LUMBAR DISC HERNIATION SURGERY

– NOVEL APPROACHES, TIMING AND OUTCOMES

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DON'T COMPROMISE. EVEN
IF IT HURTS TO BE YOURSELF.

— TOBY KEITH

JOEL BECK

CONTENTS

JOEL BECK

ABSTRACT

Lumbar Disc Herniation Surgery – Novel Approaches, Timing and Outcomes

BACKGROUND

Lumbar disc herniation surgery is among the most common procedures in spinal surgery. Full-Endoscopic lumbar discectomy (FELD) was introduced in 2013 in Sweden as a minimally invasive procedure to treat lumbar disc herniation. Further research of new surgical methods and preoperative patient factors such as proper surgical timing and mental health status may likely affect the outcomes after lumbar disc herniation surgery.

AIM

The purpose of the thesis was to study the outcomes following the Swedish introduction of FELD and to acquire further knowledge of important predictors of an unsuccessful result after lumbar disc herniation surgery.

STUDY POPULATION

The study population in Studies I and II contain the first 92 patients undergoing a FELD procedure at Sahlgrenska University Hospital, Gothenburg, Sweden. The control group in Study II and all the patients in Studies III+IV were retrieved from the Swedish national spine register – Swespine.

METHODS

The studies in this thesis were conducted in a tertiary hospital setting; Sahlgrenska University Hospital in Gothenburg, Sweden. The studies were approved by the local ethics committee. The Swedish introduction of the FELD procedure was described using a cohort of lumbar disc herniation patients. The patients were matched with controls from the Swespine register undergoing standard discectomy surgery during the same time period and their postoperative patient-reported outcome measurements were compared. In a large national cohort, the preoperative duration of sciatica, anxiety and depression as predictive factors of postoperative residual leg pain were studied in lumbar disc herniation patients. The results were based on stratified preoperative leg-pain duration groups or the level of anxiety and depression. Leg pain measured by the numerical rating

scale and disability measured by the Oswestry Disability Index were chosen as the primary outcomes and the EQ-5D as well as satisfaction with the surgical procedure were also studied.

RESULTS/DISCUSSION

The FELD procedure was successfully introduced and delivered good clinical results in terms of postoperative leg pain and disability, with a low rate of complications, comparable to that of standard surgery. When examined in a national cohort, the prolonged duration of preoperative sciatica led to a greater risk of obtaining patients reporting a higher level of residual leg pain and poor outcomes after a lumbar disc herniation procedure. Patients with a short duration of pain reported better results in all patient-recorded outcome measures. Most patients stating preoperative anxiety and depression were able to reach the same level of quality of life and satisfaction as other lumbar disc herniation patients, but with a higher risk of residual leg pain and complications.

CONCLUSION

The FELD procedure was an excellent alternative to standard surgery for lumbar disc herniation producing good clinical outcomes. Patients with a longer duration of sciatica reported worse results after lumbar discectomy. Patients with anxiety and depression may achieve the same significant improvements after a lumbar discectomy as other patients, but are at a higher risk of worse outcomes and residual pain.

KEY WORDS

FELD, Full-Endoscopic Lumbar Discectomy, PELD, Percutaneous Endoscopic Lumbar Discectomy, disc herniation, sciatica, pain duration, discectomy, time to surgery.

ABSTRACT

JOEL BECK

SAMMANFATTNING PÅ SVENSKA

INTRODUKTION

Diskbråckskirurgi i ländrygg är en av de vanligaste ryggkirurgiska operationerna. Cirka 2000 ingrepp utförs årligen i Sverige. Efter att ha genomgått en snabb teknisk utveckling alltsedan operationsmikroskop introducerades på 1960-talet har nu full endoskopisk lumbal diskektomi (FELD) införts i Sverige. Detta är en för svensk sjukvård ny metod för att minimalt invasivt operera lumbala diskbråck.

SYFTE

Syftet med denna avhandling var att presentera introduktionen av FELD-kirurgi i Sverige samt en jämförelse med traditionell diskbråckskirurgi. I ett urval av patienter från det svenska ryggregistret studerades sambanden mellan preoperativ smärtduration, ångest och depression samt patient rapporterat resultatet 1 år efter genomförd diskbråckskirurgi.

MATERIAL OCH METOD

I två studier studerades de patienter som opererades på Sahlgrenska Universitetssjukhuset, Göteborg med FELD-metoden åren 2013–2017 och jämfördes med kontroller från det svenska ryggregistret – Swespine. Smärtduration, ångest och depressionseffekter på postoperativt resultat studerades på 6216 patienter som genomgått konventionell diskbråckskirurgi.

RESULTAT

På ett svenskt sjukhus kunde FELD introduceras med ett bra resultat för patienter. FELD-patienterna erhöll god smärtlindring avseende bensmärta där 87% av patienterna uppgav att de var smärtfria eller förbättrade efter operationen. Operativa resultat och frekvens av komplikationer är likartad vid en jämförelse med de patienter som blivit opererade på ett traditionellt sätt.

Durationen av bensmärta inför diskbråcksoperation påverkar det patientrapporterade resultatet efter operation. Patienter med en kortare tid (<3 månader) av bensmärta uppger ett bättre resultat avseende smärtlindring jämfört med de med en längre duration. Det finns en skillnad i hur patienterna rapporterar sin

kvarvarande bensmärta och hur nöjda de är efter operationen beroende på hur länge de haft ont innan kirurgin. Om man haft bensmärta mer än 12 månader är det dubbelt så stor risk att uppge att bensmärtan är sämre efter operationen.

Depression och ångest i samband med operation kan leda till att patienterna har en ökad risk att rapportera ett sämre resultat, både gällande bensmärta och hur nöjd man är med operationen. Mer än 82% rapporterar att deras tidigare depression eller ångest har minskat efter kirurgi.

SLUTSATSER

Den endoskopiska FELD tekniken var ett bra alternativ till standardkirurgi vid diskbråck i ländryggen. En långvarig period av ischias innan kirurgi leder till att patienterna rapporterar ett sämre resultat efter operation. Patienter som uppger att de lider av depression och ångest kan erhålla bra minskning av sin bensmärta efter diskbråckskirurgi, men har en ökad risk att känna sig missnöjda med resultatet.

SAMMANFATTNING PÅ SVENSKA

JOEL BECK

LIST OF PAPERS

I. **Joel Beck, Olof Westin, Mikael Klingenstierna, Adad Baranto.**
SUCCESSFUL INTRODUCTION OF FULL-ENDOSCOPIC LUMBAR INTERLAMINAR DISCECTOMY IN SWEDEN
Int J Spine Surg 2020 Aug;14(4):563-570.

II. **Joel Beck, Olof Westin, Mikael Klingenstierna, Adad Baranto.**
FULL-ENDOSCOPIC LUMBAR DISCECTOMY VS STANDARD SURGERY FOR LUMBAR DISC HERNIATION – A MATCHED NATIONAL COHORT STUDY
Submitted

III. **Joel Beck, Olof Westin, Helena Brisby, Adad Baranto.**
ASSOCIATION OF EXTENDED DURATION OF SCIATIC LEG PAIN WITH WORSE OUTCOME AFTER LUMBAR DISC HERNIATION SURGERY: A REGISTER STUDY IN 6216 PATIENTS
J Neurosurg Spine 2021 Feb 12;1-9.

IV. **Joel Beck, Olof Westin, Adad Baranto.**
DON'T BACK DOWN – LUMBAR DISC HERNIATION SURGERY FOR THE DEPRESSED AND ANXIOUS
Manuscript

JOEL BECK

ABBREVIATIONS

AF	Annulus fibrosus
CI	Confidence interval
DDD	Degenerative disc disease
EQ-5D	Euroqol – 5 dimension
FELD	Full-Endoscopic Lumbar Discectomy
FU	Follow-up
GA	Global assessment
IL	Interlaminar
LBP	Lumbar back pain
LD	Lumbar disc
LDH	Lumbar disc herniation
MCID	Minimal clinically important difference
MIC	Minimal important change
MRI	Magnetic resonance imaging
NP	Nucleus pulposus
NRS	Numerical rating scale
ODI	Oswestry Disability Score
PASS	Patient-acceptable Symptom State
PELD	Percutaneous lumbar discectomy
PROMs	Patient-reported outcome measurements
RCT	Randomised controlled trial
SD	Standard deviation
SF-36	Short Form-36
SLR	Straight leg raise
SWESPINE	Swedish spine register
TF	Transforaminal
TTS	Time to surgery
VAS	Visual analogue scale

JOEL BECK

BRIEF DEFINITIONS

MCID – MINIMAL CLINICALLY IMPORTANT DIFFERENCE

MCID is defined as the smallest difference in an outcome considered relevant to the patient and treating physician. MCID indicates an improvement or a worsening of symptoms. It is used to distinguish between a statistical significance and medical relevance.

PASS – PATIENT ACCEPTABLE SYMPTOM STATE

PASS is defined as the level of symptoms beyond which patients would rate themselves in good health. The difference between PASS and MCID is that reaching the level of PASS reflects “feeling good”, whereas the MCID measures “feeling better”.

PROMs – PATIENT REPORTED OUTCOME MEASUREMENTS

Questionnaires that are filled in by the patient, in order to record the patient’s subjective attitudes on outcomes. Some of the most common PROMs in spinal surgery include the ODI (disability related to back pain), the EQ-5D (5-dimensional quality of life) and the SF-36 (8-domain, comprehensive physical and mental scores). Most PROMs are validated using different methods. Global Assessment ($GA_{Leg/Back}$) and other single-item questions within the Swedish spine register are also considered PROMs.

FELD – FULL-ENDOSCOPIC LUMBAR DISCECTOMY

A minimally invasive percutaneous method to treat lumbar disc herniations. A surgical technique that does not rely on a microscope, retractors or any equipment traditionally associated with open surgery. Percutaneous endoscopic lumbar discectomy (PELD) may be used interchangeably.

1

INTRODUCTION

JOEL BECK

EVOLUTIONARY BACKGROUND

Our human ancestors spent their early days walking on all fours, before developing an upright posture some 3.5 million years ago.[1] The transition from a quadruped to a bipedal walking human was swift in evolutionary terms, but it necessitated some significant adjustments to the spine.[2]

In order to position the centre of balance and spine above the pelvis, the pelvis needed to be rotated and spinal curvatures such as lumbar lordosis and thoracic kyphosis needed to evolve to accommodate proper muscular insertions. A chimpanzee's back, with its pronounced global kyphosis, permits bipedal walking but only for a short time due to muscular strain and fatigue. The human spine also had to adapt to support a head cradling a large and heavy brain. The spine and pelvis had to be able to accommodate a significant range of hip motion, as well as providing stability for the upper torso to permit upright long-distance walking. One trade-off in human bipedal walking is a spine that is prone to overload, fatigue and failure. However advantageous from a survival point of view, evolution has not been able to keep up with the physical demands on our backs. Genetic factors, trauma and the normal physiological load on our human spines eventually, with time, leads to degeneration – occasionally evident as early as in teenagers in routine X-rays.[3] Degeneration may cause back pain from a multitude of spinal anatomical locations, including the disc complex, facet joint osteoarthritis and back muscle insufficiency.[2,4]

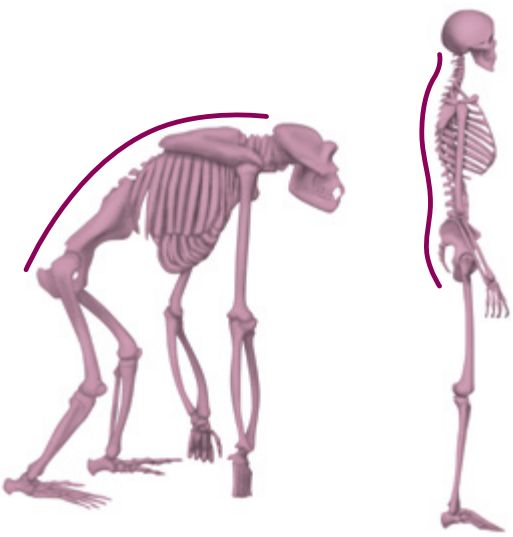


FIGURE 1: Evolution of the human spine. The spinal curvatures of the human spine, with a lumbar lordosis and thoracic kyphosis, enable upright walking. The trunk and head are positioned straight above the pelvis as opposed to the spine of a hominoid (ape) where a global kyphosis puts the trunk in front of the pelvis. With advancing age, degeneration and muscular insufficiency, the human spine tends to assume a more stooping position, remininscent to that of our evolutionary ancestors.

DISC ANATOMY AND HISTOLOGY

The human spine is made up of 33 vertebrae divided into five different distinct anatomical regions. The cervical (7 vertebrae), thoracic (12 vertebrae), lumbar (5 vertebrae), sacral (5 vertebrae) and coccygeal (4 vertebrae) vertebrae constitute the spine. Most coccygeal and sacral vertebrae are fused and are also part of the posterior ring of the pelvis. The coccygeal segments are remnants of an earlier tail lost in evolution.[5] Between all the vertebrae except atlas and axis, intervertebral discs are situated. The disc could be regarded as a crucial part of a complicated joint structure in the spine that also encompass facet joints and several strong ligaments anterior and posterior to the spinal column.[6,7]

The lumbar intervertebral disc (LD) is approximately the area of the adjacent vertebral endplate and is usually 8-10 mm thick. The embryonal origin of the centre of the disc is derived from the notochord and evolves into the nucleus pulposus (NP), a gelatinous substance composed of collagen fibres, elastin and up to 70% of water.[8] This aggregate of shock-absorbing and elastic fibres provides the spine with the ability to stabilise and cushion the impact of loads on the spine and torso during running or walking. In order to contain the NP between the cartilaginous vertebral endplates, it is surrounded by the annulus fibrosus (AF), a tough cross-weaved lamellar structure made of sturdy proteins and collagen.[9]

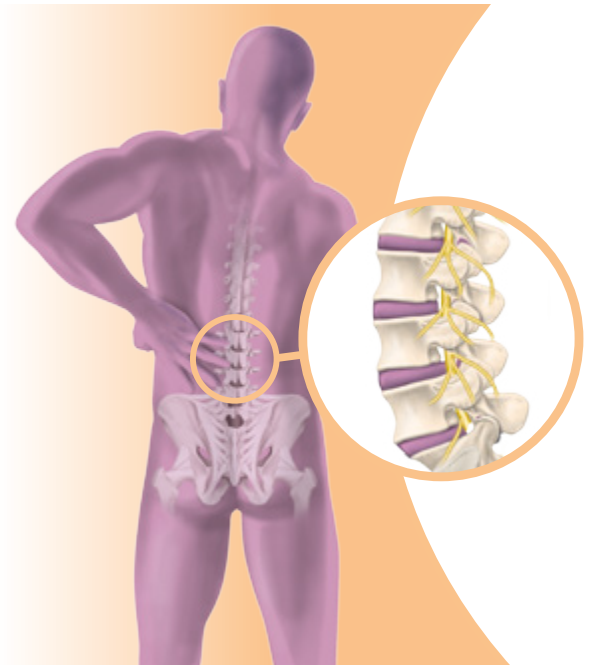


FIGURE 2: Anatomy of the lower human spine. The discs in the lower part of the back are the most prone to degeneration due to the mechanical forces exerted between the lower lumbar spine and pelvis. A lumbar disc herniation may develop, most commonly in the fourth decade of life, potentially compressing nerves and causing sciatica.

DISC DEGENERATION AND LUMBAR DISC HERNIATION

The lumbar disc is a large avascular structure in the human body. As with most tissues within the human body it is prone to degeneration depending on a number of factors. Genetics, mechanics and age-dependent changes may all influence the long-term function and structure of the disc. The resulting pathoanatomical and radiological findings of the disc are called degenerative disc disease (DDD). It is the leading cause of developing a lumbar disc herniation (LDH).

