Untuk menyelidik kestabilan tulang belakang dan parameter intrinsik selepas pembedahan dekompresi tulang belakang, analisis elemen finit pada tulang belakang lumbar dilakukan. Gerakan intersegmental, tekanan cakera intervertebral dan vertebra ditaksir semasa mensimulasikan tulang belakang yang lengkap serta reseksi yang berbeza (hemilaminektomi, hemifasetektomi, total laminektomi dan total fasetektomi).

KAEDAH KAJIAN

Model elemen finit tiga-dimensi tulang belakang lumbar yang tidak linier telah dibina menggunakan perisian Mimic 10.01 dan menggunakan perisian 3-Matic 11.0. Hanya satu model lemen finit lumbar L1-L5 dibina dari imej CT lumbar yang normal, dan model elemen finit ini diekstrapolasi untuk mewakili populasi manusia dengan tulang belakang lumbar yang normal. Oleh kerana tiada eksperimen in vitro dilakukan dalam kajian kami, pengesahan model elemen finit kami adalah berdasarkan kepada kajian eksperimen yang telah dijalankan sebelum ini. Kemudian, prosedur dekompresi tulang belakang disimulasikan pada model lumbar menggunakan perisian Marc Mentat 2010. Keputusan dianalisis secara langsung dari simulasi pembedahan dekompresi satu model elemen finit lumbar yang normal menyebabkan tidak akan ada hipotesis dalam kajian kami.

KEPUTUSAN

Bagi pembedahan yang mengekalkan proses spina (hemilaminectomi, hemifasetektomi dan total fasetektomi), pergerakan intersegmental tulang belakang adalah 1.31^o, 1.20^o, 1.37^o. Walau bagaimanapun, apabila proses spina dibuang (laminektomi), pergerakan intersegmental tulang belakang semasa fleksi meningkat sehingga 3.43^o , dimana ia meningkat 4.53% berbanding dengan model lengkap. Pergerakan intersegmental tulang belakang lumbar dalam pembedahan dekompresi ialah 1.85^o, 1.87^o, 1.91^o dan 1.95^o. Keputusan menunjukkan pergerakan intersegmental tulang belakang lumbar semasa ekstensi adalah hampir sama dalam setiap pembedahan simulasi. Terdapat kepadatan stres yang tinggi selepas pembedahan dekompresi di bahagian anterior cakera intervertebral L3 / L4 dalam kumpulan fleksi manakala kepadatan stres rendah dalam kumpulan ekstensi. Kepadatan stres pada tulangan vertebra juga menghasilkan peningkatan corak yang berbeza dalam setiap pembedahan dekompresi semasa fleksi dan ekstensi

KESIMPULAN

Laminektomi dan fasetektomi berperingkat tulang lumbar pada analisis elemen finit menunjukkan peningkatan pergerakan intersegmental yang menyebabkan ketidakstabilan tulang belakang. Total laminektomi menjejaskan kestabilan yang paling tinggi kerana menghasilkan lebih banyak pergerakan intersegmental dan juga tekanan cakera intervertebral yang tinggi dalam fleksi. Total fasetektomi menyebabkan tekanan cakera intervertebral yang lebih tinggi tetapi hanya mempunyai gerakan intersegmental yang sedikit meningkat. Ini menunjukkan bahawa total laminektomi menghasilkan ketidakstabilan yang paling ketara berbanding dengan total fasetektomi.

CHAPTER 1

INTRODUCTION

The spine is the important structure that provide mobility and supports to the human body. It consists of series of vertebral bone which divided into cervical, thoracic, lumbar and sacrum. These vertebral bones are fused together by flexible intervertebral disc which connect the skull to the pelvis. The spine, regardless of its mobility, contains and provides protection to the spinal cord from the brain, all the way down to the spinal nerves that arise from the spinal cord.

