

**LUMBAR SPINAL STENOSIS: THE RELIABILITY,  
SENSITIVITY AND SPECIFICITY OF THE NERVE  
ROOT SEDIMENTATION SIGN**

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## LIST OF ABBREVIATIONS

CCU	Coronary Care Unit
CI	Confidence Interval
CSA	Cross-sectional Area
CSF	Cerebrospinal Fluid
CT	Computed Tomography
DISH	Diffuse Idiopathic Skeletal Hyperostosis
HUSM	Hospital University Sains Malaysia
ICU	Intensive Care Unit
IQR	Inter-quartile Range
LSS	Lumbar Spinal Stenosis
MRI	Magnetic Resonance Imaging
NPV	Negative Predictive Value
PPV	Positive Predictive Value
SD	Standard Deviation
SPSS	Statistical Package for Social Science
TGF	Transformation of Growth Factor
WHO	World Health Organization

## LIST OF SYMBOLS

$<$	Less than
$>$	More than
$=$	Equal to
$\leq$	Less than and equal to
$\geq$	More than and equal to
$\%$	Percentage

## ABSTRAK

### STENOSIS TULANG BELAKANG LUMBAR (LSS): KEBOLEHPERCAYAAN, SENSITIVITI DAN SPESIFISITI TANDA PEMENDAPAN SARAF AKAR

**Pengenalan:** Stenosis tulang belakang lumbar (LSS) adalah keadaan perubatan di mana terusan tunjang menyempit dan saraf tunjang dan saraf termampat di peringkat vertebra lumbar. Tanda pemendapan dinilai daripada MRI lumbar standard dan mudah untuk dinilai. Penemuan MRI tanda pemendapan positif adalah tanda yang dipercayai untuk mendiagnosis stenosis tulang belakang lumbar dengan sensitiviti dan spesifisiti yang tinggi. Objectif kajian ini adalah untuk mengenal pasti tanda pemendapan akar saraf pada pesakit yang mengalami degeneratif LSS dan untuk menilai kebolehpercayaan, sensitiviti dan spesifisiti.

**Metodologi:** Kajian ini adalah satu kajian semakan rekod retrospektif untuk menentukan sosio-demografi dan tanda-tanda klinikal LSS. Ia juga adalah untuk menentukan kebolehpercayaan, sensitiviti dan spesifisiti tanda pemendapan akar saraf melalui MRI dan untuk menilai kebolehpercayaan inter dan intra pemerhati, sensitiviti dan spesifisiti. Seramai lapan puluh dua subjek yang telah dimasukkan dalam kajian ini untuk menentukan sosio-demografi, tanda-tanda klinikal LSS, kebolehpercayaan, sensitiviti dan spesifisiti tanda saraf akar pemendapan. Lima puluh enam subjek yang telah dimasukkan dalam menentukan kebolehpercayaan inter dan intra pemerhati, sensitiviti dan spesifisiti. Dua pemerhati iaitu ahli radiologi dan pakar bedah ortopedik telah ditugaskan untuk menganalisa tanda secara berasingan.

**Keputusan:** Terdapat 43 pesakit dalam kumpulan LSS dan 39 pesakit untuk kawalan (kumpulan bukan LSS). Terdapat hubungan yang signifikan antara klaudikasi dan kaki

kebas dengan LSS ( $p < 0.001$ ). Kelemahan kaki, sakit punggung dan sakit paha juga menunjukkan hubungan yang signifikan dengan LSS ( $p = 0,037, 0,019$  dan  $0,011$  masing-masing). Terdapat hubungan yang signifikan antara kelemahan motor dan perubahan deria dengan LSS ( $p < 0.001$ ). Tanda pemendapan akar saraf adalah 100% sensitif dalam diagnosis LSS dengan spesifisiti 82.1%. Sensitiviti tanda pemendapan akar saraf oleh Pemerhati 1 adalah 84.8% dan Pemerhati 2 adalah 78.8% manakala spesifisiti kedua-dua pemerhati adalah 95.7%. Untuk kebolehpercayaan intra pemerhati, kedua-dua pemerhati menunjukkan kebolehpercayaan yang baik. Kebolehpercayaan intra pemerhati bagi Pemerhati 1 adalah Kappa 0.785, (nilai  $p < 0.001$ ) 95% CI (0.62, 0.95) dan kebolehpercayaan intra pemerhati untuk Pemerhati 2 adalah Kappa daripada 0.857, (nilai  $p < 0.001$ ) 95% CI (0.72, 0.99). Kebolehpercayaan antara pemerhati bagi dua pemerhati didapati baik dengan Kappa 0.610, (nilai  $p < 0.001$ ) 95% CI (0.62, 0.95).

**Kesimpulan:** Hasil kajian menunjukkan bahawa tanda pemendapan akar saraf mempunyai sensitiviti dan spesifisiti yang tinggi untuk mendiagnosis LSS. Untuk kebolehpercayaan intra dan inter pemerhati menunjukkan kebolehpercayaan yang baik. Ini menunjukkan bahawa tanda ini dapat dikenal pasti dengan tepat dan ia memberikan maklumat tambahan yang dipercayai dalam mendiagnosis LSS.

*Kata kunci:* stenosis tulang belakang lumbar, tanda pemendapan akar saraf, kebolehpercayaan, sensitiviti, spesifisiti, intra dan inter pemerhati

## ABSTRACT

### LUMBAR SPINAL STENOSIS: THE RELIABILITY, SENSITIVITY AND SPECIFICITY OF THE NERVE ROOT SEDIMENTATION SIGN

**Introduction:** Lumbar spinal stenosis (LSS) is a medical condition in which the spinal canal narrows and compresses the spinal cord and nerves at the level of the lumbar vertebra. The sedimentation sign is evaluated from standard lumbar MRIs and easy to apply. MRI finding of positive sedimentation sign is a reliable sign to diagnose lumbar spinal stenosis with high sensitivity and specificity. The objective of this study is to identify the nerve root sedimentation sign in patients with degenerative LSS and to evaluate its reliability, sensitivity and specificity.

**Methodology:** This study is a retrospective record review study to determine the socio-demographic and clinical presentation of LSS. It is also to determine the reliability, sensitivity and specificity of the nerve root sedimentation sign and to evaluate the inter and intra observer reliability, sensitivity and specificity. 82 subjects were enrolled in this study to determine the socio-demographic, clinical presentation of LSS, reliability, sensitivity and specificity of the nerve root sedimentation sign. 56 subjects were included in determining the inter and intra observer reliability, sensitivity and specificity. Two observers which were a radiologist and an orthopaedic surgeon were assigned to independently elicit the sign.

