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Changes in Functioning and Pain After Lumbar Spine Surgery

Konsta Koivunen

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ABSTRACT

The aim of the study was to investigate changes in pain and functioning following lumbar spine surgery over a two-year follow up. Previous studies have found that pain and functioning generally improve with surgery. However, it has also been observed that not all patients benefit from surgical treatment. The diseases and pathologies treated with surgery vary considerably in both nature and severity, so it is natural that their prognoses also differ. The factors that might increase the likelihood of a poorer surgical outcome are uncertain. The results of this thesis show that most patients experience pain relief and their functioning improves within three months of lumbar spine surgery, and that this benefit lasts usually for at least two years. However, one tenth to one fifth of patients experienced only temporary improvement, which lasted only for the first three months after surgery or less. Age, sex, and duration of preoperative pain did not influence the risk of a poorer outcome. However, higher BMI, worse preoperative pain, and more severe disability were associated with inferior surgical outcomes. Some patients who had undergone lumbar spine surgery also experienced neck pain and disability related to this. Patients who underwent lumbar spine surgery showed greater improvement in some of the items on the Oswestry Disability Index than in others, which suggests that a single total score may not be sufficient to describe these changes. Accordingly, a functional profile of the different domains of functioning may be a better solution to evaluate the postoperative outcome after lumbar spine surgery. This thesis also investigated the suitability of the Oswestry Disability Index for investigating changes in the studied population, and found it to be a valid, reliable scale for the task. The results of this thesis can be used as an aid for selecting patients for lumbar spine surgery, as well as planning postoperative care and rehabilitation.

KEYWORDS: pain measurement, disability evaluation, treatment outcome, functioning

TURUN YLIOPISTO
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TIIVISTELMÄ

Tutkimuksen tavoitteena oli tutkia kivun ja toimintakyvyn muutoksia lannerangan leikkauksen jälkeen kahden vuoden seurannassa. Aiemmat tutkimukset ovat osoittaneet, että kipu ja toimintakyky yleensä paranevat leikkauksen myötä. On kuitenkin myös havaittu, etteivät kaikki potilaat hyödy kirurgisesta hoidosta. Leikkauksella hoidettavat sairaudet ja patologiat vaihtelevat huomattavasti sekä luonteeltaan että vaikeusasteeltaan, joten on luonnollista, että niiden ennusteet myös vaihtelevat. On vielä epävarmaa, mitkä tekijät altistavat huonommalle leikkaustulokselle. Tämän työn tulokset osoittavat, että useimmat potilaat kokevat kivun lievitystä ja heidän toimintakykynsä paranee kolmen kuukauden kuluessa lannerangan leikkauksesta, ja että tämä hyöty kestää yleensä vähintään kaksi vuotta. Kuitenkin kymmenesosasta viidennekseen potilaista koki vain tilapäistä paranemista, joka kesti vain ensimmäiset kolme kuukautta leikkauksen jälkeen tai vähemmän. Ikä, sukupuoli ja preoperatiivisen kivun kesto eivät vaikuttaneet huonomman lopputuloksen riskiin. Korkeampi painoindeksi, pahempi preoperatiivinen kipu ja heikompi toimintakyky ennen leikkausta liittyivät kuitenkin huonompiin leikkaustuloksiin. Joillakin lannerangan leikkauksen läpikäyneillä potilailla oli myös niskakipua ja siihen liittyvää toimintakyvyn heikkenemistä. Lannerankaleikatut potilaat kokivat joissain Oswestryn toimintakykymittarin kysymyksissä enemmän parannusta kuin toisissa, mikä viittaa siihen, että yksi kokonaispistemäärä ei välttämättä riitä kuvaamaan toimintakykyä. Näin ollen eri toimintakyvyn osa-alueiden kuvaaminen toimintakykyprofiililla voi olla parempi ratkaisu leikkauksen jälkeisen toimintakyvyn muutoksen arviointiin. Tässä opinnäytetyössä selvitettiin myös Oswestryn toimintakykymittarin soveltuvuutta lannerankaleikattujen potilaiden toimintakyvyn muutosten tutkimiseen ja todettiin sen olevan validi ja luotettava mittari. Tämän työn tuloksia voidaan käyttää apuna lannerangan leikkauspotilaiden valinnassa sekä leikkauksen jälkeisen hoidon ja kuntoutuksen suunnittelussa.

AVAINSANAT: kivun mittaus, toimintakyvyn arviointi, hoidon tulos, toimintakyky

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Abbreviations

PROM	Patient-reported Outcome Measure
VAS	Visual Analogue Scale
NRS	Numeric Rating Scale
ICF	International Classification of Functioning, Disability and Health
WHO	World Health Organization
ODI	Oswestry Disability Index
RMDQ	Roland–Morris Disability Questionnaire
SF-36	36-Item Short-Form Survey
NCSP	Nordic Classification of Surgical Procedures
BMI	Body Mass Index
95% CI	95% Confidence Interval
NDI	Neck Disability Index
EFA	Exploratory Factor Analysis
CFA	Confirmatory Factor Analysis
APP	Average Posterior Probability
AIC	Akaike Information Criterion
BIC	Bayesian Information Criterion
RRR	Relative Risk Ratio
GBTA	Group-based Trajectory Analysis
RMSEA	Root Mean Square Error of Approximation
ICD-10	International Classification of Diseases and Related Health Problems, 10^{th} Revision
IQR	Interquartile Range

List of Original Publications

This dissertation is based on the following original publications, which are referred to in the text by their Roman numerals:

I Konsta Koivunen, Sara Widbom-Kolhanen, Katri Pernaa, Jari Arokoski, Mikhail Saltychev. Reliability and validity of Oswestry disability index among patients undergoing lumbar spinal surgery. *BMC Surgery*, 2024. BMC Surg 24, 13 (2024).

II Konsta Koivunen, Sara Widbom-Kolhanen, Katri Pernaa, Jari Arokoski, Mikhail Saltychev. Change in functional profile after lumbar spinal surgery: a register-based study among 1,451 patients. *Acta Orthopaedica*, 2025; 96: 161-166.

III Konsta Koivunen, Jari Arokoski, Sara Widbom-Kolhanen, Katri Pernaa, Juhani Juhola, Mikhail Saltychev. Disability and pain after lumbar surgery–group-based trajectory analysis. *PLOS ONE*, 2025. 20(1): e0313528.

IV Konsta Koivunen, Roosa Lintuaho, Jari Arokoski, Katri Pernaa, Mikhail Saltychev. Concurrent changes in disability caused by back and neck pain after lumbar spine surgery – a multigroup trajectory analysis (manuscript accepted for publication in Journal of Orthopaedic Surgery and Research, October 1st, 2025)

1 Introduction

Degenerative findings in the spine are very common, even in the asymptomatic population (Brinjikji, Luetmer, et al., 2015). Degenerative changes usually do not improve on their own, but the symptoms caused by these changes may still improve with time or conservative treatment (Chiu et al., 2015; Zaina et al., 2016). The symptoms caused by some of these degenerative changes can be relieved with surgery, and the number of back operations has increased in recent decades both in Finland and worldwide (Grotle et al., 2019; Mäntymäki et al., 2023; Sivasubramaniam et al., 2015).

Surgery improves back and leg pain and functioning (Kovacs et al., 2011; Massel et al., 2020). Most previous studies have focused on the average changes in pain and functioning after surgery. Only a few have have studied changes after surgery in detail. These studies have found that pain and functioning can change in different ways between patients (Carrasco et al., 2020; Hebert et al., 2019; Wang et al., 2022). The majority of patients benefit significantly from surgery, but a smaller proportion of patients experiences only little or even no improvement. However, the proportion of patients who do not benefit from surgery varies between studies, which is probably largely due to the fact that patients are selected for surgery using different criteria in different studies. Furthermore preoperative factors, which increase the risk of poor surgical outcomes, are also a matter of debate. Most previous studies have focused specifically on describing symptoms caused by pain originating in the lumbar spine. Only a few studies have examined, whether lumbar spine surgery also affects symptoms on a broader level. Despite being a rather paradoxical finding, it has been shown that even cervical pain and disability may be relieved by lumbar spine surgery (Cao et al., 2021; Felbaum et al., 2016).

Disability and functioning are multidimensional concepts and are usually assessed using scales that can take this diversity into account by collecting data from many different domains. The Oswestry Disability Index (ODI), measures ten different functioning domains. To ensure that the measurement of disability and functioning in the study was valid, the psychometric properties of the ODI were tested in this population. Furthermore, the aim was to evaluate, whether the limitations experienced by a patient with back problems can be different in different functioning domains.

The main objective of this study was to identify patients who will or will not benefit from surgery and to determine what factors influence this.

2 Review of the Literature

2.1 Anatomy of the lumbar spine

There are usually five vertebrae in the lumbar region. Each lumbar vertebra is composed of several components. These include the vertebral body, and dorsal structures called the posterior elements (Figure 1). Immediately dorsal to the vertebral body are two pedicles that attach to the laminae. From the junction of the two laminae, the spinous process extends posteriorly. At the junction of the pedicles and laminae, there are four articular processes and two transverse processes. The transverse processes extend laterally and serve as attachment points for ligaments and muscles. Unlike other regions of the spine, the lumbar vertebrae have a mamillary process at the posterior end of the superior articular process (Sassack et al., 2025; Waxenbaum et al., 2025).

The lumbar intervertebral discs are located between the endplates of the vertebrae. They are composed of an inner gelatinous nucleus pulposus and an outer fibrous annulus fibrosus (Sassack et al., 2025).

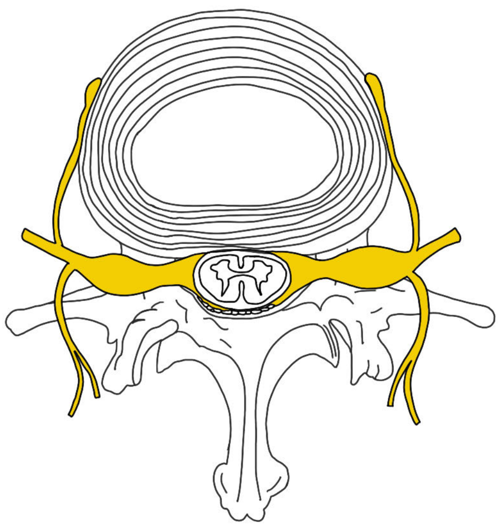

Figure 1. Spinal cord and spinal nerves at L1 level.

The lumbar vertebrae form a canal that protects the spinal cord and spinal nerves. The intervertebral discs, together with the adjacent laminae, pedicles, and articular processes, form a space through which the spinal nerves exit (Waxenbaum et al., 2025). The lumbar spinal nerves run obliquely below the corresponding vertebrae. Their ventral rami join the lumbar or lumbosacral plexus, while the dorsal ramus forms lateral and intermediate branches that innervate the iliocostalis and longissimus muscles. The medial branches innervate the lumbar zygapophysial joints and the multifidus muscle (Basit et al., 2025; Bogduk, 2016).

2.2 Degeneration of the spine

In the 1970s, Kirkaly-Willis et al. studied the pathogenesis of spinal degeneration using autopsies and concluded that spinal degeneration is a multi-stage process. In the first stage, the intervertebral discs and facet joints begin to show mild damage, which may present to the patient as intermittent pain or stiffness. In the second stage, the intervertebral discs lose height and elasticity, and the facet joints degenerate further. This stage may manifest as segmental instability, more frequent back pain, and intermittent nerve root symptoms or as disc bulges or prolapses (Figure 2). In the third stage, the instability begins to be corrected by bone growth and fibrotic changes, but these reduce mobility and can cause nerve compression and spinal stenosis (Figure 3) (Kirkaldy-Willis et al., 1978; Wilson et al., 2021).

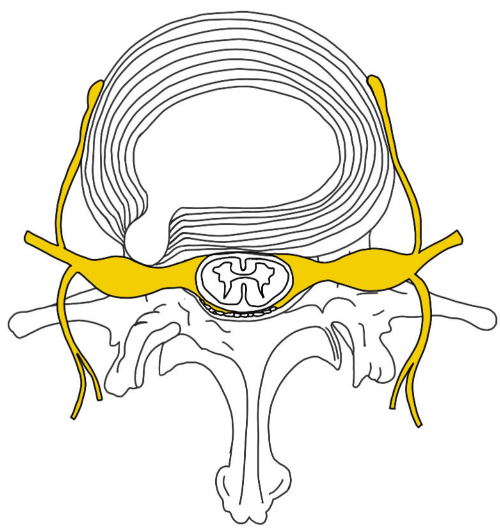

Figure 2. Disc herniation.

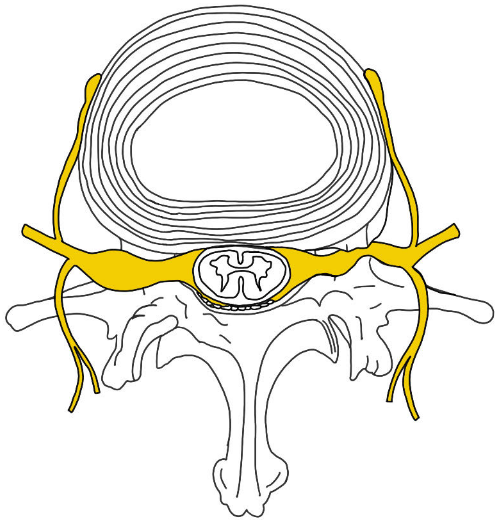

Figure 3. Foraminal stenosis.

2.3 Lumbar spine surgery

In Finland, between 1997 and 2009, the most common indications of the need for surgery, caused by lumbar degenerative spine disease and leading to an operation, were a herniated disc (60%), spinal stenosis (34%), spondylolysis and spondylolisthesis (5%) and degenerative disc disease (2%) (Salmenkivi et al., 2017). In Sweden, in 2011, the most common indications of the need for lower back surgery were central spinal stenosis (45%), disc herniation (28%), a segmental pain/disk degenerative disorder (8%), lateral spinal stenosis (7%), and isthmic spondylolisthesis (4%) (Strömqvist et al., 2013).

2.4 Surgical techniques

The techniques most commonly used in the treatment of lumbar disc herniation in Finland between 1997 and 2018 were microdiscectomy and open discectomy (Ponkilainen, Mäntymäki, et al., 2021). Microdiscectomy has increased its popularity compared to open discectomy during the recent decades, and today it is by far the most used technique to treat disc herniation in Finland (Palveluvalikoima, 2019; Ponkilainen, Mäntymäki, et al., 2021). The main point of microdiscectomy is the use of a microscope, which allows a less invasive approach. Microdiscectomy involves making a short skin incision, followed by a partial laminotomy and opening of the ligamentum flavum, which exposes the nerve root and enables the herniation to be removed (Blamoutier, 2013; Caspar, 1977). It is also possible to perform a tubular microdiscectomy, meaning the surgery is performed through a tube, which makes the skin opening even smaller (Clark et al., 2017). Of the currently used techniques, the smallest surgical wound can be achieved with endoscopic microdiscectomy (Anichini et al., 2015). A recent meta-analysis found that the endoscopic surgical style provides better short-term surgical outcomes, faster patient mobilization, and faster recovery times. However, the surgical style did not affect the risk of recurrence, the likelihood of reoperation, or the number of complications (Latka et al., 2025).

