Aus der Universitätsklinik für Neurochirurgie Tübingen

Ärztlicher Direktor: Professor Dr. M. Tatagiba

Comparison between Dynamic Radiographic Myelography and MRI for Decompression Levels in Lumbar Canal Stenosis

Inaugural-Dissertation

zur Erlangung des Doktorgrades

der Medizin

der Medizinischen Fakultät

der Eberhard Karls Universität

zu Tübingen

Vorgelegt von

Jun Li

aus

Luzhou, China

2013

Dekan: Professor Dr. I. B. Autenrieth

1. Berichterstatter: Professor Dr. F. Roser

2. Berichterstatter: Privatdozent Dr. A. Badke

CONTENTS

LIST OF ABBREVIATIONS

CM	Contrast medium
CSF	Cerebrospinal fluid
IP	Increased Patient
IS	Increased Segment
SIS	Significantly increased segment
NIS	Not Increased Segment
LCS	Lumbar canal stenosis
MS	Motion segments
NIP	Not Increased Patient
SM	Sitting lumbar myelography
SME	Standing myelography with extension
CT	Computed Tomography
FPVCT	Flat panel volumetric computed tomography
MRI	Magnetic resonance imaging
rMRI	Recumbent MRI
MS	Motion Segment

INTRODUCTION

With the aging population increasing globally, the incidence of spinal degenerative diseases has also been growing yearly. Lumbar canal stenosis (LCS) is the most common one, causing various neuropathic symptoms such as lower back pain, radiating leg pain in most cases and specific intermittent claudication [1, 2]. Within the LCS patients, the degenerative factors such as facet hypertrophy, ligamentum flavum ossification, disc herniation and spondylolisthesis might invade into the canal and to compress the fragile neural tissues, such as cauda equina and lumbar nerve roots [3, 4]. The basic feature of degenerated lumbar spine is instability, and the severity of canal stenosis is highly related to the lumbar spinal dynamics. Therefore, the dynamic factor and axial load is significantly important to the determination of the severity of canal stenosis, and both of them are still vital to the pre-operation evaluation [5-7].

The static morphological data of the lumbar canal can be acquired easily and ordinarily via normal X-ray examinations, computed tomography (CT) or Magnetic Resonance Imaging (MRI) in the supine position. On the one hand, the configuration inside the spinal canal is significantly and dynamically related to the canal surrounding structures, such as ligaments, disc tissue, joints and bony structures [8, 9]. On the other hand, the spine is a dynamically structure, which is capable to transmit the load of the gravity and is able to support the human body in different postures. However, the degenerated structures of the spinal motion segment (MS) are hard to dynamically maintain their location and motion into the normal range, and this abnormal situation might be worsen in some over loading postures. An discrete spondylolisthesis and the buckled ligaments in a supine position could be observed in an upright position [10]. Therefore, the vertebral instability due to the lumber degeneration could be invisible in the supine radiologic examination, because of the lack of axial load and movement. Commonly, decompression surgery should be designed according to both the neuropathic level and the canal stenosis level, however, if those alterable stenosis levels in different axial load positions can be involved into the pre-operation evaluation, this may bring some unexpected and fantastic results to the surgical prognosis [11].

In the early 1920's, the radiographic technique, which is termed as "Myelography", for extradural space exploration was reported by Sicard and Forestier [12]. Afterwards, this technique had rapidly developed and been widely utilized in the diagnosis of spinal stenosis [13]. With further developments in neuroradiology the contrast agents have been constantly upgraded with better contrast imaging effects, better tolerance and fewer side effects [14].

Magnetic resonance technique is the latest technique, which is employed to visually examine details of internal structures of the human body and to assist clinical evaluation of lesion in patients. In the 1950s, the creation of a one-dimensional MRI image was reported by Herman Carr, then, this technique was successfully expanded to generate 2D and 3D images by using gradients by Paul Lauterbur [15]. When compared with the traditional radiological examination (computed tomography and X-rays), the significantly improved image contrast for identifying the different soft tissues, such as neural tissues, muscles, ligaments, skeletal tissues and also degenerated soft tissue lesions, tumors etc. is especially useful and vital for the clinical specialists. By using of MRI, neurosurgeons can differentiate the degenerated and lower T2 signal soft tissues from normal, for example, degenerated discs and ligamentum flavum. More importantly, the compressed spinal sac and nerve roots can be detected in the cross-section images of MRI. The coincidence of lesion images and clinical symptoms is a restricted indication for surgical treatments. Unlike the traditional roentgen examination, the emission of ionizing radiation is not involved in the MR imaging techniques.

Radiographic myelography has been applied in the diagnosis of LCS for more than 30 years [16]. The lumbar spinal stability and canal space can be dynamically observed in an upright position with flexion and extension via the radiographic myelography. The disadvantage is the risk of lumbar puncture, which may infrequently lead to infection or cerebrospinal leaking [3, 11].

The purpose of this research is to compare the sensitivity of dynamic radiographic myelography with supine MRI for LCS patients, and to figure out that whether the dynamic radiographic myelography is an irreplaceable preliminary test in the diagnosis of LCS.

MATERIALS AND METHODS

Materials

Iodinated contrast (Omnipaque) which comes in 20-ml vials with concentrations of 180 mg I/ml was used in this study; 3g total of iodine was set as the dose limit for adult lumbar myelography, which means maximum 17 ml agents with the concentration of 180 mg I / ml was injected; the spinal needles with different lengths (3.5-, 4.5- and 6 inch) were applied for individual patient.

Lumbar spinal myelography

Patients

In our study, the imaging data of 100 LCS suspected patients were analyzed during a period of 2 years, from July 2008 to August 2010. All patients suffered from claudication spinalis and various degrees of other neural deficits, including lower limb radiating pain, sensory and motor deficits. Three kinds of lumbar spine imaging were investigated: recumbent MR imaging, upright sitting lumbar myelography (SM) and standing myelography with extension (SME). The age of patients ranged from 22 to 91 years, the average age was 62.3 years. There were 51 men and 49 women. Five hundred intervertebral segments were observed (the five lumbar intervertebral segments from L1/2 to L5/S1 for each patient).

Myelography Procedure

1. The iodinated contrast reaction history, physical conditions were checked before the myelography, the procedure of myelography was completely explained to every patient, and the agreement from every patient was obtained before the operation.

2. For the first step, the appropriate length of needle was estimated for patient. In most cases, we started with a 4.5-cm needle in order to avoid a slightly short after the attempt with 3.5- cm needle.

3. The puncture location with the correct interspinous space was carefully confirmed via the fluoroscopy. In this step, the number of rib and the number of lumbar vertebrae were also verified.

4. The patient lay on the side at the edge of the test bed with Knee-chest flexed spine. The spine is parallel to the longitudinal axis of test bench. The puncture location at L2/3 interspinous space has been confirmed and labeled previously. The approximate depth of the thecal sac was carefully estimated again, because it can be significantly different between a thin patient and a large one. The skin was then anesthetized with a mixture of 10 ml 1% lidocaine and 1 ml 8.4% sodium bicarbonate.

5. The needle was usually placed at the L2/3 interspinous space in the midsagittal approach, through the interspinous ligament. Via the AP view of fluoroscopy, the needle position was confirmed between the transverse processes as a dense dot. And the AP fluoroscopy was used periodically to verify the needle trajectory.

6. The needle was inserted into the thecal sac with the estimated depth and then the position and depth of the needle were checked on lateral fluoroscopy. The efflux of the CSF was controlled by tilting the table slightly head up.

7. After connecting the contrast syringe, 20 ml CSF was drawn up, and then 2 ml contrast was flushed through the tube, and 18 ml contrast was remained in the syringe. In order to perform sufficient contrast image, the thecal sac below the level of L1 was completely filled with contrast in the upright position.

8. Before continuously introducing into the thecal sac, at least one or two test puffs has been injected, and then the test table was tilted slightly head up. During the introducing of contrast, the filling procedure was monitored via periodic lateral fluoroscopy, and the depth of the needle tip was also monitored.

9. From the first drop of contrast agent falling away from the tip, a dense line along the ventral side of the spinal canal should be observed via lateral fluoroscopy. If the falling line of contrast agent was noted in the dorsal part of the spinal canal, or the agent accumulated at the needle tip, the subdural or epidural injection should be suspected.

10. In most cases, 13-14 ml contrast agent in the thecal sac was sufficient to provide excellent image contrast. The highest dose of 17 ml was only performed for the patient who has a patulous thecal sac. After injection, the syringe tube would be replaced by the stylet. The needle and stylet was withdrawn slightly, and then left in place to assist radiologist to localize the lumbar levels.

11. AP, lateral, sitting and standing with extension images were obtained for the lower lumbar spine.

12. The post procedure orders: At the discretion of physicians, the patients underwent a strict bedrest for 4-8h, afterwards mobilsations with bathroom privileges was allowed in the rest of the day. For 24-48 hours after discharge, the light activity was allowed.

Image Collecting and Evaluation Methods

Image Collecting

The recumbent MRI of the lumbar spine was taken firstly, and then, the images of upright lumbar myelography in a sitting position which followed by the extended lumbar myelography would be collected subsequently. The interval between MRI and myelography amounts was less than 3 month.

Image Evaluation

Images of five lumbar motion segments for each patient, from L1/2 to L5/S1, were precisely investigated by one neurosurgeon and one neuroradiologist independently. On MRI sagittal T2-weighted images and the lateral image of the myelography were evaluated. We developed a simple semi-quantitative evaluation system for the lumbar stenosis measurement. According to this

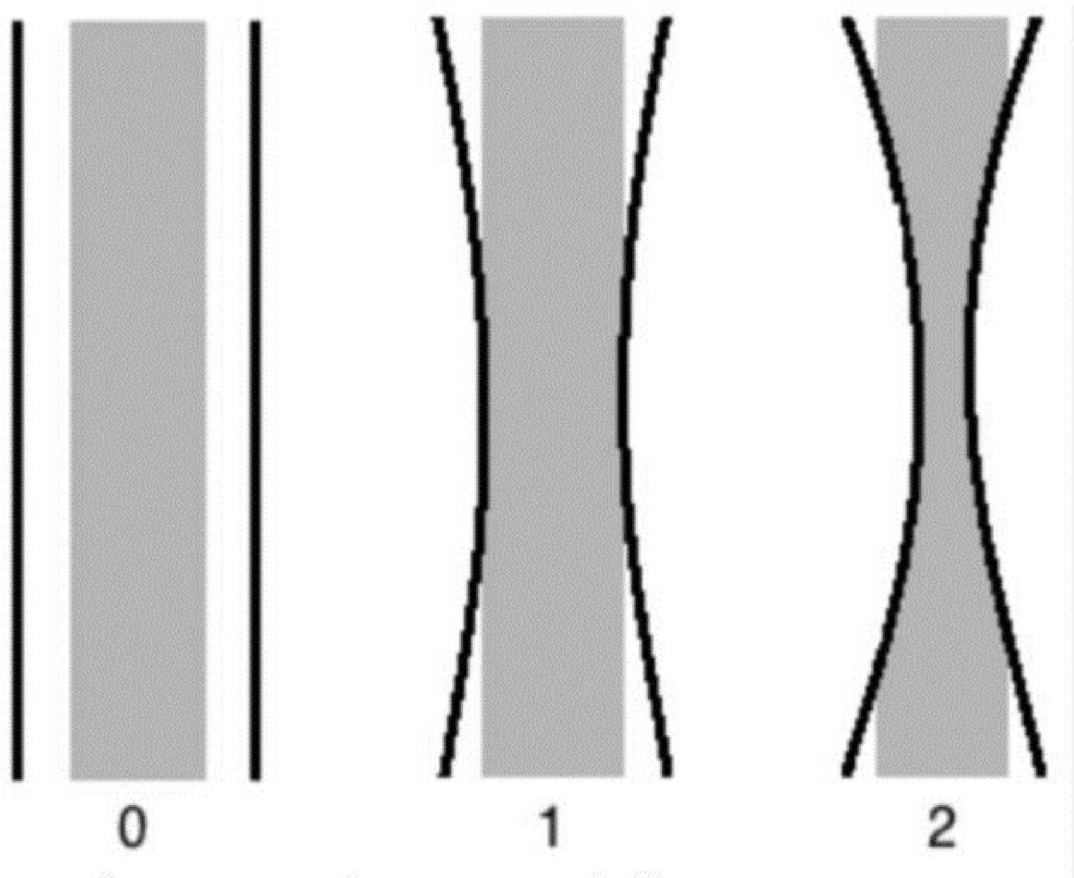


Fig. 1: Schematic drawing of the semi-quantitative evaluation for the extent of lumbar spinal stenosis. 0: segments with no compresson, 1 segments with compression of the spinal cannel, without compression of neural tissue, 2 segments with compression of neural tissue.

scoring system, the stenosis segments were divided into 3 scores by MR T2-weighted image and Myelography (Fig. 1). Segments with no compression at all were considered score 0. If either the anterior or posterior signal of Cerebrospinal fluid (CSF) in the MR T2-weighted image or contrast medium (CM) in myelography lateral view was not visible in one segment due to the canal stenosis, the segment was considered as score 1. If the anterior or posterior canal space in one segment for CSF or CM was compressed (and thus unobservable/not visible), and there was no any compression to the neural tissue inside the canal, this segment was still considered as score 1. Neural tissue compression defined score 2, regardless of if the compression was to the anterior or posterior canal space. After the evaluation, the stenosis score differences among five motion segments in the three imagining methods were analyzed.

