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Sara Widbom-Kolhanen

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The originality of this publication has been checked in accordance with the University of Turku quality assurance system using the Turnitin Originality Check service.

Cover Image: Sauli Widbom

ISBN 978-951-29-9745-9 (PRINT)
ISBN 978-951-29-9746-6 (PDF)
ISSN 0355-9483 (Print)
ISSN 2343-3213 (Online)
Painosalama, Turku, Finland 2024

To my beloved family, by His grace

UNIVERSITY OF TURKU
Faculty of Medicine
Department of Clinical Medicine
Orthopaedics and Traumatology
SARA WIDBOM-KOLHANEN: Changes in pain and disability after cervical spinal surgery
Doctoral Dissertation, 132 pp.
Doctoral Programme in Clinical Research
May 2024

ABSTRACT

The aim of this study was to monitor changes in functioning and pain after cervical spinal surgery. It was already known that both pain and functional ability change after surgery, and that the direction of these changes is usually positive. However, the magnitude and developmental trajectories of these changes in different patient groups had been studied very little. In this study, at two-year follow-up, the changes in functioning and pain after surgery were not uniform. Although in some patient groups neck pain was relieved, in other groups neck pain was still severe or had even worsened after surgery. Correspondingly, radiating pain in the upper extremities either improved throughout the follow-up or worsened after an initial improvement. The same uneven changes were seen in functioning, which improved among some patients, while in other groups it remained unchanged, either significantly reduced or relatively good throughout the follow-up. Sex, preoperative pain duration and body mass index were not related to the probability of belonging to a certain functioning level group. In terms of pain change, female sex and longer preoperative duration of pain predicted worse postoperative results. On average, overall functioning slightly decreased toward the end of follow-up. This study found that the different areas of functional capacity may show different changes after surgery. The results also suggest that even generally accepted and valid outcome measure of disability may behave slightly differently between sexes, as detection of functional restrictions was more accurate and sensitive among women. The different areas of functioning may have different levels of importance depending on the age and sex of respondents. The main result was that patients experience diverse patterns of recovery after cervical spinal surgery. These findings may have important implications for tailoring treatment plans based on individual patient characteristics.

KEYWORDS: cervical spine, surgery, neck disability index, disability evaluation, pain measurement

TURUN YLIOPISTO
Lääketieteellinen tiedekunta
Kliininen laitos
Ortopedia ja traumatologia
SARA WIDBOM-KOLHANEN: Toimintakyvyn ja kivun muutos kaularangan leikkauksen jälkeen
Väitöskirja, 132 s.
Turun kliininen tohtoriohjelma
Toukokuu 2024

TIIVISTELMÄ

Tämän tutkimuksen tavoitteena oli seurata toimintakyvyn ja kivun muutoksia kaularankaleikkauksen jälkeen. Aiemmin on havaittu, että sekä kipu että toimintakyky muuttuvat leikkauksen jälkeen, ja muutosten suunta on yleensä myönteinen. Kuitenkin näiden muutosten suuruutta ja kehityskulkuja eri potilasryhmissä on tutkittu vähän. Tässä tutkimuksessa kahden vuoden seurannassa havaittiin, että toimintakyvyn ja kivun muutokset leikkauksen jälkeen eivät olleet yhteneväisiä. Vaikka joillakin potilasryhmillä niskakipu helpotti, toisilla niskakipu oli edelleen voimakasta tai paheni leikkauksen jälkeen. Vastaavasti säteilevä kipu yläraajassa joko parani koko seurannan ajan tai paheni alun parantumisen jälkeen. Sama epätasainen muutos havaittiin toimintakyvyssä, joka parani osalla potilaista, kun taas toisilla toimintakyky pysyi ennallaan, joko merkittävästi heikentyneenä tai suhteellisen hyvänä koko seurannan ajan. Sukupuoli, leikkausta edeltävä kivun kesto ja painoindeksi eivät olleet yhteydessä todennäköisyyteen kuulua tiettyyn toimintakyvyn ryhmään. Sen sijaan naissukupuoli ja pidempi kivun kesto ennen leikkausta ennustivat kivun kannalta huonompaa leikkauksen jälkeistä tilannetta. Keskimäärin yleinen toimintakyky heikkeni hieman seurannan loppua kohden. Tutkimus osoitti, että eri toimintakyvyn osa-alueet voivat muuttua eri tavoin leikkauksen jälkeen. Tulokset viittaavat myös siihen, että jopa yleisesti hyväksytty ja päteväksi todettu toimintakyvyn muutoksen mittari voi käyttäytyä hieman eri tavalla vastaajan sukupuolesta riippuen, sillä toimintakyvyn rajoituksia havaittiin herkemmin ja tarkemmin naisilla. Tämän mittarin kuvaamien toimintakyvyn osa-alueiden merkitys voi vaihdella riippuen vastaajan iästä ja sukupuolesta. Tutkimuksen päätulos on, että potilailla on erilaisia kivun ja toimintakyvyn kehityskulkuja kaularankaleikkauksen jälkeen. Nämä havainnot voivat edesauttaa yksilöllisten hoitosuunnitelmien laatimisessa.