The goal of surgical treatment of spinal stenosis is to release compressed nerves by removing structures that compress them or the spinal canal, for example; thick ligamentum flavum, osteophytes or hypertrophic facet joints (Machado et al., 2016). Several different techniques can be used in the treatment of spinal stenosis, for example, open or minimally invasive laminectomy, hemilaminectomy, unilateral or bilateral laminotomy, and laminoplasty (Estefan et al., 2019; Machado et al., 2016).

If the spine is unstable, two or more vertebrae can be fused (Mobbs et al., 2015). The stability of the spine may be threatened by, for example, degenerative conditions, deformities, trauma, or surgery (Dunn, 2008). Fusion can be performed using several different techniques, but regardless of the technique, the goal is to prevent the movement of the pain-producing area and to decompress the involved nerve structures (Boos et al., 1997; Gaines, 2000; Mobbs et al., 2015; Palveluvalikoima, 2021).

2.4.1 Prevalence and incidence of lumbar degenerative spine disease

In Finland, research on nearly 1500 participants who had undergone magnetic resonance imaging (MRI) at the age of 47 revealed that 95 % had at least one mildly or more severely degenerated disc (Mertimo et al., 2022). Similarly, in another study, disc degeneration was found in approximately 71 % of men and 78 % of women under the age of 50, rising to about 90 % in both sexes aged over 50 (Teraguchi et al., 2014). A systematic review published in 2015, in turn, highlighted the prevalence of degenerative spine diseases that was likely to increase with age, even in an asymptomatic. For instance, it found that disc degeneration affected 52 % of 30-year-olds, 80 % of 50-year-olds, and 96 % of 80-year-olds (Brinjikji, Luetmer, et al., 2015). Thus, based on previous literature, degenerative changes in the discs are already visible in 71-95% of people aged around 50 (Brinjikji, Luetmer, et al., 2015; Mertimo et al., 2022; Teraguchi et al., 2014). Additionally, it has been reported that approximately 11% of asymptomatic individuals have spinal stenosis (Jensen et al., 2020).

Systematic reviews have reported that the diagnostic accuracy of imaging in identifying the symptomatic nerve root varies from low to moderate (Kim, van Rijn, et al., 2018; Tawa et al., 2017). However, it has been reported, for example, that disc degeneration seen on imaging occurs more frequently in patients with back pain than in asymptomatic individuals (Brinjikji, Diehn, et al., 2015). Also, degenerative spinal disease typically occurs in many ways at the same time, and finding the cause of the symptoms can be difficult (Lee et al., 2016).

A comprehensive systematic review was conducted in 2018 and reported that 5700:100000 of Europeans are diagnosed with degenerative disc disease and back pain annually (Ravindra et al., 2018). It has also been reported that spinal stenosis occurred in approximately 19% of patients with back pain (Kalichman et al., 2009).

An earlier estimate from 1992 also suggested that around 40 % of the population experienced radicular pain at some point in their lives, although this pain was only clinically significant in four to six % of cases (Frymoyer, 1992).

2.4.2 Common indications for and goals of surgery

In Finland, indications for acute surgery are, urinary retention associated with cauda equina syndrome, unbearable pain, and progressive weakness of lower limb muscle strength (Duodecim, 2017). The criteria for acute surgical treatment are generally clearer and more consistent both nationally and internationally compared to elective surgery. The decision to have elective surgery is influenced not only by medical but also by socio-economic factors and the structure of the local healthcare system.

The goals of treating lumbar degenerative spine disease are relieving pain and improving functioning and quality of life (Covaro et al., 2016; Evans et al., 2023; Teles et al., 2016). Conservative treatment is recommended for patients with back pain radiating to the leg if no need for acute surgery is indicated (Hayden et al., 2023; Luijsterburg et al., 2007). Conservative treatment is the first-line option worldwide for most spinal conditions (Kalichman et al., 2008; Ma et al., 2017; Metkar et al., 2014; Xin et al., 2022).

Recommendations on the appropriate length of conservative treatment prior to non-urgent disc herniation surgery vary in different countries, but generally, patients are treated for at least six weeks before surgery is considered (Peul, Houwelingen, et al., 2007; Yoon et al., 2021). In Finland too, surgery is considered if symptoms continue for more than six weeks (Palveluvalikoima, 2019).

A systematic review published in 2015 reported that 96 % of disc sequestrations, 70 % of extrusions, 41 % of protrusions, and 13 % of bulges regressed spontaneously without surgery (Chiu et al., 2015). Similarly, Weber et al. found that of patients with lumbar radiculopathy, 70 % obtained pain relief within four weeks of treatment with an anti-inflammatory drug or a placebo (Weber et al., 1993). Furthermore, a recent study reported that up to 80 % of patients diagnosed with lumbar disc herniation responded adequately to conservative treatment (Motiei-Langroudi et al., 2023).

Surgical treatment of lumbar spinal stenosis is considered if the patient has experienced a halting gait symptom for more than six months, which is not due to a vascular or neurological cause, or if the patient has radiating pain or loss of sensation that has lasted for more than three months (Palveluvalikoima, 2020). The World Federation of Neurosurgical Societies Spine Committee also recommends three months of conservative treatment for patients diagnosed with spinal stenosis (Fornari et al., 2020). A study reporting an 89 % follow-up rate found that 32 % of spinal stenosis patients experienced spontaneous relief of leg pain within three years of diagnosis (Wessberg et al., 2017). A South Korean study with an eight-year follow up reported that approximately 35 % of patients who had undergone MRI due to spinal stenosis received surgical treatment (Kang et al., 2022). A Danish retrospective study of more than 86,000 spinal stenosis patients between 2002 and 2018 also reported that approximately 46 % underwent surgery (Jensen et al., 2023).

2.4.3 Prevalence and incidence of lumbar spine surgery

The number of lumbar spine operations has been increasing during the recent decades (Grotle et al., 2019; Jensen et al., 2023; Mäntymäki et al., 2023; Sivasubramaniam et al., 2015). This is likely a result of the aging population. In particular, the increase in stenosis surgeries is likely due to the aging population, as stenosis surgeries are mainly performed on older patients. Similarly, the aging population explains the decrease in disk herniation surgeries, as a large proportion of patients undergoing disc herniation surgery are young. A Norwegian study published in 2019 found that the number of yearly lumbar spine operations increased by approximately 54 % from 1999 to 2013 (Grotle et al., 2019). In 2013, 120:100000 Norwegian residents underwent lumbar spine surgery (Grotle et al., 2019). In England, it was also reported that the number of yearly surgical operations to treat degenerative lumbar spine disease almost doubled between 1999 and 2013, finally reaching around 50:100000 inhabitants per year (Sivasubramaniam et al., 2015). Several studies have shown that the COVID-19 pandemic caused a momentary drop in back surgery figures, but after the pandemic, the number of operations quickly rose again to almost the pre-pandemic level (Koruga et al., 2023; Mills et al., 2023; Oshima et al., 2023; Yuh et al., 2024).

Recent decades have seen a slight downward trend in the number of operations for lumbar disc herniation (Bernstein et al., 2017; Kim et al., 2024; Mäntymäki et al., 2023; Ponkilainen, Mäntymäki, et al., 2021; van Munster et al., 2024). For example, in the United States, between 2003 and 2013, discectomy operations decreased by 19.8 % (Bernstein et al., 2017). A Finnish study found that lumbar disc herniation operations decreased by up to 29 % between 1997 and 2018 (Ponkilainen, Mäntymäki, et al., 2021).

The decision to undergo elective surgery is influenced not only by medical but also by socioeconomic factors, as well as whether the healthcare system is public, private or insurance-based, which partly explains the difference in surgery rates between countries. In private health care, changes in the number of discectomy operations can be partly explained by changes in people's ability to pay for them, so in times of financial uncertainty, the number of discectomy operations may decrease because in the short term, surgery is more expensive than conservative treatment (Hansson et al., 2007; Tosteson et al., 2008). Especially in the United States, where a large proportion of elective operations are reimbursed by a private payer, the economic downturn of 2008–2009 led to a reduction in discectomy operations (Bernstein et al., 2017). However, in Finland, between 1997 and 2018, 88 % of back operations were performed in public healthcare, and in publicly funded healthcare, medical indication determines surgical criteria (Ponkilainen, Mäntymäki, et al., 2021). One likely reason for the decrease in back surgery is that most disc hernations and their associated symptoms are resolved with conservative treatment (Chiu et al., 2015; Gugliotta et al., 2016; Peul, van Houwelingen, et al., 2007; Weber et al., 1993).

The number of surgeries for spinal stenosis has increased in recent decades (Ciol et al., 1996; Deyo et al., 2010; Kim, Chung, et al., 2018). This can probably be at least partially explained by several high-quality studies published some 15 years ago that advocated surgery for the treatment of spinal stenosis (Malmivaara et al., 2007; Slätis et al., 2011a; Weinstein et al., 2010). Advances in surgical techniques and imaging modalities have increased the number of spine surgeries until the early 2000s, but presumably did not increase the number of surgeries again after the 2000s (Deyo et al., 2005). Moreover, people are now living for longer and in better health, and thus the number of people aged over 75 who have back problems and can benefit from surgery is greater today (Ponkilainen et al., 2021). A Danish study found that between 2002 and 2018, decompression and fusion operations increased by up to 144 % and decompression operations without fusion by 128 % (Jensen et al., 2022). It also found that after 2010, significantly fewer stenosis patients had been operated on, but that due to the aging of the population and the increase in MRI, the number of diagnoses increased and the number of operations remained almost unchanged (Jensen et al., 2022) .

The number of fusion surgeries to treat lumbar degenerative disc disease and spondylolisthesis have also increased over the past decades (Kim et al., 2019; Sastry et al., 2023; Yoshihara et al., 2015). For example, in the United States, between 2000 and 2009, the number of operations to treat degenerative disc disease increased 2.4-fold. In their study, the majority of operations were fusion surgeries (Yoshihara et al., 2015). This is a phenomenon for which there is no medical basis, especially from a Nordic perspective, where today a similar patient is usually treated with decompression surgery. The number of fusion surgeries performed in Finland has decreased in recent years (Ponkilainen, Huttunen, et al., 2021). The selection of treatment options between decompression and fusion surgery may be affected by the funding of the healthcare system, i.e. insurance-based vs. publicly funded.

2.4.4 Evidence of effectiveness

Whether or not discectomy operations are superior to conservative treatment is uncertain (Gugliotta et al., 2016; Osterman et al.; Peul et al., 2008). A prospective cohort study of 380 patients found that discectomy patients had less disability than conservatively treated patients in the short term, but this difference was no longer detectable at the end of a two-year follow up (Gugliotta et al., 2016). Some studies have found that a discectomy provides better pain relief and improves functioning to a greater extent than conservative treatment, even at four- to eight-year follow up (Lurie et al., 2014; Weinstein et al., 2008). In Finland, approximately 90 % of patients operated on in 2020–2022 felt that their symptoms had improved three months after surgery for lumbar disc herniation (THL, 2024).

Systematic reviews comparing the effect of different conservative treatments and surgery to treat spinal stenosis found that in almost all studies, surgical treatment was more effective than conservative treatment (May et al., 2013; Zaina et al., 2016). This finding is supported by the results of a randomized controlled study published in 2011, according to which surgery led to greater improvement in functioning than non-operative treatment at six-year follow up (Slätis et al., 2011b). In their systematic review published in 2011, Kovacs et al. found that in the treatment of spinal stenosis, decompression surgery, either with or without fusion, was associated with less pain and better functioning three months later, and that this difference was still visible at four-year follow up (Kovacs et al., 2011). In addition, a Finnish study published in 2020 found that pain reduction and improved functioning after spinal stenosis surgery were still evident ten years after surgery (Tuomainen et al., 2020). One study found that conservative treatment achieved similar improvements in functioning as surgery. However, even in this study, half of the patients treated conservatively ultimately required surgery (Delitto et al., 2015). In Finland, between 2020 and 2022, about 76 % of patients who had undergone surgery for spinal stenosis felt that their symptoms had eased as a result of surgery 12 months later (THL, 2024).

Whether fusion surgery is more effective than conservative treatment in treating spondylosis or disc degenerative disease has been uncertain (Watters et al., 2009). However, according to a large registry-based study in Scandinavian countries, fusion surgery significantly improved the functioning of patients with degenerative disc disease (Andersen et al., 2019). In 2015, Schulte et al. published a systematic review showing that patients with degenerative spondylolisthesis benefited more from surgery than from conservative treatment (Schulte et al., 2016). The 2009 North American Spine Society guideline for the treatment of degenerative spondylolisthesis also recommends the use of fusion surgery (Watters et al., 2009). However, in recent years, there has been a lot of evidence that fusion surgery does not provide a better surgical outcome than decompression surgery alone (Austevoll et al., 2021; Försth et al., 2016; Ghogawala et al., 2016).

2.4.5 Pain severity among patients who have undergone lumbar spine surgery

The pain a patient experiences can be measured using patient-reported outcome measures (PROM) such as the Visual Analogue Scale (VAS) or the Numeric Rating Scale (NRS) (Downie et al., 1978; Haefeli et al., 2006; Hayes, 1921; Price et al., 1983). The VAS consists of a line whose endpoints are “no pain” and “pain as bad as it could be” (Haefeli et al., 2006; Hayes, 1921; Price et al., 1983). The patient marks their own pain intensity on the line, which is then determined on the basis of a scale from zero to ten or zero to one hundred (Haefeli et al., 2006; Hayes, 1921; Price et al., 1983). The NRS, on the other hand, most commonly consists of a scale of 0–10, but sometimes also 0–20 or 0–100, on which the patient circles the number that matches the intensity of their pain, when the endpoints are “no pain at all” and “worst pain possible” (Downie et al., 1978; Haefeli et al., 2006).

The Swespine study investigated the average preoperative VAS values according to diagnosis. It found that among disk herniation patients, the average VAS back value was 46 and the average VAS leg value was 67; that among central spinal stenosis patients, the average VAS back value was 56 and the average VAS leg value was 63; and that among degenerative spine disease patients who do not yet have nerve compression, the average VAS back value was 62 and the average VAS leg value was 42 (Strömqvist et al., 2013). The difference between the magnitude of leg pain in spinal stenosis patients and degenerative spine disease patients who do not yet have nerve compression is logical, as leg pain is usually a result of nerve compression caused by stenosis.

2.4.6 Correlation between back and leg pain

In degenerative conditions of the spine, mechanical compression of the nerve, inflammation and neuroinflammatory reactions can cause radicular pain (Dower et al., 2019). In general, the surgical treatment of pain caused by degenerative spine disease is based on the treatment for radicular pain (Iorio-Morin et al., 2021). A systematic review published in 2023 stated that the current literature does not recommend the surgical treatment of back pain caused by degenerative diseases (Evans et al., 2023). Other studies have also found that back pain is not strongly associated with disc herniations (Boos et al., 1995; Kjaer et al., 2005).