GENETIC FACTORS IN DISC DEGENERATION

During the last 30 years, genetic factors and their association with developing a DDD have been established.[10-13] Several twin studies have studied the impact of genetics on the development of low back pain and DDD.[14-16] There now appears to be a strong correlation between genotype and DDD as opposed to previous assumptions that emphasized excessive physiological loads or phenotypes.[17,18] A recent review indicates that excessive loads on the lumbar spine activate a genetic expression that promotes degeneration and that most DDD may be caused by a combination of genetic and mechanical factors.[19,20]

MECHANICAL FACTORS IN DISC DEGENERATION

There is a broad consensus that repetitive or acute excessive loads on the disc caused by trauma or sports activity on the lumbar spine can induce DDD.[21-24] A pressure-induced micro-trauma exerts its effect on the vertebral endplates and the structure of the disc, where oedema and inflammation lead to a vascular ingrowth and the influx of enzymes dissolving and breaking up the matrix of the disc.[20,25] Acute annular damage can be seen in severe trauma, concurrent with vertebral fractures. However, the annular damage normally seen in DDD is due to the degradation from age-dependent changes.[42]

AGE-DEPENDENT FACTORS IN DISC DEGENERATION

There is already evidence of degeneration in the lumbar disc in the second decade of life.[11,12,34] With age, the concentration and size of the proteoglycans within the disc and their ability to withstand dehydration diminishes. The disc is dependent

on cyclic physiological loading and it has been hypothesised that inactivity induces degenerative changes more rapidly.[28] With advancing age, the desiccation of the disc is altering the chemical and mechanical properties of the disc.

As one the largest structures without an organised vascular blood supply, the disc is dependent on osmosis to supply nutrients to the few intradiscal cells.[29,30] With impaired nutrient circulation, due to desiccation and degenerative endplate changes, the disc loses its original height. This causes a cascade of degenerative changes in adjacent structures, such as in the ligaments and the facet joints, both densely innervated structures and thereby able to induce back pain.[31] Degenerative changes are hypothesised to start in the NP with reduced water content, eventually causing strain on the AF and subjecting it to degeneration, leading to a subsequent change in the mechanical properties of the disc complex.[32-34]

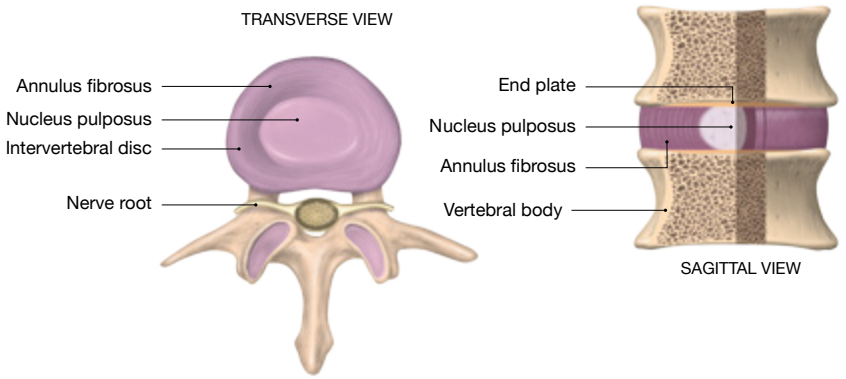


FIGURE 3: Anatomy of the human lumbar disc. The gelatinous nucleus pulposus (NP) is contained by the tough lamellar annulus fibrosus (AF). Degeneration of the NP negatively affects the biomechanical properties of the disc-joint complex. With AF failure, a disc herniation may develop, compressing nerve roots and causing sciatica.

EPIDEMIOLOGY OF LUMBAR DISC HERNIATION

Disc herniation is a common radiological finding, even in an unaffected population. Many DDD changes and LDHs found on routine MRI scans are found in an asymptomatic population. The prevalence is high, where in excess of 25% in a normal population may have signs of LDH or severe DDD on routine MR scans.[37] The prevalence increases with age and, at a mean age of 42 years for a first symptomatic LDH, this seems to be associated with an age-dependent discal desiccation.

The lifetime prevalence of discogenic pain is over 30%, with an incidence of 0.5-2 cases per 100 persons/year. More males than females are affected, with a 2:1 ratio. The most commonly affected LDH levels are the L4-L5 and L5-S1, which account for up to 95% of patients.[36,37,38]

AETIOLOGY OF LUMBAR DISC HERNIATION

There are a multitude of reasons why an LDH can suddenly develop in previously asymptomatic patients.[39,40] Ranging from traumatic ruptures caused by instant compression of the disc due to axial loading in high-energy trauma to age-dependent DDD, there is a high life-time risk of a disc bulge/herniation affecting the spinal cord or nerve roots within the spinal canal. Trauma, genetic factors, a “flat back spinal configuration”, youth sporting activity and heavy labour may all play a role in the development of LDH.[22-27,41]

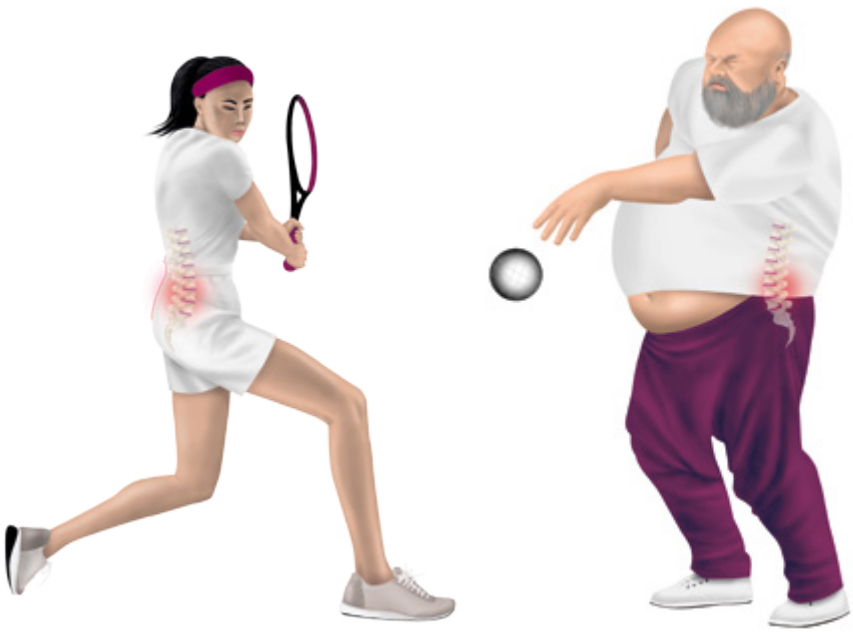


FIGURE 4: The development of an LDH may have vastly different aethiologies. Repetitive trauma in youth sports as well as senile degenerative changes may cause the rupture of Annulus fibrosus and the expulsion of Nucleus pulposus into the spinal canal causing radiating pain - sciatica.

The vast majority (~95%) of LDHs are found at the two lowermost levels of the lumbar spine – L4-L5 and L5-S1. The fact that most LDHs are found at these levels indicates that mechanical properties and forces play a decisive part in the development of LDH, since the highest loads will be imposed at the transition between the flexible lower part of the lumbar spine and the rigid pelvis.[42] In addition to this, recent research has shown that genetic factors might play a more important role than previous thought. Several twin studies have shown that genetic factors may be either a pre-requisite or an important mediator in addition to excessive spinal loads as the main culprit in many cases of LDH and DDD.[14-18] Genetic testing has been developed, and genetic risk factors that may opredispose patinets to early disc degenration or LDH has been identified.[43]

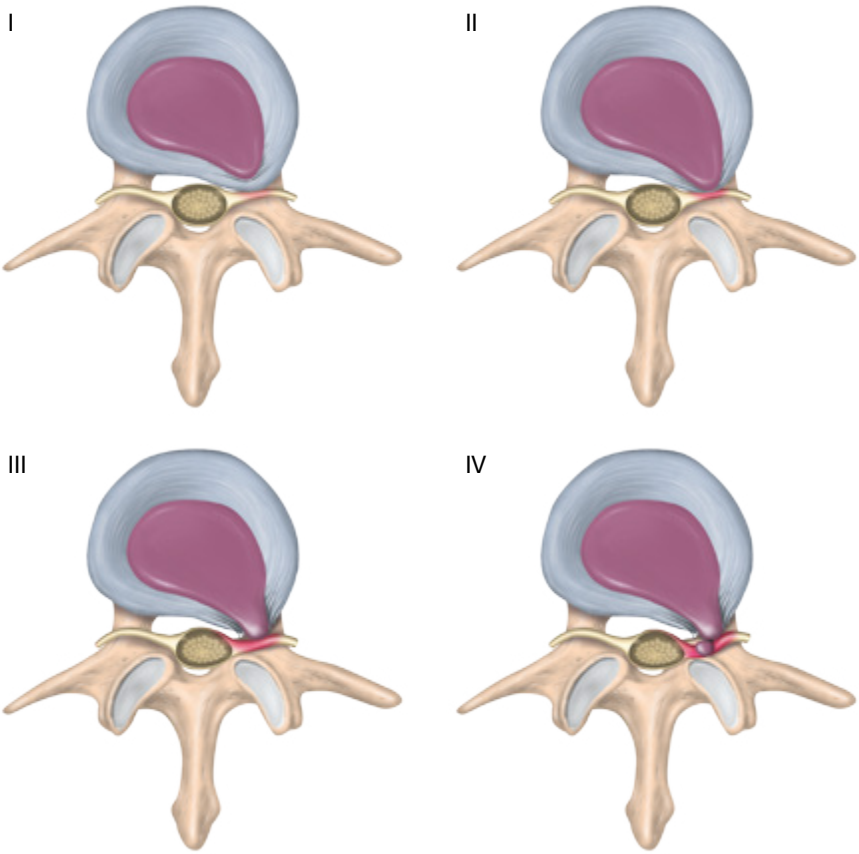


FIGURE 5: Stages of a lumbar disc herniation. Picture I depict an intraforaminal disc bulge impinging on the nerve root. Picture II is a protrusion of NP in to the AF, causing compression. Picture III is an extrusion, where the NP has pushed through a ruptured AF. Picture IV shows a sequester, a free-floating small mass of NP.

CLINICAL EXAMINATION AND FINDINGS OF A LUMBAR DISC HERNIATION

The classic clinical presentation for LDH patients is a radiating numbness and/or pain in the lower extremities.[44] This pain is called sciatica.[45]

The sciatic nerve is comprised of several nerve roots from the lumbar spine (L4-L5) and the sacrum (S1-S3). The nerves fuse in to the common sciatic nerve anterior of the piriformis muscle. The distribution of pain can take on different patterns depending on where the nerves are compressed, and which specific nerve root(s) that are affected.[45]

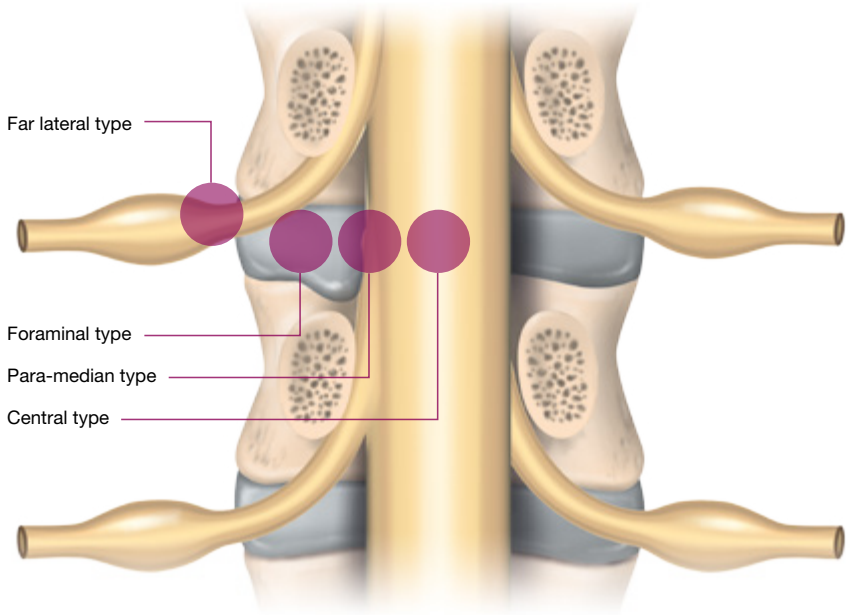


FIGURE 6: Sciatic symptoms are dependent on the exact anatomical location of the LDH. An LDH at the L4-L5 level may affect L4, L5 or S1, or a combination thereof. The anatomical location of the LDH will determine which surgical method is the most appropriate. A detailed clinical examination is a prerequisite, but should always be combined with an MRI for proper preoperative planning.

The sciatic nerve is the largest nerve in the body. In the fossa behind the knee joint, the nerve branches out in the tibial and peroneal nerves to supply motor control for muscles in the calf, controlling flexion and extension of the foot. Furthermore, the sciatic nerve provides sensation for the dorsal part of the thigh and the leg. Some patients, especially teenagers and young adults, may present with significant disc bulges but with intact AF, still causing dural sac and nerve root compression.[46,47] These patients can occasionally present with isolated low back pain and completely deny having any radiating leg symptoms, despite remarkable MRI findings usually consistent with sciatica. A symptom affecting the nerves to the bladder and genital area, perineum and anus is called the cauda equina syndrome. This is very often caused by a LDH compressing these nerves, and not necessarily causing a concomitant sciatica. The syndrome should be handled with haste, since irreversible changes or alterations to the natural functions or genital sensation induces a lifelong severe handicap, both physically and mentally.

Patients that present with a history of unilateral leg pain may have several medical conditions. Vascular insufficiency, peripheral nerve diseases and hip and knee joint osteoarthritis may all mimic sciatica and the differentiation is sometimes excruciatingly difficult. There are several clinical tests that potentially may differentiate between the beforementioned ailments. From a clinical spinal perspective, the most commonly performed test for sciatic pain are the straight leg raise (SLR) or Lasegue test.

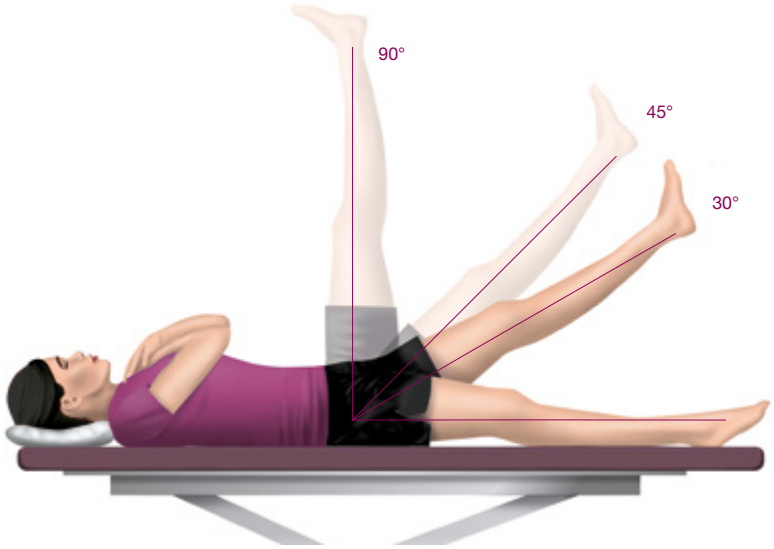


FIGURE 7: The Lasegue or SLR test. The examiner raises the straight painful leg of the patient, taking care to record at what elevation the patient expresses pain. It is most usually expressed in the buttocks and along the hamstrings and back of calf at an elevation between 30-70 degrees. A too high elevation might induce pain from hamstrings, tendons and joints and may obfuscate the clinical assessment.