AVAINSANAT: kaularanka, leikkaushoito, niskakipuindeksi, toimintakyvyn arviointi, kivun mittaus

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Abbreviations

ACDF	Anterior cervical decompression and fusion
BMI	Body Mass Index
DCM	Degenerative cervical myelopathy
DCSD	Degenerative cervical spine disease
DIF	Differential item functioning
GBTA	Group-based trajectory analysis
ICF	International Classification of Functioning, Disability and Health
MCID	Minimal clinically important difference
NDI	Neck Disability Index
NRS	Numeric Rating Scale
ODI	Oswestry Disability Index
PROM	Patient-reported Outcome Measure
RCT	Randomized Controlled Trial
VAS	Visual Analog Scale

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	Widbom-Kolhanen S, Pernaa K, Saltychev M. Reliability and validity of the Neck Disability Index among patients undergoing cervical surgery. *Int J Rehabil Res*. 2022 Sep 1;45(3):273-278. Epub 2022 Jul 1.
II	Widbom-Kolhanen S, Pernaa K, Saltychev M. Change in functioning profile after cervical surgery. *Int J Rehabil Res.* 2023 Mar 1;46(1):35-40.
III	Saltychev M, Widbom-Kolhanen S, Pernaa K. Importance of factors determining disability caused by neck pain may vary by gender and age. *Int J Rehabil Res.* 2023 Mar 1;46(1):103-107.
IV	Saltychev M, Widbom-Kolhanen S, Pernaa K. Sex-related differential item functioning of neck disability index. *Disabil Rehabil.* 2023 Feb 20:1-7.
V	Widbom-Kolhanen SS, Pernaa KI, Lintuaho RE, Kotkansalo A, Saltychev M. Disability and pain after anterior cervical decompression and fusion: A group-based trajectory analysis. *Scand J Surg.* 2024 Apr 17:14574969241241969.

1 Introduction

Degeneration of the cervical spine occurs universally as people age, and yet not everyone develops symptoms such as neck pain or neurologic deficits related to the mechanical compression and inflammation of neural elements (Theodore, 2020). Characterized by the chronic and progressive deterioration of osseocartilaginous components, degenerative cervical spine disease may give rise to neck pain, radiculopathy (compression and inflammation of the cervical nerve root), myelopathy (compression of the cervical spinal cord with inflammatory and vascular changes), or a combination of these (Akter & Kotter, 2018; Theodore, 2020). The frequency of surgical interventions for degenerative cervical spine disease has significantly increased over the past few decades (Danielsen et al., 2022). Between 1999 and 2013, the age-adjusted incidence of surgery for degenerative cervical spine disease has risen in Finland by 76% (Kotkansalo, Leinonen, et al., 2019). However, the definitive superiority of surgery over conservative treatment of degenerative cervical spine disease remains uncertain (Kotkansalo, Leinonen, et al., 2019; Taso et al., 2020).