Statistical Analysis

Our study had a sample size of 100 patients and 500 segments, and the scores of our evaluation were discontinuous data, so we were capable of comparing the score differences for each patient and every segment directly. We defined a score difference of 1 as Increased Segment, a difference of 2 as Significantly Increased Segment, and a score difference of 0 as Not Increased Segment. The same definitions were used for the patients: Increased Patient , Significant Increased Patient, and Not Increased Patient. We used the Friedmann test followed by the Dunns post test to evaluate differences among groups. A value of $p<0.05$ was considered significant. The p value is >0.0001.

RESULTS

The original SM, SME and MRI evaluation scores of all 500 segments, 100 patients, are listed respectively in Table 5. The increased scores involved in the comparison between SM and SME are showed in Table 6. And the increased scores involved in the comparison between recumbent MRI and SME are presented in Table 7.

Table.1 Stenosis scores for lumbar segments

Motion Segments	SM	SME	rMRI
L1/2	20	40	11
L2/3	45	76	28
L3/4	39	84	35
L4/5	35	79	34
L5/S1	4	5	4
Total	143	284	112

SM: Sitting Myelography
SME: Standing Myelography with Extension
rMRI: Recumbent MRI

The total score of SME position, 284, was 2 and 2.5 folds of the score of SM and Recumbent MRI position respectively (Table 1). Compared to SM and Recumbent MRI, SME position score was the highest in every segment from L1/2 to L5/S1. The highest score segment in SME was L3/4 (with a score of 84), followed by L4/5 with 79. Meanwhile, the difference between the total score of SM (143) and Recumbent MRI (112) was only 31. In every segment, the difference between SM and recumbent MRI was still small, especially in the region from L3/4 to L5/S1.

Sitting Lumbar Myelography versus Standing Myelography with Extension

We counted the number of patients whom got the increased stenosis in the comparison of SM and SME position, and the number of increased stenosis segments. Compared to the SM position, the total increased stenosis patient number in SME position was 61 and 57 patients got increased stenosis. The stenosis of 15 patients was significantly increased (Table.2). Only 39% of patients got the same.

Table.2 Comparison of the patients number and segments between SM and SME

Patients				Segments			
NP	IP	SIP	TIP	NIS	IS	SIS	TIS
39	57	15	61	379	101	20	121

Increased Segment (IS); Significantly Increased Segment (SIS); Not Increased Segment (NIS); Increased Patient (IP); Significant Increased Patient (SIP); and Not Increased Patient (NIP).

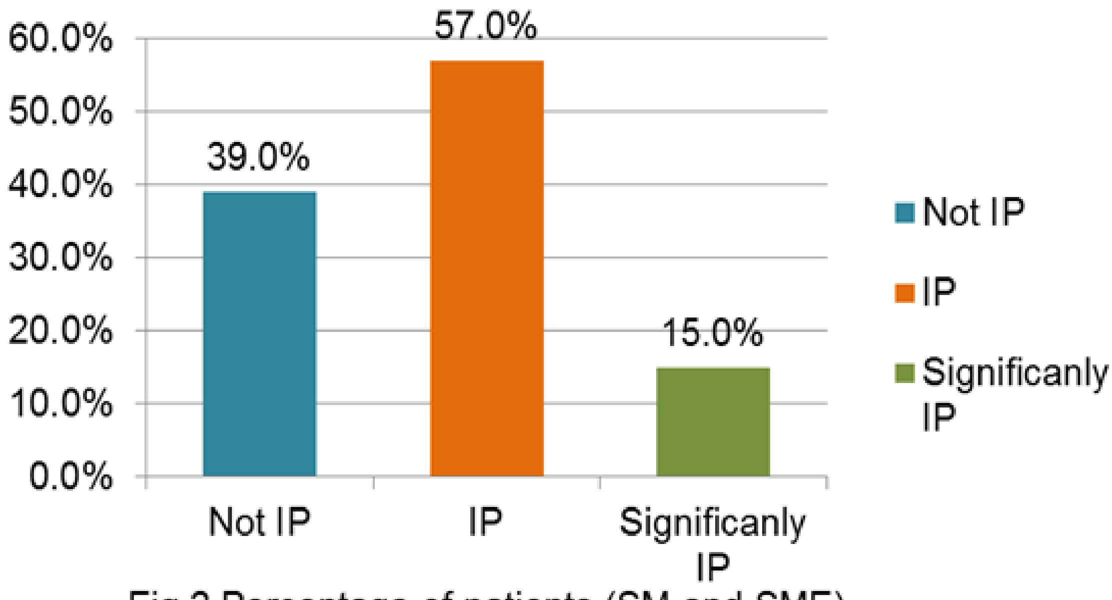


Fig.2 Percentage of patients (SM and SME)

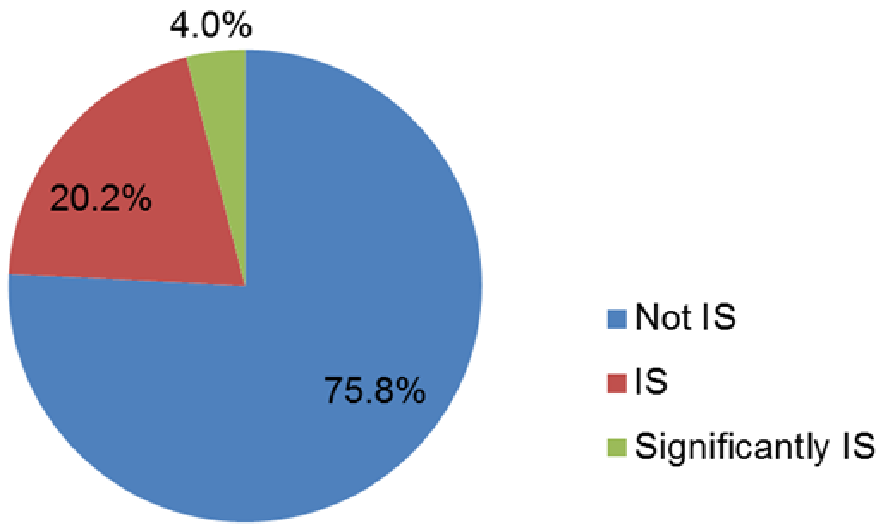


Fig.3 Percentage of segments (SM and SME)

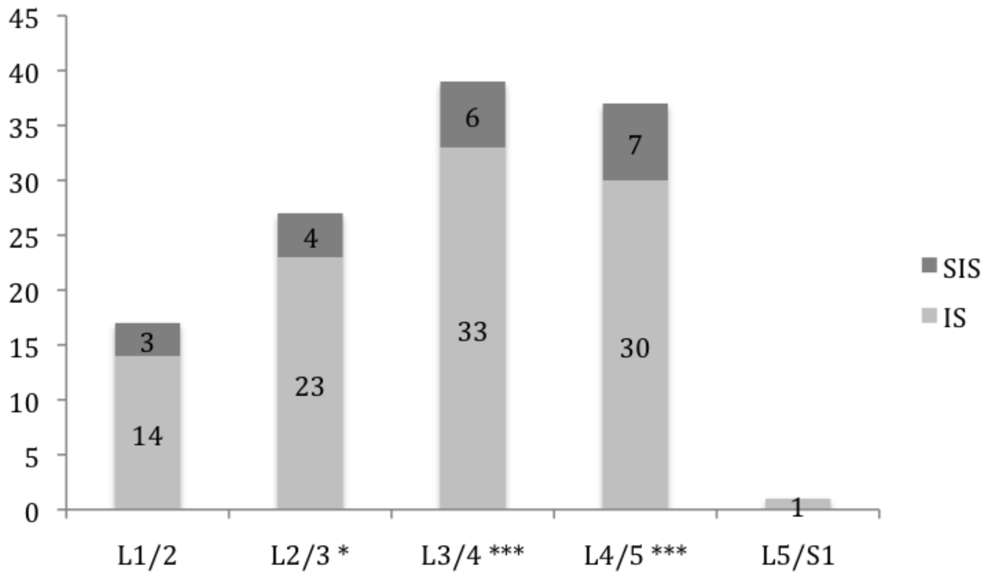


Fig. 4: Increased segments (IS) and Significantly Increased Segment (SIS) (Sitting Myelography vs Standing Myelography with Extension), $p<0.05$ (*), $p<0.001$ (***)

stenotic situation in the comparison (Fig.2). Regard to the motion segments (MS), the Total stenotic increasing segments in SME position were 121 of 500 segments, 101 Increased Stenosis segments and 20 Significantly Increased segments were found (Table.2). The percentages of increased segments and significantly increased segments in the comparison of SM and SME were 20.2% and 4.0%, respectively (Fig.3). In this comparison from L1/2 to L5/S1 of the stenotic distribution, the L3/4 motion segment (MS) was the most seriously affected segment, with 6 significantly increased segments (SIS) and 33 increased segments, followed by the L4/5 MS with 7 significantly increased segments and 30 increased segments (Fig.4). Furthermore, there was only 1 increased stenosis segment observed in L5/S1.

Supine MRI versus SME

In the comparison of recumbent MRI and SME position, the stenotic increasing patient number and the stenotic increasing segments were also counted. Compared to the recumbent MRI position, the total number of stenotic increasing patient in SME position was 64, and 59 patients got increased stenosis.

Table.3 Comparison of the patients number and segments between recumbent MRI and SME

Patients				Segments			
NIP	IP	SIP	TIP	NIS	IS	SIS	TIS
36	59	25	64	363	102	35	137

Increased Segment (IS); Significantly Increased Segment (SIS); Not Increased Segment (NIS); Increased Patient (IP); Significant Increased Patient (SIP); and Not Increased Patient (NIP).

The stenosis of 25 patients was significantly increased (Table.3), with only 36% patients getting the same stenotic situation in this comparison (Fig.5). Regard to the MS, the total stenotic increasing segments in SME position were 137 in 500 segments, 102 increased stenosis segments and 35 significantly increased segments were found (Table.3). The percentage of increased segments and significantly increased segments in the comparison of MRI and SME was 20.4% and 7.0%, respectively (Fig.6).

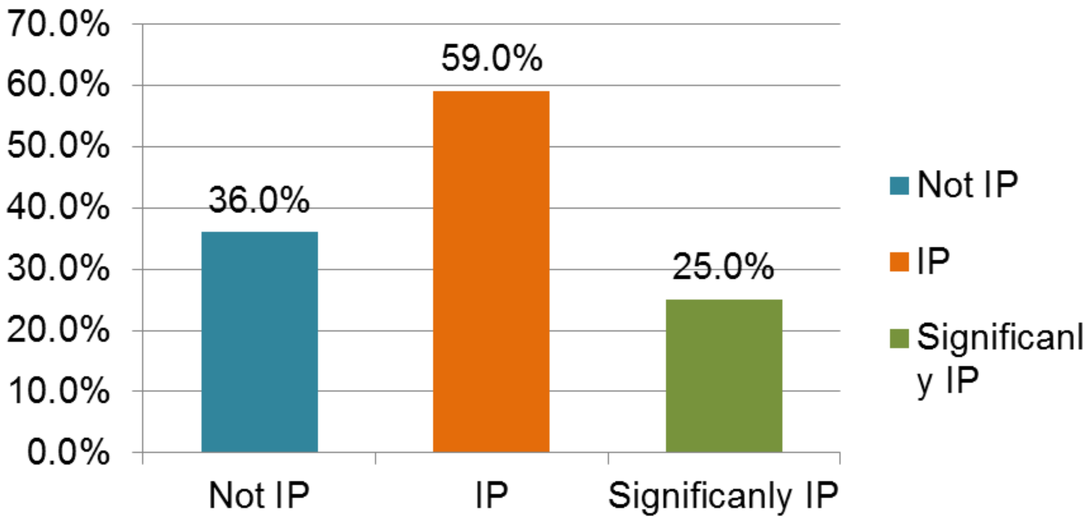


Fig.5 Percentage of patients (recumbent MRI vs SME)