The SLR test was first described by a student of Lasegue some 150 years ago.[48] It is a simple test, where the patient lies supine. The examiner lifts the heel of the affected limb, taking care to keep the knee fully extended and the patient's leg muscles relaxed. The test aims to stretch the sciatic nerve around the tuber ischiadicum and secondarily to pull the nerve root inferior and anterior within the intervertebral foramen. If the patient feels pain when stretching the nerve, the pain is usually situated around the buttock and dorsal part of the leg, consistent with symptoms from L4-S2, the nerve roots that make up the common sciatic nerve. The SLR/Lasegue test has a high sensitivity (0.8-0.97) but a low specificity (0.4).[48] No firm definition exists, but it is considered to have a positive correlation with LDH-induced sciatica if the test can reproduce patient symptoms between 30-70° elevation. The rare lateral or intraforaminal LDHs that are situated proximally to L4 do not produce the classical dorsal sciatic pain, but these patients rather describe radiating leg pain in the inguinal area and the ventral part of the leg. For these patients, femoral muscular shortness, and the femoral nerve (L2-L4) can be tested with the Ely test.[49]

INFLAMMATION AND CHARACTERISTICS OF PAIN IN LUMBAR DISC HERNIATION

In addition to the mechanical compression caused by the LDH on the nerve root(s), inflammatory mediators may play a crucial part in the perception of pain.[50-52] As evident from routine magnetic resonance imaging (MRI) scans, many LDHs may cause nerve root compression but without the patient experiencing sciatic pain.[37] Some studies claim that the combination of LDH compression and the associated inflammation from a discal injury is a prerequisite for pain perception. To further support this theory, studies have found an increased concentration of inflammatory proteins surrounding LDHs and increased levels of pain in animal models when inflammatory proteins are applied to compressed nerve roots.[51,53-56]

The sciatic pain caused by compression and inflammation is often characterised as "electric", "burning" or "stabbing", where the presentation is attributed to the different types of sensory nerve affected.[57]

SPINAL ANATOMICAL SHAPE AND LUMBAR DISC HERNIATION

Anatomical studies of the importance of “sagittal balance” or “sagittal alignment” in patients with degenerative disease or LDH have emerged.[26,27] The concept of sagittal balance has been developed by Roussouly et al.[58-60] The Roussouly classification divides the spinal subtypes and corresponding morphology into four different sagittal profiles, based on their respective degree of lumbar lordosis and thoracic kyphosis.

Concerning the development of LDH, the most interesting sagittal profile is the type-2 that is characterised by a flat thoracic kyphosis and a corresponding flat hypolordotic lumbar profile. It has been suggested that the lumbar lordosis determines the load distribution within the lumbar spine and that an overly ventral load distribution, such as in a low lumbar lordosis – “flat back”, increases the stress on the anterior part of the spine, in particular the disc complex, potentially leading to early disc degeneration and a subsequent development of a LDH.[26,27,61,62]

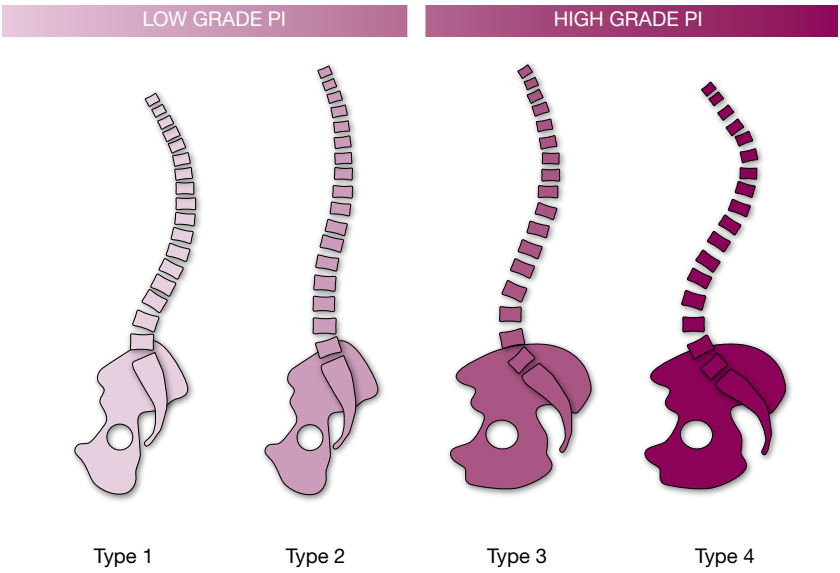


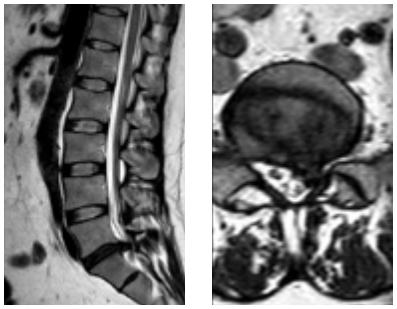
FIGURE 8: The Roussouly classification. Each spinal curvature positions the head above the pelvis but with different degrees of lumbar lordosis and pelvic rotation. The type 1 and type 2 sagittal alignment are the most prone to develop LDH, which is hypothesised based on a more ventral weight distribution through the spine.

RADIOLOGICAL EXAMINATIONS

In addition to a thorough clinical examination, a radiological assessment is mandatory to evaluate an LDH before surgical intervention.[63] Several different modalities are currently in use.

▸ Magnetic resonance imaging (MRI) is the primary radiological modality of choice, as it has the highest sensitivity to visualise soft tissues such as the NP and AF.[64] Disc bulges and herniated discs can be classified in three dimensions and a differentiation between sequesters and LDH can be made, which also can direct the treatment selection. Nerve impingement and nerve calibre changes can be assessed. Soft tissues such as hypertrophic facet joint capsules, ligamentum flavum (LF) and intraspinal fat can also be evaluated, which may determine the final surgical approach.[65] Oedema and blood are easily visualised and, by adding Gadolinium contrast, the extent and a differential diagnosis of inflammatory changes, infections, abscesses and tumours can be evaluated.[64]

▸ Computed tomography (CT) is excellent when it comes to studying the vertebrae and the bony structures surrounding the spinal canal.[66,67] Structures comprised of bone are better visualised with CT than MRI and calcified disc herniations can also be assessed. However, in order to examine soft tissues, this modality is inferior to MRI and some assessments must be made by indirect observation. Some patients that have non-MRI-compatible implants such as pacemakers or implantable cardioverter defibrillators (ICD) need a CT myelography, with an intraspinal contrast injection, to provide the best possible imaging.



▸ Standard X-rays are very economical and quick to use. However, from a LDH diagnostical point of view, they have in western society been phased out from modern practice, due to their limited value. A standard X-ray may still be used to determine spinal instability and to provide an anatomical assessment of spinal configuration and curvatures.[67]

FIGURE 9A+B: A large lumbar disc herniation at the L5-S1 level in an adult man. This patient had a disc herniation that was large enough to cause considerable discomfort from the impinged S1 nerve root. The lack of high intensity signal within the disc in this T2-weighted image, signifies the dessication and degeneration of the nucleus pulposus. On the transverse picture, there is evidence of AF-rupture and concomittant extrusion and formation of a disc sequester.

TREATMENT OF LUMBAR DISC HERNIATION

Most cases of sciatica have a favourable outcome using non-surgical treatment. In a recent review article, the authors found that, in the conservative treatment arm in several RCTs, half the participating patients reported sciatic improvement within two weeks and another 25% after a month.[68] A previous Norwegian RCT reported that 60% of patients recover within three months and a further 10% after 12 months.[69] However, in contrast, another study in a primary care setting found that just over 50% of patients were completely pain free at a one-year interval.[70]

NON-SURGICAL TREATMENT

The results of conservative treatment are comparable to those after surgery, at least in long-term outcomes at the one- to two-year interval, but in some cases surgery seems to produce a faster recovery and thus a shorter duration of sciatica.[71]

Non-surgical treatment does not necessarily mean that it is not interventional in some way. Including but not limited to bed rest, back support braces, physiotherapy, chiropractic manipulations, traditional natural remedies and modern pain medication, conservative treatment takes many forms, reflecting local practises and customs.[72] Conservative, or non-surgical treatments work by providing pain relief for the patient, while the LDH resorbs and the concomitant sciatica fade away. No non-surgical treatment has been shown to significantly change the course of healing, or of being able to speed up the recovery process.[72-74] One high-quality review compared acupuncture, chiropractic treatment, bed rest, physiotherapy, traction and injections and "no treatment" and was unable to find any strong evidence of long-term benefit or effect.[75] Some "conservative" treatments, such as chiropractic treatment or osteopathic manipulations, have been known to cause severe side-effects, including fractures and paralysis.[76]

NON-SURGICAL PERCUTANEOUS PROCEDURES FOR LUMBAR DISC HERNIATION

Injections are included amongst non-surgical management methods. Several different types of injections exist, some targeting the area around a compressed nerve root and others within a bulging disc. A simple lumbar nerve root block providing local anaesthetic and cortisone at the site of the LDH and nerve compression may reduce the inflammation and pain while the LDH is being spontaneously resorbed.[77] Using a local anaesthetic, a percutaneous approach

is utilised. Some intradiscal procedures are hypothesized to decrease the size of disc bulge or LDH by deliver heat distributed by either laser or radiofrequency to the disc tissue. This is used to coagulate the inner parts of the disc, creating space and reducing the disc bulge by indirect methods. This is sometimes marketed as an alternative to spinal surgery, often performed by interventionists or pain medicine doctors, and with scant scientific evidence. Another variant of injection therapy is chemonculeolysis. This is an intradiscal injection as opposed to heat lesions, and was heavily marketed.[78,79] The use of chymopapain, derived from the papaya plant, and other similar substances has been generally discontinued, because of the risk of side-effects and the lack of scientific evidence of effectiveness.[78,79] The aforementioned procedures are hypothesised to work by indirect decompression, similar to heat lesions, and the shrinkage and solidification of the lumbar disc and LDH.

SURGICAL TREATMENT OF A LUMBAR DISC HERNIATION

Spinal surgery has historically been a crude surgical discipline with significant morbidity and mortality.[80,81] During the last 90 years, this surgical discipline, with an ancestry in both orthopaedics and neurosurgery, has seen a rapid development and evolution towards minimally invasive techniques. With modern techniques a reduction in surgical complications and iatrogenic tissue damage has led to a subsequent shorter length-of-stay and a lower patient morbidity and mortality.[82-85]

HISTORICAL BACKGROUND OF LUMBAR DISC HERNIATION SURGERY

One of the most common procedures in spinal surgery – LDH surgery – clearly illustrates this last 2,400 years of technological advances.[84]

▸ Hippocrates (c460-c370BC) – the founding father of modern western medicine – described several spine-related diseases, performed seminal anatomical studies and also prescribed the first treatment for dislocated vertebrae using traction-like devices.[85,86] Mainly working with acquired spinal deformities, he laid the foundations of early scoliosis treatment. The concept of referred pain (sciatica) was described by Hippocrates.

▸ In the ancient Roman empire, anatomical work had to be carried out on animals or gladiators that perished in the arenas, and as a consequence, a thorough understanding of human spinal anatomy did not exist. Galen of Pergamum (129-c216 AD) carried out dissections on monkey corpses and established the basis for spinal anatomy with segmental nerve distribution.[87] Despite the scarcity

of available anatomical specimens, the spinal column with its different sections (cervical, thoracic and lumbar) and curvatures was described. Galen was the first to describe the clinical findings of damage to the intervertebral disc, facet joints and nerve injuries on different anatomical levels and the symptoms associated with them. Galen was also the first to use the words “scoliosis, lordosis and kyphosis”.

▸ Later work by Assyrian doctors and Arabic preservers of earlier Greek research led to the use of cauterisation (coagulation of tissue using fire or heated materials) for the relief of sciatic pain, which is a historic precursor of a crude practical nature to the gateway control theory of pain.[88,89]

▸ During the 18th century, Domenico Cotugno (1735-1822) correctly described different types of sciatic pain distribution, based on an awareness of the segmental structure of the spine and nervous system in 1764, but he failed to associate this with an LDH.[85]

▸ It was not until the mid-19th century that Rudolf Virchow (1821-1902) first described a ruptured disc, but he erroneously called it “Virchow’s tumour”.[85] In the late 19th century, Horsley described the first version of a sequesterectomy but classified the protrusion as an enchondroma.[90] LDH considered being a benign tumour or osteochondritis dissecans was the prevailing diagnosis in the early 20th century. Later, an understanding of the difference between degenerative disc disease (DDD), LDH and sciatica began to develop

▸ With the advancement of anaesthesia and the development of neurosurgical procedures, LDH surgery was further refined by surgeons Krause, Cushing and Dandy, who independently each described different versions of LDH surgery.[85,91,92]

▸ The early experimental LDH surgery which was performed in the 1920s often involved an extensive open lumbar surgical procedure with muscle detachment, complete laminectomy and finally a dura-splitting approach to reach the disc. These patients had to endure a prolonged invasive surgical procedure, at the risk of considerable morbidity. The surgeries were regarded as an occasional experimental procedure and were not a major part of a neurosurgical practice.[93]

▸ In the 1930s and 1940s, the procedure was further developed and described by Mixter and Barr.[94,95] Their detailed analysis of the underlying pathophysiology and thorough description of the surgical technique led to a widespread introduction and acceptance in the field of spinal surgery. The technique was further developed by Love to become the current mini-open surgery.[96]

MODERN SURGICAL ADVANCES

The field of lumbar disc herniation surgery has seen rapid technological advances. With the introduction of practical surgical loupes – providing magnification, the extent of the surgical exposure could be minimised. Further advances in optics eventually led to a rapid surgical microscope development in the 1960s and 1970s. This enabled microscopic surgical spinal procedures where the anatomical extent could now be measured in millimetres instead of using a centimetre scale.[97]

A symptomatic LDH can be treated using several different modalities. Methods and treatments encompass the entire range from very strict prolonged bed rest to an early aggressive surgical approach. The decision on how to treat an LDH is based on local traditions and experience, access to surgical care and radiological imaging and economic healthcare reimbursement practices. There is a tremendous difference in treatment strategies and modalities and the diversity makes a comparison between different cultures and countries cumbersome. The incidence of LDH surgeries varies significantly between countries, even within the western hemisphere, and this may make American (52/100.000) and Swedish (29/100.000) surgical incidences, indications and treatment practices difficult to compare.[98,99]

Open surgery, sometimes called "mini-open surgery" performed with or without loupes is still being performed in significant numbers.[100,101] Both the standard LDH surgical techniques have similar incision lengths and may both be regarded as open surgeries. The microscopic approach has the potential benefit of less tissue resection and better visualisation and magnification than that provided by using surgical loupes. However, a Swedish RCT has investigated these two treatments and found that there are no significant differences in any of the measured outcomes.[101] In a Swedish setting, the microscopic and mini-open approach are therefore considered equal and approximately 50% of surgeries utilise each method today.[151]

Micro-endoscopic procedures are performed using an endoscope within a tubular microscopic retractor, in order to alleviate the restrictions with directional light and vision of the microscope.[102,103] This technique has not gained widespread acceptance in Sweden.

The trend towards minimising the extent of surgical dissection for LDH procedures has been constant since the early 1960s. Scar reduction, reduced tissue damage and faster recovery have been touted as major advantages of new techniques.[104,105] The visible scar length is reduced, and potentially also the risk of internal nerve-scar adhesions.[106] Clinically significant PROM improvements appear elusive, despite several randomised, controlled trials (RCT) to compare different surgical methods.[107-110]

THE MICROSCOPIC DISCECTOMY

The gold standard of surgical treatment for LDH is a microscopic approach.[107] Minimal and microscopic neurosurgical procedures and associated equipment were pioneered and developed by Yasargil, who is universally regarded as the founding father of microscopic neurosurgery.[111] The surgical microscopes provided previously unsurpassed magnification and illumination, but they required significant investments and alterations to surgical instruments. Using a standard mini-open approach, but with the potential for an extremely narrow and deep surgical operating field, the traditional instruments blocked the view and the light from the microscope. Specialised retractors, scissors and needle holders were developed, with the handling part of the shaft offset from the surgical end, to enable full visualisation of the LDH.[112] The introduction in the USA was championed by RW Williams and the microscopic approach rapidly became the gold standard, often replacing the open approach.[104,105] The procedure did not necessarily lead to better measurable outcomes, but the scar length could be kept to a minimum to the satisfaction of discerning patients.