As healthcare resources are limited, the effectiveness of expensive interventions such as spine surgery must be critically evaluated (Godil et al., 2015). Although several studies have shown anterior cervical discectomy and fusion to have good overall outcomes (Burkhardt et al., 2016; Faldini et al., 2010; Hamburger et al., 2001; Hermansen et al., 2023; Sugawara et al., 2009; Thorell et al., 1998), for some patients pain and disability may persist after surgery (Peolsson et al., 2003; Peolsson, Vavruch, & Oberg, 2002). Traditionally, the evaluation of surgical outcomes has primarily focused on average change in disability and pain across the entire sample, potentially masking differences among dissimilar patient subgroups. To improve the inclusion criteria for surgery and postoperative care, several factors that predict surgical outcome have been identified (Hermansen et al., 2013).

This doctoral thesis aimed to investigate the changes in pain and disability following cervical spinal surgery. One objective was to examine the potential existence of significant subgroups demonstrating different trajectories of pain and disability after surgery and to identify the factors that influence these differences. Another goal was to evaluate whether certain areas of functioning exhibit more pronounced changes than others. To ensure the accuracy of the measurement of disability level, the properties of the Neck Disability Index, used here as the main outcome measure in the studied sample, were tested. The objective of exploring these aspects was to deepen the current understanding of cervical spinal surgery outcomes and to advance personalized treatment approaches for patients with degenerative cervical spine disease.

2 Review of the Literature

2.1 Degenerative cervical spine disease

2.1.1 Etiology

Magnetic resonance images (MRI) have revealed that 90% of the general population has disc degeneration over the entire spine before the age of 50 (Teraguchi et al., 2014). The highest prevalence of disc degeneration in the cervical spine has been detected at the C5/6 level (Teraguchi et al., 2014). The distinction between disc degeneration and degenerative disc disease lies in the absence of painful symptoms (Baptista et al., 2020). During a 20-year observation of initially asymptomatic individuals, disc degeneration progressed in 95% of the participants, but clinical symptoms developed in only 67% (Daimon et al., 2018). Age has consistently been associated with the prevalence of disc degeneration in all regions of the spine, but overweight and obesity have notably impacted degeneration in the cervical and thoracic areas (Teraguchi et al., 2014). Other risk factors are genetic inheritance, inadequate metabolite transport, and environmental factors such as high and repetitive mechanical stress (Adams & Roughley, 2006).

2.1.2 Pathophysiology

The underlying pathophysiology of radiculopathy is multifactorial. Nerve damage may result from both mechanical and chemical pathways, including localized ischemia and pro-inflammatory cascade (Iyer & Kim, 2016). Nerve root impingement in degenerative cervical spine disease (DCSD) arises either from a “soft” disc herniation or cervical spondylosis, which involves disc degeneration over time, resulting in reduced disc height, narrowing of the foramina, and bony hypertrophy, referred to as “hard” disc pathology (Iyer & Kim, 2016). Spondylosis may lead to the narrowing of the cervical spinal canal, which in turn results in compression associated with degenerative cervical myelopathy (DCM) (Milligan et al., 2019). In DCM, mechanical compression may be combined with inflammatory and vascular changes of the cervical spinal cord (Akter & Kotter, 2018; Theodore, 2020).