**Results:** There were 43 patients in LSS group and 39 patients for control (non LSS group). There was significant association between spinal claudication and leg numbness with LSS ( $p < 0.001$ ). Leg weakness, buttock pain and thigh pain also showed significant association with LSS ( $p = 0.037, 0.019$  and  $0.011$  respectively). There were significant association of

motor weakness and sensory changes with LSS ( $p < 0.001$ ). The nerve root sedimentation sign were 100% sensitive in diagnosed LSS with specificity of 82.1%. The sensitivity of the nerve root sedimentation by Observer 1 was 84.8% and Observer 2 was 78.8% while the specificity by both observers was 95.7%. For the intra observer reliability, both observers showed good reliability. The intra observer reliability for Observer 1 was Kappa of 0.785, ( $p$  value  $< 0.001$ ) 95% CI (0.62, 0.95) and the intra observer reliability for Observer 2 was Kappa of 0.857, ( $p$  value  $< 0.001$ ) 95% CI (0.72, 0.99). The inter observer reliability for two observers was found to be good with Kappa of 0.610, ( $p$  value  $< 0.001$ ) 95% CI (0.62, 0.95).

**Conclusion:** The results showed that the nerve root sedimentation sign had high sensitivity and specificity for diagnosing LSS. For the intra rater reliability, both observers showed good reliability. This showed that this sign can be identified accurately and it gives reliable additional information in diagnosing LSS.

*Keywords:* lumbar spinal stenosis, nerve root sedimentation sign, reliability, sensitivity, specificity, intra and inter observer

## ABSTRACT

### LUMBAR SPINAL STENOSIS: THE RELIABILITY, SENSITIVITY AND SPECIFICITY OF THE NERVE ROOT SEDIMENTATION SIGN

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**Supervisor:** Prof Dr Mohd Imran yusof



# CHAPTER ONE

## INTRODUCTION

### 1.1 Overview of Lumbar Spinal Stenosis (LSS) and Nerve Root Sedimentation Sign

Lumbar spinal stenosis (LSS) is a medical condition in which the spinal canal narrows and compresses the spinal cord and nerves at the level of the lumbar vertebra. LSS means reducing the space available for nerve elements (Amundsen *et al.*, 1995). LSS is either developmental and/or acquired condition that results in the formation of a neural arch smaller than normal in diameter and result triangular rather than round (Epstein *et al.*, 1964). Overlapping changes normally seen in the aging spine (Djurasovic *et al.*, 2010). On the basis of the involved anatomical location, LSS is further classified into central stenosis, lateral stenosis (including lateral recess or foraminal stenosis), and combined stenosis (Onel *et al.*, 1993).

The incidence of LSS varies between 1.7% and 8% in the general population, and it is greater in the beginning of the fifth decade of life (Lieberman, 2009). LSS occurs in 12% of older community dwelling men (Vogt *et al.*, 2006) and up to 21% of those in retirement communities (Hicks *et al.*, 2008).

The most common symptoms are intermittent neurogenic claudication, low back pain in the standing position (94%), paresthesia of the lower limbs (63%) and subjective muscle weakness (43%) (Resende *et al.*, 2013). It is exacerbated by lumbar extension and improves with lumbar flexion (Katz and Harris, 2008). Lying on the side is often more comfortable than lying flat, since it permits greater lumbar flexion. Vascular claudication can resemble spinal stenosis, and some individuals experience unilateral or bilateral symptoms radiating down the legs rather than true claudication (Djurasovic *et al.*, 2010). Additional symptoms in

the legs may be fatigue, heaviness, weakness, a sensation of tingling, pricking, or numbness and leg cramps, as well as bladder symptoms (Genevay and Atlas, 2010).

The diagnosis of LSS typically relies on history, clinical examination, and confirmatory imaging findings. Some patients can have a narrowed canal without symptoms, and do not require therapy. Plain x-rays of the lumbar or cervical spine may or may not show spinal stenosis. The definitive diagnosis is established by either computerized tomography (CT) scanning or either magnetic resonance imaging (MRI). Identifying the presence of a narrowed canal makes the diagnosis of spinal stenosis. MRI and CT scan can detect the cardinal features of stenosis — reductions in the cross-sectional area of the central canal and neural foramina due to a combination of disk protrusion, redundancy and hypertrophy of the ligamentum flavum, and hypertrophy of facet joints, with accompanying osteophytes (Katz and Harris, 2008).

The Nerve Root Sedimentation sign is a new radiological sign firstly reported by Barz *et al.* (2010). Nerve root will sink posterior to the dura base due to gravity in normal non stenosis patient. In those patients with lumbar spinal stenosis, the nerve root will disperse ventrally through dural sac. A positive sedimentation sign was defined as the *absence* of sedimented nerve roots. The sedimentation sign was reported to be 94% sensitive and 100% specific for LSS in the study by Barz *et al.*, using the criteria of walking distance <200m and cross sectional area (CSA) of the dural sac <80mm<sup>2</sup> to define the LSS cases.

Non-operative therapies and laminectomy are the standard treatment for LSS (Burnett *et al.*, 2010). A trial of conservative treatment is typically recommended. Individuals are generally advised to avoid stressing the lower back, particularly with the spine extended. A physical therapy program to provide core strengthening and aerobic conditioning may be

recommended (Djurasovic *et al.*, 2010). The evidence for the use of medical interventions for LSS is poor (Tran *et al.*, 2010).

## **1.2 Rationale of the Study**

The nerve root sedimentation sign in transverse magnetic resonance imaging (MRI) has been shown to discriminate well between selected patients with and without lumbar spinal stenosis (LSS), but the performance of this new test, when used in a broader patient population, is not yet known. In presence of this nerve root sedimentation sign with other clinical sign in diagnosing LSS, the possibility of LSS is high.

Based on the literatures, the sign is very useful but never been assessed in our population. The study is to assess the reliability, sensitivity and specificity in our local practicing physician and to report its usefulness in our population. Studies on the nerve root sedimentation sign in LSS patients in Malaysia never been done and thus the result of this study will be hopefully applicable for further reference and research for benefits of patients.

## CHAPTER TWO

### LITERATURE REVIEW

#### **2.1 Anatomy and Physiology of Lumbar Spine**

The basic anatomical and functional unit of the vertebral column is the articular triad consisting of the fibrous intervertebral joint and the two synovial vertebral joints. This articular triad is stabilized at the joints of the extremities by a ligamentous apparatus and permits movements in the spine by the action of a complex coordination of muscle function and gravity (Hirsch *et al.*, 1963).