In an attempt to minimise the length of the surgical incision and the extent of tissue trauma, tubular retractors were developed, ranging in size to less than 10 mm. These tubes are inserted using a small dilator and, as a result, this does not involve cutting or detaching muscle fibres, which is beneficial in any surgical procedure.[107,108,113] However, one disadvantage of the sometimes long and slender tubular retractors is impaired visualisation and illumination, despite the surgical microscope. Furthermore, since no actual dissection takes place, there is a risk of inducing muscular necrosis due to the compressive pressure on the surrounding tissues caused by the tubes. Some surgeons started experimenting with modified surgical endoscopes or orthopaedic arthroscopes within the tubular retractors. This created a high degree of magnification with optimal lighting, but the surgical echnique was difficult to master and had a cumbersome learning curve and was fraught with complications related to approach issues and equipment failures.[114]

ENDOSCOPIC SURGERY FOR LUMBAR DISC HERNIATION

In order to further minimise muscular, soft tissue, scar length, facet joint injuries and to minimise the risk of iatrogenic complications, alternative treatments and therapies to microscopic LDH surgery have been developed.

A Full-Endoscopic Lumbar Discectomy (FELD) surgery should be regarded as a true percutaneous procedure, technically having been developed from other percutaneous procedures rather than being a refinement of open surgery. The FELD procedure completely preserves the posterior ligaments and other structures of the spine.[110]

Endoscopic equipment dedicated to intraspinal procedures became available in the late 1990s.[115] The resemblance to arthroscopes was by design, and standard arthroscopes were simply put into the spine instead of in to their usual working spaces such as knee and shoulder joints.

Initially, all procedures were performed in a "dry" environment, since it was thought that water under pressure could damage the surrounding tissues and nerves. Eventually, the advantages from the arthroscopic world, using constant irrigation, also became obvious in a spinal setting. By adding continuous low-pressure water irrigation, a potential space can be created by removing and coagulating tissues using the endoscopic instruments. The water pressure is able to keep the working space open and resists the inward pressure from surrounding tissues, it also flushes away bleeding and detritus, providing a clearer view. The use of angled lenses gave the FELD the possibility to "look around the corner" such as in resection of facet joints or the removal of intraforaminal LDH. The slender and fragile, specialized long instruments necessitated by the spinal approach were prone to mechanical failure and it took several years and metallurgical advances before reliable instruments could be used. Developmental work by Ruetten and Yeung in the 2000s formed the basis of this new and emerging minimally invasive field in spinal surgery.[110,116-121]

Within the spinal endoscopes, there are three dedicated channels that provide light, optics and a combined irrigation and working channel.

The different surgical instruments that can be used through the working channel of the endoscope offer a variety of opportunities. Micro instruments include scissors, rongeurs and depressors, all either angled or straight. The diathermy device (radiofrequency bipolar, RF) is made of a flexible composite material and is constructed so the surgeon can adjust both reach and 360° direction over the entire visual field during the procedure. At the tip, a radiofrequency electrode efficiently coagulates small vessels and is also able to vaporise fat, cartilage, and other soft tissues.

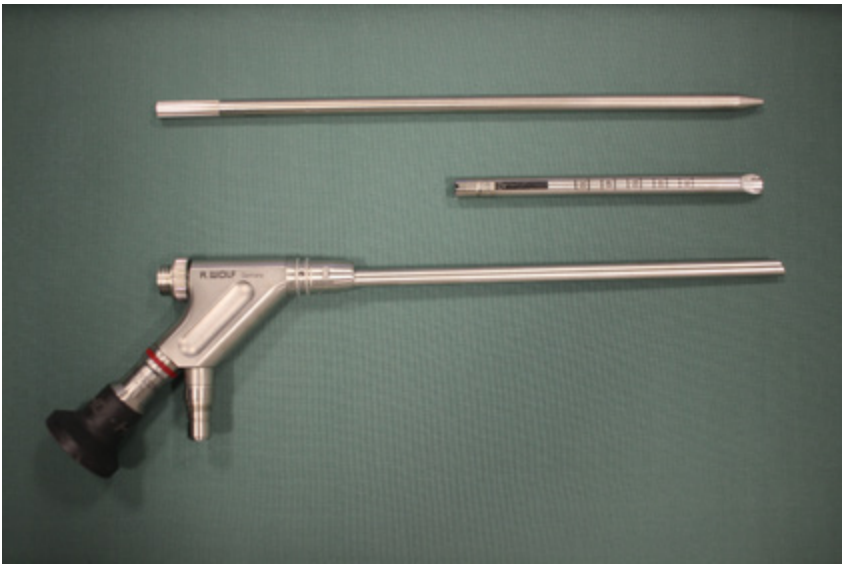


FIGURE 10: Trocar, bevelled working sleeve and the spinal endoscope. The diameter is slightly smaller than that of a regular ballpoint pen. At the end of the endoscope, there are connections for a light source, camera and irrigation. The instruments are inserted at the time of surgery in a top-to-bottom order.

FIGURE 11: The endoscope has three channels, providing light, optics and a working/irrigation channel. Protruding through the working channel is a straight micro-scissor.

FULL-ENDOSCOPIC LUMBAR DISCECTOMY

The FELD procedure allows the surgeon to perform a complete lumbar sequesterectomy/discectomy with a single minimal 6 mm skin incision. The procedure has been described in several original articles.[118,120] The two most common approaches in the lumbar spine are the interlaminar (IL) and transforaminal (TF) approach. The total procedure time is estimated to be between 15-60 minutes depending on patient habitus, anatomical factors and the type of LDH. Bleeding is usually non-measurable and immediate mobilisation of the patient is advised. No drains are necessary. Most patients can be discharged the same day. Since immediate mobilisation is possible, thrombosis prophylaxis is usually not needed unless patient-related risk factors exist.

FIGURE 12: Some of the most common instruments used in FELD surgery. From the top; heavy angled scissors, light straight scissors, micro-rongeur. Pictured at the bottom is a No 3 Kerrison for size comparison.

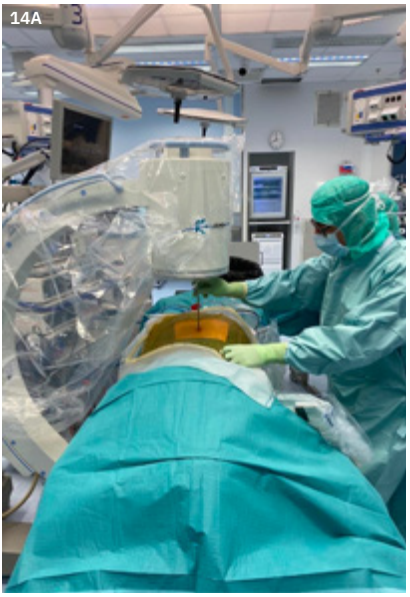
THE INTERLAMINAR APPROACH

This procedure is similar in the approach to the original surgical open discectomy method. In Sweden, as is the case in most European countries, general anaesthesia with endotracheal intubation is utilised, whereas in several Asian countries, local anestehic is the preferred aneastethic.

The patient is positioned prone on a radiolucent table equipped with a Wilson frame. Using C-arm fluoroscopy, the incision entry point is marked on the skin overlaying the interlaminar window on the affected side using an anterior-posterior view.

FIGURE 13: The FELD procedure requires high-quality fluoroscopy and a surgeon familiar with triangulation techniques and an intrinsic 3-dimensional anatomic knowledge of the lumbar facet joints. A detailed pre-surgical radiographic assessment is a prerequisite for a successful surgical outcome. “Failing to plan is planning to fail.”

A small incision is made and a blunt dissector/dilator is inserted using fluoroscopy, to the level of the posterior medial border of the zygapophyseal joints. A bevelled operating sleeve tube is subsequently inserted over the dilator, which is removed to allow the introduction of the endoscope. Constant flow low-pressure-controlled irrigation is applied. A working space is created using the radiofrequency (RF) probe and micro-rongeurs. After resecting and vaporizing any obscuring spinal fat tissue using the RF probe, a small cut in the ligamentum flavum (LF) is performed using the micro-scissors. By inserting and advancing the bevelled operating sheath through the LF, the dura is exposed. The nerve root, axilla and disc herniation are dissected using a combination of the RF probe and dissector. The bevelled working sleeve is then rotated to protect the dura and neural structures. A resection of cartilage or bone in the facet joint or laminae of the adjacent vertebrae is usually not necessary. The removal of the disc herniation is performed using microrongeurs. After the appropriate sequesterectomy/discectomy is performed, the previously compressed nerve root can be observed free floating in its original normal position, without pressure from a bulging disc.



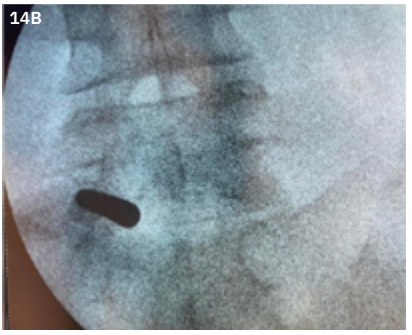


FIGURE 14A+B: Insertion of a trocar for the interlaminar procedure. The entire procedure requires repeated fluoroscopic guidance. The antero-posterior fluoroscopic image shows the dilator inserted to the medial border of the facet joint, between the laminae of L5 and S1. The FELD procedure requires access to a significant amount of equipment, including an endoscopic camera, light source, pressure-controlled irrigation and fluoroscopy. An overly small operating theatre can become fairly crowded.

The endoscope is retracted and the water is turned off. Any small remaining bleeding capillaries are identified and coagulated with the RF probe. The IL approach is usually reserved for the L4-L5-S1 disc levels, as a large spinal canal diameter and a sufficient interlaminar window is a prerequisite for easy access.

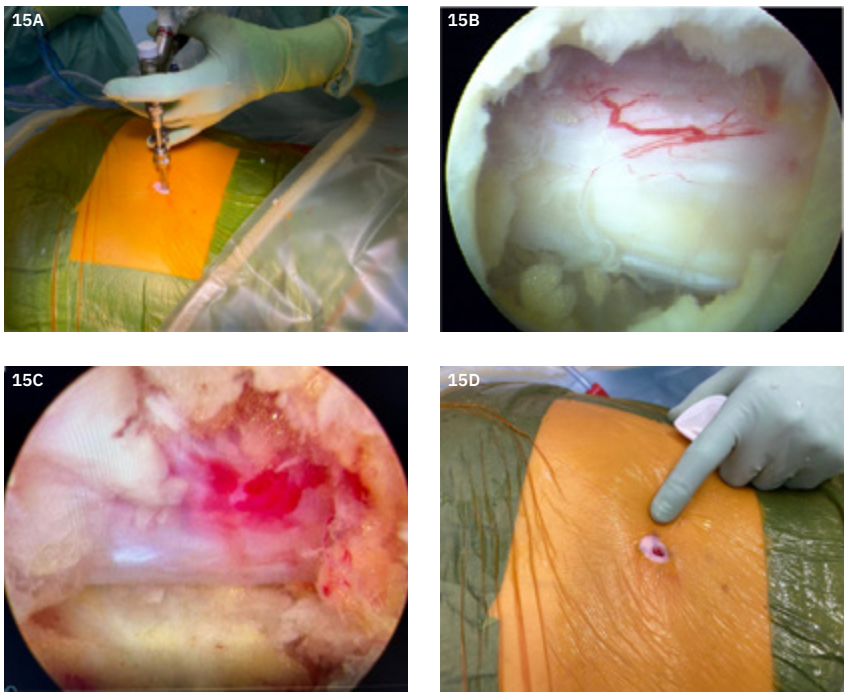
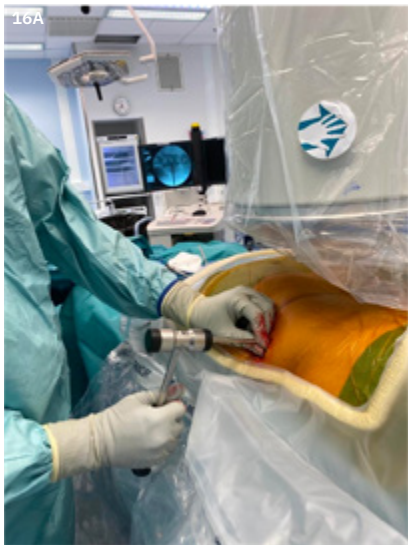


FIGURE 15A-D: A) The endoscope is held and stabilized with the left hand, whilst the right hand controls the instruments. B) When the endoscope is within the spinal canal, the magnification is clearly illustrated by the small capillaries in the epineurium. The white fringe surrounding the visual field is a small hole in the flavum made by the micro-punches. C) The root is observed, framed by yellow fat, and some small bleeding capillaries. The disc herniation is pressing the root in posterior direction towards the endoscope. D) When the endoscope is retracted, skin closure can be performed with a single suture.

THE TRANSFORAMINAL PROCEDURE

This procedure is performed technologically and endoscopically similar to the IL procedure, but with the patient prepped for a lateral approach on the operating table.[122] This requires ultra-long slender instruments, since the endoscopes must measure more than 20 cm in length in order to reach the spinal canal. The entry point is extremely dorsal/lateral, slightly above the spina iliaca

posterior superior. A small diameter Kirchner wire is inserted and advanced with fluoroscopy to the inferior part of the foraminal orifice, where a foraminal disc herniation is situated. A dilator is inserted over the K wire and is advanced until the tip is lodged between pedicle and facet joint in the inferior part of the neuroforamina. Sometimes a slight tap with a hammer is needed to correctly position the dilator in the correct place inferior to the nerve root. The exiting nerve root is situated just above the disc and is often compressed by the LDH towards the pedicle of the superior vertebra. After the dilator is in the correct position, the working sleeve is advanced to the level of the lateral border and ventrally to the facet joint. This anatomic area is bordered by the exiting nerve root, the lumbar disc and the superior endplate and pedicle of the inferior vertebra. The anatomy, approach and numerous surgical hazards requires a detailed anatomic awareness. This was first described by Kambin, and the surgical space is subsequently named Kambin's triangle.[123] A dissection of inflammatory tissues allows a safe identification of the nerve root and LDH. The LDH is removed using micro-scissors and micro-rongeurs. Upon removal of the endoscopic instrument, potential bleeding vessels should be coagulated, if needed. Skin closure is performed using a single suture or surgical glue.



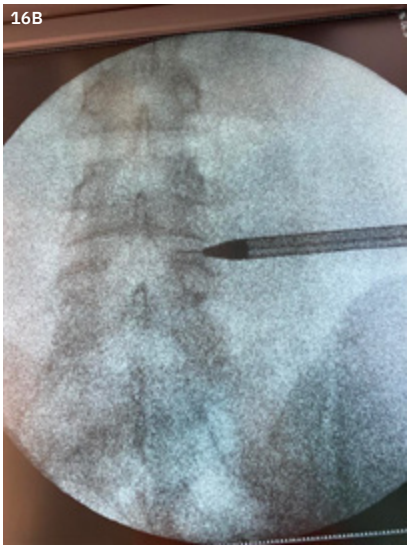


FIGURE 16A+B: A) A transforaminal approach is perfectly suited to address a foraminal or lateral disc herniation. A K wire is placed in the safe zone of Kambin's triangle and a trocar is advanced to the lower part of the intervertebral foramina to the lateral border of the facet joint, resting on the disc. The procedure is performed under fluoroscopic guidance. B) The fluoroscopic image shows a K-wire situated within the lateral part of the disc, and a dilator in the lower part of the intervertebral foramen.