The whole spine function as a single unit. The spine has a dual functions which are for body mobility and spinal cord protection. These functions are unique as both serves a distinct and conflicting roles (protecting spinal cord while providing flexible and mobile spine). The synchronization of mobility and stability of the spine is crucial to fulfill this goals simultaneously

Both functions are sustained by interconnection of interverbral disc and facet joints between the vertebras, providing stable articulation and control the motion of each segment. Motions that are allowed are flexion-extension, axial rotation, right and left lateral bending.

Instability is a mechanical entity. Unstable structure is one that is not in an optimal state of equilibrium. In the spine, stability is affected by restraining structures that, if damaged or lax, will lend to altered equilibrium and thus instability (Pope and Panjabi, 1985).

A lumbar motion segment is considered to be unstable when it exhibits abnormal movement. This movement can be abnormal in quality (abnormal coupling patterns) or in quantity (abnormal increased motion). This instability can be symptomatic or asymptomatic, depending on demands made on the motion segment (Dupuis *et al.*, 1985).

The motion segment is composed of two vertebrae joined by three joints (two facet joints and one intervertebral disc), each having its own set of stabilizers. The three joint are mechanically balanced so that the permanent problem in one will ultimately affect the integrity of other two (Kirkaldy-Willis and Farfan, 1982).

Resections of posterior bony or ligamentous parts (decompression surgery) normally lead to a decrease in stability. The degree of instability depends on the extent of posterior element resection (Zander *et al.*, 2003). In order to investigate the biomechanical properties of lumbar spine , our study constructs a three-dimensional non-linear finite element model of lumbar spine and simulate spinal decompression surgery to calculate the spinal stability (intersegmental motion) and stress on intervertebral disc and vertebra bodies.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

Spinal instability is defined as the loss of the spine's ability to maintain its patterns of displacement under physiologic loads so there is no initial or additional neurologic deficit, no major deformity, and no incapacitating pain (Panjabi, 2003). Physiological loads are those that are incurred during the normal activity. Incapacitating pain is defined as pain that cannot be controlled by non – narcotic drugs. It is essental to identify between mechanical instability and clinical instability. Mechanical instability defines inability of the spine to carry spinal loads, while clinical instability defines the clinical consequences of neurological deficit and/or pain. Clinical instability can occur from trauma, disease, operation or combination of the three (Panjabi and White III, 1980).

Clinical instability of the spine has been studied in vivo since 1944 using functional radiographs (Knutsson, 1944) .There have been several similar studies but the results have been unclear, some studies found increased motion (Friberg, 1987; Lehmann and Brand, 1983) , whereas others found decreased motion (Dvorak *et al.*, 1991; Pearcy and Shepherd, 1985).

White and Panjabi performed the first systematic approach to the analysis of mechanical stability of the spine using an in vitro biomechanical model of the cervical spine (Panjabi *et al.*, 1975; White III *et al.*, 1975). Fresh cadaveric functional spinal units of two adjacent vertebrae with interconnecting disk, ligaments, and facet joints, but devoid of musculature were loaded either in flexion or extension, and the anatomic elements (disk, ligaments, and facet joints) were transected either from anterior to posterior or from posterior to anterior. This study resulted in the development of a checklist for the diagnosis of lumbar spine instability (Panjabi, 1990b) which uses several elements, such as biomechanical parameters, neurologic damage and anticipated loading on the spine

Element	Point value
Anterior elements destroyed or unable to function	2
Posterior elements destroyed or unable to function	2
Radiographic criteria	4
Flexion–extension radiographs	
Sagittal plane translation > 4.5 mm or 15%	2
Sagittal plane rotation	
15° at L1-2, L2-3, and L3-4	2
20° at L4-5	2
25° at L5-S1	2
Resting radiographs	
Sagittal plane displacement > 4.5 mm or 15%	2
Relative sagittal plane angulation >22°	2
Cauda equina damage	3
Dangerous loading anticipated	1