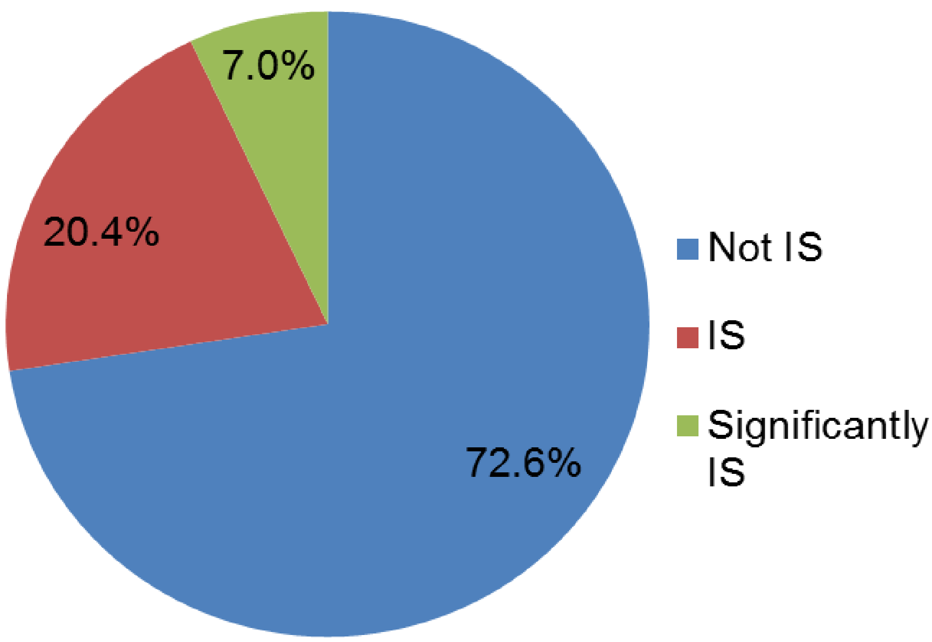


Fig.6 Percentage of segments (sMRI vs SME)

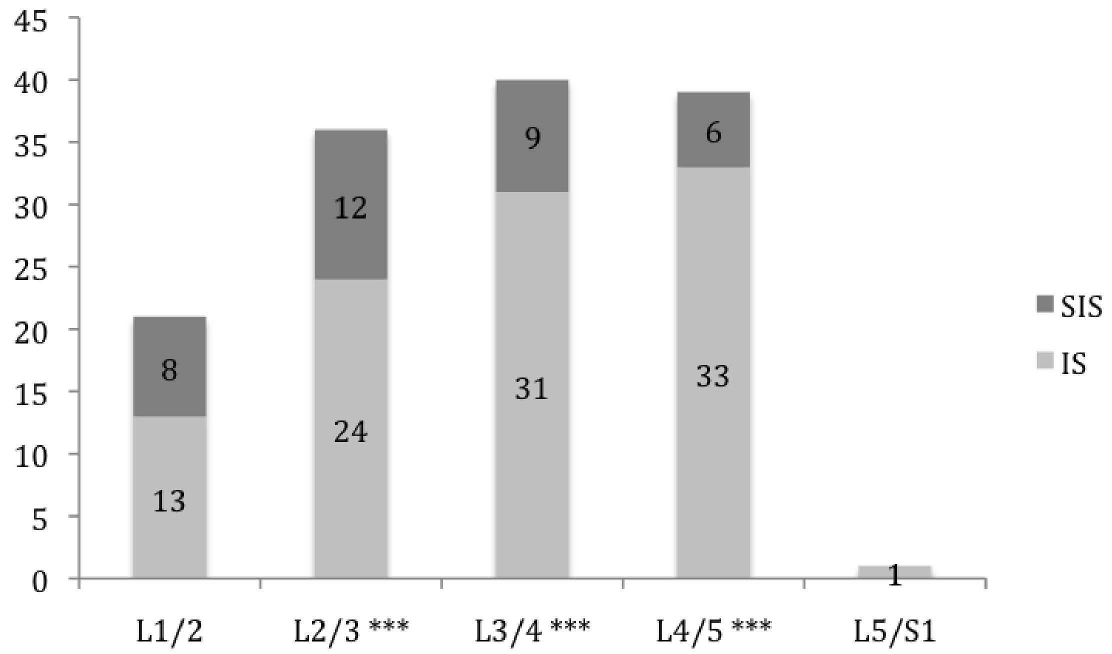


Fig. 7: Increased segments (IS) and Significantly Increased Segment (SIS) (supine MRI vs Standing Myelography with Extension), $p<0.001$ (***)

In this comparison, the stenotic increasing distribution in lumbar region was almost the same to the last comparison (SM vs. SME). The L3/4 motion segment (MS) was still the most seriously affected segment, with 9 significantly increased segments and 31 increased segments, followed by the L4/5 MS with 6 significantly increased segments and 33 increased segments (Fig.7). Meanwhile, L5/S1 was still the least affected segment with only 1 increased segment.

Stenotic increasing segments in SME with inconspicuous MRI

We observed stenotic increasing segments by SME with inconspicuous results on the recumbent MRI (Fig. 9). There were Twenty-three patients and 38 segments showed in this comparison (Table.4). Twenty-nine of these segments were increased segments, and 9 segments were considered as significantly increased segments, which accounts for 5.8% and 1.8% of the 500 total segments respectively (Fig.8).

Fig. 9 Clinical examples

Inconspicuous MRI (A) with load dependent narrowing of the spinal canal at level L3/4 in myelography (B); Patient with multisegmental MRI changes but only slight narrowing of the spinal canal at L2/3 level (C) and regular display of L2/3 in the sitting myelography (D), but severe spinal canal stenosis in standing myelography (E).

Table.4 Increased in SME with inconspicuous MRI

Patients	23
Segments	38
IS	29
SIS	9

Increased Segment (IS); Significantly Increased Segment (SIS)

DISCUSSION

The Degeneration of Lumbar Spinal Stenosis

Degenerative lumbar canal stenosis (LCS) is found in the older population, primarily in people in the sixth and seventh decades of life. One of the most important issues to understand the functional anatomy of spine, the motion segment (MS) is seriously involved in the pathological changes of lumbar spinal degeneration, which is composed of the intervertebral disc and facet joints connecting between any two adjacent vertebrae [17]. Degeneration of any of the components of the motion segment may result in abnormal function of that segment. Generally, the degenerative process usually begins in either the facet joints or in the disc, the L3/4 and L4/5 levels are most commonly involved, and there may be a degenerative pseudo-spondylolisthesis. Additionally degenerative lumbar deformities (Kyphosis and Scoliosis), osteopenia and osteoporosis occur quite often [18, 19]. These pathological changes together induce the instability of the lumbar spine accelerating the procedure into a “circulus virtuosus”. They may occur in a cascading sequence or may occur simultaneously in all components. Changes in the three-joint complex of the motion segments are thought to lead to narrowing of the canal and nerve tracts.

Changes in the Intervertebral Disc

In most of cases, the water and proteoglycan decreased disc is often the first component to experience anatomical changes with advancing age. By the age of fifty years, over 95% of all people will have evidence of lumbar disc degeneration [20]. The most significant alterations to the disc are: 1. significant decrease of water content and proteoglycan in the nucleus pulposus; 2. distortion of the collagen fibers of the annulus fibrosus; 3. tears in the lamellae and strength loss of annular. As a result of these changes, the disc begins to lose normal height and volume. It looses resilience and become progressively less resistant to loading forces. The nucleus looses the ability to sustain hydrostatic pressure and deform properly because of water loss and because the annular fibers can no longer maintain tension of their web-like lattice structure [21]. In essence, the disc no longer fully acts like a shock absorber between the vertebral bodies. More axial load is then transferred from the central nucleus to the peripheral annulus, which results in anatomical changes to the vertebral endplates, bodies, and facets. Narrowing of the disc space also causes instability in the motion segment, which in turn places additional stresses on the other components, particularly the ligaments [22]. The disc may then protrude into the central canal or lateral recesses as it degenerates, thereby narrowing the canal.

Changes in the Facet Joints

Following the degenerative changes of disc, the MS can produce repetitive minor trauma to the facet joints which may lead to a nonspecific synovitis [23]. Gradually, the hyaline cartilage that lines the joint loses its water content. Eventually, the cartilage wears away completely. The articular processes begin to override each other as the joint capsules become stretched. This results in a malalignment of the joints and abnormal biomechanical function of the MS. Consequently, the facet joints may become hypertrophy, and pinching the nerve tract.

Changes in the Vertebral Body

Many kinds of degeneration related anatomical changes may occur in the vertebral body over time. Two important changes that may affect function of the motion segment are sclerosis of bone and formation of the osteophyte [24]. The increased bone formation in the subchondral bone adjacent to the endplate, which is known as sclerosis [25], can significantly decrease the amount of nutrients diffusing across the cartilaginous endplate into the intervertebral disc. The main nutrients supply channel for intervertebral disc would be cutting off, especially for the nucleus pulposus . Certainly, disc degeneration is the only consequence. In addition to the sclerosis, the formation of peripheral bony projections, which are termed as osteophytes, are found near the attachment points of the annulus fibrosus to the cortical rim of the vertebra [26]. On the one hand, traction osteophytes have a beneficial mechanical effect in an attempt to restabilize the MS as the disc space loses height and volume. On the other hand, however, they can also have a detrimental effect when they project into an area occupied by a neurological structure in upstanding, flexion and extension position due to the dynamical unstabilized MS, for example, canal space compromising and lateral recesses.

Changes in Ligaments

Spinal ligaments show the effects of aging through partial ruptures, necrosis and calcifications of fibers. The most typical changes of degenerated lumbar ligaments are thickening and Calcification. Calcification may cause shortening of ligament fibers and reduce the amount of joint motion to less than the normal range. With the overriding of the facets, the ligamentum flavum becomes redundant and thickened, and may also protrude into the central canal to squeeze the spinal sac and nerve root tracts [27].

LCS may occur in different locations within the spinal motion segment which could result in different sub-diagnosis and symptoms. If the LCS locates in the central spinal canal where the cauda equine are located, it will be defined as central stenosis; when the stenosis was noticed in the lateral foramen where the nerve root exits to the extremities, it would be diagnosed as foraminal stenosis; and if the stenosis is observed around the lateral recess where the nerve root enters nerve root canal, it would be termed as lateral recess stenosis. Symptoms appear gradually, and back pain is almost always present. There may also be associated buttock and leg pain, usually bilaterally. Unilateral symptoms indicate a lateral recess or foraminal stenosis, while bilateral symptoms point toward a more central narrowing. However, the correlation between the severity of symptoms and the severity of stenosis has never been demonstrated.

Magnetic Resonance Imaging

Compared with the traditional radiography examination, by using magnetic and radio wave energy, the MRI test is a noninvasive, non-radiated, high-definition and high-sensitivity exam, especially in the field of neurological (brain and spinal cord) and musculoskeletal (extremities and spine) imaging. In general, the higher magnetic field used the better image quality with higher resolution can be provided. However, the MR scanner with the traditional "tunnel" shape, especially the high-field canner, probably drives a significant proportion of patients to suffer from terrible claustrophobia during the test. Moreover, when the MR imaging is request for agitated children, obese patients, traumatic patients, or any patient who cannot lie down comfortably, the extremely limited spare space in the tunnel may induce several inexpediency, difficulties to acquiring qualified images and also risks to patients accidently. Unfortunately, there are also several contraindications for doing the MRI, the most common contraindication is a variety of medical implants, which have the potential risk of life threaten due to the malfunction of these devices, such as cardioverter-defibrillators, deep brain stimulators, insulin pumps and cochlear implants, etc. [28]. Of course, any kind of ferromagnetic material is absolutely forbidden to approach the MRI test room due to the potential injuries caused by magnetic heating-up and directly trauma.

In the past, the multiple two-dimensional (2D) cross-sections and three-dimensional (3D) reconstructions with the high resolution of tissue images, that are meaningful and important information for neurosurgeons and orthopedists, were not able to be acquired via traditional computed tomography; after the utilizing of MRI techniques, these visualized information can be demonstrated in the morning conference at every morning and analyzed by doctors for every necessary case. However, the technique of CT scanner has been also well developed in the past decades; the appearance of multi-detector CT scanner with near-isotropic resolution led this technique into a new era. With or without the introduction of contrast medium, the digital data can be perfectly reconstructed to generate 2D images of any plane and 3D images for any tissue [29].

Although the MRI technique provides several benefits for diagnosis, the economics of MRI is a key problem in the development of this technique. The expensive price for MRI examination not only increased the burden of the self-pay patients, but also increased the burden on the statutory health insurance in some countries, such as Germany. In the United States, a MRI test for the lumbar spine can generally cost US$ 4,537. And, for private patients without medical insurance, US$3,176 will be charged for such an examination [30]. In Germany, a public health insurance country, the cost for the lumbar spine MR-examination is about EUR €1,200 to 1,500 for citizens and self-pay visitors [31].