STATE OF CURRENT EVIDENCE

THE INTRODUCTION OF FELD IN SWEDEN

When introducing a surgical method, care must be taken to do this in an ethically tenable manner. The initial FELD procedures were developed more than 20 years ago and it has undergone significant refinements since its clinical introduction. This procedure is already in constant everyday clinical use, and in many surgical centres it is the only available technique for LDH. FELD can thus no longer be regarded as experimental. However, when introducing a surgical technique at a new centre, it is important to be aware of the learning curve and the higher rate of complications that initially often accompanies the introduction of ultra-minimally invasive approaches.[124-126] The learning curve and associated complications are a well-described phenomena and special care must be taken in terms of surgical training and patient selection. The first introduction in Sweden of the FELD procedure was at the Sahlgrenska University Hospital, Gothenburg, in 2013, by professor Adad Baranto.. After attending several international courses and acquiring the necessary instruments, FELD was offered as an alternative to standard surgery for LDH to prospective patients. Following the introductory phase, several seminars and webinars have been offered during the last years to interested collegues throughout Sweden.

FELD AS AN ALTERNATIVE TO STANDARD SURGERY FOR LUMBAR DISC HERNIATION

Several articles and RCTs have investigated the clinical application of FELD.[107,127-129] FELD surgery has been found to be as effective and safe as standard surgery for LDH. In some studies, FELD was found to be superior for certain selected outcomes, such as length of hospital stay and return to work. Studies investigating outcomes such as the ODI and the EQ-5D have yet to identify medically relevant differences.[130] Several of the defining initial studies that introduced FELD and endoscopic spinal surgery for different diagnoses and approaches in a worldwide clinical setting are performed by the inventors of the instruments and are prone to bias.[117,119,120,131-134] A number of meta-analysis studies have been performed, but, as the included studies have been performed in several different centres and countries, with very different surgical and postoperative traditions, a comparison between the included studies is prone to interpretational bias and skewed reporting.[108,109,135] Further studies are still needed to confirm whether FELD is comparable to standard surgery in a national relevant clinical setting.

TIMING OF LUMBAR DISC HERNIATION SURGERY

Historically, until the 1940s, only conservative treatment was available for the majority of patients. Physiotherapy, over-the-counter medications, or the avoidance of physical exertion can provide short-term pain relief and most people become significantly less symptomatic within six to 12 weeks.[136] Studies by Weber revealed that surgical and conservative treatment might yield similar long-term results regarding PROMs.[137] Peul et al. and Weinstein et al. also reported comparable long-term outcomes between surgical and conservative treatment.[138,139] In some cases, a statistical difference was observed between the different cohorts, but the medical significance of these findings can be debated. These seminal RCT studies are either hampered by outdated practices or methodological problems pertaining to statistical randomisation, cross-over and intention-to-treat discrepancies. However, a shorter pain duration and thereby a quicker return to the preoperative level of quality of life was observed in all studies for patients undergoing surgical treatment. This indicates a benefit from surgery in achieving a faster recovery, albeit with the same end result at the one- and two-year follow-up as conservative treatment.

Cochrane collaborations, meta-analyses and the aforementioned studies have led to a national Swedish tradition of reserving surgery for refractory cases that have not responded to 6-12 weeks of conservative therapy.[139,140] The appropriate timing of LDH surgery has been debated for many years, heavily influenced by local traditions, economic reimbursements and general healthcare practices.[127,141,142] As a result, an LDH surgery timing regimen cannot easily be compared or made applicable between different countries or regions across the globe.

LUMBAR DISC HERNIATION SURGERY IN ANXIOUS AND DEPRESSED PATIENTS

A strong connection between body and mind has been assumed for millennia. It was not until René Descartes (1596-1650) that a division between self and body was philosophized.[143] In historic times the body-mind interaction had been described using different explanatory models, including imbalances of bodily fluids or by divine intervention.[87] In the modern westernised medical world, the focus is now firmly set on biochemical imbalances and the dopamine-serotonin-noradrenaline pathways in the brain.[144] Treatment is not necessarily always medication, and counselling and therapy still play a vital role in treating anxiety and depression.

Previous studies have found that anxious or depressed patients run an increased risk of poorer results following surgery, with a reported higher

complication rate and less satisfaction with the outcome.[145-147] There is also a risk that a failed surgical procedure could enhance an ongoing depression. However, the opposite is also true; surgery might be able to alleviate some of the pre-operative psychological complaints, since pain and discomfort from an LDH might have been the triggering factor of anxiety or depression.[148] Several methodologies and systems have been developed to detect mentally burdened patients at risk of poorer outcomes. Wadell developed a system using certain non-relevant clinical examinations and tests, that potentially could trigger non-physiological responses from some patients with pain.[149,150] Other systems are based on data from registers.[151] Unemployment, low income, smoking, workers' compensation claims and excessive opioid consumption are some factors regarded as "flags" and they should be taken into careful consideration when scheduling a surgical procedure.[152-155] If all these guidelines were followed blindly, a substantial number of anxious or depressed patients could face the prospect of being excluded from surgical procedures. The effect of anxiety and depression on PROMs after an LDH procedure requires further studies.

2

AIMS

JOEL BECK

GENERAL AIMS

The overall aim of this dissertation was to gather evidence and increase knowledge about the introduction of the FELD procedure in Sweden. Moreover, to study the influence of timing, anxiety and depression on patient-reported outcomes one year after LDH surgery, assessed in a very large national cohort.

SPECIFIC AIMS

❶ Firstly, our aim was to describe the introduction of FELD in Sweden (Study I).

❷ Secondly, we aimed to compare the outcomes between FELD and standard LDH surgery regarding the results and outcomes at a one-year follow-up, with special emphasis on residual leg pain and personal satisfaction with the surgical outcome (Study II).

❸ Thirdly, we aimed to study the impact of preoperative leg pain duration on PROMs after LDH surgery in a very large national cohort (Study III).

❹ Lastly, we aimed to describe the outcomes after LDH surgery in a group of patients who indicated preoperatively that they were severely affected by depression or anxiety (Study IV).

PATIENTS AND METHODS

JOEL BECK

3

DATA SOURCES

The data in all the studies included in this dissertation are based wholly or in part on data from the Swedish spine register (Swespine).[100,151] For Studies I and II, the Swespine data are supplemented by data from local medical charts from Sahlgrenska University Hospital, Gothenburg, Sweden. A large national cohort of LDH patients from Swespine in 2013-2017 were included in Studies III and IV. The flowchart for inclusion in the studies is shown in Figure 17.

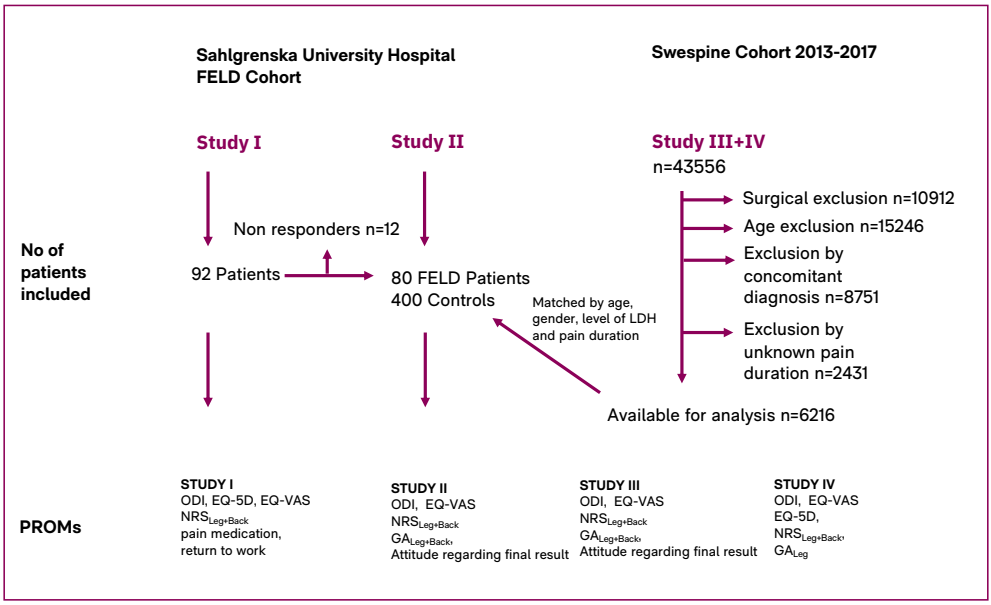


FIGURE 17: Flowchart of the inclusion of patients in Study I-IV and the PROMs analysed.

FULL-ENDOSCOPIC LUMBAR DISCECTOMY PATIENTS

The FELD patients in Studies I and II were recruited from Sahlgrenska University Hospital, Gothenburg, Sweden, between November 2013 and December 2017. The data include the very first patient undergoing surgery with this technique in Sweden and several of the early learning phase surgeries. A total of four surgeons contributed to the surgeries included in the studies. The initial patients selected for the FELD procedure were regarded as "optimal" patients in terms of anatomy, age and LDH presentation in order to minimize the risk of learning phase complications, whereas, towards the end of the study period, a more general attitude to LDH patients was accepted.

SWESPINE

The Swespine register was started in 1993 and it has grown to encompass the majority of all hospitals and clinics performing spinal surgery in Sweden.[100] The register is managed by the Swedish society of spinal surgeons, with additional management by the County of Jonkoping.[151] The catchment rate of the register is close to 90% and patient loss at the one-year follow-up is approximately 25%, depending on the specific diagnosis.

Swespine has made a transition to internet-based questionnaires during the last years, starting in 2002. The register records baseline data (before surgery) and at one, two, five and 10 years. All the questionnaires are answered by the patient. The patient-specific data contain several PROMs, including the ODI, EQ5D, SF-36 (removed as of 2016) and several quality-control retrospective Likert-style questions. The surgeon enters surgical data, such as diagnosis and the level of LDH, laterality, grading of disc degeneration and surgical complications.

STUDY DESIGN

STUDY I: THE INTRODUCTION OF FELD IN SWEDEN

Study I is a register-based, observational cohort study of Swespine and local data. The patients entered data prospectively and at the one-year follow-up. The patients that had a FELD procedure carried out in 2013-2017 with preoperative data were included. The patients had a routine clinical follow-up at three months, but data from this visit were not included in the study or this thesis. The study contains a total of 92 FELD patients. With the inherent limitations of this study design, insights can still be gained from observational studies of rare diseases or new procedures.[156]

STUDY II: FELD COMPARED WITH STANDARD LUMBAR DISC HERNIATION SURGERY

The FELD patients included in Study I were matched to controls from the Swespine register that underwent standard LDH surgery during the same years as the FELD patients (2013-2017). Age, gender, level of disc herniation and preoperative pain duration were used as matching parameters. Patients missing preoperative or long-term follow-up data were excluded. A total of 80 FELD patients were included and matched by exact age, gender, preoperative pain duration and level of disc herniation. The FELD patients were matched with a 1:5 ratio to 400 controls. The matched controls from Swespine all had prospectively collected data and a one-year follow-up.

STUDIES III AND IV: DURATION OF SCIATICA, ANXIETY AND DEPRESSION AS PREDICTORS OF PROMs AFTER LDH SURGERY

Studies III and IV are based on the Swespine register from 2013-2017. The selection process for these LDH patients is illustrated in Figure 17. The inclusion criteria was a single-level LDH that required a simple discectomy without complete laminectomy nor a concomitant fusion procedure of any kind. Teenagers aged below 18 and patients above the age of 65 were also excluded. This selection process aimed to create a cohort that contained only standard LDH surgeries in a population previously not surgically treated without significant degenerative changes. A total of 6,216 patients were analysed.

Study III hypothesised that a prolonged duration of preoperative leg pain would be negatively associated with reported PROMs. The cohort was divided into four groups with < 3, 3-12, 12-24 and > 24 months of leg pain respectively and inter-group differences in PROMs were analysed.

The participants in Study IV, based on the same cohort as in Study III, were studied and divided according to their preoperative self-reported mental health status based on the psychometric domain of the EQ5D.

PATIENT-REPORTED OUTCOME MEASUREMENTS (PROMs)

In Studies I-IV at the one-year follow up, the patients responded to a questionnaire sent out by the Swespine register. The questionnaire is comprehensive and only a small subset of PROMs were utilised in this thesis.

EUROQOL-5 DIMENSIONS 3-LEVELS (EQ-5D-3L)

The EQ-5D was used to assess quality of life in Studies I, III and IV. This small questionnaire was created to make it possible to classify and evaluate different states of health.[157] The five dimensions are mobility, self-care, daily activities, pain/discomfort and depression/anxiety where each dimension is rated on three levels. Each dimension gives a score between 1 (no problems) and 3 (severe problems) and these are in turn added to a formula. There are therefore 3^5 combinations of different health states. The calculation then returns a sum score between -0.59 and 1. The sum score of 1 denotes a perfect health state, whereas 0 indicates death. The calculation is based on interviews with a Swedish population, where individuals are asked to evaluate different diseases/health states according to a time trade-off (TTO) scenario – i.e. "Would you be willing to trade off 10 days at the end of your life if you did not develop severe sciatica at the age of 30?").[158] Negative values indicate a state of sickness and quality of life regarded as worse than death.

THE PSYCHOMETRIC DIMENSION OF THE EQ-5D

The psychometric dimension from EQ-5D was used in study III to examine the impact of self-reported anxiety and depression on LDH surgical outcomes.

This question is regarding anxiety/depression, where patients are asked to grade their symptoms according to the following three levels:

1. "I am not…
2. "I am moderately…
3. "I am extremely…

… anxious or depressed."

THE EQ-VISUAL ANALOGUE SCALE

This EQ-5D instrument can also be used to assess quality of life on a visual analogue scale.[159] A graphically depicted vertical ruler is numbered 0-100 and the patient puts a mark where he considers his current health status is, where 100 signifies the best imaginable health state and 0 the worst imaginable health state.

THE OSWESTRY DISABILITY INDEX (ODI)

The ODI is a back disability-specific index that measures the impact of back problems/pain on common everyday tasks and activities.[160] The ODI index is a composite score made up of 10 questions including pain intensity, lifting, sleeping, sitting, walking, standing, personal care, travel, sex and social life. The resulting sum score ranges from 0-100, where 0-20 indicates perfect health and 80-100 denotes a bed-ridden or exaggerating patient.

THE VISUAL ANALOGUE SCALE (VAS) AND THE NUMERICAL RATING SCALE (NRS)

The VAS and NRS-scales are used to assess back and leg pain in the Swespine register. The VAS ranges from 0-100, where 100 indicates the worst possible pain. Patients mark their symptom intensity on a 100 mm horizontal ruler-like scale that is not numbered or marked for the patient to ensure a graphical interpretation of pain. The NRS is similar to the VAS, but it has integer numbers 0-10 visible for the patient.[161] The NRS can be used orally, where 0 denotes a pain-free state and 10 the worst pain imaginable. The NRS and VAS could be regarded as interchangeable but not completely equal according to previous studies.[162] The VAS values within Swespine have been re-calculated to NRS values and rounded off to the closest integer in this thesis. The VAS was removed from Swespine in 2016.

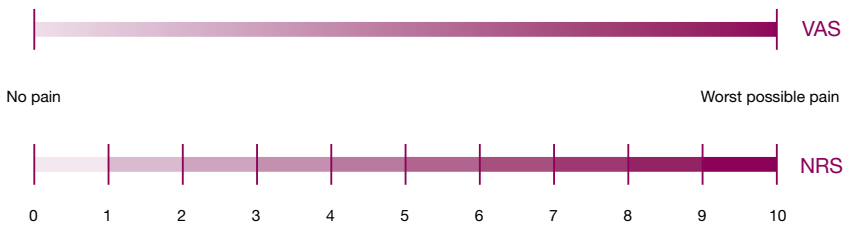


FIGURE 18: A comparison between the NRS and VAS scales for pain assessment.