Table 1 : Check list for the diagnosis of clinical instability in the lumbar spine (Panjabi, 1990a). A point of value total of 5 or more indicates clinical instability

2.2 The Spinal Stabilizing System

The concept of mechanical stability of the spine, especially in dynamic conditions and under heavy loads, is provided by the spinal column and the precisely coordinated surrounding muscles. The spinal stabilizing system was conceptualized by Panjabi to consist of three subsystems (Panjabi, 1992a):

1) spinal column - providing intrinsic stability
2) spinal muscles that surrounded the spinal column - providing dynamic stability,
3) neural control unit - evaluating and determining the requirements for stability and coordinating the muscle response.

Under normal conditions, the three subsystems work in harmony and provide the needed mechanical stability. The components of the spinal column and muscles provide information about the mechanical status of the spine, such as position, load and motion of each vertebra, in a dynamic fashion. The neural control unit computes the needed stability and generates appropriate muscle pattern, for each instance.

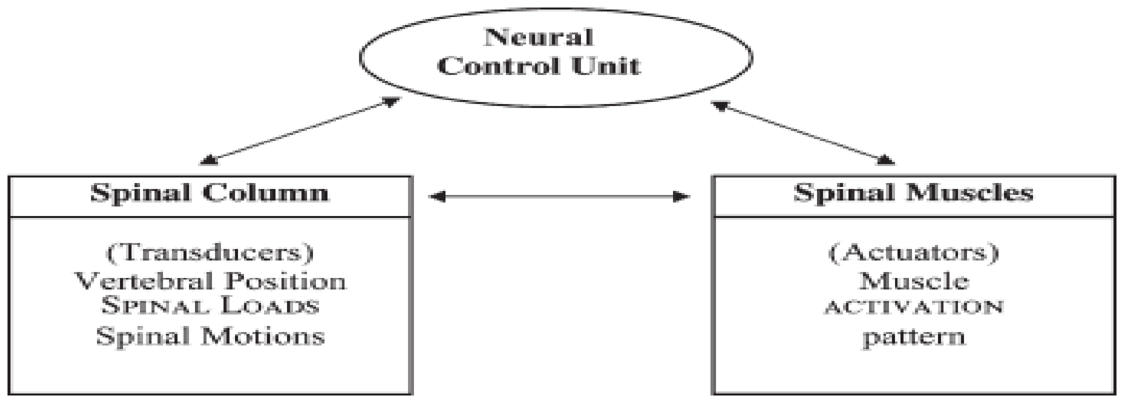

Figure 1 : The spinal stabilizing system (Panjabi, 2003)

2.3 The Spinal Column

Biomechanical studies have contributed some insight into the role of spinal column components (disk, ligaments and facets) in providing spinal stability. The load–displacement curve is used as a measure of physical properties of the spinal column. The load displacement curve of the spine is nonlinear. A schematic load displacement curve (nonlinear curve) of a spinal segment for flexion and extension motion is shown in (Fig. 2). The spine is flexible at low loads and stiffens with increasing load. The slope of the line (stiffness of the spine) varies with the load.

Nevertheless, this behavior is not adequately represented by a single stiffness value hence two parameters are used: range of motion (ROM) and neutral zone (NZ) (Panjabi *et al.*, 1982). The NZ is that part of the ROM within which there is minimal resistance to intervertebral motion (Panjabi, 1992b).