MRI for Lumbar Stenosis

Based upon the obvious advantages over myelography or CT-myelography, MRI seems to be a better choice for spinal imaging without lumbar puncture, X-ray exposition and iodinated contrast agents. Beyond the imagination, the MRI does not automatically and completely replace the “old-fashioned” myelography in the option list of spinal surgeons. In some situation, the MRI would be not as reliable as the old and invasive myelography. Bartynski and Lin reported that, the nerve root compression in the lateral recess can be underestimated by MRI in nearly 30% of surgically confirmed cases compared with only 5 to 7% in myelography [32]. in 2005, Moon et al. reported that MRI provides no more diagnostic information and predictive value of severe spinal stenosis, when compared with myelography, CT-myelography [7]. Furthermore, when compared with MRI, the combination of myelography with CT myelography was considered as a more reliable and reproducible method to decide the decompression level for lumbar stenosis [33]. Moreover, in some anatomical and clinical parameters investigations, the width of the spinal canal and foramina and the spinal canal cross section may be evaluated incorrectly by MRI [34, 35].

Traditional Tunnel-MRI

To our knowledge, the first report of MR-Myelography (MRM) published by Schnarkowski etc. in 1993, the dependence of spinal degenerative disease diagnosis on MRI has significantly increased over the decades [36]. At present, spinal MR imaging is replacing CT and radiography, to become the most valuable test in spinal surgery. Some studies suggested that spinal MRI is an efficient examination, and the traditional imaging tests, such as CT and myelography cannot provide more information [37, 38]. Several MR images grading systems for the lumbar spinal stenosis were reported to be good evaluated and good clinical correlated, for example, Lee system and the Wildermuth grading system [39]. Standard, recumbent MRI equipment generally provides high-resolution images by employing a high field magnet with 1.0T or higher with 3.0T. However, as we discussed before, the recumbent MRI machine is typically a tube-shape scanner, the potential claustrophobic and anxious suffering and the limited space for obesity patients within the machine are their problems. Moreover, the weight-bear test and dynamic test for lumbar spine is not able to be performed neither.

When compared with Myelography and CT-Myelography, the significant progress of the repeatability and reliability by using the recumbent MRI scans for lumbar stenosis lesions still remains controversial. Utilizing a visual and quantitative assessment of lateral lumbar spinal canal stenosis with recumbent MRI, Sipola et al. reported a moderate inter-rater repeatability of visual assessments of lateral stenosis and, substantial reproducibility of both subarticular width and the cross-sectional area of the foramen which is unfortunately and particularly useful for longitudinal studies and research purposes [40]. When compared with upright MRI, the recumbent MRI demonstrate less changes of degeneration parameters which correlated with the severity of LCS symptoms, such as duration of symptoms, walking distance, visual analogue scale of leg pain/numbness, and Japanese Orthopaedic Association score [41].

In the study of Hiwatashi et al., the effect of axial loading MR imaging on treatment decisions in 200 spinal stenosis patients was examined, the axial loading was reported to be vital for the treatment decision [42]. For these symptomatic spinal stenosis patients, the normal MRI and axially loaded recumbent MRI were performed. After the axially loaded MR imaging, 20 of these patients were confirmed as lumber stenosis. The images acquired from two different methods were comprehensively analyzed with the report of physical examination. After viewing the axially loaded images, the conservative management for five patients in the first decision was changed to decompressive surgery by all three surgeons. Two of these surgeons changed their minds for two patients, and the other has changed his mind for three patients. Generally, the conventional recumbent MRI provides much less valuable information than axial-load MRI for assessing patients with LCS. But the axial loading in recumbent MRI scanner is neither a convenient and effective method of manipulating for radiologists, nor a comfortable experience for patients.

Open-MRI

As an obvious improvement of “old-fashion tunnel”, a variety of configurations of open MRI scanner was discussed and reported by scientists. The common open system provide a completely open widow along the side of “circle”, and the semi-open machine has a short scan tunnel which is only for the portion of the body being imaged. With both of the open and semi-open systems, the claustrophobia and the anxious emotion of patients can be solved well; furthermore, the scanning for different position and loading can be easily performed.

In order to “open” a window on the machine, the magnetic circle is hard to be designed to produce high magnetic field, the typical magnetic strength of common open MRI system range from 0.2 to 0.5 Tesla [43], When compared with the traditional tunnel shape scanner, they can only provide compromised resolution, smaller fields of view, and longer scan time spent [44]. Although higher field scanners are becoming available in the research laboratory, there is still a long way to reach the availability of clinical daily using. This significant deficiency limited the application of open-MRI in the diagnosis of spinal degenerative disease which requires the clear identification of compressed neural tissue and degenerated soft tissues.

Upright-MRI

In the recent years, a type of vertically open MRI system, that can provide the possibility of upright sanding in the test, has been developed. From the appearance point of view, this latest up-right normally has an open position at the front, two magnetic poles on both side of the machine. The patient just need to step into the open space, and follow the order from doctors to post different postures, then the standing images or dynamic kinetic images can be acquired. Unlike the open-MRI, the upright MRI systems are generally composed of medium magnetic fields, for example, 0.5 Tesla system for GE company and 0.6 Tesla system from FONAR. Therefore, the image quality of upright MRI is better than normal open-MRI systems. According to the report from the Upright MRI center of Seattle, more than half of the total examination request comes from spinal disease patients, particularly for the patient who has lumbar spine problem [45].

The cost of upright MRI for the spine in up-standing, flexion and extension can up to US$ 5,000 in USA [30]. In the upright MRI center in London, the price for lumbar spine examination can range from £750 to £900 without the results explaining [46]. The imaging quality of mid-field upright MRI is better than traditional low-field open-MRI, but the difference between mid-field upright MRI and high-field MRI is still remarkable. More importantly, this difference of image quality does not show any high cost performance.

The abilities to scan the spine in the symptoms pronounced position, and to evaluate the spine in the weight bearing position with dynamic movement pushed the upright MRI into the sight of spinal specialists. In the last ten years, a number of scientists have published their works on the effects of standing position with/without loading [10, 47-51]. The most concerning point among studies is whether the occult lesions in the supine position test can be elucidated in the standing position with dynamic changes (flexion and extension). In a study of 50 patients who suffer from single level symptoms, Vitzthum et al. investigated the mobility of lumbar vertebral bodies in dynamic sitting positions by means of a 0.5T open MR imaging system [47]. They reported that the “important additional information” was noticed in the flexion and extension positions in 32 patients. However, this additional information was to the clinical examinations, not to the imaging of supine position. In the study of Karadimas et al. 30 patients with low back pain were investigated. To versus the seated neutral position with supine position, the changes of lumbar end plate angles and lumbar disc height in these two positions were observed by them, and the lumbar lordosis was also assessed. [10]. For obtaining images in the supine position and upright seating position, a 0.2 T Open MRI and a 0.6 T upright MRI scanner was involved into their study, respectively. In the comparison of supine and sitting position, interestingly, both of the increasing and decreasing of disc height were observed in degenerated and healthy discs. In addition, significant changes of lumbar lordosis were identified neither. Based on all of these results, authors could only make a "no clear trend" conclusion for this comparison study. Although, the study by Karadimas et al., contributed to a greater understanding of spinal kinematics; however, it did address no evidence to clarify whether upright MRI improves the diagnosis of disc degeneration when compared with recumbent MRI. Gilbert et al. has reported a significant difference in the comparison between weight-bearing upright-MRI (0.6 T Midfield) and recumbent MRI (0.3 T Lowfield) within LCS symptomatic patients [50]. In total 986 serial recumbent scans and 997 upright scans, the identification rate of central stenosis (12%), lateral recess stenosis (9.2%) and foraminal stenosis (33.2%) in the recumbent scans was significantly increased to 13.6%, 20.7% and 52.6% in upright position, respectively. In our opinion, the significant difference between supine and upright position can also be induced by the twice difference of magnetic field strength. With 0.6 Tesla magnetic fields, the low resolution image can also take a comparative long scan time. For example, a 0.6 Tesla upright MRI scanner needs 0.1 seconds for generating one slice image, a 3.0 Tesla upright system from Siemens generate 178 high-resolution images within 1 seconds [52]. Therefore, we do believe that slower imaging times with upright MRI can bring difficulties to severe LCS patients, to remain still while in a upright standing, flexion, extension position can bring suffering experience to them, and sometimes, it is a "mission impossible".

Myelography and CT-Myelography

By using the technique of myelography to display the anatomical structure in assisting of lumbar stenosis diagnosis, neurologists can distinctly identify the compression of sac or nerve roots which may induced by either degenerated soft tissues inside the spinal canal, such as herniated discs, hypertrophied ligamentum flavum, or the instability of vertebrae [13]. Even the most difficult stage of lateral recess stenosis and nerve root canal stenosis can be clearly revealed though myelography technique [32]. More importantly, addition to the prone position during the myelography examination for spinal canal, the up-standing position with flexion and extension, as well as lateral radiculographs can be performed to detect some invisible stenosis levels which demonstrate corresponding neural deficits.

The introduction of computed tomography and water-soluble nonionic contrast agents is a milestone in the development of lumbar stenosis myelography. This technique amelioration made the procedure more convenient, safer and more precise in diagnosis. With the application of computed tomography, a high spatial myelography resolution was provided by the flat panel volumetric computed tomography (FPVCT) with one third radiation of ordinary multisclice CT [53]. Although the upright position is available in non-invasive MR Myelography, both the increased financial cost and the time cost to a neuropathic symptoms suffering patient are disadvantages [54]. Comparatively, the radiographic myelography was a preliminarily choice to the surgeon for an outpatient suspected to have LCS [55], which is time and cost saving, but invasive.

Advantages and Potential Risks

Advantages

As a primary and useful radiographic examination that uses a contrast medium to detect pathology of the spine, Myelography are not performed as frequently today as in the past. However, they still have a significant place in evaluating spinal pathology, especially for the dynamic images of lumbar stenosis. The patients would be asked to perform flexion-extension or side-bending movements following injection of the contrast media. By using this dynamic test, spine surgeons may find the occult lesion which is not visualized on the other test in supine position. Some authors have reported the severity of myelographic findings is significantly related to the surgical outcome [7, 11]. Although Madsen etc. insisted that the horizontal MRI with the supine position was comparable to vertical position whether axial load was added or not, they still thought the spinal extension was the dominant dynamic test position rather than the straight upright position [56]. Morishita etc. reported that the neurological deficits are greatly affected by the variation of dynamic mechanical stress, rather than the static mechanical stress [8]. When compared the cost-effect with the latest open/upright MRI which we mentioned above, in Germany, the "old fashioned" myelography and the following CT-myelography for lumbar spine can win a beautiful victory with extremely favorable price which is €500 and €400, respectively [31].

By means of the contrast agent, a clear outline of the soft tissue (e.g. thecal sac, nerve roots and ligaments) can be sketched out. With the dynamic positions, such as standing, flexion and extension, it can assist with the detection of lumbar spinal stenosis which caused by disc herniation, foremen stenosis, ligaments hypertrophy and osteophytes. The application of computed tomography (CT) with myelography can further enhance the accuracy of diagnosis. The myelography test for LCS requires only a common fluoroscopic equipment or a traditional CT scanner which are much more widely used than the advanced Open-MRI, Upright-MRI or even normal recumbent MRI. In the present, myelography is usually considered as an alternative for MR imaging when the patient has some contraindications of doing MRI scan, such as an arrhythmia patients with pacemakers or fracture patient with incompatible metallic fixation. Based on the study of dural sac size comparison among normal MRI, axial loaded MRI and myelography in upright position, Kanno et al. reported significant correlations of the dural sac diameters with the upright myelography and axial loaded MRI, rather than any assumptive differences [57]. Furthermore, the conventional recumbent MRI was confirmed as less sensitivity and specificity when compared with the other two methods. In their conclusion, the axial loaded MRI was only considered to be able to represent the diameters which detected by the upright myelography in patients with LCS, however, more time and costs would be spent for this more advanced MRI test.

In some patients, the degenerated lumbar spine demonstrates severe deformities in different planes, e.g. scoliosis, kyphosis, which can bring difficulties to the stenosis evaluation by using of MR images. Fortunately, by means of myelography, radiologists can easily illustrate the border of contrast medium which represents the border of soft tissues. When the multidetector-row CT-myelography was combined to scan the bony structures and to reconstruct it in 3D, the server degenerated lumbar deformities would not able to bring any more difficulties to diagnosis and treatment decision. In a morphometric parameter analysis study within degenerative lumbar scoliosis patients, Kaneko et al. successfully elucidated the relationships between foraminal morphology and segmental deformities by means of multidetector-row computed tomography [58]. In another study, Eun et al. compared the effectiveness of multidetector CT and MRI in visualizing soft tissues in LCS patients. They reported that spinal canal area was more narrowed on CT than on MRI in axial cuts which may be caused by the superior ability of multidetector CT to discriminate cortical bone from soft tissue such as the ligamentum flavum [59]. Yan et al. investigated the sensitivity, specificity and total consistent rate of Multispiral CT-myelography and MRI in 26 patients with lumbar nerve root canal stenosis. According to their study, with the ability of obtaining clearly identified images of degenerated soft-tissue and bony tissue, the Multispiral CT-myelography can provide significantly better imaging characteristics for the diagnosis of lumbar nerve root canal stenosis than MRI scans [60].