GLOBAL ASSESSMENT OF LEG/BACK PAIN ($GA_{LEG/BACK}$)

The $GA_{Leg+Back}$ is a Likert-style question regarding the patient's perception of the surgical outcome in regard to the preoperative level of pain.

"How is your leg/back pain compared with before you had your surgery?" with six response levels:

1. I had no preoperative leg/back pain
2. Completely pain free
3. Much better
4. Somewhat better
5. Unchanged
6. Worse

Since this question is put to the patient after the surgery has been performed, at the one-year follow-up, it is a retrospective assessment and might be subject to recall bias. The validity of this question has been studied and compared with other scales of measurements, and could be considered to be acceptable.[163]

SATISFACTION WITH THE SURGICAL RESULT

Within the Swespine register, one question relates to the patient's perception of the overall surgical outcome. It is phrased as "How would you describe your satisfaction with the surgical outcome?". Three answer options are available: Satisfied, Uncertain, Dissatisfied.

STATISTICAL METHODS

STUDY I

Statistical analyses were performed using SPSS version 20.0 (SPSS Inc, Chicago, Illinois) and JMP, version 15 (SAS Institute Inc, Cary, North Carolina). Variables describing demographics were presented with descriptive statistics. Data were presented as the means for normally distributed data and with median values when not normally distributed with the corresponding interquartile range. The paired sample t-test with 95% confidence intervals was used for the variables that were tested one year apart (for example, NRS_{Leg} pre- and post-operatively respectively) to compare the means in the same group on two different occasions. Student's t-test was conducted to confirm inter-group differences when normally distributed. The Mann-Whitney U test was used to compare variables between two independent groups with non-normal distributions. For ordered categorical variables, the X^2 test was used,

STUDY II

All the data from the FELD and control group were compiled in SAS System version 9.4 (SAS Institute Inc) for statistical analysis. The design was a matched cohort study comparing FELD with standard surgery. Descriptive statistics for patient demographics and outcomes were reported as the proportion and count for categorical variables. Continuous variables were reported as the mean and standard deviation and the median with the first and third quartiles. For comparisons between two groups, Fisher's non-parametric permutation test was used for continuous variables. Fisher's exact test was used for dichotomous variables, while the Mantel-Haenszel chi-square test was used for ordered categorical variables. Pearson's chi-square test was used for non-ordered categorical variables and compares the distribution within two groups. The Jonckheere-Terpstra test was used for continuous variables and is a non-parametric test comparing two or more independent samples of different sample sizes.

Wilcoxon's test was used for paired data in the subgroup analysis. Wilcoxon's test is a non-parametric test that compares two paired groups and the difference between sets of pairs to test whether the groups are statistically different from one another.

For analyses of change from baseline to the 12-month follow-up, Fisher's non-parametric permutation test was used for continuous variables and an independent sample t-test was used for dichotomous and ordered categorical variables. The Mann-Whitney U-test was used for interval and ordinal data. McNemar's test was used to compare paired samples for nominal and dichotomous variables. All significance tests were two sided and conducted at the 5% significance level. A statistical power analysis for NRS_{Leg} was performed at 80%.

The Global Assessment of leg and back pain (GA_{Leg}, $_{Back}$), as well as the Attitude and Satisfaction to the final result, were dichotomised to enable a comparison.

STUDIES III AND IV

Statistical analyses were performed with SAS System version 9.4 (SAS Institute Inc.). Descriptive statistics for patient demographics and outcomes were reported as the proportion and count for categorical variables. Continuous variables were reported as the mean and standard deviation and the median with the first and third quartiles. For comparisons between two groups, Fisher's non-parametric permutation test was used for continuous variables. Fisher's exact test was used for dichotomous variables, the Mantel-Haenszel chi-square test was used for ordered categorical variables, the Pearson chi-square test was used for non-ordered categorical variables and the Jonckheere-Terpstra test was used for continuous variables.

Adjusted analyses between groups were performed with ANCOVA. For Study III, multivariable logistic regression was performed to analyse the association between predictors and the change in the NRS score for leg pain (ΔNRS; leg pain NRS score at one year minus leg pain NRS score preoperatively) at the 12-month follow-up was used as a dependent variable. Gender, age and level of disc herniation were included as independent variables. Finally, for the purpose of finding the best predictive model for ΔNRS 12 months after lumbar discectomy, a stepwise multivariable linear model was used. Predictors with $p < 0.20$ were entered into a forward stepwise analysis.

For Study IV, the patients were divided by their preoperative answers on the psychometric domain from EQ-5D. The groups were compared regarding the outcomes for leg pain (NRS), disability (ODI) and GA_{Leg} and satisfaction with the surgical result. The patient-specific changes in the psychometric domain from EQ-5D were analysed.

ETHICAL APPROVAL

Studies I-IV included in this dissertation were approved by the Regional ethics committee in Gothenburg (Regionala etikprövningsnämnden i Göteborg), Sweden (Dnr 753-17, and complemented Dnr 2019-05058, 2020-04478).

The FELD patients in Studies 1 and 2 were informed orally and in writing about the procedure and were asked to complete the prospective questionnaires, similar to standard surgery LDH patients. The patients and controls in Studies II, III, and IV were recruited from Swespine. Swespine is a national quality register and functions on an opt-out basis, where patients can ask to have their data removed. The use of data from Swespine requires ethical permission and the approval of the managing board of the register.

5

RESULTS

JOEL BECK

STUDY I

During the introduction of FELD at Sahlgrenska University Hospital, a total of 92 consecutive patients with a mean age of 31.2 years (range 15-59) were enrolled in the study. The majority (76%) of the patients had a positive SLR, and 53.7% had preoperative sensory deficits and almost a quarter (22%) had both motor and sensory disabilities or alterations.

TABLE 1. Patient Demographics and LDH data.

Age	31.22 (15-59)
Gender (female)	50% (46)
Body Mass Index (BMI)	25.5 (20-33)
Preoperative pain duration	n=92
<3 months	15% (14)
3-12 months	60% (55)
12-24 months	12% (11)
>24 months	13% (12)
Disc herniation level	
L4-S1	1.1% (1)
L4-L5	27.2% (25)
L5-S1	71.7% (66)
Laterality	
Left	57.6% (53)
Right	42.3% (39)
Positive SLR test	75.7% (53) n=70
Sensory affection	53.7% (40) n=76
Motor affection	34.2% (26) n=76

Means and (range). Percentage and (totals) SLR=Straight Leg Raise

Following the FELD procedure at the one-year follow-up, quality of life and disability improved on both the EQ-5D (+0.39) and ODI (-30.48).

Leg pain (NRS) decreased on average -4.54 or (61%) which could be considered exceeding normal MCID values. [165-169]

TABLE 2. Patient-reported outcome measurements.

	PREOPERATIVE	POSTOPERATIVE	
EQ-5D	Mean 0.31 (±0.32) Median 0.16 (IQR 0.09-0.69)	Mean 0.70 (±0.28) Median 50.00 (IQR 28.50-58.00)	Mean difference 0.39 (0.21-0.57) 95% CI **p<0.001**
EQ-VAS	44.26 (±18.02) Median 40.00 (IQR 27.00-58.75)	73.87 (±18.10) Median 75.00 (IQR 68.18-77.30)	Mean difference 29.62 (22.63-36.60) 95% CI **p<0.001**
ODI	Mean 46.76 (±19.60) Median 50.00 (IQR 28.50-58.00)	16.28 (±16.22) Median 10.00 (IQR 4.00-26.00)	Mean difference -30.48 -(36.27-23.73) 95% CI **p<0.001**
Leg pain (NRS)	Mean 7.4 (± 2.25) Median 8.0 (IQR 7.0-9.0)	Mean 2.76 (± 2.70) Median 2.0 (IQR 0.25-4.5)	Mean difference -4.54 -(3.62-5.46) 95%CI, **p<0.001**
Back pain (NRS)	Mean 5.3 (± 2.79) Median 6.0 (IQR 3.0-7.0)	Mean 2.61 (± 3.07) Median 2.0 (IQR 0.0-4.75)	Mean difference -2.46 -(3.29-1.64) 95%CI, **p<0.001**
Pain medication use	n=48	n=62	
None	2%	54.8%	**p<0.001**
Occasionally	31%	37.1%	
Regularly	67%	8.1%	
Opioid use	50%	22.9%	
Return to work	n=38	n=62	
Unemployed/student	35.1%	6.5%	**p<0.001**
Full time	2.7%	69.4%	
Part time	2.7%	14.5%	
Not able to work	59.5%	9.7%	

Means and (Standard Deviation, SD). Median and (Interquartile Range, IQR)
Numerical Rating Scale (NRS), EuroQol 5D (EQ-5D), Oswestry Disability Index (ODI)

More than half of the patients did not need pain medication postoperatively and the percentage of patients using opioids halved. Almost 85% of patients were back to working at the follow-up.

SURGICAL OUTCOMES, RECURRENCE AND COMPLICATIONS

The surgical duration of the FELD procedure was recorded at a mean of 55 ± 19 minutes. The mean duration of the last 15 surgeries in the series was below 40 minutes.

The average blood loss was less than < 7ml. The average hospital stay was 0.8 days (range 0.5-2) and 67% of the patients had the procedure as day surgery with no overnight stay as illustrated in Table 3.

TABLE 3. Surgical data for the FELD cohort.

Surgical duration	53.37 min (range 13-108) n=87
Total time in operating theatre	187.8 min (range 115-300) n=83
Radiation minutes	0.5 (range 0.1-4.0) n=43
Radiation (KAP value)	260.63 (range 15-2055) n=43
Blood loss	6.78ml (range 0-50) n=64
Dural tears	1 (1.1%) n=92
Nerve injuries	1 (1.1%) n=92
In-hospital stay (days)	0.8 (range 0-2) n=92

Means and (range), Kerma Area Product (KAP)

Fifty percent (n=46) of the patients reported that they had experienced transient changes or affected sensation postoperatively in a dermatome at follow-up. A recurrence of disc herniation, defined as a pain-free interval of at least six weeks, with new onset of previous symptoms at the same disc level requiring revision surgery, occurred in eight cases (8.7%) within one year. In the one-year follow-up question regarding satisfaction, 78% of the patients rated their overall postoperative attitude as satisfied.

STUDY II

A total of 80 patients that had a FELD procedure at the Sahlgrenska university hospital were eligible for the study. They were matched to 400 controls from the Swespine register creating a 1:5 inclusion. At inclusion, the patient groups were matched for age, gender, preoperative leg pain duration and level of LDH. The duration of preoperative pain in the study showed that 7.5% of patients were having pain <3 months and more than 30% of the patients were having a pain duration in excess of 12 months. Mean preoperative leg pain intensity measured by NRS_{Leg} was 7.04 SD (2.15) and mean back pain (NRS_{Back}) was 4.85 SD (2.82) respectively. The patients were according to their ODI 46.5 (17.9) affected by their LDH resulting in a marked disability.

At the one-year follow-up, the FELD group rated their residual leg pain as comparable to standard surgery. A comparison with the control group did not detect differences in any of the measured PROMs one year after surgery. (Table 4).

TABLE 4: Postoperative PROMs for FELD vs Controls (Swespine).

	TOTAL (N=480)	FELD (N=80)	CONTROLS (N=400)	P-VALUE	DIFFERENCE BETWEEN GROUPS MEAN (95% CI)
NRS_{Leg} (1yr)	2.13 (2.55) (1.84; 2.43) n=290	2.69 (2.68) (2.03; 3.34) n=67	1.97 (2.49) (1.64; 2.30) n=223	0.065	0.718 (-0.040; 1.429)
NRS_{leg} decrease	-4.88 (3.09) (-5.26; -4.51) n=262	-4.35 (2.93) (-5.25; -3.45) n=43	-4.99 (3.12) (-5.40; -4.57) n=219	0.24	0.637 (-0.421; 1.657)
NRS_{leg} % change	-64.4 (61.2) (-71.9; -57.0) n=262	-60.2 (36.7) (-71.4; -48.9) n=43	-65.3 (65.0) (-73.9; -56.6) n=219	0.57	5.13 (-18.07; 22.31)
NRS_{Back}(1yr)	2.39 (2.44) (2.11; 2.68) N=286	2.56 (2.38) (1.96; 3.17) n=62	2.34(2.46) (2.02; 2.67) n=224	0.54	0.221 (-0.444; 0.891)
NRS_{Back} decrease	-2.50 (2.98) (-2.89; -2.12) n=236	-2.72 (2.59) (-3.60; -1.85) n=36	-2.47 (3.05) (-2.89; -2.04) n=200	0.66	-0.257 (-1.310; 0.848)
NRS_{Back} % change	-34.3 (101.3) (-47.2; -21.3) n=236	-46.5 (47.8) (-62.7; -30.3) n=36	-32.1 (108.1) (-47.1; -17.0) n=200	0.47	-14.4 (-57.0; 14.6)
Oswestry Disability Index (1yr)	16.0 (15.1) (14.3; 17.8) n=289	17.3 (16.7) (13.2; 21.5) n=64	15.6 (14.7) (13.7; 17.6) n=225	0.46	1.67 (-2.79; 5.89)
1-year ODI decrease	-28.7 (18.9) (-31.0; -26.4) n=264	-28.4 (19.2) (-34.5; -22.3) n=41	-28.7 (18.9) (-31.2; -26.2) n=223	0.92	0.336 (-5.833; 6.645)
ODI % change	-62.7 (35.6) (-67.1; -58.4) n=264	-61.7 (38.6) (-73.9; -49.5) n=41	-62.9 (35.1) (-67.6; -58.3) n=223	0.84	1.22 (-11.43; 13.17)
EQ-VAS (1yr)	75.4 (17.5) (73.4; 77.5) n=282	72.1 (19.1) (67.3; 76.8) n=64	76.4 (16.9) (74.2; 78.7) n=218	0.095	-4.35 (-9.14; 0.65)
EQ-VAS increase	27.3 (24.5) (24.2; 30.3) n=250	28.1 (21.5) (21.4; 34.8) n=42	27.1 (25.2) (23.6; 30.5) n=208	0.80	1.03 (-6.71; 9.38)
EQ-VAS % change	98.5 (154.6) (79.1; 117.9) n=247	98.3 (121.3) (60.5; 136.1) n=42	98.6 (160.9) (76.4; 120.7) n=205	0.96	-0.284 (-56.365; 43.688)

For continuous variables, the mean (SD)/median (min; max)/(95% CI for mean)/n= is presented.

The PASS-score for this study was set at 2 for leg and back pain, and at 22 for ODI signifying a minimal residual disability.[170,171] The PASS is defined as the highest score where patients are feeling good. This is irrespective of any change within the measured PROMs. The two surgical cohorts showed equal results regarding the percentage of patients reaching the patient-acceptable symptom state (PASS).

TABLE 5: Pass scores for the surgical cohorts.

	TOTAL (N=480)	FELD (N=80)	CONTROLS (N=400)	P-VALUE	DIFFERENCE BETWEEN GROUPS MEAN (95% CI)
NRS Leg Pain <= 2					
No	91 (31.4%)	28 (41.8%)	63 (28.3%)		13.5 (-0.6; 27.7)
Yes	199 (68.6%)	39 (58.2%)	160 (71.7%)	0.055	-13.5 (-27.7; 0.6)
Missing	190	13	177		
NRS Back Pain <= 2					
No	112 (39.2%)	28 (45.2%)	84 (37.5%)		7.7 (-7.3; 22.6)
Yes	174 (60.8%)	34 (54.8%)	140 (62.5%)	0.34	-7.7 (-22.6; 7.3)
Missing	194	18	176		
NRS ODI <= 22					
No	72 (24.9%)	18 (28.1%)	54 (24.0%)		4.1 (-9.2; 17.5)
Yes	217 (75.1%)	46 (71.9%)	171 (76.0%)	0.60	-4.1 (-17.5; 9.2)
Missing	191	16	175		

The minimal important change regarding leg pain was defined as 3.5 in NRS_{Leg}. The MIC values were in line with previous published research.[166] In the NRS_{Leg} and NRS_{Back}, ODI and EQ-VAS, no differences between the two cohorts could be found regarding the percentage attaining the minimal important change (MIC).