##### **2.1.1 Lumbar Vertebrae**

The lumbar vertebral column consists of five separate vertebrae, which are named according to their location in the intact column. From above downwards they are named as first, second, third, fourth and fifth lumbar vertebrae (Bogduk, 2005). They are the largest segments of the vertebral column and note that the lumbar vertebrae have no facets for articulation with ribs and no foramina in transverse processes (Snell, 2000).

As with other vertebrae, each lumbar vertebra consists of a *vertebral body* and a *vertebral arch*. The vertebral arch, consisting of a pair of *pedicles* and a pair of *laminae*, encloses the *vertebral foramen* and supports seven processes (Gray, 2009).

The vertebral body of each lumbar vertebra is large and kidney shaped (Snell, 2000). The pedicles are very strong, directed backward from the upper part of the vertebral body; consequently, the inferior vertebral notches are of considerable depth. The pedicles change in morphology from the upper lumbar to the lower lumbar in which they increase in sagittal

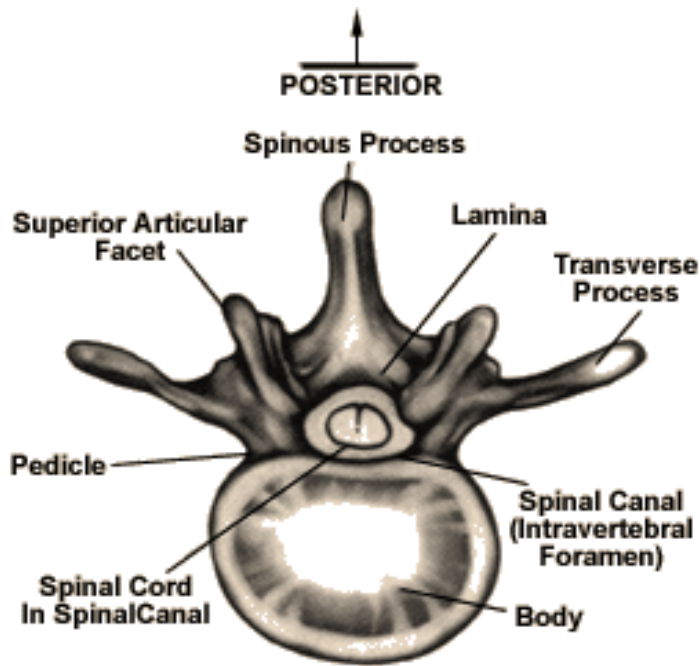
width from 9 mm to up to 18 mm at L5. They also increase in angulation in the axial plane from 10 degrees to 20 degrees by L5 (Gray, 2009).

The laminae are broad, short, and strong. They form the posterior portion of the vertebral arch. In the upper lumbar region the lamina are taller than wide but in the lower lumbar vertebra the lamina are wider than tall. The lamina connects the spinous process to the pedicles (Gray, 2009).

The vertebral foramen within the arch is triangular, larger than in the thoracic vertebrae, but smaller than in the cervical vertebrae (Snell, 2000).

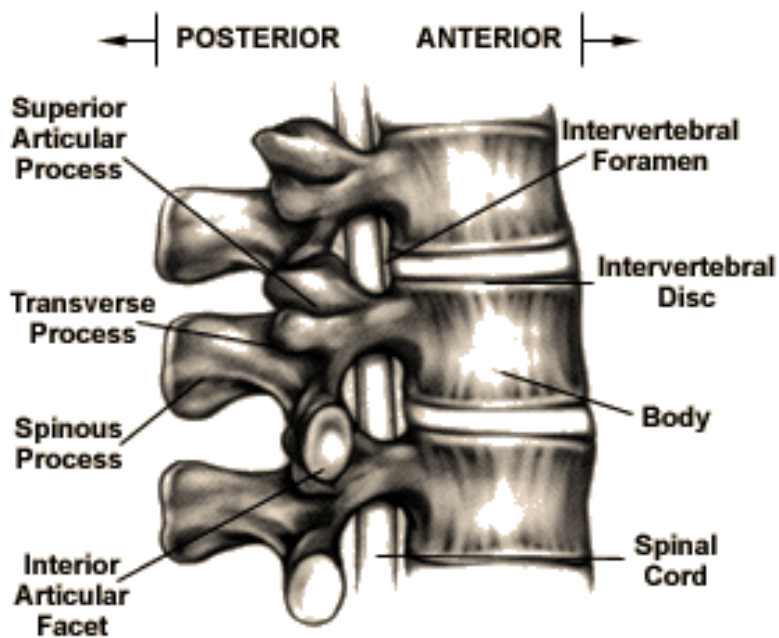
The spinous processes are short, flat and quadrangular and project backward. The articular surfaces of the superior articular processes face medially, and those of inferior articular processes face laterally (Snell, 2000).

Three portions or *tubercles* can be noticed in a transverse process of a lower lumbar vertebrae: the lateral or *costiform process*, the *mammillary process*, and the *accessory process*. The costiform is lateral, the mammillary is superior (cranial), and the accessory is inferior (caudal). The mammillary is connected in the lumbar region with the back part of the superior articular process. The accessory process is situated at the back part of the base of the transverse process. The tallest and thickest costiform process is usually that of L5 (Gray, 2009).



**Figure 2.1:** Represents a Top View of a Lumbar Vertebra

Source: Robert Pashman at <http://espine.com/normal-spinal-anatomy/> Retrieved 23 September 2014



**Figure 2.2:** The View of a Segment of Three Lumbar Vertebrae

Source: Robert Pashman at <http://espine.com/normal-spinal-anatomy/> Retrieved 23 September 2014

The first lumbar vertebra is level with the anterior end of the ninth rib, transpyloric plane. The fifth lumbar vertebra is characterized by its body being much deeper in front than behind, which accords with the prominence of the sacrovertebral articulation; by the smaller size of its spinous process; by the wide interval between the inferior articular processes, and by the thickness of its transverse processes, which spring from the body as well as from the pedicles. The fifth lumbar vertebra is by far the most common site of spondylolysis and spondylolisthesis (Gray, 2009).

The range of segmental movements in a single segment is difficult to measure clinically, not only because of variations between individuals, but also because it is age and gender dependent. Furthermore, flexion and extension in the lumbar spine is the product of a combination of rotation and translation in the sagittal plane between each vertebra (White and Panjabi, 1990). Ranges of segmental movements in the lumbar spine are showed in table 2.1.