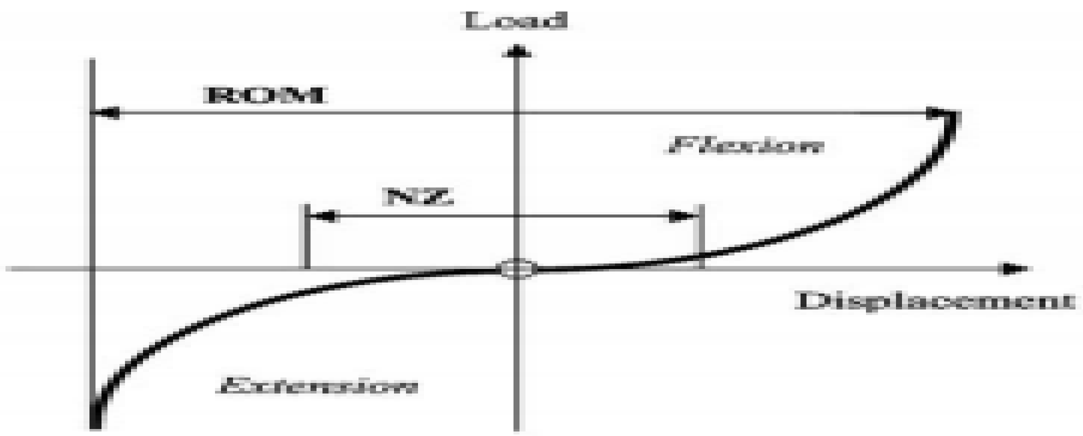

Figure 2 : Load–displacement curve (Panjabi, 2003)

2.4 The Spinal Muscles

The importance of muscles in stabilizing the spinal column is quite obvious when a cross-section of the human body is viewed at the lumbar level . Not only is the total area of the cross-sections of the numerous muscles surrounding the spinal column much bigger than the area of the spinal column, but the muscles have significantly larger lever arms than those of the intervertebral disc and ligaments.

The muscles provide mechanical stability to the spinal column. Euler, in 1744 developed mathematical theories for analyzing the load carrying capacity of upright columns (Timoshenko and Gere, 1972). According to this theory, the critical load is directly related to the stiffness of the column. If the column was thicker (higher stiffness), the critical load will be higher, and the column would stand and remain stable . If the column is made thinner (lower stiffness), then the column will buckle. The in vitro critical load for the lumbar spinal column has been determined to be 90 N (Crisco, 1989). This is much smaller than the estimated in vivo spinal loads of 1500 N and above (Nachemson and Morris, 1964). This difference between the in vitro and in vivo loads can be explained only on the basis that the muscles act as tension cable in stiffening the spine and, thus, increasing its critical load and stability.

Because of difficulties of measuring muscle forces in vivo, two approaches have been used. First, in vitro models have been created to simulate the effects of muscle forces. Second, mathematical models have been constructed to simulate mathematically the spinal column and surrounding spinal muscles.

In an in vitro study, Panjabi et al used fresh cadaveric two-vertebrae human lumbar spine specimens and measured multidirectional flexibilities before and after several injuries of increasing severity (Panjabi *et al.*, 1989).

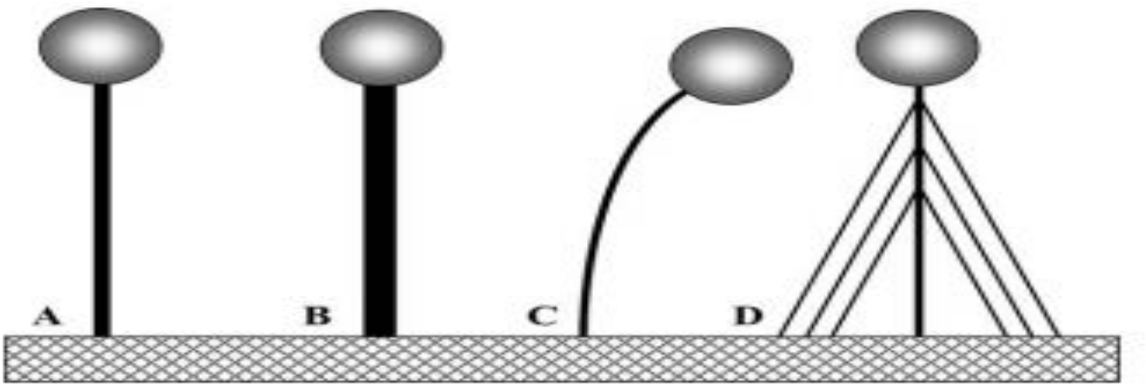

Figure 3 : Buckling of a column carrying a load. (A) A column with a critical load is at the brink of buckling or instability. (B) A stiffer column is stable. (C) A more flexible column is unstable. (D) The unstable column can be restabilized by adding tension cables (Panjabi, 2003)