TABLE 6: Minimal Important Change values for the surgical cohorts.

	TOTAL (N=480)	FELD (N=80)	CONTROLS (N=400)	P-VALUE	DIFFERENCE BETWEEN GROUPS MEAN (95% CI)
NRS_{Leg} change >= 3.5					
No	75 (28.5%)	17 (39.5%)	58 (26.4%)		13.2 (-3.9; 30.3)
Yes	188 (71.5%)	26 (60.5%)	162 (73.6%)	0.12	-13.2 (-30.3; 3.9)
Missing	217	37	180		
NRS_{Back} change >= 2.5					
No	148 (57.1%)	23 (59.0%)	125 (56.8%)		2.2 (-16.1; 20.4)
Yes	111 (42.9%)	16 (41.0%)	95 (43.2%)	0.94	-2.2 (-20.4; 16.1)
Missing	221	41	180		
ODI change <= 20					
No	174 (65.9%)	26 (63.4%)	148 (66.4%)		-3.0 (-20.4; 14.5)
Yes	90 (34.1%)	15 (36.6%)	75 (33.6%)	0.84	3.0 (-14.5; 20.4)
Missing	216	39	177		
EQVAS change >= 30					
No	127 (50.8%)	18 (42.9%)	109 (52.4%)		-9.5 (-27.4; 8.3)
Yes	123 (49.2%)	24 (57.1%)	99 (47.6%)	0.34	9.5 (-8.3; 27.4)
Missing	230	38	192		

MIC=Minimal Important Change
NRS=Numerical Rating Scale
ODI=Oswestry Disability Index
EQVAS=EuroQol Visual Analogoue Scale

STUDY III

From the total number of 43,556 patients registered in the Swespine register in 2013-2016, 6,216 patients with a first-time surgical discectomy were eligible for analysis in the study. The patients rated their preoperative leg pain as considerably worse than their back pain, mean NRS_{leg} 7.02(6.96;7.07) 95% CI and mean NRS_{back} 4.94(4.87;5.02) 95% CI respectively. In the study 4548 (73%) had a pain duration less than 12 months and 1668 (27%) in excess of 12 months. More than 94% (5854 patients) had their LDH at L4-L5-S1.

Regardless of preoperative pain duration or intensity, there was an improvement in postoperative radiating leg pain with a decrease in the entire study group to a residual mean of NRS_{leg} 2.16. The largest reported improvement in NRS_{leg} -5.59 (-5.85; -5.33) 95% CI) was reported in the group with the shortest duration of radiating leg pain < 3 months, as illustrated in Figure 19.

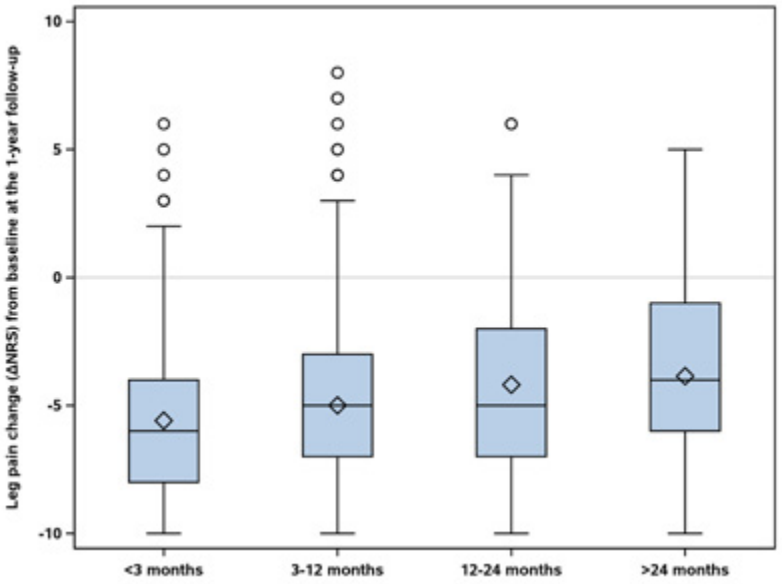


FIGURE 19: NRS_{Leg} pain change from baseline in the four duration groups. A negative value means that the patient is experiencing less pain postoperatively.

When comparing the stratified sciatica duration groups (<3, 3-12, 12-24, >24) using Fisher's non-parametric permutation test, there was a significant difference between all groups ($p \leq 0.001$), except between the 12-24-month and the > 24-month groups ($p=0.11$) regarding leg pain change (ΔNRS leg).

DURATION OF SCIATICA AND GLOBAL ASSESSMENT LEG PAIN (GA_{LEG})

A total of 36.61% (n= 1490) of the patients rated their sciatica as completely recovered, while 8.13% (n= 331) reported unchanged or worse pain. There were significant albeit small differences between all the different duration groups as illustrated in Figure 20.

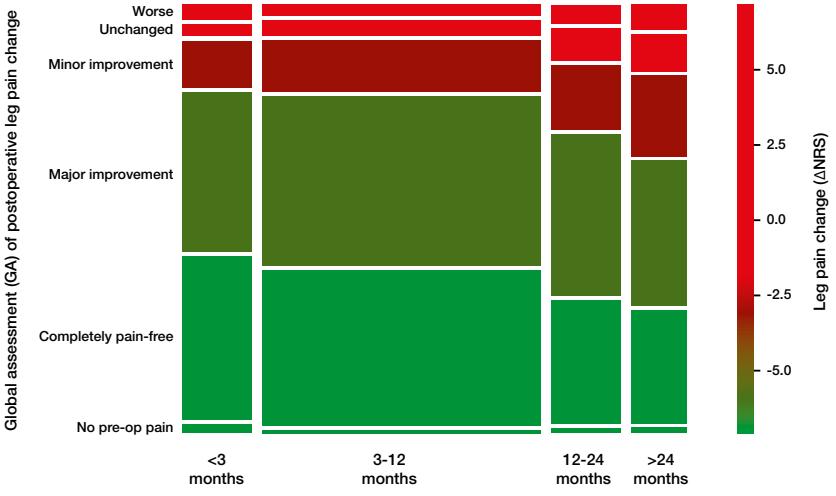


FIGURE 20: Graph illustrating the reported GA_{Leg}, NRS_{Leg} pain change and preoperative pain duration.

STUDY IV

The patients in Study IV were recruited from the same cohort as in Study III. As illustrated in Table 7 the cohort was divided into two groups based on the question from the mental domain of the EQ-5d-3L.

Significant differences were observed in all PROMs regarding residual leg pain measured by the NRS_{Leg} and disability in the ODI. Extremely anxious or depressed patients also ran a higher risk of being dissatisfied with the surgical outcome (15.3% vs 5.6%, p<.001).

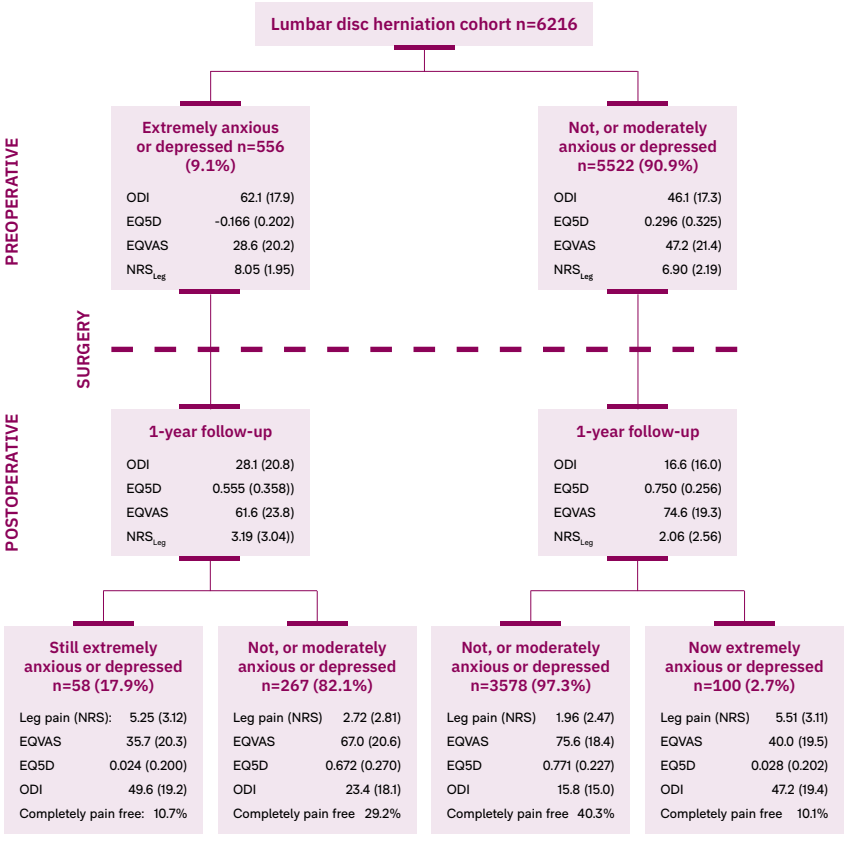
TABLE 7: The patients divided by the mental domain of the EQ-5D-3L and the outcomes leg pain (NRS_{Leg}) disability (ODI) and (dis)satisfaction.

	TOTAL (N=6078)	NOT OR MODERATELY ANXIOUS OR DEPRESSED (N=5522)	EXTREMELY ANXIOUS OR DEPRESSED (N=556)	P-VALUE
Leg pain				
Completely pain free (NRS=0)	1517 (25.0%)	1435 (26.0%)	82 (15.0%)	
Pain (NRS=1-7)	4314 (71.0%)	3435 (70.0%)	434 (78.0%)	
Severe pain (NRS=8-10)	247 (4.0%)	207 (4.0%)	40 (7.0%)	<.0001
Oswestry Disability Index				
ODI<20 (minimal disability)	2540 (63.8%)	2407 (65.8%)	133 (41.2%)	
ODI>20	1440 (36.2%)	1250 (34.2%)	190 (58.8%)	<.0001
Satisfaction				
Dissatisfied	253 (6.4%)	204 (5.6%)	49 (15.3%)	
Satisfied/ undecided	3718 (93.6%)	3446 (94.4%)	272 (84.7%)	<.0001

For categorical variables, n (%) is presented.

In the group that had no mental complaints preoperatively but reported a dismal outcome surgically, the amount of mean leg pain (NRS_{Leg} 5.51) and the resulting poor mean quality of life (EQ-5D 0.028) and high mean levels of disability ODI (47.2) were comparable to those that remained anxious and depressed with severe leg pain, despite having LDH surgery. However, in contrast, the depressed and anxious patients that had a successful surgical outcome attained almost as high a level of satisfaction and low residual pain as their initially happier peers. In fact,

this group had the largest gain in leg pain decrease, and disability, starting from a lower level. A high level of postoperatively stated anxiety/depression was associated with high levels of residual leg pain NRS_{Leg} (5.25-5.55) and a poorer outcome on the ODI regardless of preoperative mental status.



For continuous variables Mean (SD) / Median (Min; Max) / (95% CI for Mean) / n= is presented.

FIGURE 21: Flowchart over patient reported outcomes measures in the cohort, based on the patient's preoperative assessment of anxiety and depression according to the mental dimension within EQ-5D.

6

DISCUSSION

JOEL BECK

DON'T FIX IT IF IT AIN'T BROKEN?

When standard surgery for LDH delivers consistently good results, what is the rationale for the introduction of a novel technique that has a cumbersome learning curve and carries the inherent risks known in minimally invasive methods?[172]

LDH surgery appears better than placebo in several RCTs in terms of short-term outcomes, but for PROMs evaluating 12-24 months postoperatively, the differences are not significant or medically relevant. Offering such an invasive surgical procedure in order to achieve short-term pain relief imposes heavy pressure on the clinician to minimise the risk of iatrogenic damage.[137-139] FELD may offer a remedy and has exactly this potential – the chance to reduce nerve, skeletal, ligamentous, soft tissue and muscular damage during surgery.[173]

Standard mini-open surgery for LDH has been clinically available for more than 80 years.[95,96] The microscopic approach and technique has replaced open surgery as the gold standard, without producing superior medically relevant long-term results, and still producing complications and residual back pain affecting PROMs.[174] New technologies are often introduced, after heavy marketing and at a high cost offered to prospective patients, not always with long-lasting benefits. A tell-tale example can been seen in general surgery, where there was an aim of reducing scar tissue to such an extreme extent that NOTES surgery was developed at a very high cost, heavily marketed, eventually with disappointing outcomes and complications, before finally almost disappearing after unconvincing clinical results.[175] FELD is a new surgical method for LDH that holds all the allure of advanced futuristic technological progress. It is thus apposite to carefully examine the risks and benefits before a widespread clinical introduction.[176]

Theoretically, FELD has several potential advantages over microscopic surgery for LDH: (1) A very short operating time, (2) Almost non-existent blood loss, (3) Extremely low levels of postoperative discomfort related to the wound, (4) Extremely low risk of infection, (5) A short recovery time and minimal hospital length of stay and (6) the procedure can potentially be performed under local anaesthesia.[108,122,125,135,172,177-183] All these factors could in theory promote less postoperative pain and a faster return to work, daily activities and sports. More importantly, the almost non-existent risk of infection and low rate of nerve complications could be touted as major benefits. One of the main drawbacks of the procedure is the steep learning curve, potentially causing an increased rate of complications in the introductory phase.[124] The cost of equipment is substantial, but it could perhaps be compensated for in part by a shorter recovery time and hospital stay.[184]

One of the challenges when introducing a new clinical practice is to use evaluatory instruments specific and sensitive enough to discern clinically relevant differences. The PROMs currently in clinical use might not be the most sensitive or appropriate to use, but, in view of the lack of contemporary commonly accepted alternatives, these are the instruments within Swespine and clinical practice that are currently available to study.

STUDY I

In Study I, we describe the introduction of FELD in Sweden. The effect of the learning curve on operating duration is described within the study. The learning curve of the FELD procedure is regarded as steep.[124,126] This means that it is not a technique that is easy to master, nor is it without the risk of complications for an extended number of cases. One common estimate is that it takes 30-40 surgeries to acquire the skills necessary to perform this procedure safely and efficiently and achieve similar outcomes as with standard surgery for LDH.[124,126] The standard surgical methods for LDH have the same basic approach and technique as other lumbar spinal procedures such as lumbar decompressions and TLIF (Transforaminal Lumbar Interbody Fusion) procedures, and thus have the benefit of being synergistic in shortening the learning curve for aspiring spinal surgeons for a number of procedures. The FELD procedure is in this regard a surgical outlier, where a familiarity with fluoroscopy and arthroscopic triangulation techniques might be of more benefit.

The majority of the first cases in Studies I and II belong to this learning phase at our centre and this should be taken into consideration when interpreting the results. The first surgeries included in Study I are the subject of selection bias. These initial cases were carefully chosen to allow for the smooth introduction of the FELD procedure at our centre. We hypothesised that the FELD procedure would be an excellent method for patients with exceptional demands – such as athletes and non-overweight young patients, because of the non-tissue-disruptive properties of the procedure. However true this might be, the complete opposite in patient selection is also applicable. Extremely obese LDH patients benefit tremendously from a procedure that does not require extensive tissue-disruptive dissection and a prolonged surgical duration. Furthermore, the excellent visualization and minimal blood loss, simplifies this common procedure in less-than-ideal patients. The average age of our included patients was 31 years which is lower than the average age for LDH surgery in Sweden (45 years). Despite this, we could not find an increased rate of early revision surgery when compared to standard procedures. The discectomy and removal of disc material in young patients is sometimes more challenging and this may affect the presented results.