However, in 2016, Arnbak et al. found that greater spinal degeneration, shown in MRI, was associated with more frequent back pain episodes (Arnbak et al., 2016). A few studies have found that removing the factor causing radicular pain also relieves back pain (Carrasco et al., 2020; Hareni et al., 2021; Owens et al., 2018). Why back pain is relieved by lumbar spine surgery is not fully understood, but it has been reported that surgery may cause significant placebo effects (Turner et al., 1994). Another speculation is that possible local inflammation is relieved when the compression of the lumbar region is relieved, which leads to the reduction of local back pain (Li et al., 2021). Furthermore, some patients may have difficulty in identifying whether the pain originates in the leg or the back (Wai et al., 2009).

2.4.7 Changes in back and leg pain severity

The results vary regarding how much pain relief patients with low back surgery experience. A few studies found that one year after microdiscectomy, leg pain had decreased to approximately 10–30 % of its original level, but that back pain remained at 30–60 % of its original level (Hareni et al., 2021; Osterman et al.; Peul, van Houwelingen, et al., 2007). For example, among 14,000 patients, one year after microdiscectomy surgery, leg pain averaged at 31 % of its baseline level and back pain 53 % (Hareni et al., 2021). In some smaller studies, the magnitude of the change in back pain was the same as that of leg pain, although back pain alone is not an indication for surgery (Iorio-Morin et al., 2021; Toyone et al., 2004).

In a few studies, leg pain among patients who had undergone decompression surgery for spinal stenosis has improved by about 40–50 % compared to baseline level one year after surgery, while back pain had improved by about 50–70 % (Massel et al., 2020; Srinivas et al., 2019; Weinstein James et al.). For example, Weinstein et al. found that one year after surgery, leg pain had improved by 47 % compared to its original level, and back pain by 68 % (Weinstein James et al.). However, in several studies, leg and back pain have improved almost equally (Cha et al., 2021; Malmivaara et al., 2007; Taiji et al., 2021).

Several studies have investigated the average change in back and leg pain after low back surgery (Cha et al., 2021; Hareni et al., 2021; Iorio-Morin et al., 2021; Malmivaara et al., 2007; Massel et al., 2020; Osterman et al.; Peul, van Houwelingen, et al., 2007; Srinivas et al., 2019; Weinstein et al., 2010). However, only a few studies have considered the possibility that there may be patients who undergo lumbar spine surgery whose pain and functioning changes differ from the average trends of the patient population, which is a natural variation according to a Gaussian curve (Carrasco et al., 2020; Hebert et al., 2019; Yang et al., 2020). These studies have identified that most patients benefit significantly from surgery. For some, the improvement is great, but a smaller group of patients hardly benefit from surgery at all. For example, Hebert et al. reported that although most patients experienced significant pain reduction and improvement in functioning, 29–42% of patients experienced little or no benefit from surgery (Hebert et al., 2019).

2.4.8 Widespread character of back pain

2.4.8.1 Correlation between neck and back pain

A few studies have found that back and neck pain are often present at the same time (Coggon et al., 2013; Fernandez-de-las-Penas et al., 2011; Hagen et al., 2006; Leboeuf-Yde et al., 2012; Yabe et al., 2023). The main reason for the simultaneity is certainly that spinal degeneration is often widespread, and when degenerative changes occur in the lumbar region, similar changes are likely to occur elsewhere in the spine, such as in the cervical spine (Oh et al., 2017; Teraguchi et al., 2014). Neck and low back pain caused by aging of the spine may manifest as concurrent pain in the upper and lower spine (Kaaria et al., 2009)

There are also other speculative explanations for the co-occurrence of neck pain and back pain. One explanation for this simultaneous occurrence could be the central sensitization process (Woolf, 2011). Hagen et al. suggest that the tendency of low back pain patients to also experience pain elsewhere in the back could be due to muscle dysfunction (Hagen et al., 2006). Muscle dysfunction may start in the lower back area and affect several muscles in the back through the thoracic fascia. The simultaneous occurrence of neck and back pain could also be partly due to the fact that they have the same risk factors (Yabe et al., 2023).

2.4.8.2 Change in neck pain after lumbar spine surgery

Changes in neck pain after lumbar spine surgery have been studied very little. Only few studies have followed changes in low back pain after cervical decompression surgery or changes in neck pain after lumbar decompression surgery (Alvin et al., 2018; Epstein et al., 1984; Felbaum et al., 2016). For example, Felbaum et al. observed that cervical spine surgery relieved lower back pain, concluding that cervical stenosis may also mimic symptoms typically experienced in lumbar stenosis, and that cervical spine surgery may alleviate these symptoms (Felbaum et al., 2016). On the other hand, Alvin et al. reported that after cervical surgery, neck pain was reduced but back pain was not (Alvin et al., 2018). Also, Pennington et al. found that when stenosis occurred simultaneously in the cervical and lumbar spine, lumbar surgery alone could relieve the symptoms of both cervical and lumbar stenosis (Pennington et al., 2019). According to current literature, there is no clear or generally accepted explanation for this somewhat anecdotal phenomenon.

2.5 Functioning of patients who have undergone lumbar spine surgery

2.5.1 Functioning and disability according to the International Classification of Functioning, Disability and Health (ICF)

The ICF is the international classification of functional ability, functional limitations, and health approved by the WHO General Assembly in 2001 as the new international standard for describing functioning (WHO, 2001). In the ICF, the description of functioning is divided into three areas: 1) body functions and structures, 2) activities and participation, and 3) environmental factors. It takes into account the entire chain of events that led to the change in functioning. Diseases affect the structures and functions of the body, which lead to changes in performance, which in turn affect participation. All of these ultimately depend on individual factors as well as environmental factors.

As the original classification may be difficult to use in clinical work, separate core sets have been developed for clinical use (brief core sets) and research (comprehensive core sets) (Castaneda et al., 2014). In 2004, Cieza et al. developed the ICF Core Set for Lower Back Pain (Cieza et al., 2004). This contains 78 subcategories of factors that affect functioning, whereas the brief core set contains 35 subcategories. When the ICF Core Set for Lower Back Pain was developed, by interviewing experts around the world it was found that the limitations and restrictions of the activities and participation components seemed the most relevant for patients experiencing low back pain.

The use of ICF-based tools among back pain patients has shown to be beneficial (Bautz-Holter et al., 2008; Ibsen et al., 2021; Ibsen et al., 2022; Kirschneck et al., 2011; Kirschneck et al., 2008; Røe et al., 2008; Stier-Jarmer et al., 2009). However, the ICF remains seldomly used in spine surgery, and only a few studies have investigated its use among spine surgery patients (Abbott et al., 2011; Finkelstein et al., 2019). For example, according to Finkelstein et al., none of the PROMs currently used in spine surgery comprehensively cover all the aspects of the ICF framework (Finkelstein et al., 2019).

2.5.2 Measuring the functioning of patients with back pain

The impact of back pain on everyday activities is measured using PROMs such as the ODI, the Roland-Morris disability Questionnaire (RMDQ), or the Short-Form-36 (SF-36) (Stokes et al., 2017). At least 200 different PROMs are used in back surgery worldwide (Guzman et al., 2016).

2.5.2.1 The Oswestry Disability Index

The ODI is the most common PROM used for assessing the functioning of back surgery patients (Table 1) (Fairbank et al., 1980; Fairbank et al., 2000; Finkelstein et al., 2019; Stokes et al., 2017). It has been translated into different languages and has several modified versions (Fairbank, 2014; Fairbank et al., 2000; Sheahan et al., 2015). In Finland, the Finnish version of the ODI is used (Pekkanen, Kautiainen, Ylinen, Salo, & Häkkinen, 2011).

The ODI contains ten questions on functioning, one question of which is related to the pain experienced by the patient, and nine questions on activities of daily living (Fairbank et al., 1980; Fairbank et al., 2000). Each question of the ODI has six response options, scored on a scale from zero to five. Finally, the question-specific points are calculated as a total, then divided by the total score and multiplied by 100, resulting in a percentage of the maximum score. The higher the percentage, the greater the restrictions to functioning.

Table 1. The Oswestry Disability Index version 2.0.

Item 1. Pain intensity 0. I have no pain at the moment. 1. The pain is very mild at the moment. 2. The pain is moderate at the moment. 3. The pain is fairly severe at the moment. 4. The pain is very severe at the moment. 5. The pain is the worst imaginable at the moment.	**Item 6. Standing** 0. I can stand as long as I want without extra pain. 1. I can stand as long as I want, but it gives me extra pain. 2. Pain prevents me from standing for more than 1 hour. 3. Pain prevents me from standing for more than ½ an hour. 4. Pain prevents me from standing for more than 10 minutes. 5. Pain prevents me from standing at all.
Item 2. Personal care (washing, dressing, etc.) 0. I can look after myself normally without causing extra pain. 1. I can look after myself normally, but it is very painful 2. It is painful to look after myself and I am slow and careful. 3. I need some help but manage most of my personal care. 4. I need help every day in most aspects of self care. 5. I do not get dressed, wash with difficulty and stay in bed.	**Item 7. Sleep** 0. My sleep is never disturbed by pain. 1. My sleep is occasionally disturbed by pain. 2. Because of pain I have less than 6 hours of sleep 3. Because of pain I have less than 4 hours of sleep 4. Because of pain I have less than 2 hours of sleep 5. Pain prevents me from sleeping at all.
Item 3. Lifting 0. I can lift heavy weights, without extra pain. 1. I can lift heavy weights, but it gives extra pain. 2. Pain prevents me from lifting heavy weights off the floor, but I can manage if they are conveniently positioned, e.g. on a table. 3. Pain prevents me from lifting heavy weights, but I can manage light to medium weights if they are conveniently positioned. 4. I can only lift very light weights. 5. I cannot lift or carry anything at all.	**Item 8. Sex life** 0. My sex life is normal and causes no extra pain. 1. My sex life is normal but causes some extra pain. 2. My sex life is nearly normal but is very painful 3. My sex life is severely restricted by pain. 4. My sex life is nearly absent because of pain. 5. Pain prevents any sex life at all.
Item 4. Walking 0. Pain does not prevent me walking any distance. 1. Pain prevents me walking more than 1 mile. 2. Pain prevents me walking more than ½ of a mile. 3. Pain prevents me walking more than 100 yards. 4. I can only walk using a stick or crutches 5. I am in bed most of the time and have to crawl to the toilet.	**Item 9. Social life** 0. My social life is normal and causes me no extra pain. 1. My social life is normal but increases the degree of pain. 2. Pain has no significant effect on my social life apart from limiting my more energetic interests, e.g. sport, etc. 3. Pain has restricted my social life, and I do not go out as often. 4. Pain has restricted social life to my home. 5. I have no social life because of pain.
Item 5. Sitting 0. I can sit in any chair as long as I want without extra pain. 1. I can sit in my favourite chair as long as I like. 2. Pain prevents me from sitting for more than 1 hour. 3. Pain prevents me from sitting for more than ½ an hour. 4. Pain prevents me from sitting for more than ten minutes. 5. Pain prevents me from sitting at all.	**Item 10. Travel** 0. I can travel anywhere without pain. 1. I can travel anywhere, but it gives extra pain. 2. Pain is bad, but I manage journeys over two hours. 3. Pain restricts me to journeys of less than one hour. 4. Pain restricts me to short necessary journeys under 30 minutes. 5. Pain prevents me from travelling except to receive treatment.

2.5.3 Changes in functioning after lumbar spine surgery

The level of functioning of patients who have undergone lower spine surgery has varied greatly in different studies. This is probably mainly due to the fact that different studies have used different symptoms and findings to make surgical decisions. It is also known that preoperative functioning in patients with disc prolapse, spinal stenosis or spinal instability can vary greatly. Different studies have also used different surgical techniques. In several studies, the average ODI score before surgery has been between 35 and 50 (Hareni et al., 2021; Pekkanen et al., 2013; Sivaganesan et al., 2020; Strömqvist et al., 2013; Werner et al., 2020). However Feng et al., for example, reported in their systematic review that the baseline ODI score of disc herniation patients who had undergone surgery varied between 30 and 70 (Feng et al., 2024). Fritch et al. also found great variation in preoperative functioning among patients with spinal stenosis, and Koenders et al. reported similar variability in other degenerative conditions of the spine (Fritsch et al., 2017; Koenders et al., 2016).

Changes in functioning have also varied greatly. For example, Fritch et al. found that the average ODI value one year after surgery was 35 % of the preoperative value. However, Lee et al. reported that one year after surgery, the ODI value was only 29 % of the preoperative value (Lee et al., 2022). Furthermore, Hareni et al. reported that the ODI value was 55–64 % of the preoperative value one year after surgery (Hareni et al., 2021).

Several studies have investigated the average level of functioning and its changes after surgery, but only a few studies have investigated whether groups exist within the studied populations whose functioning changes abnormally (Carrasco et al., 2020; Hebert et al., 2019; Wang et al., 2022). For example, Hébert et al. used the group-based trajectory analysis (GBTA) in their study. This statistical method, instead of assuming that the functioning of all patients will follow similar developmental trajectories after surgery, distinguishes patients whose trajectories of functioning follow similar paths to each other (Hebert et al., 2019; Nagin, 2005). They identified three separate groups in which the changes in functioning varied in relation to each other. In their study, 31 % of the patients belonged to a group in which the ODI value was only 20 % of the preoperative value one year after the operation, that 40 % belonged to a group in which the ODI value was 58 % of the preoperative value one year after the operation, and that 29 % belonged to a group in which the ODI value was 86 % of the original value one year after the operation.

2.6 Relationship between back pain and functioning

Back pain and functioning often both improve after lower spine surgery (Fritsch et al., 2017; Hareni et al., 2022; Lee et al., 2022). Several studies have found that changes in back pain and functioning often occur simultaneously implying that logically a reduction in back pain improves functioning (Doualla et al., 2019; Ogunlana et al., 2015; Sirbu et al., 2023). However, many studies have also suggested that pain and functioning are only weakly related to each other and should be thought of as separate phenomena (DeVine et al., 2011; Kovacs et al., 2004; Millard et al., 1991; Stefane et al., 2013; Waddell, 1987, 1992).

2.7 Factors that affect changes in back pain and functioning after lumbar spine surgery

2.7.1 Preoperative pain intensity

Previous studies have associated stronger preoperative back pain intensity with stronger back and leg pain and greater restrictions to functioning, also after surgery (Anwar et al., 2024; Carrasco et al., 2020; Iversen et al., 1998; Jacob et al., 2023). However, one study has also reported patients having the same level of functioning after surgery, regardless of the initial level of their pain (Virk et al., 2020). In other studies, the change in pain and functioning has been equal to or greater than that among patients with less preoperative pain (Anwar et al., 2024; Jacob et al., 2021). However, Carrasco et al. reported that more severe preoperative back or leg pain also predicted less benefit from surgery (Carrasco et al., 2020). Thus, the level of preoperative back pain does not seem to predict the outcome of surgery.

This is logical, as the degenerative process cannot be stopped by surgery. Back pain alone is usually not an indication for disc herniation or spinal stenosis surgery. In fusion surgery, back pain can be an indication for surgery, for example in spondylolisthesis patients whose spine is otherwise in good condition. Another group in which back pain can be an indication for surgery are patients with spinal deformities. In these patients, the position of the spine is corrected with extensive surgery.