**Table 2.1:**Ranges of Segmental Movements in the Lumbar Spine in Degrees. Adapted from (White and Panjabi, 1990)

	<b>L1-L2</b>	<b>L2-L3</b>	<b>L3-L4</b>	<b>L4-L5</b>	<b>L5-S1</b>
Flexion/ Extension	12	14	15	16	17
Lateral flexion	6	6	8	6	3
Axial rotation	2	2	2	2	1

The lumbar spine has several distinguishing characteristics. The lower the vertebra is in the spinal column, the more weight it must bear. The five vertebrae of the lumbar spine (L1-L5) are the biggest unfused vertebrae in the spinal column, enabling them to support the

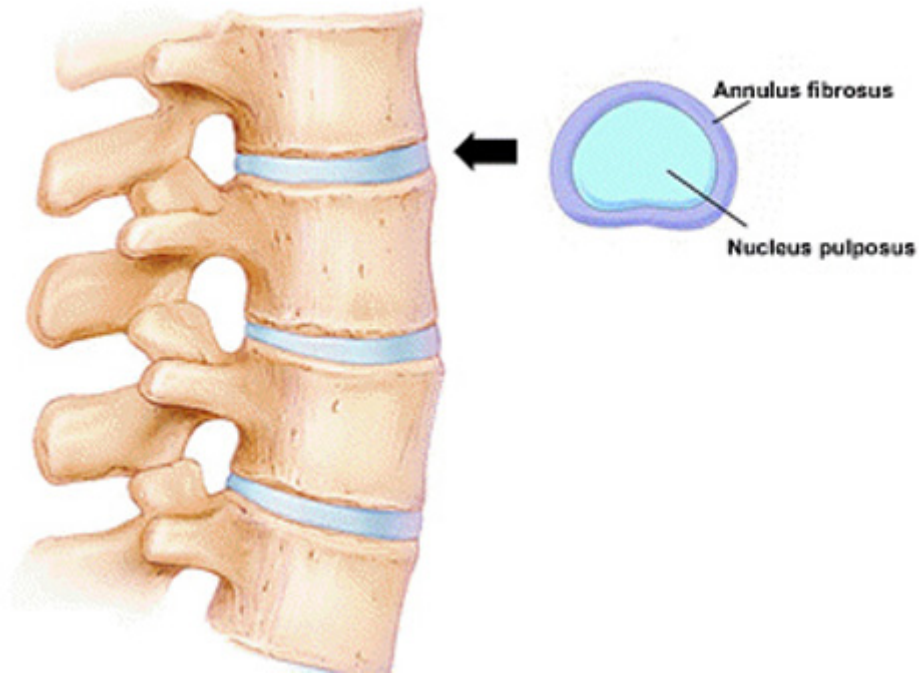
weight of the entire torso. The lumbar spine's lowest two spinal segments, L4-L5 and L5-S1, which include the vertebrae and discs, bear the most weight and are therefore the most prone to degradation and injury. The lumbar spine meets the sacrum at the lumbosacral joint (L5-S1). This joint allows for considerable rotation, so that the pelvis and hips may swing when walking and running.

### **2.1.2 Intervertebral Disc**

An intervertebral disc lies between adjacent vertebrae in the vertebral column. The intervertebral discs are responsible for one-fourth of the length of vertebral column. They are thickest in the cervical and lumbar regions, where the movements of the vertebral column are greatest. They may be regarded as semielastic discs and permit them to serve as shock absorbers when the load on the vertebral column is suddenly increased. Their elasticity allows the rigid vertebrae to move one on the other (Snell, 2000).

Each disc consists of a peripheral part, the annulus fibrosus and a central part, the nucleus pulposus (Snell, 2000). The annulus fibrosus consists of several layers (laminae) of fibrocartilage made up of both type I and type II collagen. Type I is concentrated towards the edge of the ring where it provides greater strength. The stiff laminae can withstand compressive forces. The fibrous intervertebral disc contains the nucleus pulposus and this helps to distribute pressure evenly across the disc. This prevents the development of stress concentrations which could cause damage to the underlying vertebrae or to their endplates. The nucleus pulposus contains loose fibers suspended in a mucoprotein gel. The nucleus of the disc acts as a shock absorber, absorbing the impact of the body's activities and keeping the two vertebrae separated (Gray, 2009).



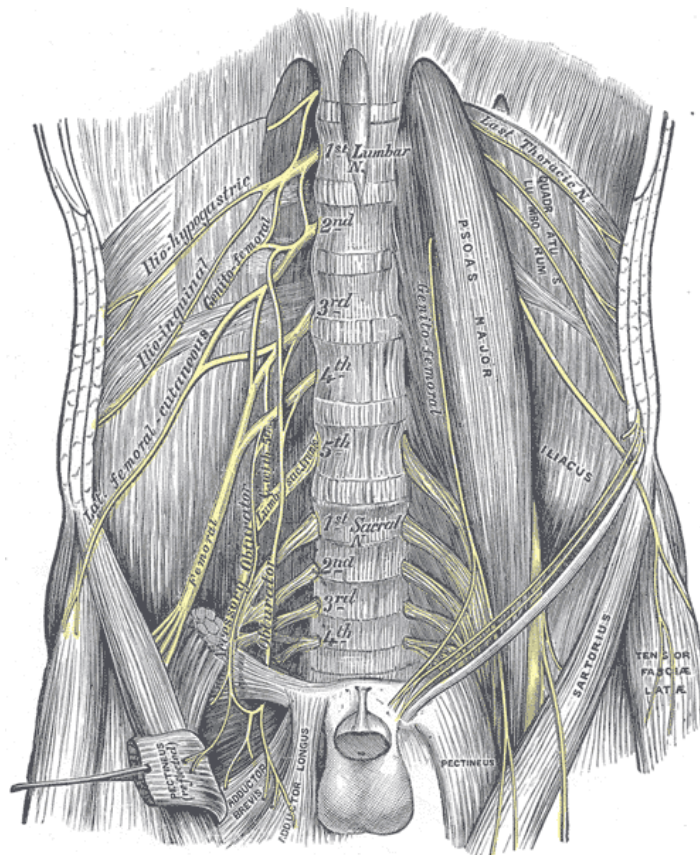


**Figure 2.3:** The Intervertebral Disc

Source: Wellington Hospital at <http://www.thewellingtonneurosurgeryunit.com/spine-anatomy-intervertebral.asp> Retrieved 25 September 2014

### **2.1.3 Lumbar Plexus and Nerves**

The lumbar nerves are the five pairs of spinal nerves emerging from the lumbar vertebrae. They arise from either side of the spinal cord and travel through the intervertebral foramen. The nerves then split into an anterior branch, which travels forward, and a posterior branch, which travels backwards and supplies the area of the back (Buckwalter, 1995).