Potential Risks

As an invasive and radiation examination, the myelography and CT-myelography, that requires a lumbar puncture for injection of dye into the spinal canal and around the nerve roots, has some potential risks, such as, radiation exposure, intra-thecal infection, headache and other rare complications. In nowadays, with the development of myelography techniques, all those potential risks above can be well prevented and controlled by radiologists and surgeons.

The X-ray radiation is a widely used examination techniques in the hospital. In the science, millisievert (mSv) is defined as the unit for measuring the effective dose of radiation. In daily life, people are exposed to natural background radiation all the time. According to the latest report, one person may receive about 3 mSv radiation per year from the natural environment in the U.S. [61]. Compared with the natural background radiation, the radiation exposure of one X-ray test for spine is only 1.5 mSv, and one CT test for spine may expose the patient to 6 mSv. The approximate additional risk of fatal cancer for an adult from these two common examinations is 1 in 100,000 to 1 in 10,000 and 1 in 10,000 to 1 in 1000, respectively [62]. Comparatively speaking, the 1 in 5 chance of dying from cancer is much more horrible than both of these examinations and the benefit of an accurate diagnosis far outweighs the risk. On the other hand, special attention and care of preventing unnecessary exposure to radiation were always taken during all kinds of roentgen tests, and the lowest radiation dose for the best image quality is the principle for radiation control. Moreover, tightly controlled x-ray beams with significant filtration and dose control methods to minimize stray or scatter radiation can be introduced by the application of the State-of-the-art x-ray systems. With this technique, the non-image parts of a body will only exposure to the minimal radiation [63].

Although they are uncommon, both intrathecal infection and headache associated with the needle puncture are potential risks of myelography. The post myelography headache usually begins when the patient begins to sit upright or stand. If the patient lay down again, the headache will be relieved well. When present, the headache usually begins within 2-3 days after the myelography. Rest with the supine position and drinking more water can efficiently relieve mild headaches, but if the headaches getting worse, the medication should be considered [64]. In our 100 patients, there were no post-operation cases of infection reported, and only 9 patients were suffered from mild headache for a few days. A careful operation can avoid these post-operation complications.

In addition to the headache this major complications, the other rare complications of myelography [65]. should also be noted, which include nerve injury by spinal needle, bleeding in the thecal sac, cerebro-spinal meningitis and the most rare Seizures following the procedure of myelography [66]. For female patients, the possibility of the pregnancy should be particularly concerned.

Presented Study

In this study, we investigated dynamic myelography and supine MRI in lumbar canal stenosis. The Open-MRI, Upright-MRI and Axial loading in recumbent MRI were not included in our study due to the extremely high costs, uncommon existence and inconvenient manipulating. We did not measure some objective parameters of lumbar spine, such as cross-sectional area, because we don’t believe that clinical surgeons would use these kinds of parameters to decide the operation level in the daily work. We chose just one radiologist and one neurosurgeon to study all the images in order to stimulate the usual clinical situation.

In general, our primary hypothesis has been well supported by results from this study, that the lumbar myelography cannot be completely replaced by MR imaging for making accurate diagnosis of lumbar stenosis so far. With the "stenosis scores" evaluation, significantly increased stenosis scores were clearly revealed by the dynamic myelography (SME position) from level L2/3 to L4/5, which was consistent with the anatomic feature of degenerated lumbar spine [18, 19]. In comparison, the rMR imaging demonstrated a similar capability of lumbar stenosis examination with sitting myelography; it was then completely defeated by the dynamic myelography. The dynamic myelography demonstrated significantly greater advantages on lumbar stenosis examination with the highest stenosis scores which was 2.5 folds higher than rMRI (Table 1). When compared with the lumbar myelography with normal position (SM position), the dynamic lumbar myelography also demonstrated significantly increased efficiency of detecting the stenotic levels (2 folds).

In further analysis, two pairwise comparisons of the three radiological examinations were performed for evaluating the efficiency of detecting the lumbar stenosis in patients and motion segments, respectively.

Within the comparisons about the stenosis of motion segments, dynamic lumbar myelography showed significant advantages when compared with normal lumbar myelography and rMRI, respectively. Comparing SME and SM, nearly 25% stenosis increased motion segments (121 segments) were detected by dynamic lumbar myelography (SME), containing 20.2% increased segments and 4.0% significantly increased segments. As the result showed in Fig 4., the most affected segment is L3/4 which involves 39 motion segments, and the significantly worsened stenosis was also observed in L4/5. The p-values for these two levels are both less than 0.001. Even in the upper lumbar level L2/3, the stenotic increasing was also significant ($p<0.05$). Comparing SME and rMRI, more than 27% stenotic increased motion segments (137 segments) were reported by dynamic lumbar myelography (SME), which contains 20.4% increased segments and 7.0% significant increased segments. The increase in stenosis at the levels from L2/3 to L4/5 was significant ($p<0.001$). As Morita etc. reported before [33], our results confirmed that the lumbar stenosis in extension position is more remarkable. Based on these results, we reasonably believe that the accurate diagnosis and well-planned surgical treatment should not be based solely on the latest techniques. A comprehensive evaluation combined with dynamic myelography and MRI is still necessary for confirming symptom-responsible stenotic segments and for achieving favorable prognosis.

In order to evaluate the number of affected patients due to the different radiological examinations, comparisons about the number of stenotic increased segments in patients were performed among three methods. In the comparison between SME and SM, state of lumbar stenosis in as many as 61 patients was underestimated by the normal lumbar myelography (SM). According to our stenosis-score evaluation, 15 patients were significantly underestimated. In the comparison between SME and rMRI, 64 patients who had demonstrated worsened stenosis state were observed by means of dynamic lumbar myelography (SME). As many as 25 patients were significantly underestimated by the normal rMRI. Therefore the underestimation of lumbar stenosis in MRI exams without the involvement of dynamic myelography was not clinically acceptable. With an inappropriate surgical planning, the promising excellent prognosis for lumbar stenosis patients, especially in serious lumbar stenosis with degenerated scoliosis, cannot be guaranteed.

The most important finding in our study is the stenotic increasing segment in SME position with inconspicuous result in recumbent MRI. These 23 patients who were suffering from various neural deficits, especially intermittent claudication, received negative results in recumbent MRI. If we only depended on the latest imaging technology to simplify the pre-operation image evaluation, we would get a 23 percent misdiagnosis. Although the decision of decompression level should be made according to an integrated analysis of canal stenotic severity on image and clinical findings, the precise and efficient image is still necessary.

Our Suggestion

Due to the demonstrated valuable advantages of x-ray examination with myelography, an optimized workflow for lumbar stenosis patients was developed and recommended by us (Fig. 9). The consistency of patient's symptoms, physical examinations and results of radiology is the principle of this workflow. The degenerated lumbar scoliosis accompanied LCS patients were specifically concerned. In order to achieve the best prognosis for LCS patients, reliably conforming of the responsible lumber level(s) for surgical plan design is the main purpose of this workflow. With this explicit, reliable and cost-effective workflow, an individualized and appropriate surgical plan can be finally made.

Steps:

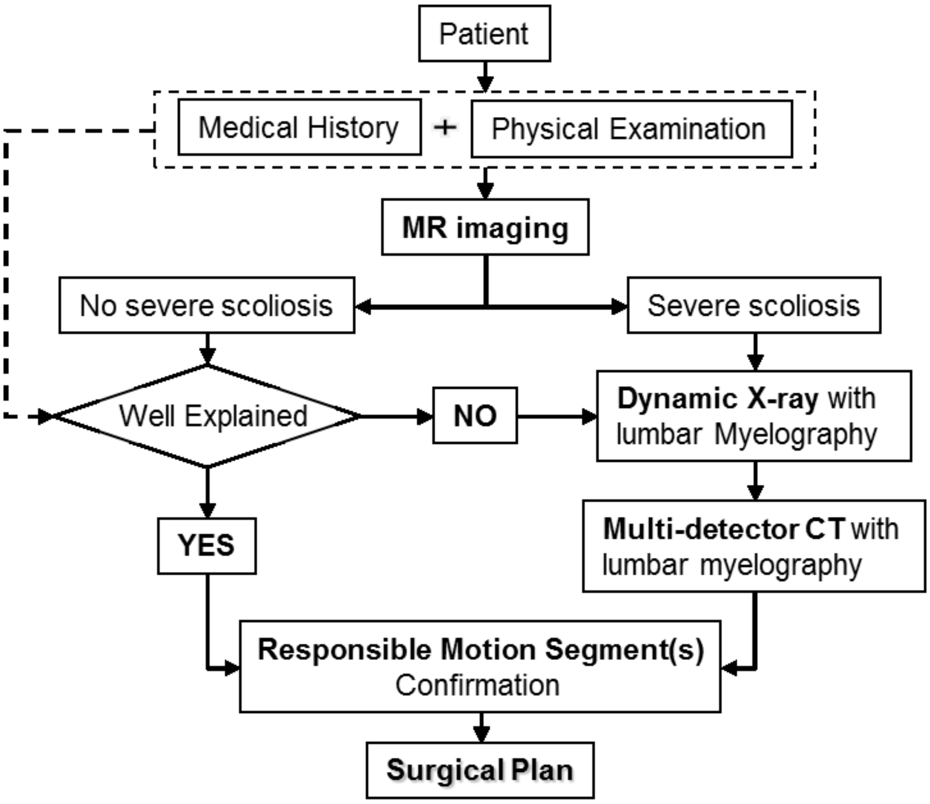
1. In the first step, the details of medical history and symptoms of LCS patient must be obtained carefully and comprehensively, which include location of low back pain, radiating pain, region of sensory deficits, motor function deficits, pathological reflexes, bowel and bladder dysfunction, etc;
2. Thereafter, a MR imaging will be recommend for the lumbar spine as the first radiologic examination. In this step, the state of stenosis and the compression on neural tissues will be evaluated.
3. After the MR imaging, if no severe degenerative lumbar scoliosis was identified, the MR images, medical history and symptoms will be comprehensively analyzed by neuroradiologists and surgeons. And if the

symptoms can be well explained by MR images, the symptom responsible motion segment(s) should be able to be confirmed. Then, an appropriate surgical treatment can be planed afterwards;

4. If the symptoms cannot be well explained (e.g. multi-level stenosis) by MR images and/or a severe degenerative lumbar scoliosis was identified in the previous steps, a dynamic lumbar myelography and a multi-detector CT scan with lumbar myelography will be performed sequentially.
5. In addition to the normal positions, the sitting position with extension and flexion will be involved in this dynamic lumbar myelography. For the patient who is not able to maintain the body erect during the test, the dynamic sitting position can be replaced by side-lying position with extension and flexion. In this step, to discovery the stenotic increasing segment(s) which is inconspicuous in recumbent MR images is the main purpose, especially for multilevel stenosis patients;
6. Within 30 minutes after the dynamic X-ray, the multi-detector CT scan with lumbar myelography will be performed due to the effective time limit of myelography contrast. In this step, the relationships among dural sac, soft tissues, and degenerated vertebrae bony structures will be carefully analyzed. Thereafter, all images from three examinations will be analyzed with symptoms together to confirm the responsible motion segment(s), and an appropriate surgical treatment can be planed afterwards.

Special emphasis: Contraindications and complications of all three radiological examinations should be seriously considered before performance. For example, allergic reaction to the contrast agent, non-magnetic compatible implantations, severe claustrophobia, post-puncture intracranial hypotension, infections, etc.

Fig.9 Surgical planning workflow for LCS patients



CONCLUSION

With this study we proved evidence that myelography can still provide valuable diagnostic information in the diagnostic setup of lumbar canal stenosis, especially when combined with the introducing of CT technology. Full of hope for the distant future, a high magnetic field and valuable identification among degenerated bony structure, soft tissue and compromised nerve root, can be involved in the clinical upright MRI with an acceptable cost. That would be the final termination of the age of myelography.

In conclusion, the 23% misdiagnosis rate of patients with lumbar canal stenosis who received an inconspicuous result in recumbent MRI is clinically unacceptable, and this kind of misdiagnosis can be avoided by performing a dynamic myelography. The dynamic myelography is safe and necessary to LCS patients as a primary imaging procedure, especially for multimorbid patients who might have contraindications for MRI scans. The standing myelography with extension is the best position for detecting lumbar spinal stabilization. The dynamic myelography is irreplaceable in the pre-operation evaluation, and the combination of recumbent MRI and dynamic myelography is significantly important to LCS evaluation. Furthermore, in order to make a precise evaluation of the degenerated lesion and, to make a correct decision in the surgical planning of the decompressive level for LCS patients with severe degenerative scoliosis, the combination of dynamic myelography and multidetector CT-myelography is highly recommended.