2.7.2 Preoperative level of functioning

Patients with worse preoperative functioning have been reported to also have poorer postoperative functioning, and more severe back pain, and leg pain (Dorow, Löbner, et al., 2017; Hébert et al., 2020; Jacob et al., 2022). However, one study published in the 1990s found poorer preoperative functioning to be associated with an equal or even greater improvement in functioning and pain after surgery (Iversen et al., 1998). Interestingly, a few studies have also found an association between better preoperative functioning and postoperative functional deterioration (Nerland et al., 2015; Solberg et al., 2004). Exactly how the preoperative level of functioning affects surgical results remains uncertain (Halicka et al., 2022b).

2.7.3 Duration of preoperative pain

Longer preoperative pain duration has been associated with worse back and leg pain and greater restrictions to functioning, also after surgery (Celestin et al., 2009; Cushnie et al., 2019; Hébert et al., 2020; Ng et al., 2007; Radcliff et al., 2011). However, some studies have not found a longer duration of symptoms to be associated with a poorer surgical outcome (Halicka et al., 2022b; Zweig et al., 2017). The evidence of whether the duration of preoperative pain affects the intensity of postoperative pain and functioning is still conflicting.

2.7.4 Age

Older age has been associated with worse surgical outcomes in previous studies (Celestin et al., 2009; Dorow, Loebner, et al., 2017; Halicka et al., 2022a; Rihn et al., 2015). In particular, age-related comorbidities, extended surgery time, and longer hospital stays can increase the risk of surgery (Kleimeyer, 2024; Murphy et al., 2017; Tan et al., 2019). Several studies have reported that even the elderly benefit significantly from surgery (Gerhardt et al., 2018; Katz et al., 1999; Nanjo et al., 2013; Rihn et al., 2015). As recently as 2024, evidence of the effect of age on surgical outcome was reported to be mainly weak (Kleimeyer, 2024). It therefore seems that it is also worth treating the elderly with surgery if the limitations in functioning are due to problems with the spine and the risks of surgical treatment are acceptable compared to the expected benefit.

2.7.5 Sex

Previous studies have reported that female sex is associated with poorer functioning and worse pain after low back surgery (Donnarumma et al., 2016; MacLean et al., 2020; Siccoli et al., 2018). Gehrchen et al. claim that women report lower satisfaction, slower return to work, and more pain medication use than men after lumbar spine surgery (Gehrchen et al., 2002). However, several studies have found that although female sex has been associated with worse postoperative pain and functioning, the changes in pain and functioning after surgery have been of the same magnitude or even greater than among men (MacLean et al., 2020; Nolte et al., 2021; Siccoli et al., 2018; Triebel et al., 2017). In addition, a systematic review published in 2022 reported that only 55% of studies found that women had worse pain and poorer functioning after back surgery (Salamanna et al., 2022). Thus, sex does not seem to predict the outcome.

2.7.6 Overweight

Obesity has been associated with worse postoperative back pain and functioning (Ghobrial et al., 2022; Knutsson et al., 2013; Nie et al., 2023; Park et al., 2020; Rihn et al., 2012). Obesity also increases surgery-related risks (Jiang et al., 2014). For example, a recent systematic review found that in almost all studies, patients with a BMI of less than 30 had a greater improvement in ODI than patients with a BMI of more than 30. However, patients with a BMI of more than 30 also benefited significantly from surgery (Ghobrial et al., 2022). Similar results were reported in a systematic review published in 2016. In their study, patients with a BMI below 30 had better outcomes after surgery at four years of follow-up. This difference was seen in patients with disc herniation, spinal stenosis, and spondylolisthesis. However, in their study also, even though overweight patients did not benefit as much, they still had significant improvement from surgery (JacksonIi et al., 2016). BMI>30 seems to be a cutoff for a worse outcome from surgery (Park et al., 2020). However, in several studies, the postoperative functioning or pain of overweight people has not been worse than that of people with normal weight (Divi et al., 2020; Hébert et al., 2020; Lingutla et al., 2015; Nakajima et al., 2023; Nerland et al., 2015). Studies have been published where even patients with a BMI over 35 or have received significant benefit from surgery (Divi et al., 2020; Zammar et al., 2024).

2.7.7 Depression

Several studies have found preoperative depression to be associated with more severe back pain and poorer functioning after back surgery (Aalto et al., 2006; Hébert et al., 2020; Held et al., 2022; Iversen et al., 1998; McKillop et al., 2014; Sinikallio et al., 2009). For example, among spinal stenosis patients, even mild depressive symptoms seemed to increase the risk of worse postoperative pain and poorer functioning over a ten-year follow up (Tuomainen et al., 2017). Only a few studies, have found no association between depression and a poorer surgical outcome (Ng et al., 2007).

2.7.8 Smoking

Previous studies have also associated smoking with more severe back pain and worse functioning after surgery (Gulati et al., 2015; Hareni et al., 2021; Holmberg et al., 2020). Not smoking has also been associated with better functioning, measured using the ODI, after spinal stenosis surgery (Aalto et al., 2012). The adverse effect of smoking on surgical outcomes is not surprising, as it is known to significantly affect several stages of bone healing and repair (Berman et al., 2017; Hadley et al., 1997; Jackson et al., 2016; Khurana, 2021). However, significant improvement in pain and functioning following surgery has also been observed among smokers (Gulati et al., 2015).

3 Aims

The aims of this thesis were:

1. To validate the ODI among patients who have undergone lumbar spine surgery (Study I).
2. To investigate changes in the functional profile of patients who have undergone lumbar spine surgery (Study II).
3. To investigate whether groups of lumbar spine surgery patients can be distinguished in which leg or back pain or functioning changes differently, and to identify the factors that increase the probability of a patient being classified into a specific trajectory group (Study III).
4. To investigate whether groups exist in which back and neck pain change simultaneously after lumbar spine surgery, and to identify the factors that increase or decrease the probability of a patient being classified into a specific trajectory group (Study IV).

The hypotheses were:

1. The ODI will be a valid, reliable measure of disability in patients undergoing lumbar spine surgery (I)
2. The functioning of patients who have undergone lumbar spine surgery will change unevenly across functional domains (II).
3. Patients who have undergone lumbar spine surgery can be divided into groups on the basis of their changes in pain and functioning. Some demographic factors influence the likelihood that a given patient will be classified into a particular trajectory group (III).
4. The changes in neck and back pain or in restrictions to functioning caused by them after lumbar spine surgery will follow similar trajectories, at least in some patient groups. Some demographic factors will influence the likelihood that a given patient will be classified into a particular trajectory group (IV).

4 Materials and Methods

4.1 Study cohort

The data were collected from patients who had undergone any type of lumbar spine surgery at Turku University Hospital between June 21, 2018, and August 17, 2021. Patients were included in the study if they had undergone any of the operations listed in Table 2. Patients who had undergone any other surgery during the two-year follow up were excluded.

The patients responded to a questionnaire on their demographics, pain, and functioning. (Marjamaa et al., 2023). The patients received a protected link to the survey. Some of the data were provided by doctors and nurses and some were retrieved from electronic patient databases. The patients responded to the survey: ≤2 months before surgery; 2–4 months after surgery; 11–13 months after surgery, and 23–25 months after surgery.

Table 2. Procedure codes according to Nordic classification of surgical procedures (NCSP) version 1.15

SURGERY CODES	PROCEDURE
ABC07[A]	Percutaneous endoscopic discectomy for lumbar intervertebral disc displacement
ABC16[A]	Microsurgical excision of lumbar intervertebral disc displacement
ABC26[A]	Open discectomy of lumbar spine
ABC36	Decompression of lumbar nerve roots
ABC56	Decompression of lumbar spinal canal and nerve roots
ABC66	Decompression of lumbar spinal channel
NAG61	Posterior fusion of lumbar spine without fixation
NAG62	Posterior fusion of lumbar spine with fixation, 2-3 vertebrae
NAG63	Posterior fusion of lumbar spine with fixation >3 vertebrae
NAG66	Posterior interbody fusion of lumbar spine, 2 vertebrae
NAG67	Posterior interbody fusion of lumbar spine >2 vertebrae
NAJ32[A]	Posterior reduction of fracture of lumbar spine

[A] Only included in Studies I and IV

4.1.1 Variables used in the analysis

Age was calculated in full years on the day of surgery. BMI was calculated on the basis of the patient's self-reported height and weight in kg/m^2, and divided into two categories: <30 kg/m^2 and ≥30 kg/m^2. Sex was dichotomized into male and female. Leg and back pain duration was defined as <6 weeks, 6–12 weeks, 3–12 months and >12 months before surgery in Study I. Pain duration was dichotomized as ≤1 year vs. >1 year in Studies II to IV.

Back, leg and neck pain intensity were measured using VAS, in which 0 indicated "no pain" and 100 indicated "pain as bad as it could be". The VAS values were classified as follows: 0–4 points: "no pain"; 5–44 points: "mild pain"; 45–74 points: "moderate pain"; and 75–100 points: "severe pain" (Jensen et al., 2003).

Back pain-caused restrictions to functioning were measured using the ODI, Finnish version 2.0 (Pekkanen, Kautiainen, Ylinen, Salo, & Hakkinen, 2011). The ODI contains questions about different areas of functioning. Each of its ten questions has six response options on a scale of 0 to 5. Zero means no restrictions to functioning and 5 means the worst possible disability in that area of functioning. (Fairbank et al., 1980; Fairbank et al., 2000). The total ODI score is calculated by adding the item-specific scores together, dividing this number by the maximum score (i.e., fifty), and multiplying the result by one hundred. The ODI results were interpreted as follows: 0–20 points: Minimal disability, 21–40 points: Moderate disability, 41–60 points: Severe disability, 61–80 points: Crippled, 81–100 points: Bedbound. In Study IV, the term "crippled" was changed to the more appropriate term "housebound". In Study IV, the Neck Disability Index (NDI) was also interpreted on the same scale as the ODI (Vernon et al., 1991).

4.2 Statistical analysis

The descriptive statistics were presented as means and standard deviations, absolute numbers and percentages, or as medians and interquartile ranges. The statistical significance level was set at 0.05, and when appropriate, 95% confidence intervals (95% CI) were presented with the estimates.

4.2.1 Group-based trajectory analysis (Studies III and IV)

The GBTA is a finite mixture modeling application that is used to separate individuals whose changes follow similar trajectories and to cluster them into groups. Whereas traditional statistical methods only show the average trajectory of change, the GBTA is able to detect subgroups in the studied cohort, the trajectories of which are different from each other or from the average. In this thesis, the GBTA was used to identify groups among the patients who had undergone low back surgery in whom leg and back pain and functioning changed abnormally in comparison to the average population (Studies III and IV). In addition, Study IV investigated whether back pain and neck pain or functional limitation due to back pain and functional limitation due to neck pain followed similar trajectories after lumbar spine surgery.

The number of clusters and the regression order were determined by trying from one to four clusters and from first- to third-order regression models (Figure 4). The highest possible regression order with a significant p-value of <0.05 was chosen. In this thesis, the smallest possible cluster was set at ten % of the cohort. The cut-off for the Average Posterior Probability (APP) was set at 0.7. The goodness-of-fit of the selected model was checked by calculating the Akaike Information Criterion (AIC) and Bayesian Information Criterion (BIC), preferring estimates close to zero. After identifying the clusters, the probability of belonging to a group in terms of age, sex, obesity, and preoperative pain duration was calculated using multinomial regression analysis. This probability was expressed as a Relative Risk Ratio (RRR) and its 95% CI.

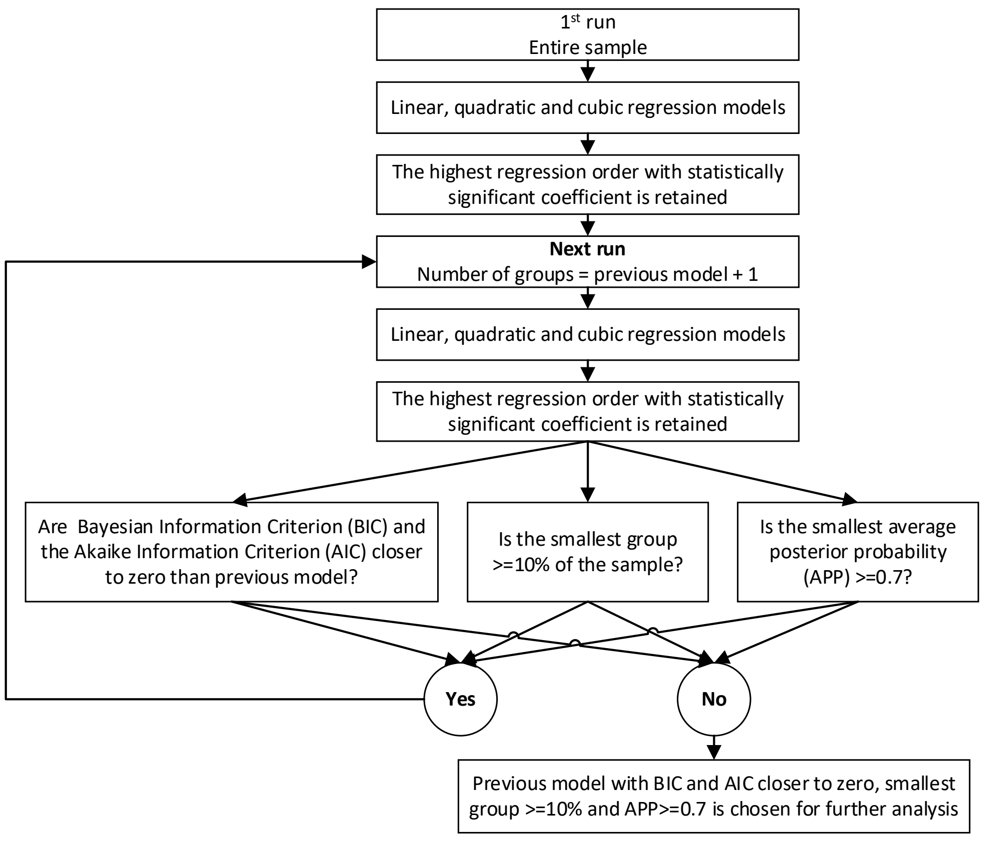

Figure 4. Group-based trajectory analysis. Reproduced from Study IV.

4.2.2 Reliability and validity of ODI and changes in functional profile (Studies I and II)

Cronbach's alpha was used to examine the internal consistency of the ODI. An alpha of $\alpha \geq 0.9$ was considered excellent, $0.9 > \alpha \geq 0.8$ good, $0.8 > \alpha \geq 0.7$ acceptable, $0.7 > \alpha \geq 0.6$ questionable, $0.6 > \alpha \geq 0.5$ poor, and $\alpha < 0.5$ unacceptable. Sensitivity testing was conducted by removing each item, one at a time.

To investigate whether the ODI measures only one latent trait, exploratory factor analysis (EFA) was used. The data were randomly divided into two equal age- and sex-adjusted parts, the first of which was used for EFA and the second for confirmatory factor analysis (CFA). EFA (principal factors) was applied with a minimum eigenvalue for retention set at >1.0 (Kaiser's rule) (Kaiser, 1960).