**Figure 2.4:** The Lumbar Plexus and Its Branches

Source: *Boundless Anatomy and Physiology* at <https://www.boundless.com/physiology/textbooks/boundless-anatomy-and-physiology-textbook/peripheral-nervous-system-pns-13/distribution-of-spinal-nerves-133/lumbar-plexus-718-6505/> Retrieved 2 December 2014

The lumbar plexus is a nervous plexus in the lumbar region of the body which forms part of the lumbosacral plexus. It is formed by the ventral divisions of the first four lumbar nerves (L1-L4) and from contributions of the subcostal nerve (T12), which is the last thoracic nerve. This plexus lies within the psoas major muscle. Nerves of the lumbar plexus serve the skin and the muscles of the lower abdominal wall, the thigh, and external genitals (Schulte and Schumacher, 2006).

The largest nerve of the plexus is the femoral nerve and it runs downward and laterally between the psoas and the iliacus muscles and enters the thigh behind the inguinal ligament and lateral to the femoral vessels and the femoral sheath. In the abdomen it supplies the iliacus muscle (Snell, 2000).

The iliohypogastric nerve runs anterior to the psoas major on its proximal lateral border to run laterally and obliquely on the anterior side of quadratus lumborum. Lateral to this muscle, it pierces the transversus abdominis to run above the iliac crest between that muscle and abdominal internal oblique. It gives off several motor branches to these muscles and a sensory branch to the skin of the lateral hip. Its terminal branch then runs parallel to the inguinal ligament to exit the aponeurosis of the abdominal external oblique above the external inguinal ring, where it supplies the skin above the inguinal ligament (i.e., the hypogastric region) with the anterior cutaneous branch (Schulte and Schumacher, 2006).

The ilioinguinal nerve closely follows the iliohypogastric nerve on the quadratus lumborum, but then passes below it to run at the level of the iliac crest. It pierces the lateral abdominal wall and runs medially at the level of the inguinal ligament, where it supplies motor branches to both transversus abdominis and sensory branches through the external inguinal ring to the skin over the pubic symphysis and the lateral aspect of the labia majora or scrotum (Schulte and Schumacher, 2006).

The obturator nerve crosses the pelvic brim in front of the sacroiliac joint and behind the common iliac vessels. The genitofemoral nerve emerges on the anterior surface of the psoas. It runs downward in front of the muscle and divides into a genital branch, which enters the spermatic cord and supplies the cremaster muscle and a femoral branch which supplies a small area of the skin of the thigh (Snell, 2000).

## 2.2 Low Back Pain

Low back pain is an important clinical, social and economic problem affecting the population indiscriminately. Low back pain is one of the most common health problems and affects 80 to 85% of people over their lifetime (WHO, 2003). In United State, it is estimated that 28% experience disabling low back pain sometime during their lives, 14% experience episodes lasting at least 2 weeks, 8% of the entire working population will be disabled in any given year, and the lifetime prevalence of low back pain is 65% to 80% (Manchikanti, 2000). About 11.6% out of 2600 populations in a semirural area, Malaysia were diagnosed with low back pain problem (Veerapen *et al.*, 2007).

Most low back pain is acute or short term, and lasts a few days to a few weeks. It tends to self limiting with no residual loss of function. The majority of acute low back pain is mechanical in nature. Subacute low back pain is defined as pain that lasts between 4 and 12 weeks while chronic back pain is defined as pain that persists for 12 weeks or longer, even after an initial injury or underlying cause of acute low back pain has been treated. About 20% of people affected by acute low back pain develop chronic low back pain with persistent symptoms at one year. Treatment successfully relieves chronic low back pain in some cases, but in other cases pain persists despite medical and surgical treatment (George, 2003).

There are generally three types of low back pain which are mechanical back pain, non-mechanical back pain and referred pain from internal organs. Mechanical or musculoskeletal problems underlie most cases (around 90% or more), and of those, most (around 75%) do not have a specific cause identified, but are thought to be due to muscle strain or injury to ligaments (Manusov, 2012).

Another classification is based on the signs and symptoms. Nonspecific pain low back pain is pain that does not change in response to particular movements, and is localized to the lower back without radiating beyond the buttocks and it is the most common classification. Radicular pain is pain that radiates down the leg below the knee, is located on one side (in the case of disc herniation), or is on both sides (in spinal stenosis), and changes in severity in response to certain positions or maneuvers, making up 7% of cases. Pain that is accompanied by trauma, fever, a history of cancer or significant muscle weakness may indicate a more serious underlying problem and need urgent or specialized attention (Manusov, 2012).

Sprains are caused by overstretching or tearing ligaments, and strains are tears in tendon or muscle and they are the most common cause of acute back pain. Both can occur from twisting, overstretching or lifting something improperly or too heavy. Such movements may also trigger spasms in back muscles, which can also be painful (Wollman, 2013).

Intervertebral disc degeneration is one of the most common mechanical causes of low back pain; as a part of aging process and they lose their cushioning ability. In other hand, herniated or ruptured discs also causing low back pain (Fraser *et al.*, 1993).

Radiculopathy is a condition caused by compression, inflammation and/or injury to a spinal nerve root. The pressure on the nerve root results in pain, numbness, or a tingling sensation that radiates to other areas of the body that are served by that nerve. Radiculopathy may occur when spinal stenosis or a herniated or ruptured disc compresses the nerve root (Benzon, 1986). Sciatica is a form of radiculopathy caused by compression of the sciatic nerve in which causes shock-like or burning low back pain combined with pain through the buttocks and down one leg, occasionally reaching the foot. In the severe cases, the symptoms may not only pain but in combination of numbness and muscle weakness in the leg because

of interrupted nerve signaling as the nerve is pinched between the disc and the adjacent bone (Frymoyer, 1988).

Spinal stenosis is a narrowing of the spinal column thus causes pressure on the spinal cord and nerves lead to pain or numbness during walking and over time leads to leg weakness and sensory loss (Johnson *et al.*, 1992).

### 2.3 Lumbar Spinal Stenosis (LSS)

Lumbar spinal stenosis (LSS) is commonly used to describe patients with symptoms related to anatomical reduction of the lumbar spinal size. In lumbar stenosis, the pedicles and laminae are short and thick. Therefore, the facets extend inward to the midline and downward to the floor of the canal. The anteroposterior diameter of the canal and the lateral recesses reduced (Table 2.2). The transverse interpedicular diameter may be less than 25 mm. Disk protrusion anteriorly and massive hypertrophy of the ligamentum flavum posteriorly may encroach further upon the space available for nerve roots, substantially reducing the circumferential area of the thecal sac and eliminating the cushion of cerebrospinal fluid (CSF) surrounding the cauda equina.