REFERENCES

1. Chi, D., et al., *Symptomatic lumbar mobile segment with spinal canal stenosis in a fused spine associated with diffused idiopathic skeletal hyperostosis.* Spine J, 2008. **8**(6): p. 1019-23.
2. Coulier, B., *[Evaluation of lumbar canal stenosis: decubitus imaging methods versus flexion-extension myelography and surface measurements versus the diameter of the dural sac].* JBR-BTR, 2000. **83**(2): p. 61-7.
3. Lian, P., et al., *Correlative study on findings of dynamic myelography and surgical operation in non-bony lumbar spinal canal stenosis.* Chin Med J (Engl), 1994. **107**(12): p. 924-8.
4. Jia, L.S. and Z.R. Shi, *MRI and myelography in the diagnosis of lumbar canal stenosis and disc herniation. A comparative study.* Chin Med J (Engl), 1991. **104**(4): p. 303-6.
5. Hansson, T., et al., *The narrowing of the lumbar spinal canal during loaded MRI: the effects of the disc and ligamentum flavum.* Eur Spine J, 2009. **18**(5): p. 679-86.
6. Niggemann, P., D. Grosskurth, and H.K. Beyer, *[Pathomechanisms of spinal canal stenosis - upright MRI image gallery].* Z Orthop Unfall, 2009. **147**(2): p. 205-9.
7. Moon, E.S., et al., *Comparison of the predictive value of myelography, computed tomography and MRI on the treadmill test in lumbar spinal stenosis.* Yonsei Med J, 2005. **46**(6): p. 806-11.
8. Morishita, Y., et al., *Neurogenic intermittent claudication in lumbar spinal canal stenosis: the clinical relationship between the local pressure of the intervertebral foramen and the clinical findings in lumbar spinal canal stenosis.* J Spinal Disord Tech, 2009. **22**(2): p. 130-4.
9. Rapala, K., et al., *Digital computed tomography evaluation of spinal canal and dural sac before and after surgical decompression of lumbar stenosis.* Ortop Traumatol Rehabil, 2010. **12**(2): p. 120-35.
10. Karadimas, E.J., et al., *Positional MRI changes in supine versus sitting postures in patients with degenerative lumbar spine.* J Spinal Disord Tech, 2006. **19**(7): p. 495-500.
11. Herno, A., et al., *The predictive value of preoperative myelography in lumbar spinal stenosis.* Spine (Phila Pa 1976), 1994. **19**(12): p. 1335-8.
12. Sicard, J.A. and J. Forestier, *Méthode radiographique d'exploration de la cavité épidurale par le lipiodol.* Revista de Neurología, 1921. **28**: p. 1264-1266.
13. Ozdoba, C., et al., *Myelography in the Age of MRI: Why We Do It, and How We Do It.* Radiol Res Pract, 2011. **2011**: p. 329017.
14. Kent, M., et al., *Imaging diagnosis-CT myelography in a dog with*

intramedullary intervertebral disc herniation. Vet Radiol Ultrasound, 2011. **52**(2): p. 185-7.

15. Huk, W.J. and G. Gademann, *Magnetic resonance imaging (MRI): method and early clinical experiences in diseases of the central nervous system.* Neurosurg Rev, 1984. **7**(4): p. 259-80.
16. Sortland, O., B. Magnaes, and T. Hauge, *Functional myelography with metrizamide in the diagnosis of lumbar spinal stenosis.* Acta Radiol Suppl, 1977. **355**: p. 42-54.
17. Abbas, J., et al., *Degenerative lumbar spinal stenosis and lumbar spine configuration.* Eur Spine J, 2010. **19**(11): p. 1865-73.
18. Enomoto, M., et al., *Increase of Paravertebral Muscle Activity in Lumbar Kyphosis Patients by Surface Electromyography Compared With Lumbar Spinal Canal Stenosis Patients and Healthy Volunteers.* J Spinal Disord Tech, 2012.
19. Lee, B.H., et al., *Osteoporotic profiles in elderly patients with symptomatic lumbar spinal canal stenosis.* Indian J Orthop, 2012. **46**(3): p. 279-84.
20. Umehara, S., et al., *Effects of degeneration on the elastic modulus distribution in the lumbar intervertebral disc.* Spine (Phila Pa 1976), 1996. **21**(7): p. 811-9; discussion 820.
21. Haefeli, M., et al., *The course of macroscopic degeneration in the human lumbar intervertebral disc.* Spine (Phila Pa 1976), 2006. **31**(14): p. 1522-31.
22. Hangai, M., et al., *Factors associated with lumbar intervertebral disc degeneration in the elderly.* Spine J, 2008. **8**(5): p. 732-40.
23. Geisser, M.E., et al., *Spinal canal size and clinical symptoms among persons diagnosed with lumbar spinal stenosis.* Clin J Pain, 2007. **23**(9): p. 780-5.
24. Imagama, S., et al., *The effect of beta-carotene on lumbar osteophyte formation.* Spine (Phila Pa 1976), 2011. **36**(26): p. 2293-8.
25. Urano, T., et al., *Single-nucleotide polymorphism in the hyaluronan and proteoglycan link protein 1 (HAPLN1) gene is associated with spinal osteophyte formation and disc degeneration in Japanese women.* Eur Spine J, 2011. **20**(4): p. 572-7.
26. Parmar, K.A., et al., *Bridging osteophyte of the anterosuperior sacroiliac joint as a cause of lumbar back pain.* Br J Sports Med, 2004. **38**(6): p. e33.
27. Matsumoto, Y., et al., *Clinical characteristics and surgical outcome of the symptomatic ossification of ligamentum flavum at the thoracic level with combined lumbar spinal stenosis.* Arch Orthop Trauma Surg, 2012. **132**(4): p. 465-70.
28. Schmerber, S., E. Reyt, and J.P. Lavieille, *Is magnetic resonance imaging still a contraindication in cochlear-implanted patients?* Eur Arch Otorhinolaryngol, 2003. **260**(6): p. 293-4.

29. Tsuchiya, K., et al., *Application of multi-detector row helical scanning to postmyelographic CT.* Eur Radiol, 2003. **13**(6): p. 1438-43.
30. *Wentworth Douglass Hospital Radiology Price List.* Retrieved 2012-03-25, 2012.
31. *The price information from neuroradiology department.* Neuroradiology, Uniklinikum Tuebingen, 2012.
32. Bartynski, W.S. and L. Lin, *Lumbar root compression in the lateral recess: MR imaging, conventional myelography, and CT myelography comparison with surgical confirmation.* AJNR Am J Neuroradiol, 2003. **24**(3): p. 348-60.
33. Morita, M., et al., *Comparison between MRI and myelography in lumbar spinal canal stenosis for the decision of levels of decompression surgery.* J Spinal Disord Tech, 2011. **24**(1): p. 31-6.
34. Grams, A.E., J. Gempt, and A. Forschler, *Comparison of spinal anatomy between 3-Tesla MRI and CT-myelography under healthy and pathological conditions.* Surg Radiol Anat, 2010. **32**(6): p. 581-5.
35. Naganawa, T., et al., *Comparison of magnetic resonance imaging and computed tomogram-myelography for evaluation of cross sections of cervical spinal morphology.* Spine (Phila Pa 1976), 2011. **36**(1): p. 50-6.
36. Schnarkowski, P., et al., *[MR-myelography of the lumbar spine using a PSIF sequence: first experiences].* Aktuelle Radiol, 1993. **3**(1): p. 53-6.
37. Postacchini, F., et al., *Magnetic resonance imaging in the diagnosis of lumbar spinal canal stenosis.* Ital J Orthop Traumatol, 1991. **17**(3): p. 327-37.
38. Modic, M.T., et al., *Lumbar herniated disk disease and canal stenosis: prospective evaluation by surface coil MR, CT, and myelography.* AJR Am J Roentgenol, 1986. **147**(4): p. 757-65.
39. Park, H.J., et al., *Clinical correlation of a new MR imaging method for assessing lumbar foraminal stenosis.* AJNR Am J Neuroradiol, 2012. **33**(5): p. 818-22.
40. Sipola, P., et al., *Visual and quantitative assessment of lateral lumbar spinal canal stenosis with magnetic resonance imaging.* Acta Radiol, 2011. **52**(9): p. 1024-31.
41. Kanno, H., et al., *Dynamic change of dural sac cross-sectional area in axial loaded magnetic resonance imaging correlates with the severity of clinical symptoms in patients with lumbar spinal canal stenosis.* Spine (Phila Pa 1976), 2012. **37**(3): p. 207-13.
42. Hiwatashi, A., et al., *Axial loading during MR imaging can influence treatment decision for symptomatic spinal stenosis.* AJNR Am J Neuroradiol, 2004. **25**(2): p. 170-4.
43. Takasaki, H., et al., *Normal kinematics of the upper cervical spine during the Flexion-Rotation Test - In vivo measurements using magnetic resonance imaging.* Man Ther, 2011. **16**(2): p. 167-71.
44. McGregor, A.H., et al., *The use of interventional open MRI to assess*

the kinematics of the lumbar spine in patients with spondylolisthesis. Spine (Phila Pa 1976), 2002. **27**(14): p. 1582-6.

45. *Personal communications with representative regarding charges and billing practices.* Upright MRI of Seattle Renton, WA, 2007.
46. Madge, B., *The Price information from London Upright MRI Centre.* www.uprightmri.co.uk, 2012.
47. Vitzthum, H.E., A. Konig, and V. Seifert, *Dynamic examination of the lumbar spine by using vertical, open magnetic resonance imaging.* J Neurosurg, 2000. **93**(1 Suppl): p. 58-64.
48. Vitaz, T.W., et al., *Dynamic weight-bearing cervical magnetic resonance imaging: technical review and preliminary results.* South Med J, 2004. **97**(5): p. 456-61.
49. Hirasawa, Y., et al., *Postural changes of the dural sac in the lumbar spines of asymptomatic individuals using positional stand-up magnetic resonance imaging.* Spine (Phila Pa 1976), 2007. **32**(4): p. E136-40.
50. Gilbert, J.W., et al., *Lumbar stenosis rates in symptomatic patients using weight-bearing and recumbent magnetic resonance imaging.* J Manipulative Physiol Ther, 2011. **34**(8): p. 557-61.
51. Schmid, M.R., et al., *Changes in cross-sectional measurements of the spinal canal and intervertebral foramina as a function of body position: in vivo studies on an open-configuration MR system.* AJR Am J Roentgenol, 1999. **172**(4): p. 1095-102.
52. *MR-Tip. Magnetic Resonance Imaging MRI.* http://www.mr-tip.com/. 2007.
53. Engelhorn, T., et al., *Myelography using flat panel volumetric computed tomography: a comparative study in patients with lumbar spinal stenosis.* Spine (Phila Pa 1976), 2007. **32**(18): p. E523-7.
54. Kent, D.L., et al., *Diagnosis of lumbar spinal stenosis in adults: a metaanalysis of the accuracy of CT, MR, and myelography.* AJR Am J Roentgenol, 1992. **158**(5): p. 1135-44.
55. Saint-Louis, L.A., *Lumbar spinal stenosis assessment with computed tomography, magnetic resonance imaging, and myelography.* Clin Orthop Relat Res, 2001(384): p. 122-36.
56. Madsen, R., et al., *The effect of body position and axial load on spinal canal morphology: an MRI study of central spinal stenosis.* Spine (Phila Pa 1976), 2008. **33**(1): p. 61-7.
57. Kanno, H., et al., *Axial Loading During Magnetic Resonance Imaging in Patients with Lumbar Spinal Canal Stenosis: Does It Reproduce the Positional Change of the Dural Sac Detected by Upright Myelography?* Spine (Phila Pa 1976), 2011.
58. Kaneko, Y., et al., *Morphometric analysis of the lumbar intervertebral foramen in patients with degenerative lumbar scoliosis by multidetector-row computed tomography.* Eur Spine J, 2012.
59. Eun, S.S., et al., *MRI versus CT for the diagnosis of lumbar spinal*

stenosis. J Neuroradiol, 2012. **39**(2): p. 104-9.