CFA was used to verify the construct structure seen in the EFA. The results of the CFA were reported as correlation coefficients. A correlation of <0.2 was considered poor, 0.21–0.4 fair, 0.41–0.6 moderate, 0.61–0.8 substantial, and >0.8 perfect (Akoglu, 2018).

To determine how well the model fit the data, the Root Mean Square Error of Approximation (RMSEA) was used. First, the model fit was tested by assuming that there were no covariances between unique factors, then the software-suggested covariance indices were used to add covariances between factors one at a time, each time testing the lower 90% CI of the RMSEA closeness to 0.05 and the upper 90% CI closeness to 0.10. The probability that the RMSEA was ≤0.05 was also reported. After finding a suitable RMSE value, no more covariances were imputed and the overall goodness-of-fit was evaluated using a chi square test, which compared the used model with the theoretically best model. The results were supported by the AIC, the BIC, the comparative fit index, the Tucker–Lewis index, the standardized root mean squared residual, and the coefficient of determination.

The significance of the change in the ODI total score was assessed by a symmetry test, which indicated the p-values and Chi square statistics for an asymptotic symmetry test and the Stuart–Maxwell test for marginal homogeneity. Due to abnormal distribution, the significance of the change in the ODI total score was assessed by median regression. Quantile regression was used to examine item-specific changes. All the analyses were conducted using Stata/IC Statistical Software Releases 17 and 18. College Station (StataCorp LP, TX, USA)

4.2.3 Population heterogeneity

The thesis covered heterogeneous surgical techniques and indications for surgery. In Study I, the impact of this heterogeneity on the performance of the ODI was investigated by subgroup analysis, dividing the sample into two groups: the "discectomy" group (ABC07, ABC16, ABC26) and the "decompression" group

(ABC36, ABC56, ABC66, NAG61, NAG62, NAG63, NAG66, NAG67). In Study III, the sensitivity test compared patients who had undergone fusion surgery (NAG61, NAG62, NAG63, NAG66, NAG67) with those who had not (ABC36, ABC56, ABC66). In Study IV, a sensitivity analysis compared the initial situation and the surgical methods used among the older with those used among the younger patients, men and women, and patients with longer and shorter preoperative back pain duration.

5 Results

5.1 The data

The data were collected from patients who had undergone any type of lumbar spine surgery at Turku University Hospital between June 21, 2018, and August 17, 2021. The amount of baseline data available depended on the study-specific data required for the analyses in each article (Table 3). In studies II and III, preoperative data were available for 1,439 patients, data from the three-month follow-up point was available for 708 patients (49%), data from the one-year follow-up point was available for 824 patients (57%), and data from the two-year follow-up point was available for 413 patients (29%).

5.2 Descriptive characteristics, surgical techniques and diagnoses

The baseline characteristics of the studied cohort are presented in Table 3. The distribution of different surgical techniques in the different studies is presented in Table 4. The main diagnoses of the patients by study are presented in Table 5.

Table 3. Baseline characteristics of the study population.

CHARACTERISTIC	STUDY			
	I	II	III	IV
	MEAN (SD)			
N	1515	1451	1451	1627
Age, years	58.5 (15.8)	66.9 (12.1)	66.9 (12.1)	61.1 (15.6)
Age group 1, years	-	-	50.2 (8.5)	48.4 (11.7)
Age group 2, years	-	-	64.6 (2.9)	73.7 (5.7)
Age group 3, years	-	-	72.5 (1.8)	-
Age group 4, years	-	-	80.2 (3.2)	-
Body mass index, kg/m^2	28.5 (5.0)	28.9 (4.9)	28.9 (4.9)	28.7 (5.1)
Back pain intensity, points	60.4 (26.8)	58.9 (26.8)	58.9 (26.8)	59.5 (26.9)
Leg pain intensity, points	-	63.6 (26.3)	63.6 (26.3)	64.1 (26.7)
Total ODI score, points	43.4 (17.4)	41.9 (16.9)	41.9 (16.9)	43.4 (16.5)
Total NDI score	-	-	-	28.3 (17.4)
	N (%)			
Sex				
Female	809 (53%)	793 (55%)	793 (55%)	856 (53%)
Male	706 (47%)	658 (45%)	658 (45%)	771 (47%)
Pain duration before surgery				
≤1 year	681 (46%)	567 (39%)	567 (39%)	804 (49%)
>1 year	801 (54%)	884 (61%)	884 (61%)	823 (51%)

Table 4. Distribution of different surgical techniques in Studies I to IV.

SURGERY CODES[a,b]	STUDY			
	I	II	III	IV
ABC16 Microsurgical excision of lumbar intervertebral disc displacement	439 (29%)	-	-	411 (26%)
ABC36 Decompression of lumbar nerve roots	297 (20%)	-	418 (29%)	327 (21%)
NAG62 Posterior fusion of lumbar spine with fixation, 2–3 vertebraea	282 (19%)	-	370 (26%)	321 (21%)
ABC56 Decompression of lumbar spinal canal and nerve roots	271 (18%)	-	412 (28%)	306 (20%)
Others	226 (15%)	-	251 (17%)	192 (12%)

[A]Nordic Classification of Surgical Procedures (NCSP), version 1.15

[B]In Study II, the surgery codes were divided into three categories: Decompression: ABC36, ABC56, ABC66 N=856 (59%), Fusion: NAG62, NAG63, NAG66 N=573 (39%), and Others N=22 (1%)

Table 5. Main diagnoses in Studies I to IV.

MAIN DIAGNOSES[C]	STUDY			
	I	II	III	IV
M48 Spondylopathies	570 (38%)	862 (59%)	862 (59%)	682 (42%)
G55/M51 Intervertebral disc disorders	586 (39%)	144 (10%)	144 (10%)	552 (34%)
M43 Deforming dorsopathies	189 (12%)	224 (15%)	224 (15%)	196 (12%)
M47 Spondylosis	86 (6%)	114 (8%)	114 (8%)	102 (6%)
Others	84 (6%)	107 (7%)	107 (7%)	95 (6%)

[C]International Classification of Diseases ICD-10

5.3 Changes in functioning and pain severity (Studies III and IV)

In Study III, two trajectory groups were observed for all three variables of functioning, back pain and leg pain: the long-term improvement group and the short-term improvement group (Figures 5-7). Most patients belonged to the long-term improvement group.

Regarding functioning, 83% of the patients belonged to the long-term improvement group and 17% to the short-term improvement group (Figure 5). In the long-term improvement group, the preoperative mean disability level measured with the ODI was moderate at 36.7 (95% CI 35.5 to 37.9) and changed to a minimal of 15.0 (95% CI 13.0 to 17.1) after surgery. In this group, restrictions to functioning remained minimal until the end of the two-year follow up. In the short-term improvement group, the mean preoperative ODI score was 57.6, and although functioning improved near the limit of moderate disability after surgery, disability remained severe, at 41.6 (95% CI 38.1 to 45.0), and had worsened slightly at two-year follow up, ultimately reaching 46.5 (95% CI 42.7 to 50.3). However, even in the short-term improvement group, patients experienced significant improvement in functioning even after two years.

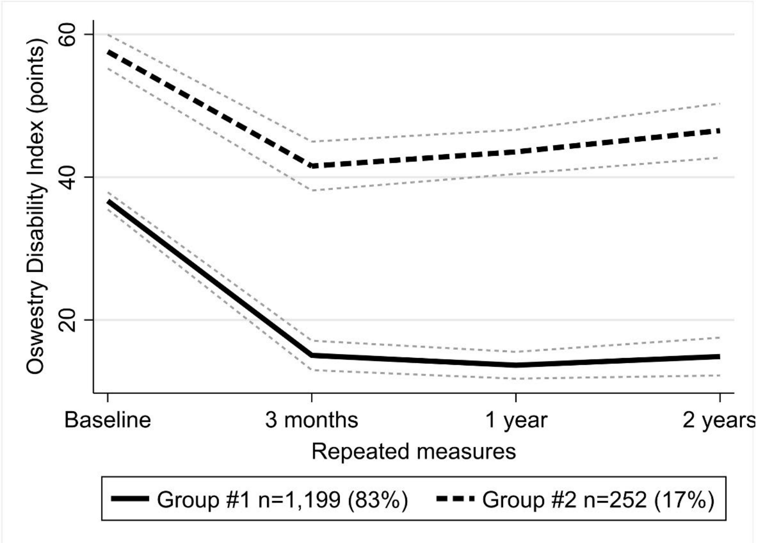

Figure 5. Trajectories of disability measured with the ODI. Originally published in PLOS ONE. Reproduced under CC-BY NC license.

Leg pain and back pain changed in very similar ways (Figures 6 and 7). For example, for back pain, 69% of patients were in the long-term improvement group and 31% in the short-term group (Figure 6). In the long-term improvement group, the level of preoperative mean pain was moderate, at 51.9 (95% CI 47.9 to 55.9) and changed to mild, at 16.1 (95% CI 12.8 to 19.3) after surgery. In this group, back pain remained at approximately the same level until the end of the two-year follow up. In the short-term improvement group, the mean level of preoperative back pain was moderate, at 68.0 (95% CI 62.8 to 73.2), and although it improved after surgery, pain had worsened to the preoperative level at two-year follow up, eventually reaching 66.0 (95% CI 59.4 to 72.6).

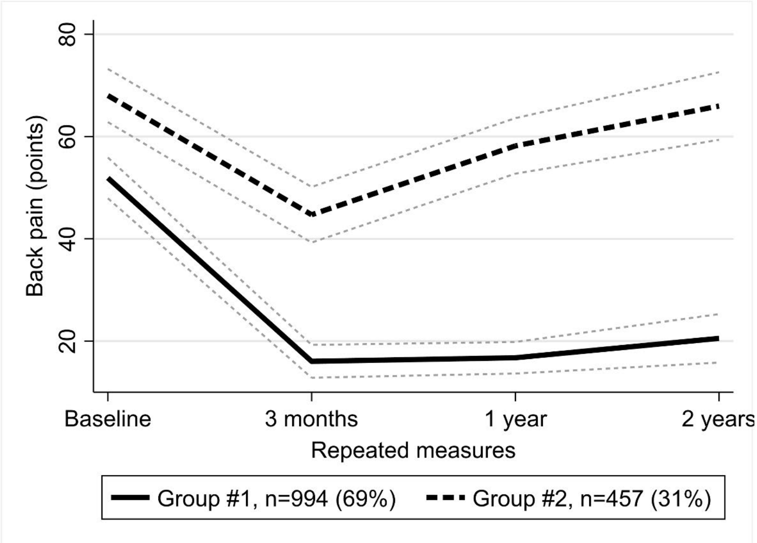

Figure 6. Trajectories of back pain. Originally published in PLOS ONE. Reproduced under CC-BY NC license.

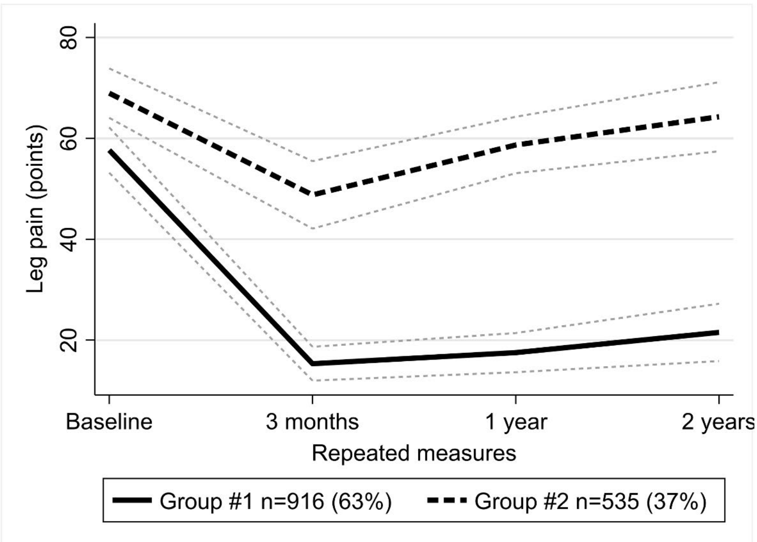

Figure 7. Trajectories of leg pain. Originally published in PLOS ONE. Reproduced under CC-BY NC license.

In Study IV, a larger group (82%) experienced significant improvement in back pain after surgery, and a smaller group (18%) experienced only a short-term benefit from surgery, after which pain returned to near preoperative levels (Figure 8). The group who benefited long-term from surgery had a preoperative moderate back pain level of 55.9 points (95% CI 52.6 to 59.2), which improved rapidly after surgery and remained mild throughout the follow up. The patients in this group preoperatively had almost no neck pain concomitant with back pain, and their neck pain remained low throughout follow up. The group that only obtained short-term benefit from surgery had preoperative moderate back pain (67.8, 95% CI 61.7 to 73.9) and moderate neck pain (53.9, 95% CI 49.5 to 58.2). In this group, both back and neck pain eventually returned to near the preoperative pain level.

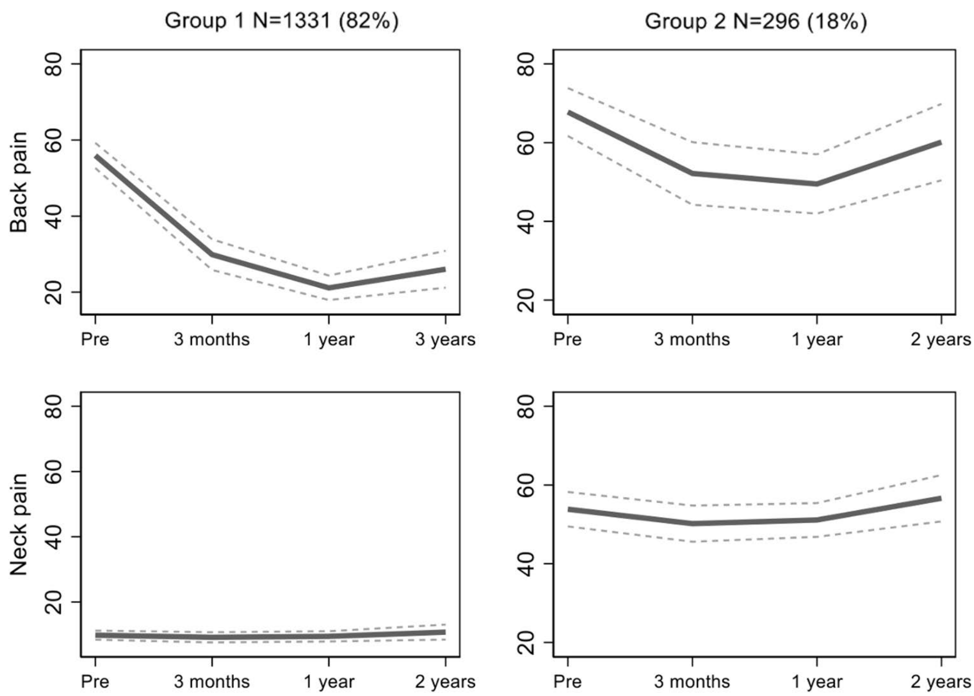

Figure 8. Simultaneous changes in back pain and neck pain. Reproduced from Study IV.