**Table 2.2:** Normal and Stenotic Lumbar Spinal Canal Dimensions. Adapted from (Binder *et al.*, 2002)

<b>Dimension</b>	<b>Neural Canal (mm)</b>	<b>Lateral Recess (mm)</b>
Normal anteroposterior	15 – 25	3 – 5
Stenotic anteroposterior	5 – 10	1 – 2

Lumbar stenosis can be classified by its cause; generally divided into developmental or congenital and acquired types. Another classification is by the location of the stenosis; classified as central, lateral, or combined, based on radiographic measurements. By using anatomical classification is perhaps the most practical approach and helps determine the nature and extent of surgical treatment (Binder *et al.*, 2002).

#### **2.4 Etiology and Pathophysiology of LSS**

Acquired type of stenosis can be resulting from degenerative changes or as consequences of local infection, trauma or surgery. Degenerative LSS anatomically can involve the central canal, lateral recess, foramina or any combination of these locations. The stenosis develops focally at the intervertebral junctions from a complex process of disc degeneration, facet arthropathy, ligamentum flavum hypertrophy, spondylosis and spondylolithesis (Binder *et al.*, 2002).

Central canal stenosis may result from a decrease in the anteroposterior, transversal or combined diameter secondary to loss of disc height with or without bulging of the intervertebral disc, and hypertrophy of the facet joints and the ligamentum flavum. Ligamentum flavum hypertrophy mainly due to fibrosis caused by accumulated of mechanical stress, especially along the dorsal aspect of the ligamentum flavum. In early phase of hypertrophy, stimulation of fibrosis occurs because of the transformation of growth factor (TGF)- $\beta$  released by the endothelial cells (Sairyo *et al.*, 2005). The processes also cause in the decreased disc height, facet joint hypertrophy (with or without spondylolisthesis) and/or vertebral endplate osteophytosis result in lateral recess stenosis.

Foraminal stenosis can be either anteroposterior resulting from a combination of disc space narrowing and overgrowth of structures anterior to the facet joint capsule, and/or vertical resulting from posterolateral osteophytes from the vertebral endplates protruding into the foramen along with a laterally bulging annulus fibrosis or herniated disc that compresses the nerve root against the superior pedicle. Foraminal stenosis more frequently involves the L5 nerve root, as the L5-S1 foramen is the one with the smaller foramen/root area ratio (Jenis and An, 2000).

**Table 2.3:** Causes of Lumbar Spinal Stenosis. Adapted from (Binder *et al.*, 2002)

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**Congenital/ developmental**

1. Idiopathic
2. Achondroplasia
3. Hypophosphatemic vitamin D-resistant rickets  
(spondyloepiphyseal dysplasia)
4. Morquio's syndrome
5. Spinal dysraphism (lipoma, myelomeningocele)

**Acquired**

1. Degenerative  
Spondylosis, Spondylolisthesis, Scoliosis, Ossification of the posterior longitudinal ligament, Ossification of the ligamentum flavum, Intraspinous synovial cysts
  2. Postoperative  
Laminectomy, Fusion, Fibrosis
  3. Traumatic  
Laminectomy, Kyphosis/scoliosis, Burst fracture
  4. Metabolic/endocrine  
Epidural lipomatosis (Cushing's disease), Osteoporosis, Acromegaly, Pseudogout (calcium pyrophosphate dehydrate deposition), Renal osteodystrophy, Hypoparathyroidism
  5. Skeletal  
Paget's disease, Ankylosing spondylitis, Rheumatoid arthritis, Diffuse idiopathic skeletal hyperostosis (DISH)
-



## **2.5 Diagnosis of LSS**

The clinical history often distinguishes lumbar stenosis from other causes of radiculopathy. Spinal radiographs are needed to demonstrate degenerative changes of the disc and facet joints as well as evidence of instability, spondylolithesis, scoliosis or traumatic deformity. While definitive diagnostic information is most readily obtained from lumbar spinal MRI and/ or CT scans with sagittal reconstructions (Binder *et al.*, 2002).

### **2.5.1 Clinical Symptoms of LSS**

Despite a clinical definition that often relies on anatomic findings, the clinical diagnosis and the assessment of the severity of LSS depends primarily on the patient's history and on the physical examination. Patients develop pain, paresthesias, numbness and weakness in the back and legs due to entrapment of the lumbosacral nerve roots in the constricted neural canal and foramina. The pain usually during standing exacerbated by walking and relieved by rest in a flexed or seated position (Weinstein, 1982).

The most common symptom is neurogenic claudication consists of the progressive onset of radicular pain, paresthesias, numbness and in some cases weakness, initiated or worsened by walking. Fatigue, numbness or weakness to the extent of footdrop or knee buckling may occur without or before the appearance of pain. incapacitating sensory dysesthesias may also occur without pain or weakness (Binder *et al.*, 2002).

A key feature of neurogenic claudication is its relationship to the patient's posture. The lumbar extension increases while flexion decreases pain. Symptoms worsen by standing or walking and are relieved by sitting. Laying flat is often associated with less relief while

lying on the side (permitting lumbar flexion) is more comfortable. The walking distance before symptoms occur is more variable in those with neurogenic claudication as compared with vascular claudication. It is increased by forward bending of the torso (increased thoracic kyphosis and decreased lumbar lordosis) lead to adoption of a position with hip and knee slightly flexed sometimes referred as “simian stance” (Bridwell, 1994) In contrast to those with vascular claudication, sitting but not standing will relieve symptoms, walking uphill will be better tolerated than downhill walking, and exercise on a stationary bicycle in a seated flexed position will be better tolerated than walking in the erect position (Genevay and Atlas, 2010).

LSS can present with symptoms that are more radicular in nature in addition to neurogenic claudication. In neurogenic claudication, it is more commonly bilateral and associated with central canal stenosis but in radicular symptoms due to LSS are more often unilateral and related to stenosis of the lateral recess or the foraminal canal. Patients tend to be younger and often have pain at rest and at night and increased by the Valsalva maneuver (Jenis, and An, 2000).

### **2.5.2 Physical Examination Findings**

The Romberg maneuver, in which the patient stands with eyes closed and is observed for imbalance, may reveal unsteadiness and a wide-based gait. It reflects the involvement of proprioceptive fibers in the posterior column. A wide-based gait among patients with back pain had a specificity of more than 90% for LSS (Katz *et al.*, 1995).

Leg pain is often described as severe and radicular in distribution, and may be exacerbated with lumbar extension to the painful side; tested by using Kemp's test (Jenis and An, 2000). Other findings may include a limited lumbar range of motion especially in extension, variable straight-leg tension signs, focal motor weakness in a specific root distribution, and diminished subjective sensation and reflexes in specific root distributions (Genevay and Atlas, 2010).