Despite being studied during the clinical introduction at our hospital, the PROMs after a FELD procedure are at an acceptable level and the results from

Study I indicate that the FELD technique could be regarded as safe, with similar outcomes and LDH recurrence rates as standard surgery. Keeping an ever-present awareness of the learning curve, FELD can be introduced as an alternative to standard surgery for LDH.[129,130,167,173,185-188]

STUDY II

In order to compare FELD and standard surgery in Study II, a matching procedure was carried out on commonly used matching parameters. A power analysis revealed that there was sufficient power to discern medically relevant differences in the main outcomes, the NRS_{Leg} and the ODI. A very slight trend in benefit was noted for the standard surgery group in terms of postoperative residual leg pain, perhaps illustrating that the removal of the lamina, flavum and facet joint capsule could add a significant decompressive advantage for open surgery compared with the ultra-minimally invasive FELD. Without the benefit of open surgery decompression, any recurrence of LDH is likely to be more damaging for the FELD patient.[189,190] It is thus essential that a careful inspection is carried out during the FELD procedure to ensure that the nerve root is sufficiently decompressed following the removal of the LDH in order to achieve an acceptable low re-operation rate due to recurrence. Earlier introductory series in other countries report similar outcomes when compared with our results.[116,191]

Whenever a surgical procedure has the ambiguity of being minimally invasive, but with a steep learning curve and an increased potential for a symptomatic recurrence of LDH, careful patient selection is critical, since this greatest disadvantage of FELD is also one of the strongest arguments *in favour of* the procedure. The minimal tissue-disruptive properties of the procedure could help reduce the amount of residual back pain following LDH surgery. This is known to be a major late clinical complication, to such an extent that it is an established concept, previously called *failed back surgery syndrome* (FBSS) or, more recently and more appropriately, *Chronic Pain after Spinal Surgery* (CPSS).[192] Our FELD patients were able to achieve a higher level of back pain reduction vs the control group and had similar residual back pain at the one-year follow-up. In our studies, FELD was not inferior to standard surgery for LDH regarding NRS_{Back} and ODI. Back pain improved in 80% of the FELD patients and 70% stated that their leg pain had completely disappeared or was much better, which is comparable to other surgical methods for LDH.

STUDY III

During our initial experience with FELD, we found that, in the introductory phase of Swedish FELD surgery, the patients with shorter sciatic pain duration had easier surgeries and a faster recovery. It was easier endoscopically to remove a “new”

LDH or sequester than the LDHs that were found in patients with prolonged pain duration. We hypothesised that a prolonged duration of sciatica might produce poorer PROMs, due to the possibility of longstanding neurogenic pain and more difficult surgical procedures. The gateway control theory of pain formulated by Melzack and Wall and the associated wind-up syndrome assume prolonged exposure to noxious stimuli and have been associated with the risk of developing neuropathic pain.[193] An LDH causing rapid and long-standing compression on a nerve root has a very similar mechanism to those used in many animal experiments to investigate and produce neuropathic pain stemming from de-myelinisation, inflammation and hyperesthesia.[50-53] Since the vast majority of LDH patients recover without surgery within six to 12 weeks, it can be assumed that the few that require surgery already have significant neurapraxia, if not axonotmesis, resulting in the risk of permanent nerve damage. The timing of surgery might thus be of extreme importance. There may be a fine line between operating prematurely, performing unnecessary procedures and a complacent attitude causing permanent nerve damage. In Studies I-IV, a significant proportion of LDH patients had residual leg pain one year postoperatively, indicative of axonotmesis with a residual NRS_{Leg} slightly in excess of generally acceptable PASS scores (NRS_{Leg}=2) perhaps illustrating that waiting times to LDH surgery in Sweden might be too long.[171]

A surgical attitude that encourages an earlier timing of surgery might reduce the number of patients with residual symptoms. Using strict criteria of outcomes of surgical success, a third of LDH patients did not reach a PASS in the NRS_{Leg} one year after surgery. If this were to be regarded as a surgical failure, the success rate of LDH surgery is on a par with or just slightly better than placebo treatment. This is arguably also the result in the several RCTs that are unable to prove that LDH surgery offers any significant long-term benefits over conservative management.[69,71,137] Surgery should thus be reserved for those patients that have unbearable symptoms and these patients are probably the most likely to have surgery within three months. It is also possible to infer that there is no medical reason to delay surgery after three months, since these groups of patients have very similar results, despite different time to surgery (3 vs 12-24 months of sciatica).[141,142] In our study examining the duration of preoperative sciatica and PROMs, there is a correlation between a short duration and greater satisfaction with the surgical outcome. However, regardless of sciatic duration, most patients improve following surgery, but those patients with the longest duration run a significantly higher risk of being disappointed, both in the NRS_{Leg} (perceived actual residual leg pain) and in their perception of sciatic pain reduction (GA_{LEG}).

The reason why patients with a shorter duration of sciatica report better postoperative leg pain results cannot be discerned from a register-based study. Patients undergoing “early” surgery might have failed early conservative management, having unbearable pain symptoms or are having a neurological deterioration.

This cannot be correctly assessed within Swespine. Without adjusting for these factors, with an RCT investigating a time-to-surgery hypothesis, firm inferences regarding preoperative pain duration and outcomes cannot be drawn. An RCT investigating this would be impractical or even unethical to perform and the art of spine surgery might have to make do with clinical experience, previous research, register-based studies and sound judgement regarding the optimal surgical timing.

STUDY IV

Body and mind are intertwined in the mindset of a large part of the population, and long-standing sciatica and pain might be associated with the onset of anxiety and depression.[147,154,155,194-196] Depressed and anxious patients with sciatica may experience more symptoms than their "happier" peers.[197] Mental illness and complaints have traditionally been considered yellow flags and a warning against a successful surgical outcome. However, a high preoperative depression/anxiety level could also be due to a pre-existing condition unrelated to back pain.[198] Discerning between these two causes of mental illness might be relevant when assessing depression/anxiety as a preoperative predictor.[145]

Specialised quality-of-life and disability scores such as the EQ-5D, Zung self-rating depression score, Beck depression inventory, Minnesota Multiphasic Personality Inventory, the Mental Component Score (MCS) and Mental Health (MH) sub-scores of the SF-36 and the anxiety domain of the EQ-5D can all be used to assess preoperative mental health.[66,157,164,199,200] The plethora of scores currently in use underline the challenge involved in quantifying patient mental health. In Study IV, we aimed to explore the association between a self-reported high preoperative level of anxiety and depression and PROMs after LDH surgery. We found that a "low" preoperative score on the EQ-5D mental health domain is associated with an increased risk of being dissatisfied with the surgical outcome. However, more than 80% of patients with depression/anxiety nevertheless improved both mentally and physically following surgery and achieved results on a par with the group without preoperative mental complaints. Even when adjusting for age, gender and pain duration, the depression/anxiety-affected group reported a significantly higher risk of achieving and reporting unsuccessful outcomes in the PROMs measured. It is fallacious to assume that depression and anxiety would automatically lead to poorer outcomes, and these patients deserve the same preoperative assessment as their peers, but they do run an increased risk of achieving poorer outcomes, albeit not to the extent that it would merit a more conservative attitude towards surgery. The symptoms and manifestations of pain still require a careful personalised assessment based on the surgeon's clinical experience and special care should be taken to convey realistic expectations regarding outcomes to LDH patients reporting anxiety or depression.

STRENGTHS AND LIMITATIONS

All the studies included in this thesis have their strengths and limitations. Studies I-IV contain patients retrieved from a national quality spine register – Swespine. Some specific areas of interest and concern are inherent to all register-based studies.

REGISTER-BASED STRENGTHS AND LIMITATIONS APPLICABLE TO THIS THESIS

First, the sheer volume of LDH surgeries available for analysis in Studies II, III and IV yields such a large sample size and, at the same time, a very high precision in the estimates. However, statistical significance does not equal medical significance. Regardless of the p-value, the changes or differences need to have a clinical implication for the doctor and a meaningful perceived change for the patient in order to be of value.

Second, there is always a loss to follow-up and missing data in register-based studies. In Studies III-IV, there is a significant loss to follow-up. Special care has to be taken when interpreting these results and conclusions. Previous work has explored the validity of the registers in the light of loss to follow-up and it has also examined the characteristics of the patients that are non-responders. It seems that non-responders fare somewhat less well than responders, but conflicting results obfuscate a definitive conclusion as to whether or not this is of serious significance.[201,202]

Third, the PROMs included in Swespine have been validated in a large number of previous articles. In Studies I-IV, we chose PROMs that are commonly used throughout the spinal research field. Two exceptions are the Global Assessment ($GA_{Leg+Back}$) and the question regarding satisfaction with the surgical outcome. These questions are unique to Swespine, but the validity of the GA as a single follow-up question has been the subject of previous research regarding degenerative lumbar spine surgery.[163] Some of the most common PROMs in use are currently under scrutiny regarding their applicability in spine surgery research.

For example, the SF-36 has been removed from Swespine due to economy, time constraints and questionable clinical value. Others, such as the EQ-5D, might not be the most appropriate tools to evaluate outcome after LDH surgery. The most widely used PROM (ODI) in spinal research contains questions related to disability and back pain. Questions pertaining to personal hygiene, walking, standing and sitting might not be accurate enough to discern meaningful change

or pertinent to determine the level of incapacity experienced by a 15-year-old with LDH, but they may be more suited to the elderly patient with chronic back pain or spinal stenosis. While some PROMs have been removed, others have been added. In 2016 a question regarding opioid use was added. This late addition explains the substantial loss of data regarding this variable in the presented studies.

Fourth, all the included studies would benefit from a non-surgically treated control group. Several previous RCTs have investigated whether surgery for LDH is superior to conservative non-surgical treatment. It seems that surgery produces better short-term results, but, in the long term, significant gains over conservative management appear to be elusive. However, the willingness among patients and doctors alike appears to be low, when it comes to managing the prospect of enduring an extended period of severe sciatica with sick leave and prescription of pain medications.

STUDY I - THE SWEDISH INTRODUCTION OF FELD

The patients in Study I constitute the largest prospectively recruited cohort of FELD patients in Northern Europe known to us. The patients were all recruited from Sahlgrenska University Hospital and they all had their surgeries performed by four different surgeons. This could be regarded as both a strength and a weakness. This circumstance allows for a more complete follow-up and standardised level of care, but it might not be applicable to smaller hospitals and other clinical settings.

STUDY II – A COMPARISON BETWEEN FELD AND STANDARD SURGERY FOR LUMBAR DISC HERNIATION

In Study II, the FELD patients were matched to controls from Swespine having standard surgery during the same time period. The matching procedure was based on age, gender, level of LDH and preoperative pain duration. However relevant these parameters are, several others have been omitted. Level of education, previous sick leave, unemployment and personal insufficient pain-coping mechanisms have all been linked to poorer-than-expected outcomes following surgery. Patients could be matched ad infinitum, but, for practical purposes, a limit of matching parameters in register-based studies must be set.

STUDY III - AN EXTENDED DURATION OF SCIATIC LEG PAIN AND OUTCOMES AFTER LDH SURGERY

In Study III, the selection process for included patients aims to exclude all patients apart from first-time, single-level LDH surgeries. Imprecise inclusion would affect the internal validity of the findings and potentially skew the results. An extensive data quality assessment has not been performed, other than the exclusion of patients with clearly abnormal and faulty values, or those cases in which patients are missing relevant follow-up data to a serious degree. An adjusted analysis was performed for the preoperative duration of sciatica and the mean difference in ΔNRS between the groups, which revealed statistical significance, but this does not necessarily translate into medically relevant inter-group differences.

STUDY IV – LUMBAR DISC HERNIATION SURGERY FOR THE ANXIOUS AND DEPRESSED

The patients included in study IV are from the same cohort as in study III. This group of patients were divided into two groups based on their answer to the mental dimension question from the EQ-5D. This one-dimensional question has not been validated, and cannot be used as a replacement for a proper clinical diagnosis of depression or anxiety. It is the patients' own assessments of their feelings, and is thus prone to interpretational bias, which might skew the results.

7

CONCLUSIONS

JOEL BECK

To summarise, based on the studies included in this dissertation, it is possible to infer that the FELD procedure can be introduced at a Swedish hospital and produce similar good outcomes as when compared to standard surgery. Furthermore, patients with a shorter duration of leg pain generally report better results in the PROMs measured. Finally, patients that express depression or anxiety are able to reach a postoperative leg pain reduction and improvement in disability similar to other patients, but should receive information regarding the increased risk of non-satisfactory outcomes.

STUDY I

The introduction of the surgical procedure FELD for LDH, could be performed with good results in a Swedish tertiary hospital.

STUDY II

FELD was able to achieve results on a par with standard surgery for LDH. A comparison between the postoperative PROMs for the different methods does not reveal medically relevant differences. FELD might have advantages for the patient related to the minimally invasive features of the procedure.

STUDY III

For LDH-patients, a prolonged duration of preoperative sciatica is associated with patients reporting poorer postoperative outcomes in the most commonly used PROMs after a lumbar discectomy.

STUDY IV

Patients reporting a feeling of extreme anxiety and depression are able to achieve good results following LDH surgery, but a higher risk of dissatisfaction and a higher level of residual pain.

CLINICAL IMPLICATIONS

STUDY I

FELD is now an established practice at Sahlgrenska University Hospital, Gothenburg, Sweden. There is a growing clinical interest within the spine surgery community and further hospitals are acquiring this methodology.

STUDY II

FELD was able to achieve good outcomes with a rate of satisfaction similar to standard surgery and is thus a surgical alternative to open surgery in selected patients.

STUDY III

Preoperative duration of sciatica was not an excellent predictor of surgical outcome after LDH surgery. Most patients improve their leg pain regardless of the pain duration. However, the patients with the shortest duration of sciatica reports a higher mean improvement postoperatively in all the measured PROMs. Patients with a longer duration of sciatica report inferior results after LDH surgery in Swespine and a higher rate of dissatisfaction.

STUDY IV

Anxiety and depression should be taken into consideration when scheduling LDH surgery. The patients are not unable to achieve results similar to those of other patients, albeit at a higher risk of adverse events and worse patient reported outcomes.

FUTURE PERSPECTIVES

JOEL BECK

8

FELD is a surgical method that has won widespread acceptance in Asian countries, where the procedure has replaced microscopic approach as the new gold standard. No study has so far been able to convincingly prove that one single surgical method is superior to the others. This may be unlikely to ever happen, using the current outcome measurements included in the national registers. One reason why this is unlikely to ever happen, is that all surgical methods have the same end-result, and the difference lies in the approach.

To discern if there truly is a significant benefit using FELD, it needs to be further evaluated regarding proper long-term outcomes. Facet joint osteoarthritis after LDH surgery could potentially affect long term outcomes, and the negative impact of iatrogenic damage might not be noticeable until several years later with the insidious onset of low back pain. Further research in long term outcomes is warranted.

FELD is the pioneering procedure of modern minimal invasive LDH-surgery, but it also the gate-opener to further minimal invasive developments. After the introduction of FELD in Sweden, a new spinal surgical foundation has been established, that permits further developments, procedures, and new indications.

Lumbar endoscopic decompression is being introduced in Sweden 2022 and will be able to perform single and multi-level decompression without muscle detachment through a minimal incision. This method will be compared with standard decompressive procedures in future research.

Endoscopically performed transforaminal lumbar interbody fusions, will be a minimal tissue disrupting fusion procedure, able to be performed as day surgery, able to treat low-back pain. This is opposed to the surgical options of today that occasionally requires several days in hospital and opioid medication.

The addition of computer-controlled 3D navigation to the endoscopic procedures can significantly decrease the amount of operative radiation exposure, to the benefit of surgeon and patient. Navigational aid will expand the current indications, to also include cervical and thoracic procedures.

Robotic controlled endoscopic procedures are already in experimental clinical use, and may assist the surgeon both ergonomically and precision-wise in the approach and also create completely new surgical approaches and possible procedures.

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10

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