2.1.3 Prevalence

Comprehensive data on the incidence or prevalence of radiculopathy or myelopathy is limited (Kotkansalo, Leinonen, et al., 2019). An epidemiological survey in Minnesota from 1976 to 1990 reported the annual rate of radiculopathy diagnosis to be 83 per 100,000 individuals (Radhakrishnan et al., 1994). Age-adjusted incidence of radiculopathy was higher among men (Radhakrishnan et al., 1994). In 1987, a door-to-door survey in a small Sicilian municipality elicited the prevalence of cervical spondylotic radiculopathy, leading to a diagnosis rate of 350/1000,000 people (Salemi et al., 1996). The prevalence reached its highest point at the age of 50–59 and was higher among women (Salemi et al., 1996). From 1993 to 2002 in the United States, hospitalizations for DCM escalated from 3.73/100,000 to 7.88/100,000 (Lad et al., 2009). In 2015, a study of 1,200 healthy individuals aged 20 to 70 found that 88% of the study cohort had disc herniation, whereas only 5% were diagnosed with spinal cord compression (Nakashima et al., 2015).

2.1.4 Main clinical manifestations and symptoms

DCSD may include various conditions such as disc herniation, foraminal stenosis, spinal stenosis, and instability of the cervical spine (Denaro & Di Martino, 2011). These conditions manifest as neck pain, radiculopathy (pain radiating to the arms), and myelopathy (spinal cord dysfunction) (Fehlings et al., 2015; Iyer & Kim, 2016; Rhee et al., 2007). Cervical radiculopathy involves the compression of cervical nerve roots, leading to symptoms such as pain, sensory and motor deficits, and reduced reflex response (Iyer & Kim, 2016). Patients with radiculopathy often exhibit unilateral neck pain, which may be accompanied by pain radiating into the arm on the same side, following dermatomal distribution. However, an absence of arm pain does not necessarily rule out the presence of radiculopathy. Patients may also report sensory loss along the affected dermatomal distribution or have a weakness in the associated myotome (Iyer & Kim, 2016).

DCM may lead to a range of symptoms, from numbness and dexterity problems to incontinence and quadriparesis (Milligan et al., 2019). Nouri et al. have classified DCM as a hypernym, i.e., a collection of different clinical entities (Nouri et al., 2015). Patients with myelopathy usually present upper motor neuron signs, such as hyperreflexia, change in gait, and challenges with fine motor tasks (Iyer & Kim, 2016).

2.2 Cervical spinal surgery

The rate of surgery for DCSD has risen in the United States, Norway, and Finland. Between 2008 and 2014, the surgical rate increased by 74% (12.5/100,000 inhabitants) in Norway (Kristiansen et al., 2016). In the United States, the rate of surgery for DCSD has reached 72.2/100,000 adults in 2013 (Liu et al., 2017). Similarly, in Finland, the age-adjusted incidence of anterior cervical decompression and fusion (ACDF) rose from 6.5 to 27.3 operations/100,000 adults between 1999 and 2015 (Kotkansalo, Malmivaara, et al., 2019).

2.2.1 Common indications for surgery

Nonsurgical approaches, such as immobilization, physical therapy, traction, manipulation, pain medication, and steroid injection may be used to treat cervical radiculopathy when concerning signs (progressive neurologic deficits, signs of myelopathy, fractures or other signs of instability, or osseous lesions) are absent (Iyer & Kim, 2016; Rhee et al., 2007). According to an evidence-based clinical guideline for degenerative cervical radiculopathy by the North American Spine Society, for most patients, symptoms are self-limiting and resolve spontaneously over a variable length of time (Bono et al., 2011). Surgery is generally only considered in cases with severe or progressive weakness or numbness, or when persistent pain does not respond to nonsurgical treatment (Rhee et al., 2007).

Although the optimal duration of conservative treatment remains uncertain, a six-month threshold has been suggested, as many patients experience improvement within four to six months, and prolonged preoperative symptom duration has been linked to poorer surgical outcomes (Burneikiene et al., 2015; Engquist et al., 2015; Iyer & Kim, 2016). However, in contrast to this timeframe, surgery has been recommended for patients who, despite adequate conservative treatment for at least six weeks, continue to have radicular pain, sensory disturbance or muscle weakness corresponding to radiological findings (Woods & Hilibrand, 2015). Although the optimal timing of surgical intervention has not been definitively defined, the existing literature suggests eight weeks from the onset of symptoms as an appropriate period (Alentado et al., 2014). Controlled trials are needed to provide insights into nonsurgical management of pain, and to determine the optimal timing and necessity of surgical intervention (Carette & Fehlings, 2005). In Finland, indications for urgent or immediate surgical evaluation include progressive muscle weakness or myelopathy (Duodecim, 2017).