2.5 The Neural Control Unit

The spinal stabilizing system functioned by altering the muscle activation pattern in response to the ligamentous tissue mechanoreceptor signals via the control unit (Panjabi, 1992a). There are several animal studies which have attempted to better understand this important relationship between the mechanoreceptor signals and the paraspinal muscle activation pattern. In the first study of this type using a porcine model, Indahl et al electrically stimulated the lateral annulus at one level and found a response in the multifidus at multiple levels (Indahl *et al.*, 1995), while stimulation of the facet joint capsule activated only the muscles at the stimulated level.

The ligament–muscle relationship was found to be modulated by the facet joint injection. The muscle response decreased with injection of both lidocaine (Indahl *et al.*, 1995) and physiological saline (Indahl *et al.*, 1997). Solomonow et al furthered the study by using mechanical stimuli (Solomonow *et al.*, 2003; Solomonow *et al.*, 1998). They used a feline model and stretched the supraspinous ligament, while monitoring the EMG of multifidus. They found a ligament–muscle reflex response. These observations may explain the muscle spasm seen in patients after a ligamentous injury. The EMG activity of the muscles (feline multifidus) decreased due to stretching of the ligament for prolonged duration as well as by cyclic stretching (Gedalia *et al.*, 1999; Solomonow *et al.*, 2003; Williams *et al.*, 2000). Based upon these findings, one should avoid long duration repetitive activities as this may decrease the muscle stability and, therefore, the spine may become prone to injury.

2.6 Spinal Instability after Decompression Surgery

Spinal decompression surgery involves in decompressing of the neural structure. However, when extensive decompression is performed, mechanical spinal instability can develop which may lead to worsening of back symptom even before the spinal surgery

Currently, graded laminectomy and facetectomy are the standard methods of spinal decompression surgery. Even though good results of post decompression had been reported as 85 – 90%, this procedure also complicated with alteration of various spinal column components which lead to mechanical spinal instability and increase of stress over the affected and adjacent lumbar vertebra. As a result, the change in biomechanical properties of the lumbar spine leads to possible increased propensity for back pain or acceleration of segmental degeneration.

2.7 Spinal Instability in Experimental Study

Several experimental studies (Abumi *et al.*, 1990; Kato *et al.*, 1998; Natarajan *et al.*, 1999; Quint *et al.*, 1997) have quantified the degree of instability caused by resecting dorsal parts in spinal decompression surgery.

1) Abumi and Panjabi investigated spinal stability by applying pure moments together with an axial preload to intact functional spinal units and to those with division of posterior ligaments and medial or total facetectomies. The major conclusions were that transection of the supraspinous and intraspinous ligaments did not affect lumbar spine motion. However, unilateral medial facetectomy increased flexion, total facetectomy of one side increased axial rotation to the opposite side, and complete facetectomy increased the axial rotation to both sides. The extension and lateral bending movements did not show significant increases by any of the injury (Abumi *et al.*, 1990; Panjabi *et al.*, 1989).

2) Quint et al. loaded six human lumbar spine specimens with pure moments in the three main anatomic planes, recorded load-deformation hysteresis curves and measured the neutral zone and range of motion in relation to the extent of resection. Besides the intact specimens, four extents of resection were examined: left and bilateral hemifacetectomy, left hemilaminectomy and laminectomy at L4/L5. They found an increased range of motion for all loading situations and concluded that a laminectomy leads to marked instability (Quint *et al.*, 1997).