Study IV observed three distinct groups for back pain-related restrictions to functioning and neck pain-related restrictions to functioning (Figure 9). The largest group (56%) of patients preoperatively experienced moderate back pain-related disability (32.7, 95% CI 31.0% to 34.4%) and minimal neck pain-related disability (15.7, 95% CI 13.6% to 17.9%). In this group, both back pain- and neck pain-related disability had improved at the first postoperative measurement point and continued to improve throughout follow up. The second group (33%) consisted of patients who had experienced severe disability due to back pain (48.4, 95% CI 46.3% to 50.5%) and moderate limitations due to neck pain (36.4, 95% CI 34.0% to 38.7%) before surgery. In this group, both back and neck pain-related disability decreased after surgery, but was slightly worse at the end of follow up, though still better than preoperatively. The third group was the smallest (11%), and its patients were classified preoperatively as housebound due to a back pain-related disability score of 64.9 (95% CI 61.3% to 68.5%), and a severe neck pain-related disability score of 56.7 (95% CI 53.8% to 59.6%). In this small group, a slight improvement in back pain-related disability, but not in neck pain-related disability, was observed.

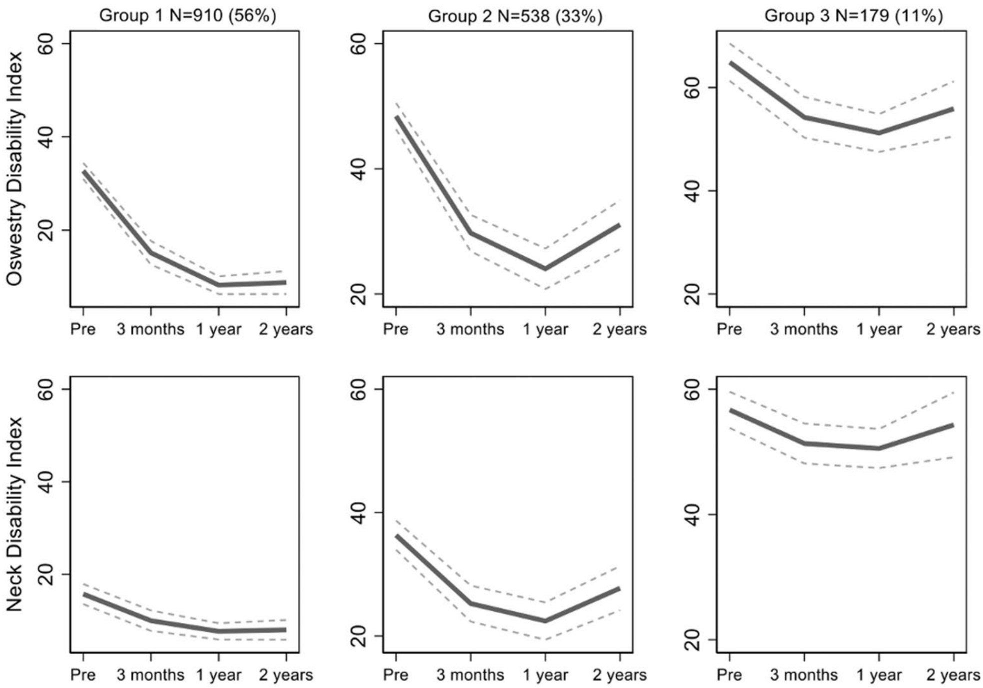

Figure 9. Concurrent changes in ODI and NDI. Reproduced from original Study IV.

Those in the short-term improvement groups had worse pain, worse preoperative restrictions to functioning, and overweight (Table 6 and 7). In addition, female sex, older age, and longer preoperative pain duration were characteristic of those in the groups in which little improvement was observed when neck pain and disability due to neck pain was included in the analyses (Table 7).

Table 6. Relative risk ratios (RRRs) of being classified to a short-term improvement group. Originally published in PLOS ONE. Reproduced under CC-BY NC license.

Variable/group	RRR	95% CI	
Groups based on disability level			
Women vs. men	1.00	0.76	1.32
Pain duration >=3 months vs. <3 months	1.09	0.82	1.45
BMI ≥30 vs. BMI <30	**1.45**	**1.10**	**1.90**
Age (older vs younger)	1.06	0.81	1.39
Groups based on back pain severity			
Women vs. men	1.09	0.87	1.37
Pain duration >=3 months vs. <3 months	**1.28**	**1.01**	**1.61**
BMI ≥30 vs. BMI <30	**1.32**	**1.05**	**1.65**
Age (older vs younger)	0.86	0.69	1.07
Groups based on leg pain severity			
Women vs. men	1.17	0.94	1.45
Pain duration >=3 months vs. <3 months	1.05	0.84	1.31
BMI ≥30 vs. BMI <30	**1.26**	**1.02**	**1.56**
Age (older vs younger)	1.13	0.92	1.40

Table 7. Relative risk ratios (RRRs) adjusted for age and gender of being classified to a certain trajectory group.

Factors & groups	RRR	95% CI	
Back pain & Neck pain			
Women vs. men			
Group 1	1.00	1.00	1.00
Group 2	**1.54**	**1.19**	**1.99**
Age (older vs. younger)			
Group 1	1.00	1.00	1.00
Group 2	**1.30**	**1.01**	**1.68**
Pain duration ≥3 months vs. <3 months			
Group 1	1.00	1.00	1.00
Group 2	**1.51**	**1.17**	**1.96**
BMI ≥30 vs. BMI <30			
Group 1	1.00	1.00	1.00
Group 2	1.27	0.98	1.63
Disability caused by back pain & Disability caused by neck pain			
Women vs. men			
Group 1	1.00	1.00	1.00
Group 2	1.13	0.92	1.41
Group 3	1.32	0.95	1.82
Age (older vs. younger)			
Group 1	1.00	1.00	1.00
Group 2	**0.76**	**0.62**	**0.95**
Group 3	0.84	0.61	1.15
Pain duration >=3 months vs. <3 months			
Group 1	1.00	1.00	1.00
Group 2	1.07	0.86	1.32
Group 3	**1.54**	**1.11**	**2.15**
BMI ≥30 vs. BMI <30			
Group 1	1.00	1.00	1.00
Group 2	**1.36**	**1.09**	**1.68**
Group 3	**1.44**	**1.04**	**1.98**

5.4 Changes in functional profile (Study II)

In Study II, the median preoperative ODI total score was 40 (IQR 30 to 54); three months postoperatively, 18 (IQR 8 to 30); one year postoperatively, 18 (IQR 6 to 30); and two years postoperatively, 20 (IQR 6 to 34). Statistically significant improvement was seen in all items of the ODI, but the changes in the different items were of different magnitudes (Figures 10 and 11). Even though the change in the "sleeping" item was statistically significant, it was so small that it is not graphically visible. The largest changes were seen in the "standing" and "social life" items.

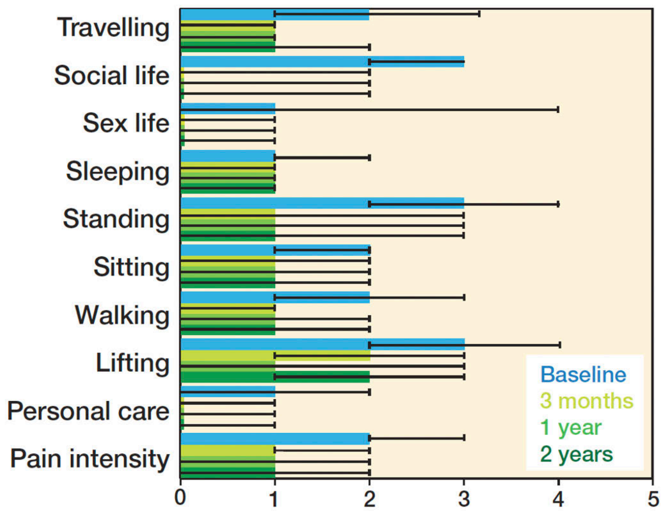

Figure 10. Change in functional profile with 95% CI. Originally published in Acta Orthopaedica. Reproduced under CC-BY NC license.

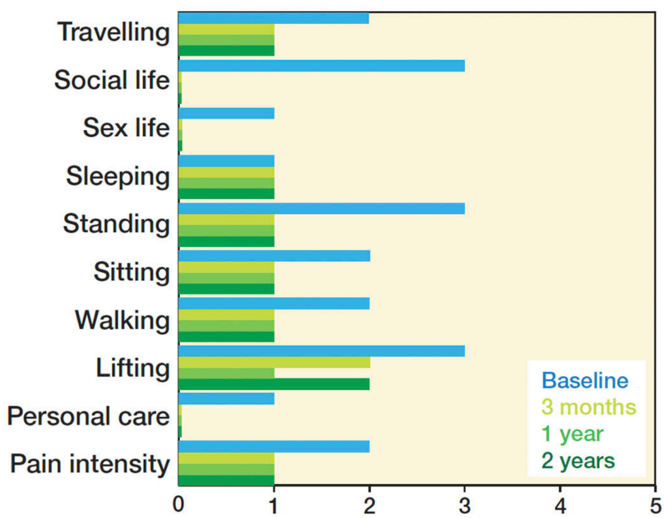

Figure 11. Change in functional profile. Figure for clinical use. Originally published in Acta Orthopaedica. Reproduced under CC-BY NC license.

5.5 Reliability and validity of the ODI (Study I)

A Cronbach's alpha of 0.87 (95% CI 0.86 to 0.88) was considered good. All items showed good item-test and item-rest correlations. Excluding one item at a time did not contribute to an improvement in the alpha.

The EFA showed one factor structure of the ODI, with one factor retaining a 4.02 eigenvalue (Figure 12). Item loadings ranged from 0.52 to 0.76, and all were acceptable.

The CFA confirmed the single-factor structure. The correlations between the main factor of the ODI—disability—and the individual items were all acceptable (Figure 13). The strongest correlations were found with "traveling" (0.76), "personal care" (0.74) and "social life" (0.69). The weakest correlation was with "standing" (0.44).

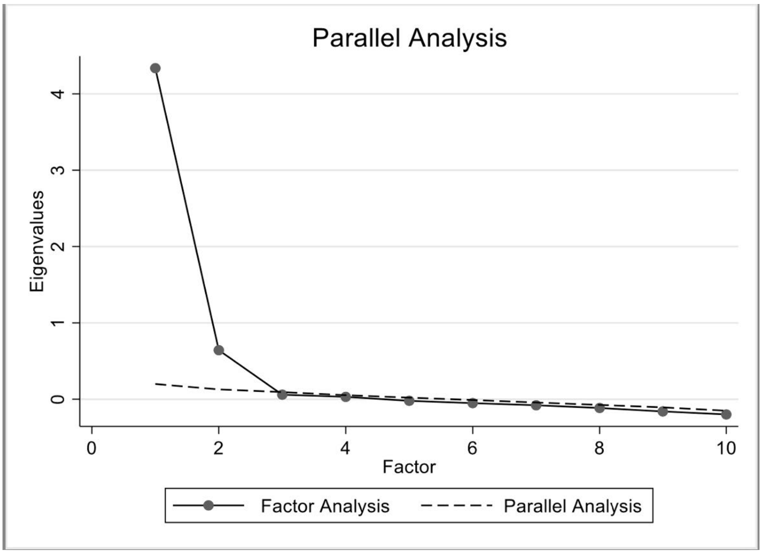

Figure 12. Factor structure of ODI among patients who had undergone lumbar spine surgery, examined using EFA. Originally published in BMC Surgery. Reproduced under CC-BY NC license.

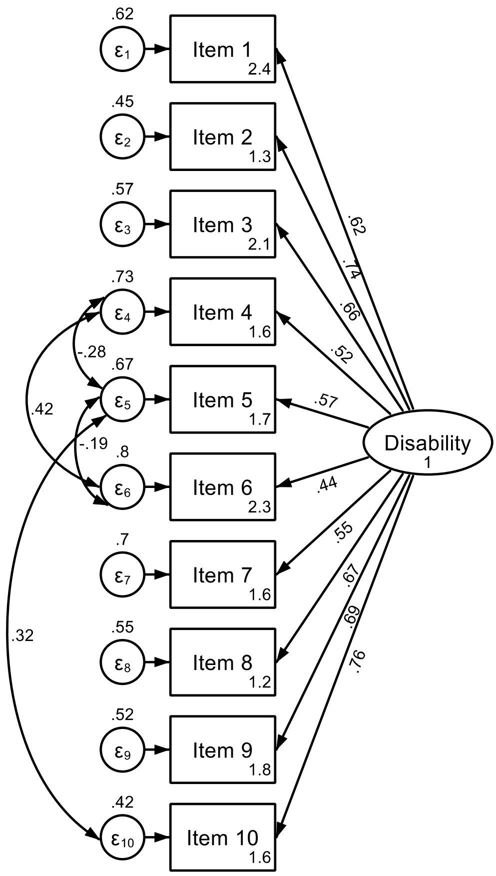

Figure 13. Correlation coefficients between main factor—disability—of ODI and individual items among patients who had undergone lumbar spine surgery, examined using CFA. Originally published in BMC Surgery. Reproduced under CC-BY NC license.

5.6 Population heterogeneity

In Study I, Cronbach's alpha was 0.88 in the discectomy group (95% CI 0.86 to 0.90) and 0.86 in the decompression group (95% CI 0.85 to 0.88). In addition, the EFA and CFA values of these two groups were very similar.

In Study III, the trajectories obtained from the fusion vs. no-fusion sensitivity analysis were closely in line with the trajectories of the population as a whole (Figures 5 to 7 and 14 to 19). Among both the fusion and non-fusion patients, overweight was the major predictor of belonging to the short-term improvement group, as it was in the cohort as a whole (table 8).

In Study IV, older patients were diagnosed with more "M48 Spondylopathies" than younger patients (60% vs. 14%). Younger patients had more "M51 intervertebral disc disorders" (61% vs. 16%). Of the surgical techniques, "ABC16 microsurgical excision of lumbar intervertebral disc displacement" was more common among the younger patients (49% vs. 10%). Decompression was used more often to treat older patients (26% vs. 12% for "ABC36" and 28% vs. 5% for "ABC56"). There were no significant differences between sex in absolute numbers. Patients with longer pain duration had more "M48 Spondylopathies" than those with shorter pain duration (52% vs. 32%). Those with shorter pain duration had more "M51 intervertebral disc disorders" than those with longer preoperative pain duration (50% vs. 18%). "ABC16 Microsurgical excision of lumbar intervertebral disc displacement" was used more frequently to treat patients with shorter preoperative pain duration (49% vs. 10%). Decompression and fusion techniques have been more frequently used to treat patients with longer preoperative pain duration (23% vs. 15% for "ABC56" and 27% vs. 12% for "NAG62"). However, the trajectories of concurrent changes in neck and back pain were similar in the comparison groups (Figures 14 to 19). That is, even though patients were divided into smaller groups based on age, gender, and duration of preoperative pain, similar trajectories were observed as when all patients were analyzed together.