Guidelines for managing DCM recommend surgery for severe and moderate cases (Fehlings et al., 2017). For patients with mild DCM, the options are either surgical intervention or a supervised trial of structured rehabilitation (Fehlings et al., 2017). However, operative intervention is recommended in cases of neurological deterioration and suggested if conservative treatment fails to yield improvement (Fehlings et al., 2017). A systematic review in 2009 concluded that the natural history of DCM is variable, and that this may affect treatment decisions (Matz et al., 2009).

The primary goal of surgery is to prevent the disease's progression (Toci et al., 2023) through effective decompression of neural structures and restoring spinal stability (Song et al., 2020). Surgery for DCM has been associated with improvement in functional, disability-related, and quality-of-life outcomes at one-year postoperative follow-up, regardless of the severity of baseline myelopathy (Fehlings et al., 2013). Previous research suggests that early diagnosis of DCM and surgical management could potentially improve the neurologic outcome (Behrbalk et al., 2013).

In a Finnish study of almost 20,000 patients with DCSD operated during 1999–2015, the most common reasons for surgery were disc protrusion (35%), foraminal stenosis (35%), and spinal canal stenosis (28%) (Kotkansalo, Leinonen, et al., 2019). During the study period, surgery for radiculopathy increased more steeply than surgery for DCM (Kotkansalo, Leinonen, et al., 2019). This rise has been especially pronounced in surgery for foraminal stenosis, while surgery for disc protrusion has only slightly increased (Kotkansalo, Leinonen, et al., 2019). The distribution of diagnoses is similar to that in Norway, where 79% of surgeries for DCSD have been performed for radiculopathy and 21% for myelopathy (Kristiansen et al., 2016). Degenerative conditions were also the primary indication of all cervical fusion surgeries in New York between 1997 and 2012 (Salzmann et al., 2018). However, only 13% of the procedures were performed for spinal stenosis, implying potential differences in operation indications between countries (Salzmann et al., 2018).

2.2.2 Common surgical techniques

According to Rossi et al., the surgical management of degenerative cervical spinal disorders primarily consists of three procedures: posterior cervical laminoforaminotomy (PCF), total disc replacement (TDR), and ACDF (Rossi & Adamson, 2021). In addition to these, the posterior procedures of laminectomy and posterior decompression and fusion (PDF) are also mentioned, due to their clinical relevance in Finland.

PCF is characterized by the widening of the foramen and decompression of the indirect nerve root, and often requires a partial laminotomy and medial facetectomy. It enables motion preservation and avoids the potential complications associated with anterior approaches such as dysphagia, pseudoarthrosis and injury to the carotid and vertebral arteries or recurrent laryngeal nerve (Iyer & Kim, 2016; Sahai et al., 2019; Woods & Hilibrand, 2015). The complications linked to PCF are transient neuropraxia, wound-related complications, and durotomy (Sahai et al., 2019). PCF is recommended for unilateral pathology, including disc herniation and foraminal stenosis without myelopathy (Sahai et al., 2019). PCF may also be performed following ACDF if incomplete anterior decompression results in persistent or recurrent radiculopathy (Dodwad et al., 2016).

The surgical approach and technique for neural decompression in TDR is essentially identical to that of ACDF, the key difference being the use of an artificial disk in the decompressed disc space (Rhee et al., 2007). TDR has been introduced as a motion-preserving alternative to ACDF (Byvaltsev et al., 2020). The potential disadvantages of TDR include implant migration and a higher incidence of heterotopic ossification, the formation of bone in the soft tissues (Byvaltsev et al., 2020).