3) Kato et al studied the the biomechanical stability of the lumbar spine after two surgical procedures of total facetectomy and osteoplastic laminectomy using fresh-frozen

human cadaveric lumbar spine specimens. The result showed no significant increases in ROM in lateral bending after the two procedures. However, flexion-extension ROM increased significantly after the total facetectomy, but not after osteoplastic laminectomy. Axial rotation ROM increased remarkably after the total facetectomy, but only moderately after the osteoplastic laminectomy. They concluded that the osteoplastic laminectomy, which preserves the spinous process as well as the facet joints, maintains greater spinal stability than the total facetectomy (Kato *et al.*, 1998).

4) Farfan et al, studied the effects of graded facetectomy on the motions of the spine showed that complete transection of the facets significantly increases axial rotation (Farfan *et al.*, 1970). However, the effects of partial transactions of the facets have not been studied extensively.

5) Lorenz et al. conducted an in vitro experiment to study unilateral total facetectomy under compressive axial load and found that the unilateral facetectomy resulted in a decreased load on the contralateral facet (Lorenz *et al.*, 1983).

6) Pintar et al. evaluated the spinal components of lumbar functional units under various surgical alterations (bilateral facetectomy with posterior ligament transection), and noted a significant increase in overall deflection of the functional unit under flexion-compression load (Pintar *et al.*, 1992).

7) In study by Haher et al., they reported unilateral and bilateral facetectomies had little affect on the ability of the specimen to support a physiologic load. Facetectomies in combination with anterior anulus resection showed a significant change in the ability

of the specimen to support a load with an extension moment applied. Facet joints are not the principle support structures in extension. With resection of the facets, an alternate path of loading is established. The alternate path of loading transfers axial loads to the anulus and anterior longitudinal ligament to support the spine. Although facet joint resection will not produce acute instability, it will transfer the loads to the adjacent disc and conceivably accelerate its degeneration (Haher *et al.*, 1994).

8) Bisschop et al obtained twelve cadaveric human lumbar spines in their study. Single level lumbar laminectomy was performed at L2 or L4. The range of motion at the level of laminectomy increased significantly for flexion and extension, lateral bending and axial rotation. Range of motion of adjacent segments was only significantly affected in lateral bending(Bisschop *et al.*, 2014).

9) Lee et al reported that bilateral laminotomies resulted in an average increase in L2–L5 range of flexion/extension motion of 14.3%, whereas a full laminectomy resulted in an increase of 32.0%. Analysis per level demonstrated roughly two fold increase in motion with laminectomy compared with bilateral laminotomies. Stiffness was decreased by an average of 11.8% after the 3-level-laminotomies and by 27.2% after the 3-level-laminectomy. The study concluded that bilateral laminotomies induce significantly less hypermobility and less stiffness reduction compared with a full laminectomy (Lee *et al.*, 2010).

10) Delank et al performed segmental biomechanical examination of nine human lumbar cadaver spines (L1 to L5). Measurements were done after progressive resection of dorsal elements like lig. flavum, hemilaminectomy, laminectomy and facetectomy. In

the sagittal and frontal plane, flavectomy and hemilaminectomy on the operated segment and adjacent segment did not achieve any relevant change in the ROM in both directions.Resection of the facet also does not lead to any distinct increase of mobility in the operated segment in flexion and right/left bending. However there is increase in mobility in extension of more than 1 degree in the operated segment. It is concluded that monosegmental decompression of the lumbar spinal canal does not essentially destabilise the motion segment during in vitro conditions (Delank *et al.*, 2010).

11) Phillips et al in their study tested nine human lumbar spines (L1 to sacrum) in flexion-extension, lateral bending, and axial rotation. Specimens were tested intact, after complete L3 laminectomy with L3–L4 facetectomy. Result showed that complete laminectomy-facetectomy increased L3–L4 ROM compared with intact in flexion-extension, lateral bending and axial rotation (Phillips *et al.*, 2009).