Examination of the lower back will often reveal non-specific reduced mobility. Extension may be more limited than flexion. Hamstring tightness is often described. The neurologic examination typically is normal or presented with mild motor weakness or sensory changes. Performing symptomatic exercises may increase these signs immediately. Half of patients reported absent or decreased ankle reflexes but this sign is frequently found in older patients (Arbit and Pannullo, 2001).

### **2.5.3 Radiological Imaging Studies**

In most cases, the history and physical examination provide sufficient evidence to make presumptive diagnosis of symptomatic LSS. Plain radiographs are useful and may show spondylolisthesis and it provide an estimation of the extent of disc-space narrowing, end-plate sclerosis and facet joint hypertrophy. The neural foramina may reveal osteophytes that suggesting of foraminal stenosis (Katz *et al.*, 1995).

Correlating symptoms and physical exam findings with imaging results is necessary to make a definitive diagnosis especially when considering invasive interventions. Either MRI or CT can clearly show the size, shape and anatomical relationship of spinal and neural

element and can demonstrate the relative contribution of developmental stenosis as well as disc, facet and ligamentous elements of nerve root compression. The sensitivities of MRI and CT for LSS exceed 70% (de Graaf *et al.*, 2006). Both can detect the cardinal features of stenosis which are the reductions in the cross-sectional area of the central canal and neural foramina due to a combination of disk protrusion, redundancy and hypertrophy of the ligamentum flavum, and hypertrophy of facet joints, with accompanying osteophytes. The presence of facet cysts (synovial outpouchings) may further compromise the space available for the dura and neural elements. Bony findings such as facet arthropathy can be seen more clearly on CT scans, while soft-tissue lesions involving ligaments and disks are more detectable on MRI scans. Imaging studies are especially useful in determining whether epidural corticosteroid injections or surgery are therapeutic options and to guide the implementation of these procedures (Schnebel *et al.*, 1989). The classic findings are a smoothly margined waist or hourglass shape on sagittal images and a trefoil-shaped neural canal on axial images. Direct multiplanar MRI construction provides more precise anatomic detail on sagittal images than CT (Binder *et al.*, 2002).

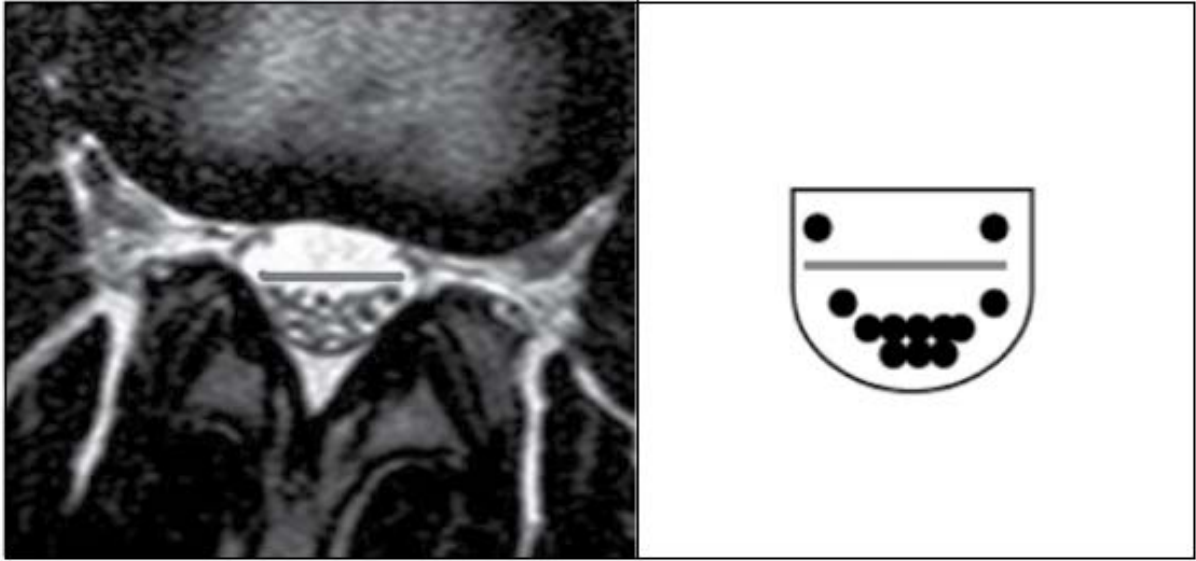
#### **2.5.4 Electro-diagnostic Studies**

Electromyography is not routinely done. It may be useful in patients with diabetes or in those with other type of neuropathy. Its usefulness is limited because spinal stenosis and peripheral neuropathy may co-exist thus it will not help in determine which process is responsible for symptoms.

## 2.6 The Nerve Root Sedimentation Sign

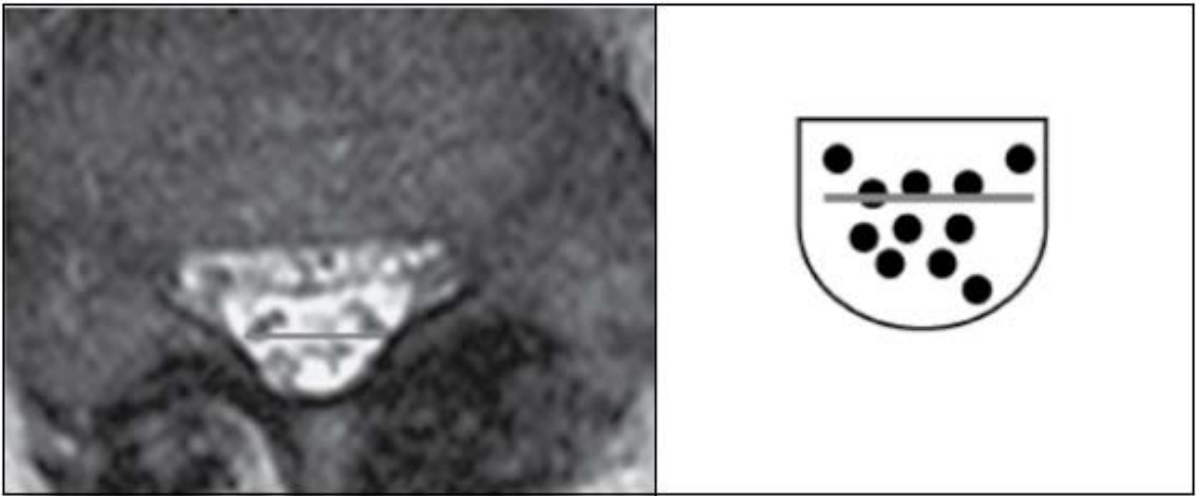
To define imaging findings of LSS which is shown by the absence of ‘sedimentation’ of the nerve roots to the dorsal region of the dural sac in MRI by force of gravity as a positive sedimentation sign (Barz *et al.*, 2010). Barz *et al.* observed on supine MRI scans that in patients without LSS, owing to gravity, the lumbar nerve roots sink to the dorsal portion of the dural sac. Conversely, in patients with LSS, such cauda equina nerve root sedimentation was rarely observed. Based on the location of the spinal stenosis, LSS is further classified into central, lateral, and combined stenosis. Macedo *et al.* demonstrated that the sedimentation sign had poor diagnostic accuracy for lateral stenosis.