60. Yan, L., et al., *The study of epidurography and multispiral CT scanning examinations in the diagnosis of lumbar nerve root canal stenosis.* Orthopedics, 2010. **33**(10): p. 732.
61. Smith-Bindman, R., et al., *Use of diagnostic imaging studies and associated radiation exposure for patients enrolled in large integrated health care systems, 1996-2010.* JAMA, 2012. **307**(22): p. 2400-9.
62. *Radiation Exposure in X-ray and CT Examinations.* http://www.radiologyinfo.org/en/safety/index.cfm?pg=sfty_xray, 2012.
63. Hendee, W.R. and M.K. O'Connor, *Radiation risks of medical imaging: separating fact from fantasy.* Radiology, 2012. **264**(2): p. 312-21.
64. Lenelle, L., et al., *[Post-dural puncture headache: treatment and prevention].* Rev Med Liege, 2011. **66**(11): p. 575-80.
65. Sandow, B.A. and J.F. Donnal, *Myelography complications and current practice patterns.* AJR Am J Roentgenol, 2005. **185**(3): p. 768-71.
66. da Costa, R.C., J.M. Parent, and H. Dobson, *Incidence of and risk factors for seizures after myelography performed with iohexol in dogs: 503 cases (2002-2004).* J Am Vet Med Assoc, 2011. **238**(10): p. 1296-300.

Table 5. Myelography and MRI evaluation scores of 100 patients

			Sitting lumbar myelography					Standing myelography with extension					Supine MR imaging				
Nr.	**Datum**	**Age**	**L1/2**	**L2/3**	**L3/4**	**L4/5**	**L5/S1**	**L1/2**	**L2/3**	**L3/4**	**L4/5**	**L5/S1**	**L1/2**	**L2/3**	**L3/4**	**L4/5**	**L5/S1**
1	13.4.2005	22	0	0	0	0	0	0	0	0	**1**	0	0	0	0	0	0
2	19.9.2005	33	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3	4.7.2006	33	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4	5.4.2005	34	0	0	0	0	0	**1**	**1**	**1**	0	0	0	0	0	0	0
5	8.2.2005	37	0	0	0	**2**	0	0	0	0	**2**	0	0	0	0	**2**	0
6	6.12.2005	40	0	0	0	0	0	0	0	0	**1**	0	0	0	0	0	0
7	11.1.2006	40	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
8	19.5.2005	41	**2**	**1**	0	0	0	**2**	**1**	0	0	0	**2**	0	0	0	0
9	22.3.2005	42	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
10	28.2.2005	44	0	0	0	0	0	**1**	**1**	**2**	0	0	0	0	0	0	0
11	29.3.2005	44	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
12	10.1.2005	47	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
13	27.7.2005	47	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
14	20.9.2005	47	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
15	7.7.2004	48	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
16	4.5.2005	48	0	0	0	0	0	0	0	**1**	0	0	0	0	0	0	0
17	1.2.2006	49	0	0	0	0	0	0	0	0	**1**	0	0	0	0	0	0
18	27.9.2004	50	0	0	**1**	0	0	0	0	**1**	0	0	0	0	**1**	0	0

19	15.12.2004	50	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
20	11.5.2005	51	0	0	0	0	0	0	0	0	**2**	0	0	0	0	0	0
21	13.7.2004	52	**2**	0	0	0	0	**2**	0	0	**1**	0	**2**	0	0	0	0
22	13.7.2005	52	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
23	3.5.2006	52	0	0	0	0	0	0	0	0	**2**	0	0	0	0	0	0
24	22.6.2006	53	0	0	0	0	0	0	0	0	**1**	0	0	0	0	0	0
25	9.5.2005	54	0	0	0	0	0	0	**1**	**1**	0	0	0	0	0	0	0
26	29.11.2005	54	0	0	**1**	0	0	0	**2**	**2**	0	0	0	0	**1**	0	0
27	29.10.2004	55	0	0	**1**	0	0	0	0	**2**	0	0	0	0	**1**	0	0
28	14.4.2005	55	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
29	28.9.2005	56	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
30	25.4.2006	56	0	0	0	0	0	0	0	0	**1**	0	0	0	0	0	0
31	7.4.2005	57	**2**	**2**	**2**	**2**	0	**2**	**2**	**2**	**2**	0	0	0	**1**	**1**	0
32	27.6.2006	57	0	**1**	**1**	**1**	0	0	**1**	**2**	**2**	0	0	0	0	**1**	0
33	12.4.2005	58	0	0	**1**	0	0	0	0	**1**	0	0	0	0	**1**	0	0
34	7.6.2005	58	0	0	0	0	0	0	**1**	**2**	0	0	0	0	0	0	0
35	18.10.2005	58	0	**2**	**2**	**1**	0	0	**2**	**2**	**2**	0	0	**1**	**2**	**1**	0
36	15.2.2006	58	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
37	16.2.2006	58	0	0	0	0	0	0	**1**	0	0	0	0	0	0	0	0
38	20.1.2006	59	0	**2**	**2**	**2**	0	0	**2**	**2**	**2**	0	0	**1**	**1**	**1**	0
39	8.3.2006	59	0	0	**1**	**1**	0	0	0	**2**	**1**	0	0	0	**1**	0	0
40	29.6.2006	59	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
41	20.12.2004	60	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

42	10.8.2004	61	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
43	23.5.2006	61	**1**	**1**	**1**	**2**	0	**2**	**2**	**2**	**2**	0	**1**	**1**	**1**	**2**	0
44	28.6.2006	61	0	0	0	0	0	0	**2**	**2**	**2**	0	0	0	0	0	0
45	30.3.2005	62	0	**2**	**2**	**1**	0	0	**2**	**2**	**2**	0	0	**2**	**2**	**1**	0
46	4.5.2005	62	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
47	5.12.2005	62	**1**	**1**	0	0	0	**2**	**2**	**2**	0	0	0	**1**	0	0	0
48	24.7.2006	63	0	**1**	**1**	0	0	0	**2**	**2**	0	0	0	0	**1**	0	0
49	6.7.2005	64	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
50	25.7.2005	64	**1**	**1**	**1**	**1**	0	**2**	**2**	**2**	**2**	0	0	0	0	**1**	0
51	24.11.2005	64	**1**	**1**	**1**	0	0	**1**	**2**	**2**	**1**	0	0	0	**1**	0	0
52	6.4.2006	64	0	0	0	**1**	0	0	0	**2**	**2**	0	0	0	0	**1**	0
53	22.7.2004	66	**1**	0	0	**1**	0	**2**	0	0	**2**	0	**1**	0	0	**1**	0
54	28.10.2005	66	0	**1**	**1**	**1**	**1**	0	**2**	**2**	**2**	**2**	0	0	**1**	**1**	**1**
55	14.9.2004	67	0	**1**	**1**	**1**	0	0	**2**	**2**	**2**	0	0	**1**	**1**	**1**	0
56	2.2.2005	67	**1**	0	0	0	0	**2**	0	0	0	0	**1**	0	0	0	0
57	24.5.2005	67	0	**2**	0	0	0	0	**2**	0	0	0	0	**2**	0	0	0
58	19.9.2005	67	0	0	0	0	0	0	0	0	**1**	0	0	0	0	0	0
59	19.5.2006	67	0	0	0	0	0	**2**	**1**	**1**	0	0	0	0	0	0	0
60	18.3.2005	68	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
61	6.12.2005	68	0	0	0	0	0	0	**1**	**1**	**2**	0	0	0	0	0	0
62	25.4.2006	68	0	0	0	**2**	0	0	0	0	**2**	0	0	0	0	**2**	0
63	27.4.2006	68	0	0	0	0	0	0	0	**1**	0	0	0	0	0	0	0
64	29.6.2006	68	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

65	7.7.2006	68	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
66	18.8.2004	69	0	0	0	0	0	0	0	**1**	0	0	0	0	**1**	0	0
67	2.3.2005	69	0	0	**1**	0	0	0	0	**1**	0	0	0	0	**1**	0	0
68	7.7.2005	69	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
69	1.9.2005	69	**1**	**1**	**1**	0	0	**2**	**2**	**2**	0	0	0	**1**	**1**	0	0
70	25.10.2005	69	0	0	0	**1**	0	0	0	0	**2**	0	0	0	0	**1**	0
71	11.1.2006	69	**1**	**1**	0	0	0	**1**	**1**	**1**	**1**	0	0	0	0	0	0
72	18.7.2006	69	0	0	0	0	0	0	**1**	**1**	0	0	0	0	0	0	0
73	9.8.2006	69	0	0	0	**1**	0	0	0	0	**1**	0	0	0	0	**1**	0
74	26.10.2004	71	**1**	**1**	0	0	0	**1**	**1**	0	0	0	**1**	**1**	0	0	0
75	5.4.2006	71	0	0	0	**1**	0	**1**	**1**	**1**	**2**	0	0	0	0	**1**	0
76	11.7.2006	71	0	0	0	0	0	0	0	**1**	0	0	0	0	0	0	0
77	23.6.2005	72	0	**2**	**2**	**1**	0	**1**	**2**	**2**	**1**	0	0	**2**	**2**	**1**	0
78	31.10.2005	72	0	**2**	**2**	**1**	0	**2**	**2**	**2**	**2**	0	0	**2**	**2**	**1**	0
79	2.8.2006	72	0	**1**	0	0	0	0	**2**	**1**	0	0	0	0	0	0	0
80	20.5.2005	74	0	0	**1**	**2**	0	0	0	**1**	**2**	0	0	0	0	**2**	0
81	9.8.2005	74	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
82	23.8.2005	74	0	0	0	0	**2**	0	0	**1**	0	**2**	0	0	0	0	**2**
83	7.12.2005	74	0	**2**	**1**	0	0	0	**2**	**2**	**2**	0	0	**1**	0	0	0
84	20.4.2005	75	0	**2**	**1**	**1**	**1**	0	**2**	**2**	**2**	**1**	0	0	**1**	**1**	**1**
85	6.9.2005	75	0	**2**	**2**	0	0	0	**2**	**2**	0	0	0	**2**	**2**	0	0
86	29.7.2005	77	0	**2**	0	0	0	**1**	**2**	0	**2**	0	0	**1**	0	0	0
87	25.8.2005	77	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

88	6.12.2004	78	0	0	0	**2**	0	0	0	0	**2**	0	0	0	0	**2**	0
89	24.5.2005	78	0	**2**	**1**	0	0	0	**2**	**1**	**1**	0	0	**2**	**1**	0	0
90	8.2.2006	78	**1**	**1**	0	0	0	**2**	**2**	**1**	**1**	0	**1**	**1**	0	0	0
91	17.1.2006	79	0	0	0	**1**	0	0	0	0	**2**	0	0	0	0	**1**	0
92	27.7.2006	79	0	0	0	0	0	0	**1**	0	0	0	0	0	0	0	0
93	6.12.2005	80	**2**	**2**	**1**	**1**	0	**2**	**2**	**2**	**2**	0	**2**	**2**	**1**	**1**	0
94	20.8.2004	81	0	**1**	**1**	**1**	0	0	**2**	**2**	**2**	0	0	**1**	**1**	**1**	0
95	6.10.2005	81	0	**2**	**2**	0	0	0	**2**	**2**	**1**	0	0	**2**	**2**	0	0
96	25.1.2006	81	0	**1**	**1**	**1**	0	**1**	**2**	**2**	**2**	0	0	**1**	**1**	**1**	0
97	17.2.2006	81	**1**	**1**	**1**	**1**	0	**2**	**2**	**2**	**1**	0	0	0	0	**1**	0
98	10.1.2006	84	0	0	**1**	0	0	0	**2**	**2**	**1**	0	0	0	**1**	0	0
99	26.7.2005	85	**1**	0	0	**1**	0	**1**	0	**1**	**2**	0	0	0	0	**1**	0
100	26.4.2005	91	0	0	0	0	0	**2**	**2**	**2**	**2**	0	0	0	**2**	**2**	0

Table 6. Increased scores involved in the comparison between SM and SME

	SM vs SME					IS	SIS	Total		SM vs SME					IS	SIS	Total
Number	L1/2	L2/3	L3/4	L4/5	L5/S1				Number	L1/2	L2/3	L3/4	L4/5	L5/S1			
1	0	0	0	**1**	0	1	0	1	51	0	**1**	**1**	**1**	0	3	0	3
2	0	0	0	0	0	0	0	0	52	0	0	**2**	**1**	0	1	1	2
3	0	0	0	0	0	0	0	0	53	**1**	0	0	**1**	0	2	0	2
4	**1**	**1**	**1**	0	0	3	0	3	54	0	**1**	**1**	**1**	**1**	4	0	4
5	0	0	0	0	0	0	0	0	55	0	**1**	**1**	**1**	0	3	0	3
6	0	0	0	**1**	0	1	0	1	56	**1**	0	0	0	0	1	0	1
7	0	0	0	0	0	0	0	0	57	0	0	0	0	0	0	0	0
8	0	0	0	0	0	0	0	0	58	0	0	0	**1**	0	1	0	1
9	0	0	0	0	0	0	0	0	59	**2**	**1**	**1**	0	0	2	1	3
10	**1**	**1**	**2**	0	0	2	1	3	60	0	0	0	0	0	0	0	0
11	0	0	0	0	0	0	0	0	61	0	**1**	**1**	**2**	0	2	1	3
12	0	0	0	0	0	0	0	0	62	0	0	0	0	0	0	0	0
13	0	0	0	0	0	0	0	0	63	0	0	**1**	0	0	1	0	1
14	0	0	0	0	0	0	0	0	64	0	0	0	0	0	0	0	0
15	0	0	0	0	0	0	0	0	65	0	0	0	0	0	0	0	0
16	0	0	**1**	0	0	1	0	1	66	0	0	**1**	0	0	1	0	1
17	0	0	0	**1**	0	1	0	1	67	0	0	0	0	0	0	0	0
18	0	0	0	0	0	0	0	0	68	0	0	0	0	0	0	0	0
19	0	0	0	0	0	0	0	0	69	**1**	**1**	**1**	0	0	3	0	3