12) Detwiler et al compared a Christmas tree laminectomy (CTL), in which bilateral facetectomies and foraminotomies are performed, with facet-sparing laminectomy (FSL), in which the facets are undercut but not resected. Sixteen motion segments obtained from five human cadaveric lumbar specimens were studied in vitro. Compared with the intact condition, CTL-treated specimens had significantly larger increases in angular motion during flexion, lateral bending, and axial rotation than their FSL-treated counterparts. The study concluded that treatment of lumbar stenosis with FSL induces less biomechanical instability and alters kinematics less than FSL (Detwiler *et al.*, 2003).

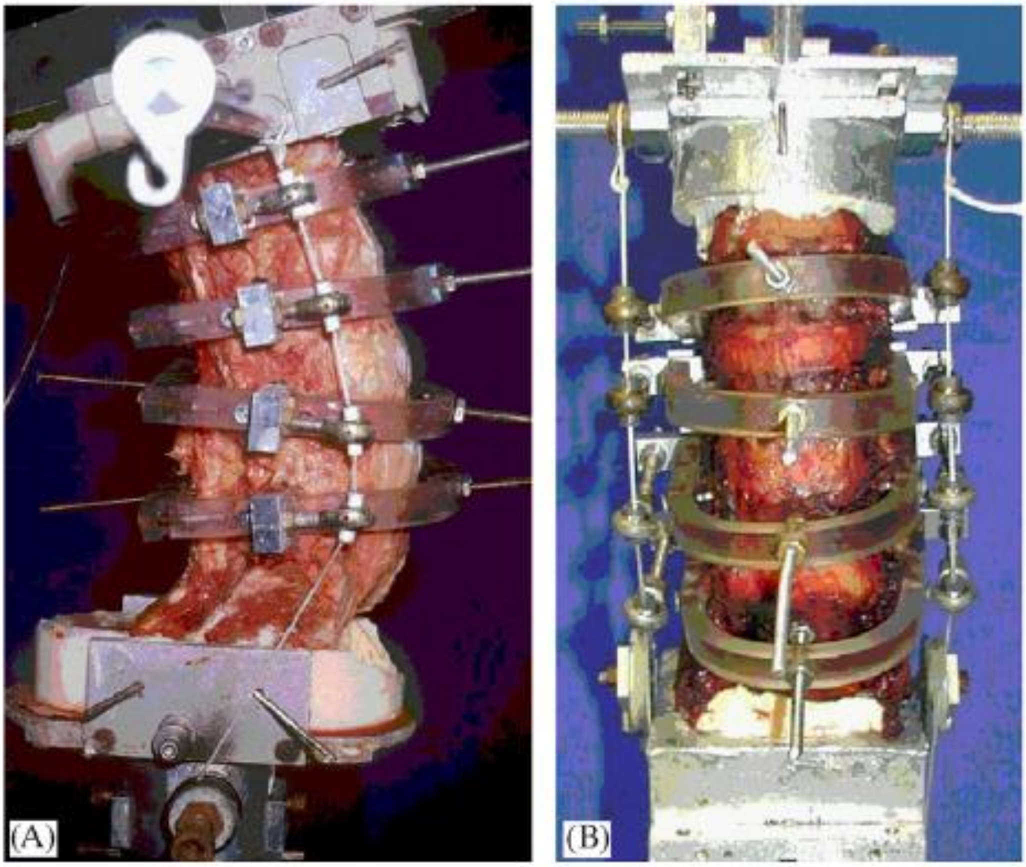

Figure 4 : In vitro cadaveric model of lumbar spine (Renner *et al.,* 2007).

2.8 Spinal Instability in Finite Element Study

It is difficult to perform reproducible experimental investigations or to apply physiological loads when using cadaver specimens. The finite element method allows the calculation of stresses, strains and movements in the different structures involved. The advantage of the analytical over the experimental approach is that no new specimens are needed to modify particular parameters such as the degree of resection, the loads or the boundary conditions.