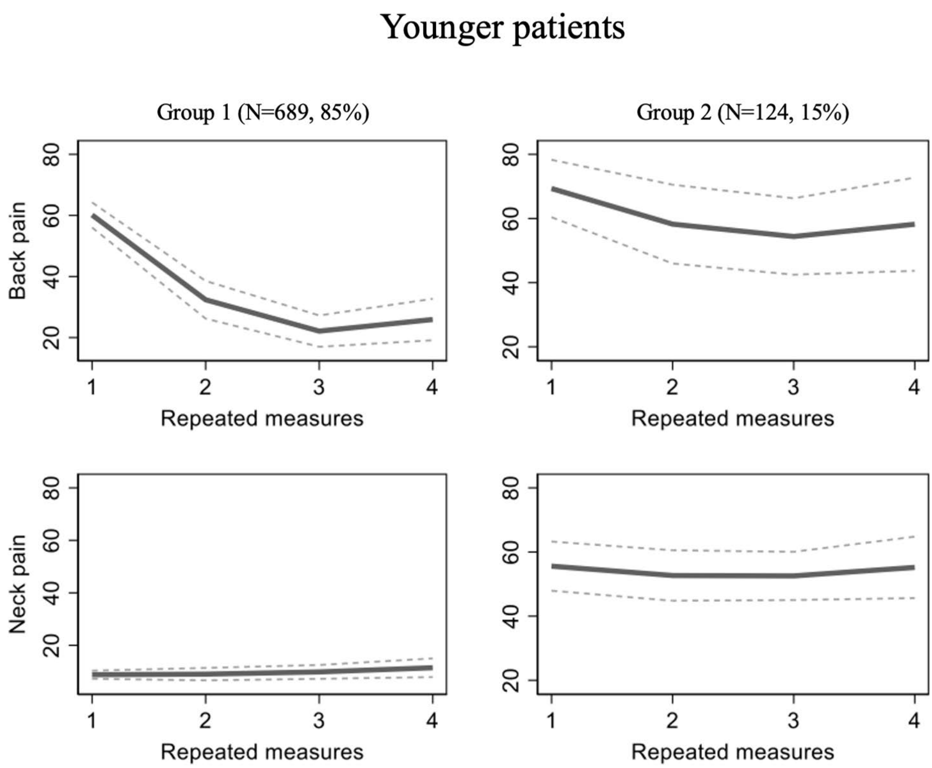

Figure 14. Trajectories of back and neck pain by age, younger patients. The mean age of younger patients was 48.4 (SD 11.7). Reproduced from original Study IV.

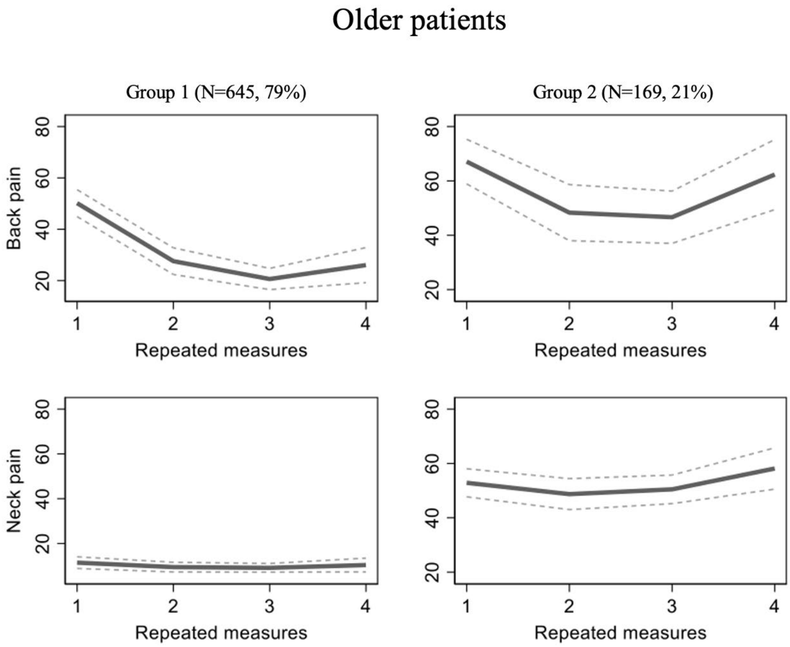

Figure 15. Trajectories of back and neck pain by age, older patients. The mean age of older patients was 73.7 (SD 5.7). Reproduced from original Study IV.

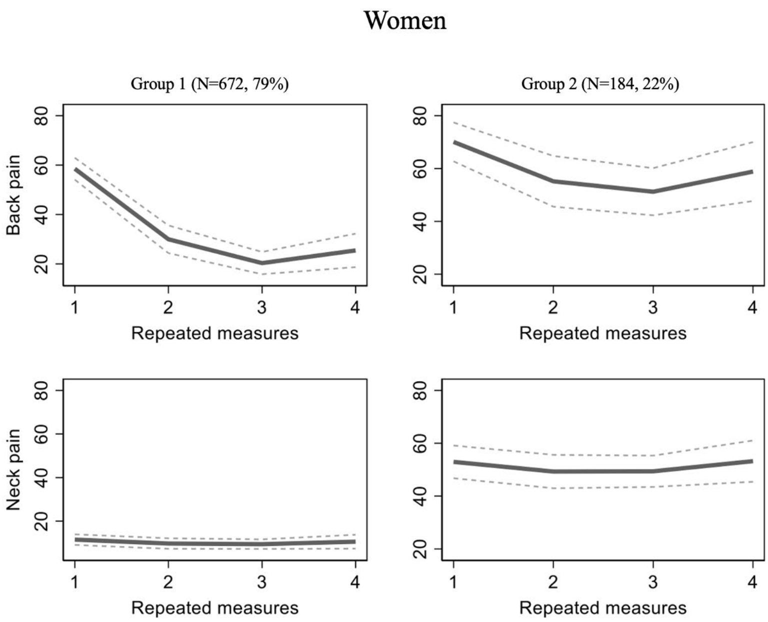

Figure 16. Trajectories of back and neck pain by sex, women. Reproduced from original Study IV.

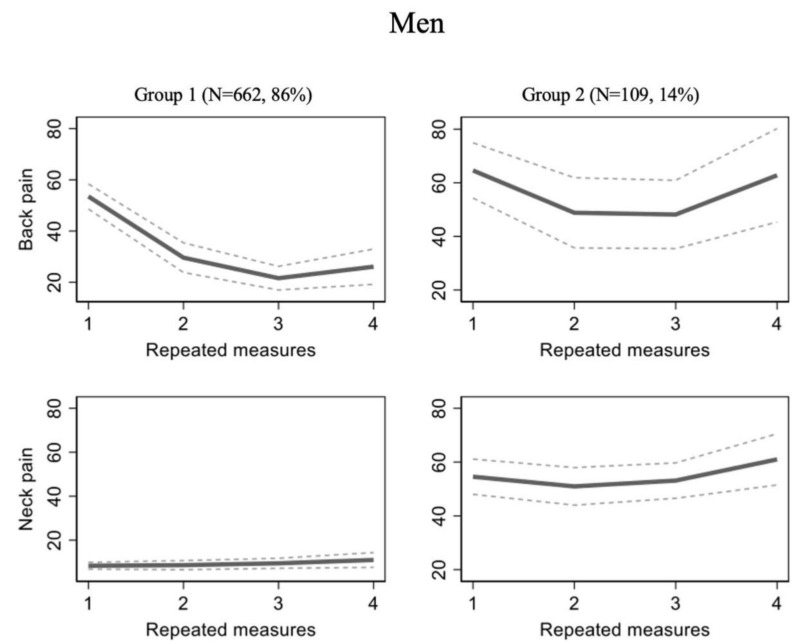

Figure 17. Trajectories of back and neck pain by sex, men. Reproduced from original Study IV.

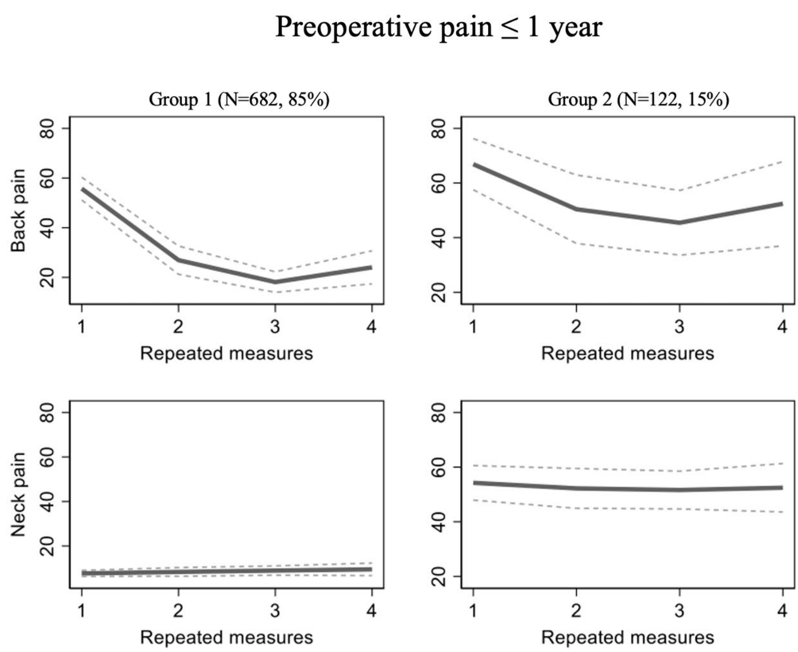

Figure 18. Trajectories of back and neck pain by length of preoperative pain, ≤1 year. Reproduced from original Study IV.

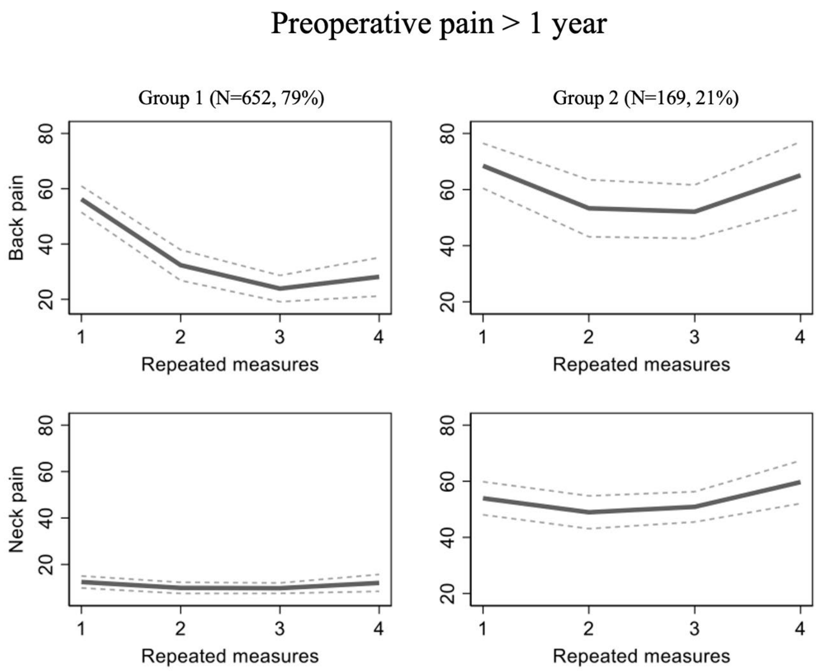

Figure 19. Trajectories of back and neck pain by length of preoperative pain, >1 year. Reproduced from original Study IV.

Table 8. RRRs of being classified to a short-term improvement group (reference is long-term improvement group) comparing fusion vs. no fusion techniques. RRRs are adjusted for age and sex. Originally published in PLOS ONE.

Comparators	RRR	95% CI	
Oswestry Disability Index			
No fusion			
Women vs. men	1.01	0.71	1.43
Age (older vs younger)	0.94	0.66	1.33
Pain duration >=3 months vs. <3 months	1.09	0.77	1.55
BMI ≥30 vs. BMI <30	**1.47**	**1.04**	**2.08**
Fusion			
Women vs. men	0.77	0.50	1.20
Age (older vs younger)	1.45	0.95	2.21
Pain duration >=3 months vs. <3 months	1.11	0.71	1.75
BMI ≥30 vs. BMI <30	1.41	0.92	2.14
Back pain			
No fusion			
Women vs. men	1.23	0.93	1.63
Age (older vs younger)	0.86	0.65	1.14
Pain duration >=3 months vs. <3 months	**1.34**	**1.01**	**1.78**
BMI ≥30 vs. BMI <30	1.19	0.90	1.58
Fusion			
Women vs. men	0.87	0.59	1.28
Age (older vs younger)	1.02	0.70	1.49
Pain duration >=3 months vs. <3 months	1.13	0.76	1.68
BMI ≥30 vs. BMI <30	**1.85**	**1.27**	**2.67**
Leg pain			
No fusion			
Women vs. men	**1.35**	**1.02**	**1.78**
Age (older vs younger)	1.08	0.82	1.43
Pain duration >=3 months vs. <3 months	1.00	0.75	1.32
BMI ≥30 vs. BMI <30	1.03	0.78	1.36
Fusion			
Women vs. men	0.88	0.61	1.26
Age (older vs younger)	1.23	0.87	1.75
Pain duration >=3 months vs. <3 months	1.03	0.71	1.47
BMI ≥30 vs. BMI <30	**1.58**	**1.12**	**2.22**

6 Discussion

6.1 Main results

The aim of spine surgery is to improve pain and function, and accordingly, functioning improves after surgery for the majority of patients (Kaiser et al., 2023; Nian et al., 2023; Wei et al., 2021). It is also self-evident that changes in functioning after back surgery can vary among patients. The aim of this study was to determine whether groups of patients can be identified whose outcomes significantly deviate from each other, and to find potential factors which influence the group a patient belongs to. This study succeeded in identifying individual groups whose trajectories of changes in functioning after surgery deviated from each other. This finding led to the identification of some preoperative factors that predicted an increased risk of being classified into groups in which the changes in functioning after surgery were less favorable than among the majority of patients. Severe, prolonged preoperative pain; prominent disability; overweight; female sex; and older age were among the risks of poorer surgical outcome, understood as less favorable trajectories of changes in the level of functioning. When dividing patients by surgical procedure into fusion and non-fusion patients, no differences were seen between these groups in functioning as measured by the ODI or in back or leg pain as measured by the VAS. This study did not investigate whether different pathologies and surgical indications affect the surgical outcome.

Disability and functioning are multidimensional concepts, and are usually assessed using scales that can take this diversity into account by collecting data from many different domains. The ODI, which was used as the main outcome measure in this study, measures ten different domains of functioning. This study aimed to show that the magnitude of the limitations experienced by a patient with back problems can vary in different functioning domains. The study found that different areas of functioning may indeed change in different magnitudes and with different time frames after surgery. The greatest improvement after surgery was seen in “standing” and “social life”, whereas “sleep” improved only very slightly.

It was assumed that at least some differences between patients in postoperative disability changes could be explained by the fact that pain and its impact on functioning may be more widespread, and that pain also plays a role in the magnitude and timing of changes in pain other than in the back or lower extremities. In general, neck pain was not a major problem in the studied sample, but about half of the patients had at least moderate functioning limitations, measured using the NDI. Overall, the ODI and NDI results followed very similar trajectories in this study. It seems that postoperative changes in disability caused by neck and back pain could be related, even though this relationship may partly be explained by the NDI being derived from the ODI, meaning that several items may overlap.