20	0	0	0	**2**	0	0	1	1	70	0	0	0	**1**	0	1	0	1
21	0	0	0	**1**	0	1	0	1	71	0	0	**1**	**1**	0	2	0	2
22	0	0	0	0	0	0	0	0	72	0	**1**	**1**	0	0	2	0	2
23	0	0	0	**2**	0	0	1	1	73	0	0	0	0	0	0	0	0
24	0	0	0	**1**	0	1	0	1	74	0	0	0	0	0	0	0	0
25	0	**1**	**1**	0	0	2	0	2	75	**1**	**1**	**1**	**1**	0	4	0	4
26	0	**2**	**1**	0	0	1	1	2	76	0	0	**1**	0	0	1	0	1
27	0	0	**1**	0	0	1	0	1	77	**1**	0	0	0	0	1	0	1
28	0	0	0	0	0	0	0	0	78	**2**	0	0	**1**	0	1	1	2
29	0	0	0	0	0	0	0	0	79	0	**1**	**1**	0	0	2	0	2
30	0	0	0	**1**	0	1	0	1	80	0	0	0	0	0	0	0	0
31	0	0	0	0	0	0	0	0	81	0	0	0	0	0	0	0	0
32	0	0	**1**	**1**	0	2	0	2	82	0	0	**1**	0	0	1	0	1
33	0	0	0	0	0	0	0	0	83	0	0	**1**	**2**	0	1	1	2
34	0	**1**	**2**	0	0	1	1	2	84	0	0	**1**	**1**	0	2	0	2
35	0	0	0	**1**	0	1	0	1	85	0	0	0	0	0	0	0	0
36	0	0	0	0	0	0	0	0	86	**1**	0	0	**2**	0	1	1	2
37	0	**1**	0	0	0	1	0	1	87	0	0	0	0	0	0	0	0
38	0	0	0	0	0	0	0	0	88	0	0	0	0	0	0	0	0
39	0	0	**1**	0	0	1	0	1	89	0	0	0	**1**	0	1	0	1
40	0	0	0	0	0	0	0	0	90	**1**	**1**	**1**	**1**	0	4	0	4
41	0	0	0	0	0	0	0	0	91	0	0	0	**1**	0	1	0	1
42	0	0	0	0	0	0	0	0	92	0	**1**	0	0	0	1	0	1

43	**1**	**1**	**1**	0	0	3	0	3	93	0	0	**1**	**1**	0	2	0	2
44	0	**2**	**2**	**2**	0	0	3	3	94	0	**1**	**1**	**1**	0	3	0	3
45	0	0	0	**1**	0	1	0	1	95	0	0	0	**1**	0	1	0	1
46	0	0	0	0	0	0	0	0	96	**1**	**1**	**1**	**1**	0	4	0	4
47	**1**	**1**	**2**	0	0	2	1	3	97	**1**	**1**	**1**	0	0	3	0	3
48	0	**1**	**1**	0	0	2	0	2	98	0	**2**	**1**	**1**	0	2	1	3
49	0	0	0	0	0	0	0	0	99	0	0	**1**	**1**	0	2	0	2
50	**1**	**1**	**1**	**1**	0	4	0	4	100	**2**	**2**	**2**	**2**	0	0	4	4

Table 7. Increased scores involved in the comparison between recumbent MRI and SME

	recumbent MRI vs SME					IS	SIS	Total		recumbent MRI vs SME					IS	SIS	Total
Number	L1/2	L2/3	L3/4	L4/5	L5/S1				Number	L1/2	L2/3	L3/4	L4/5	L5/S1			
1	0	0	0	**1**	0	1	0	1	51	**1**	**2**	**1**	**1**	0	3	1	4
2	0	0	0	0	0	0	0	0	52	0	0	**2**	**1**	0	1	1	2
3	0	0	0	0	0	0	0	0	53	**1**	0	0	**1**	0	2	0	2
4	**1**	**1**	**1**	0	0	3	0	3	54	0	**2**	**1**	**1**	1	3	1	4
5	0	0	0	0	0	0	0	0	55	0	**1**	**1**	**1**	0	3	0	3
6	0	0	0	**1**	0	1	0	1	56	**1**	0	0	0	0	1	0	1
7	0	0	0	0	0	0	0	0	57	0	0	0	0	0	0	0	0
8	0	**1**	0	0	0	1	0	1	58	0	0	0	**1**	0	1	0	1
9	0	0	0	0	0	0	0	0	59	**2**	**1**	**1**	0	0	2	1	3
10	**1**	**1**	**2**	0	0	2	1	3	60	0	0	0	0	0	0	0	0
11	0	0	0	0	0	0	0	0	61	0	**1**	**1**	**2**	0	2	1	3
12	0	0	0	0	0	0	0	0	62	0	0	0	0	0	0	0	0
13	0	0	0	0	0	0	0	0	63	0	0	**1**	0	0	1	0	1
14	0	0	0	0	0	0	0	0	64	0	0	0	0	0	0	0	0
15	0	0	0	0	0	0	0	0	65	0	0	0	0	0	0	0	0
16	0	0	**1**	0	0	1	0	1	66	0	0	0	0	0	0	0	0
17	0	0	0	**1**	0	1	0	1	67	0	0	0	0	0	0	0	0
18	0	0	0	0	0	0	0	0	68	0	0	0	0	0	0	0	0
19	0	0	0	0	0	0	0	0	69	**2**	**1**	**1**	0	0	2	1	3

20	0	0	0	**2**	0	0	1	1	70	0	0	0	**1**	0	1	0	1
21	0	0	0	**1**	0	1	0	1	71	**1**	**1**	**1**	**1**	0	4	0	4
22	0	0	0	0	0	0	0	0	72	0	**1**	**1**	0	0	2	0	2
23	0	0	0	**2**	0	0	1	1	73	0	0	0	0	0	0	0	0
24	0	0	0	**1**	0	1	0	1	74	0	0	0	0	0	0	0	0
25	0	**1**	**1**	0	0	2	0	2	75	**1**	**1**	**1**	**1**	0	4	0	4
26	0	**2**	**1**	0	0	1	1	2	76	0	0	**1**	0	0	1	0	1
27	0	0	**1**	0	0	1	0	1	77	**1**	0	0	0	0	1	0	1
28	0	0	0	0	0	0	0	0	78	**2**	0	0	**1**	0	1	1	2
29	0	0	0	0	0	0	0	0	79	0	**2**	**1**	0	0	1	1	2
30	0	0	0	**1**	0	1	0	1	80	0	0	**1**	0	0	1	0	1
31	**2**	**2**	**1**	**1**	0	2	2	4	81	0	0	0	0	0	0	0	0
32	0	**1**	**2**	**1**	0	2	1	3	82	0	0	**1**	0	0	1	0	1
33	0	0	0	0	0	0	0	0	83	0	**1**	**2**	**2**	0	1	2	3
34	0	**1**	**2**	0	0	1	1	2	84	0	**2**	**1**	**1**	0	2	1	3
35	0	**1**	0	**1**	0	2	0	2	85	0	0	0	0	0	0	0	0
36	0	0	0	0	0	0	0	0	86	**1**	**1**	0	**2**	0	2	1	3
37	0	**1**	0	0	0	1	0	1	87	0	0	0	0	0	0	0	0
38	0	**1**	**1**	**1**	0	3	0	3	88	0	0	0	0	0	0	0	0
39	0	0	**1**	**1**	0	2	0	2	89	0	0	0	1	0	1	0	1
40	0	0	0	0	0	0	0	0	90	**1**	**1**	**1**	**1**	0	4	0	4
41	0	0	0	0	0	0	0	0	91	0	0	0	**1**	0	1	0	1
42	0	0	0	0	0	0	0	0	92	0	**1**	0	0	0	1	0	1

43	**1**	**1**	**1**	0	0	3	0	3	93	0	0	**1**	**1**	0	2	0	2
44	0	**2**	**2**	**2**	0	0	3	3	94	0	**1**	**1**	**1**	0	3	0	3
45	0	0	0	**1**	0	1	0	1	95	0	0	0	**1**	0	1	0	1
46	0	0	0	0	0	0	0	0	96	**1**	**1**	**1**	**1**	0	4	0	4
47	**2**	**1**	**2**	0	0	1	2	3	97	**2**	**2**	**2**	0	0	0	3	3
48	0	**2**	**1**	0	0	1	1	2	98	0	**2**	**1**	**1**	0	2	1	3
49	0	0	0	0	0	0	0	0	99	**1**	0	**1**	**1**	0	3	0	3
50	**2**	**2**	**2**	**1**	0	1	3	4	100	**2**	**2**	0	0	0	0	2	2

DEUTSCHE ZUSAMMENFASSUNG

Die dargelegte Auswertung von einhundert Patienten mit lumbaler Spinalkanalstenose zeigt eindrucksvoll, dass die Methode der lumbalen Funktionsmyelographie mit anschließender post-Myelo Computertomographie der Magnetresonanztomografie überlegen ist. In 23 Patienten mit unauffälligem MRT des lumbalen Spinalkanals in Rückenlage konnte in der Funktionsmyelografie eine relevante Spinalkanalstenose nachgewiesen werden und so dem Patienten eine chirurgische Therapieoption angeboten werden. Auch wenn die Myelografie eine invasive diagnostische Methode mit entsprechenden Risikofaktoren darstellt, kann bei deutlich höherer Sensitivität bezgl. der degenerativen und hier insbesondere der ligamentären Spinalkanalstenose, diese Untersuchung empfohlen werden. Die Alternative einer MRT Untersuchung im Stehen oder in Funktionsstellung ist heutzutage qualitativ unterlegen und mit höheren sozio-ökonomischen Kosten verbunden. Die Kombination einer Standard-MRT Untersuchung mit Myelografie bei multisegmentalen lumbalen Spinalkanalstenosen, wird durch diese Studie an einem großen Patientenkollektiv, als Standard in der prä-operativen Diagnostik bei fehlender klinischer segmentaler Zuordnung angesehen.

ACKNOWLEDGEMENTS

I am heartily thankful to my supervisor, Professor Florian Roser, who has given me the guidance of this research topic and the help of the dissertation writing. And I want to truly thank him, for his supports of my study and final examination.

And, I want to show my great appreciation to Professor Marcos Tatagiba, whom gave me this chance to study in the Neurosurgery department Tuebingen, and the support with any questions during my study in the department.

I would like to thank Professor Boris Krischek, Doctor Martin Merkle and Doctor Sören Danz, for their good advices, excellent supports and their help of data collecting for this dissertation, and for their kindness and all the help during my study.

I would like to thank Frau Efferen who gives me a lot of help during the period of whole study.

At last, I want to thank my parents who live in China. I am so full of gratitude and deep appreciation for all you've done for me.

CURRICULUM VITAE

Name: Jun Li **Gender:** male

Date of Birth: 28.October 1981

Nationality: P.R.China

June/2010 – March/2012 **Doctoral student of Medicine**
Klinik für Neurochirurgie, Universitätsklinikum Tübingen, Eberhard Karls Universität Tübingen, Germany.
Supervisors: Prof. Dr. med. Marcos Tatagiba and Prof. Dr. med. Florian Roser

January/2011 – December/2011 **Lab. Training (Part time)**
Laboratory for NeuroRegeneration and Repair, Hertie Institute for Clinical Brain Research, Uniklinik Tübingen, Eberhard Karls Universität Tübingen, Germany.
Supervisors: Simone.Di.Giovanni, MD, PhD & Khizr.Rathore, PhD, post-doc. scientist

July/2009 – May/2010 **Residents Surgeon**
Spinal Surgery Department, Luzhou Medical College, PR. China.
Director of Spinal Surgery Department: Prof. Qing Wang

July/2009 – May/2010 **Medical Licensing**

September/2006 – June/2009 **Master of Medicine**
Spinal Surgery Department, Luzhou Medical College, PR. China.
Supervisors: Prof. Dr. Daxiong Feng

July/2005-August/2006 **Society Service**
Jiangyang District, Luzhou, Sichuan, PR. China

September/2000 – June/2005 **Bachelor of Medicine**
Luzhou Medical College, Luzhou, Sichuan, PR. China.