Major limitations of any experimental studies lie in its inability to determine intrinsic parameters (facet load, stress, strain, etc), and that significant inherent biological variation among specimens lead to defference of the resulting data.

The process of comparing numerical to experimental data and subsequently adjusting the computer model makes the finite element method a powerful tool for analysing such biomechanical properties, as other studies have proven (Calisse *et al.*, 1999; Goel *et al.*, 1993; Lavaste *et al.*, 1992; Shirazi-Adl, 1991; Zander *et al.*, 2001; Zander *et al.*, 2002)

1) Zander et al reported that unilateral hemifacetectomy increases intersegmental rotation for the loading situation of axial rotation. Expanding the resection to bilateral hemifacetectomy increases intersegmental rotation even more, while further resection up to a total laminectomy has only a minor additional effect. The study also showed that spinal stability is decreased after a laminectomy for forward bending, and after a two-level laminectomy for standing.

2) Natarajan et al. studied the effect of graded facetectomy on torsional flexibility using an analytical method (FE method). Facet joint model was created that represents the contact area as contact between two surfaces. It was concluded that a substantial sudden change in rotational motion, due to applied torsion moment, was observed after 75 percent of any one of the facet joints was removed (Natarajan *et al.*, 1999).

3) Lee et al. constructed a finite element (FE) model of L2–L3 to investigate the biomechanical effect of laminectomy with and without facetectomy. Four iatrogenic models (unilateral laminectomy, unilateral laminectomy with unilateral facetectomy, unilateral laminectomy with bilateral facetectomy and total bilateral laminectomy) were evaluated under flexion, extension, torsion, lateral bending, anterior and posterior shear load vectors to determine alterations in kinematics and annulus stress. Results show that total laminectomy with facetectomy induces considerable increase in motion and annulus stress, except for lateral bending, whereas unilateral laminectomy shows the least increases (Lee and Teo, 2004).

4) Teo et al constructed an anatomically accurate three-dimensional finite-element (FE) model of the human lumbar spine (L2-L3) and it was used to study the biomechanical effects of graded bilateral and unilateral facetectomies of L3 under anterior shear. The intact L2-L3 FE model was validated under compression, tension, and shear loading and the predicted responses matched well with experimental data. Results indicated that unilateral facetectomy of greater than 75% and bilateral facetectomy of 75% or more resection markedly alter the translational displacement and flexibilities of the motion segment. This study suggests that fixation or fusion to restore strength and

stability of the lumbar spine may be required for surgical intervention of greater than 75% facetectomy (Teo *et al.,* 2004).

5) Bresnahan et al in his research use the finite element model of lumbar spine (L1–S1) to study the biomechanical changes as a result of surgical alteration for treatment of stenosis at L3–L4 and L4–L5 using 2 established techniques and 1 new minimally invasive technique. Result shows that removal of posterior elements for treatment of stenosis at L3–L4 and L4–L5 results in increased flexion-extension and axial rotation at the surgical site. This study also shows that the segmental motion following a traditional laminectomy is greater than the minimally invasive approach in flexion, extension, left and right axial rotation. Moderate preservation of the posterior elements which occurs in the intralaminar approach generates greater segmental motion that the minimally invasive approach in extension, left and right axial rotation(Bresnahan *et al.,* 2009).

6) Guan et al constructed an anatomically accurate validated three-dimensional finite element model used it to investigate the biomechanical effects of total laminectomy on the mechanical behavior of human lumbosacral spine. A total laminectomy was simulated at L4 or L5. Flexion, extension and lateral bending were applied using pure moment. Rotations were obtained under each loading mode. Maximum von Mises stresses in the annulus fibrosis under different loading were also obtained. It was found that L5 laminectomy has a greater influence on spinal column rotation. The maximum stress in the annulus increased significantly in L5 laminectomy model but not in the L4 model (Guan *et al.*, 2007b).