To ensure the validity and reliability of the ODI in this sample, some basic psychometric properties were evaluated. The internal consistency of the ODI was good and excluding one item at a time did not improve the alpha. The ODI was unidimensional, which supported the validity of its total score. The correlations between individual items and the main factor (disability level) were all acceptable. The strongest correlations were with “traveling”, “personal care” and “social life”. The weakest correlation was with “standing”.

6.2 Changes in functioning and pain after lumbar spine surgery

Most patients experienced improvement in functioning, leg pain and back pain after surgery. However, one-fifth to one-tenth of the patients were in the group in which functioning did not improve similarly as in the majority of the population. Previous studies on spine surgery have also found that the majority of patients benefit from surgery, but that a small proportion do not benefit much (Carrasco et al., 2020; Hebert et al., 2019; Wang et al., 2022; Willems et al., 2023; Yang et al., 2020). In studies of discectomy patients, the proportion of patients with poor surgical outcomes has varied between 5 and 29 % (Carrasco et al., 2020; Wang et al., 2022; Willems et al., 2023). Part of this variability may be due to the fact that some studies used different measures of functioning (Carrasco et al., 2020; Willems et al., 2023). Differences between the results of these studies may also be explained by the use of different surgical techniques or indications, study methods, metrics, population characteristics, length of follow up, or study objectives (Carrasco et al., 2020; Hebert et al., 2019; Wang et al., 2022; Willems et al., 2023; Yang et al., 2020).

In this thesis, back and leg pain changed in very similar ways, which has also been observed in previous studies (Cha et al., 2021; Malmivaara et al., 2007; Taiji et al., 2021). The reason for this is still unclear, but one explanation could be that a procedure performed to relieve leg pain may also relieve local inflammation caused by compression and alleviate back pain (Li et al., 2021).

In the present study, the changes in pain and functioning followed slightly different trajectories. A weak association between pain and functioning has also been noted in previous studies (Andrews et al., 2013; DeVine et al., 2011). This phenomenon is actually logical and corresponds to, the current ICF classification. Pain is just one factor among many that affects overall functioning.

In this thesis, only a small number of patients experienced significant neck pain, whereas about half of them reported at least moderate NDI scores. The changes in the ODI and the NDI followed very similar trajectories after surgery in this study. For example, in the groups with severe disability due to back pain and moderate disability due to neck pain, both the ODI and the NDI showed a significant improvement. However, this may also be explained by the fact that the NDI is derived from the ODI and that several of their items overlap. It is therefore possible that the disability of a patient with back pain is reflected in the NDI, making it questionable to use the NDI with patients with back pain. It is therefore very unlikely that lower back surgery would also affect the functional limitations caused by neck pain, although this had been speculated in some previous studies (Alvin et al., 2018; Felbaum et al., 2016; Pennington et al., 2019).

6.3 Probability of being classified into groups with poor surgical outcomes

Poor surgical outcome was associated with worse preoperative pain and functioning in the current thesis. Previous studies are mainly supportive of this thesis and have found that poorer functioning and worse preoperative pain are associated with worse pain and poorer functioning after surgery (Carrasco et al., 2020; Iversen et al., 1998; Jacob et al., 2022). One previous study published in 2020 reported that preoperative pain level did not affect surgical outcome (Virk et al., 2020). A few studies have also reported that better preoperative functioning predicts poorer surgical outcomes (Nerland et al., 2015; Solberg et al., 2005). However, in the studies of Virk et al. and Solberg et al., the sample size was small.

In the thesis, Overweight was associated with poorer improvements to pain and functioning, although in many previous studies, BMI has not influenced surgical outcome (Divi et al., 2020; Hébert et al., 2020; Lingutla et al., 2015; Nakajima et al., 2023; Nerland et al., 2015). Some of this variation may be explained by different sample sizes and study designs. However, overweight has been associated with postoperative complications, worse back pain and disability in several studies (Ghobrial et al., 2022; Knutsson et al., 2013; Nie et al., 2023; Park et al., 2020; Rihn et al., 2012), which are in line with the current findings.

Female sex was associated with a group in which back or neck pain did not improve significantly with surgery. However, when neck pain was not taken into account, sex did not affect the outcome of surgery. The results regarding the effect of sex on the outcome of surgery have been conflicting. In some earlier studies, female sex has been associated with worse disability and pain after low back surgery

(Donnarumma et al., 2016; MacLean et al., 2020; Siccoli et al., 2018), but several studies have found that although female sex was associated with worse preoperative pain and functioning, the magnitude of the change in pain and functioning after surgery was the same or even greater than among men (MacLean et al., 2020; Nolte et al., 2021; Siccoli et al., 2018; Triebel et al., 2017). Therefore, according to the current study and most previous studies, gender does not significantly affect the outcome of surgery.

Longer preoperative pain duration and older age were associated with being classified into groups in which pain or functioning improved less after surgery. However, when neck pain was not taken into account, age or the duration of preoperative pain did not increase the likelihood of a worse surgical outcome. Previous studies have found an association between preoperative pain duration and worse post-operation pain (Celestin et al., 2009; Hébert et al., 2020; Ng et al., 2007; Radcliff et al., 2011). However, some studies have found no association between symptoms of longer duration and a poorer surgical outcome (Cushnie et al., 2019; Jönsson et al., 1997; Zweig et al., 2017). The reason why longer-lasting preoperative pain could be associated with worse postoperative pain could be that persistent pain may cause changes in the central nervous system (Harte et al., 2018). Older age has been associated with poorer surgical outcomes in previous studies (Celestin et al., 2009; Dorow, Löbner, et al., 2017; Halicka et al., 2022b; Rihn et al., 2015). However, several studies have reported that even the elderly benefit significantly from surgery (Gerhardt et al., 2018; Katz et al., 1999; Nanjo et al., 2013; Rihn et al., 2015).

6.4 Changes in different areas of functioning after lumbar surgery

Different functioning domains showed different levels of improvement after surgery. The “standing” and “social life” domains changed the most, whereas “sleep” improved only a little. Similar results have also been observed in previous studies: among those who had undergone surgery for spondylolisthesis, for example, “standing” changed the most and “sleep” was one of the domains that changed the least (Murphy et al., 2018). As standing is needed for many other activities, such as walking and traveling, it is understandable that it is strongly related to overall functioning (Edwards et al., 2015). It has also been reported that among patients who have undergone fusion surgery, “social life” was one of the most important functioning domains related to overall functioning (Djurasovic et al., 2012). In addition, a study by Bergland et al. reported that social networks are crucial for functioning, health, and quality of life (Bergland et al., 2015). The reason for the small change in the sleep domain may be that sleep problems can be very persistent, and external factors only have a weak impact on sleep (Morin et al., 2020; Saltychev et al., 2021).

The variation in the item-specific score changes suggests that lumbar spine surgery affects different functioning domains in different ways. Although the total ODI score provides a good indication of overall functioning, it is unevenly composed of different functioning domains. Moreover, the use of total scores is easy and they are useful especially at the population level, but at the individual patient level it may be more beneficial to present functioning using a functional profile that shows what constitutes the disability of the patient. This thesis presented a graphical way to present item-specific change in the ODI (Figures 10 and 11).

6.5 Oswestry disability index of patients who have undergone lumbar spine surgery

The ODI was found to have good internal consistency and to be a unidimensional measure. Previous studies have also reported good internal consistency (Pekkanen, Kautiainen, Ylinen, Salo, & Hakkinen, 2011; Selva-Sevilla et al., 2019; Sheahan et al., 2015), and found the ODI to be a unidimensional measure. (Davidson, 2008; Gabel et al., 2017; van Hooff et al., 2015). However, some studies have reported that the ODI has a two-factor structure (Cook et al., 2021; Pekkanen, Kautiainen, Ylinen, Salo, & Hakkinen, 2011). For example, a study of 60,000 patients who had undergone back surgery found a two-factor structure based on both EFA and CFA (Cook et al., 2021). The difference between these two results remains unclear, but one explanation could be that comorbidities significantly affect factor structure: In the Cook et al. study, at least half of the patients had serious comorbidities. However, other diseases were not addressed in this thesis. A 2011 Finnish study found that the ODI had a two-factor structure, but this study had a smaller sample size, which may have affected its results (Pekkanen et al., 2013).

6.6 Strengths and weaknesses of the study

The strengths of the study are its repeated measures design and large sample size. However, the generalizability of this thesis may be limited, for several reasons. The study data were collected in a highly specialized clinic of a university hospital, and results from primary care or clinics outside the university hospital may differ. Although the most common surgical techniques were microdiscectomy, decompression and fusion, the study included heterogeneous surgical indications and techniques. The different surgical indications and techniques differ considerably from each other. Analyzing the surgical results of such a heterogeneous population is a major limitation of this study. However, this study well describes the population of patients who have undergone lumbar spine surgery as a heterogeneous population. Analyzing heterogeneous populations is particularly necessary when assessing the success of lower back surgery when considering real-effectiveness medicine (Malmivaara, 2013). This study provides a good understanding of the changes in functioning and pain after lumbar spine surgery in patients who have undergone surgery at this Finnish university hospital. A more narrowly defined study population would not necessarily have reflected the diversity of patients observed in clinical practice (Malmivaara, 2015). Patients who had undergone multiple operations were excluded from the study, but this limitation did not apply to the collection of the register before the operations. It is therefore possible that some patients had already undergone back surgery. Excluding patients who had undergone multiple operations may also have biased the results, as patients who have undergone previous back surgery re prone to have a poorer outcome. Due to the retrospective register-based design, some data were missing and thus not available for the analysis. A retrospective register-based study may suffer from possible significant confounders as well as from information and selection biases (Muriel, 2018). In addition, data truncation is typical in register-based studies, which makes it difficult to distinguish between prevalent and incident cases. Also, the reasons why patients did not respond, or the possible differences between the responding and non-responding patients, are not known. However, previous publications suggest that non-responders are actually well-representative of the population as a whole (Elkan et al., 2018; Hojmark et al., 2016; Ingebrigtsen et al., 2023; Klimko et al., 2025). So the fact that some patients do not respond does not necessarily distort the results. A significant attrition of patients was also observed toward the end of the follow up.

Only little descriptive data were available, and information on, for example, comorbidities such as diabetes, arthritis or depression was lacking. It was also not known whether the patients smoked, were married, or were physically active. Information on complications was also lacking, so it is not possible to evaluate how surgical complications in overweight or elderly patients affected the outcomes of the current study. This thesis used only a few measures, and for example, quality of life or return to work were not measured. In addition, most of the patients were 60 to 70 years old, which may affect the generalizability of the results of this thesis to other age groups.

Due to the lack of a control group, conclusions regarding the causality of the results cannot be drawn. In addition, the results of the GBTA can only be viewed as a trend, thus the results should be verified through a large, preferably multicenter, prospective follow-up study. The NDI being a modification of the ODI and having several overlapping items may also affect the validity of using the NDI with patients with back pain. It therefore appears that in patients with restrictions in functioning caused by low back pain, it is not reliable to examine simultaneous restrictions in functioning caused by neck pain.

6.7 Suggestions for further research

Future studies could replicate these results in more homogeneous populations in terms of diagnoses and surgical techniques, and a longer follow up. The GBTA could be used more often in spine surgery. It would also be important to investigate whether other preoperative factors such as smoking, educational background, or depression influence the likelihood of belonging to a particular trajectory group. Simultaneous changes in back and neck pain could also be further investigated in different settings and populations. It would be important to see whether the changes in disability caused by neck pain and the changes in disability caused by back pain follow the same trajectories when a measure other than the ODI is used, such as the RMDQ. Simultaneous changes in back and neck pain and disability caused by back and neck pain could also be investigated after cervical surgery.

It would be interesting to study the effect of different factors on functional profiles. Creating functional profiles for other questionnaires used to measure functioning could be useful. Regarding the ODI, it would be interesting to determine whether some comorbidities or previous operations affect its psychometric properties.

This study included patients who had undergone lower back surgery at Turku University Hospital. In order to gain a better understanding of the changes in functioning among patients undergoing lower back surgery in Finland, it would be worthwhile to also study patients who had undergone surgery at other Finnish university hospitals. There are five university hospitals in Finland, and comparing surgical outcomes between them would provide important additional information on possible regional differences. It would also be interesting to investigate whether there is a difference in the surgical outcomes of patients undergoing back surgery in the private sector or at non-university hospitals compared to patients who had surgery at university hospitals.

6.8 Clinical implications

The average change in pain and functioning among patients who have undergone lumbar spine surgery has been studied extensively in previous studies. However, the important finding of this study was that among patients who have undergone lower back surgery, groups could be distinguished in which the change in pain and functioning differed from each other. It seems that the magnitude and speed of improvement expected from lumbar spine surgery varies greatly between patients.

Some preoperative factors can be used to predict the change in pain and functioning after surgery. In particular, overweight, worse preoperative pain, and greater preoperative disability were associated with worse pain and greater disability after surgery. The majority of patients who had undergone lumbar spine surgery had only mild neck pain, or none at all. However, about one-fifth of the patients had moderate neck pain in addition to back pain, which was not relieved by the surgery. Pain is nonetheless only one aspect of functioning, and it would seem that restrictions to functioning caused by neck pain are common. According to the results of this thesis, restrictions to functioning caused by neck pain are relieved among a large proportion of patients who undergo lumbar spine surgery. However, it should be noted that the NDI is derived from the ODI and some questions overlap, which may make the use of the NDI with patients with back pain questionable.

The different magnitudes of change in the different ODI items showed that different areas of functioning improved to different degrees after surgery. It would be beneficial to present this item-specific change in clinical work in a graphical form as a functional profile. The introduction of functional profiles alongside composite scores could help when planning or executing rehabilitation or a treatment intervention. Although the use of a graphically presented functional profile may sound cumbersome and time-consuming, graphically presented profiles have been used successfully in the past. An example of this is the Functional Independence Measure. The introduction of graphical functional profiles in clinical work with appropriate software solutions should be promoted. The best option would most likely be to integrate them directly into electronic patient systems.

In summary, this thesis found that pain and functioning among patients who have undergone surgery may change in very different ways to average outcomes, and different areas of functioning undergo different degrees of change with surgery. The results of this study could potentially be used to develop patient-specific treatment plans when, for example, considering surgery or the need for postoperative pain medication or rehabilitation.

7 Conclusions

1. Most patients experienced pain relief and improved functioning within three months of lumbar spine surgery, and this improvement could last for at least two years.
2. Worse preoperative pain, more severe disability and obesity were associated with an inferior surgical outcome.
3. Age, sex, and duration of preoperative pain did not affect the risk of a poorer outcome.
4. Some patients who had undergone lumbar spine surgery also experienced related neck pain and disability. The changes in disability caused by neck pain followed similar trajectories to those of the changes in disability caused by back pain.
5. The magnitude of the changes in the different domains of functioning varied after surgery. This suggests that a single total score may not be sufficient to describe these changes. Instead, in some circumstances, creating a functional profile of the different domains of functioning may be a better solution.
6. The Oswestry Disability Index was found to be a valid and reliable scale in the studied population.

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