Barz in his recent paper argued that presence of the sedimentation sign was probably due to tethering of the nerve root at the level of stenosis. In the normal spine, all the transversing roots will sink into dorsal half of the dura due to the gravity. Positive sedimentation sign (patient with LSS) would show transversing roots floating of the above the dorsal half of the dura sac. The identification of the sedimentation sign was performed at the most stenotic level, one level above and one level below the affected level.



**Figure 2.5:** Negative Sedimentation Sign

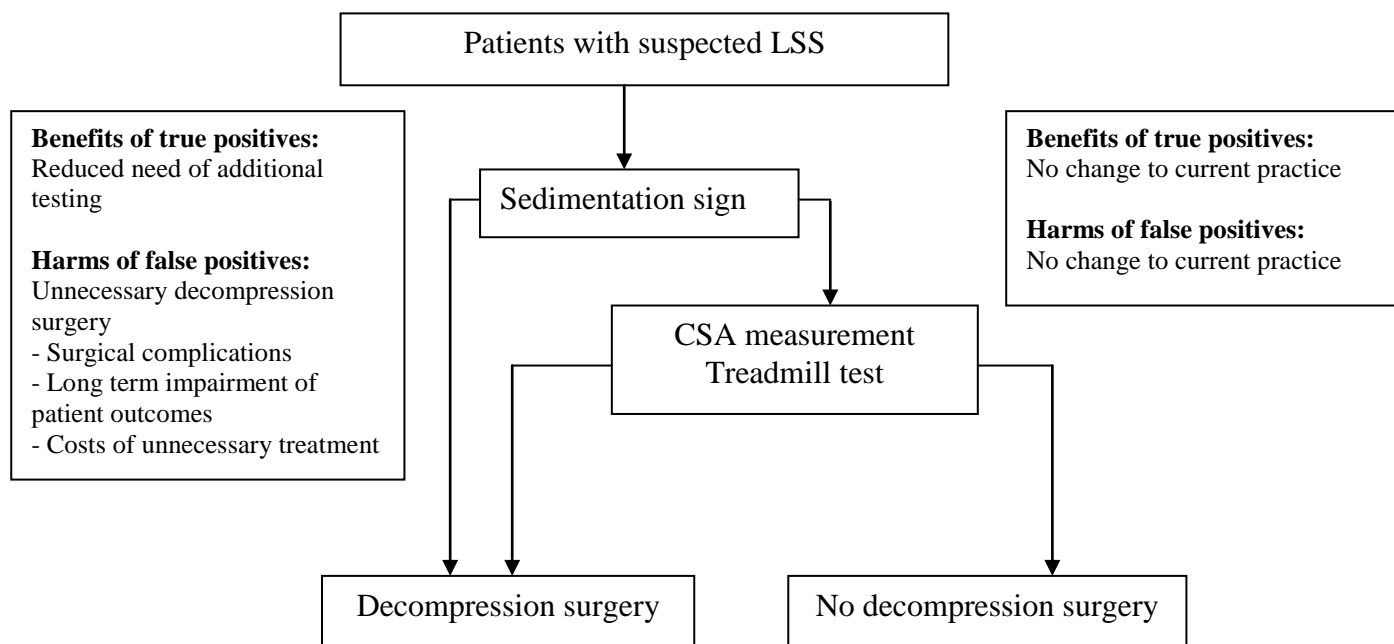
Source: Resende *et al.*, 2013



**Figure 2.6:** Positive Sedimentation Sign

Source: Resende *et al.*, 2013

Based on the preliminary evidence available, the nerve root sedimentation sign has been proposed as a triage test to guide decisions about the further use of the existing tests (Figure 2.7). If a positive sedimentation sign proves to be a strong predictor of good surgical outcomes, a positive result may convince surgeons to rule in LSS. Some of the more cumbersome additional tests, e.g. treadmill test and CSA measurement, may then be skipped and patients would directly proceed to surgery. On the other hand, a negative Sedimentation Sign would be followed by treadmill tests and CSA measurement to support therapeutic decisions. The major benefits of using the Sedimentation Sign are therefore improved patient and clinician convenience and lower costs due to the reduced need for additional testing in patients with a positive test result, and potentially improved patient outcomes due to improved detection of LSS that may benefit from surgical management (Staub *et al.*, 2011).



**Figure 2.7:** Flowchart of the proposed role of the Sedimentation Sign. The Sedimentation Sign is proposed to be used as a triage test in the work-up of patients with suspected lumbar spinal stenosis (Staub *et al.*, 2011)

The sedimentation sign is evaluated based on standard lumbar MRIs and can be easily done. Positive sedimentation sign is a reliable sign to support the diagnosis of lumbar spinal stenosis with high specificity and sensitivity. It also can be used in postoperative follow up of the patients who had undergone surgical decompression (Dawood *et al.*, 2014).

Surgery was not selected to be the diagnostic reference standard of LSS in most of studies. Recently, Fazal *et al.* reported a higher positive rate for the sedimentation sign in LSS patients treated with spinal decompression surgery, indicating that the sign was most often present in patients who had clinically significant lumbar stenosis and required surgery. Sedimentation sign is a new measurement tool that enables physicians to objectively assess and quantify spinal stenosis because it is consistently present in patients who have clinically significant lumbar stenosis and require surgery (Fazal *et al.*, 2013).

Million Visual Analogue Score (MVAS) presented the improvement of  $64.5 \pm 4.6\%$ , Korean Oswestry Disability Index (KODI),  $62.9 \pm 3.9\%$  after surgical treatment in sedimentation sign positive group. In sedimentation sign positive group, each score showed improvement of  $34.6 \pm 2.3\%$  (MVAS),  $37.1 \pm 1.8\%$  (KODI). The improvement of these scores in sedimentation sign positive group was better than in sedimentation sign positive group (Kim *et al.*, 2011).

In another study, however, reported that the sedimentation sign did not appear to predict surgical outcome in patients treated with decompression surgery. Mean baseline Oswestry disability index (ODI) in the surgical group was 54.7% and the sign was positive in 39 patients (mean ODI improvement 29.0) and negative in 30 (mean ODI improvement 28.4),