The ACDF has been recognized as the standard treatment for DCSD since its initial description by Robinson and Smith in 1955 (Rossi & Adamson, 2021). The procedure involves the extraction of the affected disc and osteophytes to decompress the impinged nerves and restore disc height (Rossi & Adamson, 2021), followed by the insertion of an intervertebral cage. Anterior plating is not usually performed in Finland or in Europe (Kotkansalo et al., 2022). The surgical approach uses the pathway through the anterior neck muscles and the dissection is directed medially to the carotid sheath, followed by blunt lateral dissection between the carotid sheath, trachea and esophagus, and medial dissection down to the prevertebral fascia (Bellabarba et al.). The recurrent laryngeal nerve is identified and protected (Bellabarba et al.). The rates of surgical site infection and wound complication are low (Rhee et al., 2007).

ACDF offers several advantages, including the direct removal of anterior spinal pathology without the need for neural retraction, the restoration of disc height through bone grafting or cages, and indirect foraminal decompression (Rhee et al., 2007). However, the procedure does have some potential drawbacks, such as dysphagia, postoperative hematoma, recurrent laryngeal nerve palsy, pseudoarthrosis, and adjacent segment degeneration (Epstein, 2019). Potential hardware-related complications include subsidence, plate loosening, and screw loosening and breakage (Song et al., 2020). Cages of diverse materials have been developed to replace bone grafts. These materials include stainless steel, titanium, carbon fiber, polymethyl-methacrylate (PMMA) and polyether-ether-ketone (PEEK) (Noordhoek et al., 2018). ACDF is widely indicated due to its ability to address most anterior issues, including cervical stenosis, foraminal stenosis, disc herniation, instability, and cervical spondylosis (Rossi & Adamson, 2021).

Cervical laminectomy involves the removal of the spinous processes, the laminae, to varying extents the facet joints and capsules, and the ligamentum flavum, to enable the decompression of the spinal cord or nerve roots (Abduljabbar et al., 2018). To avoid postoperative kyphotic deformity, laminectomies are frequently coupled with fusion, and lateral mass instrumentation is used (Kim & Dhillon, 2019). Laminectomy is indicated for multilevel cervical spondylotic myelopathy (Kim & Dhillon, 2019). In PDF, posterior decompression of the cervical spinal canal is accompanied by fusion (Youssef et al., 2019). Various surgical techniques for PDF exist, and the optimal technique is chosen on the basis of individual anatomy and surgical needs (Joaquim et al., 2020). Indications of PDF include both myelopathy and radiculopathy (Youssef et al., 2019). The complications commonly observed after PDF are C5 palsy, transient neurological deterioration, and wound infection (Youssef et al., 2019).

In the United States, ACDF has been the established primary treatment approach since the late 1990s (Patil et al., 2005). Kotkansalo et al. investigated the trends in operative techniques for DCSD in Finland between 1999 and 2015 (Kotkansalo, Malmivaara, et al., 2019). They categorized the patients into three distinct procedure groups: ACDF, PDF, and decompression only. ACDF accounted for 67% of all procedures and PDF for 3%. The majority of PDFs have been performed for rheumatoid atlanto-axial subluxation (Kotkansalo, Malmivaara, et al., 2019). Decompression only was used in 30% of the operations. During the study period, only 57 TDRs were performed, the use of PDF decreased, and the use of laminectomy remained fairly constant (Kotkansalo, Malmivaara, et al., 2019). A shift from solely decompressive procedures to ACDF was observed, as ACDF comprised 80% of all surgical techniques by the year 2008 (Kotkansalo, Malmivaara, et al., 2019). However, the limited availability of strong evidence of which technique is optimal for the various degenerative conditions has led to differences in treatment practices (Kotkansalo, Malmivaara, et al., 2019). For example, PDF incidence in Finland is only one-tenth of that observed in the United States, which is most likely due to the variations in operation indications and financial factors (Kotkansalo, Malmivaara, et al., 2019).

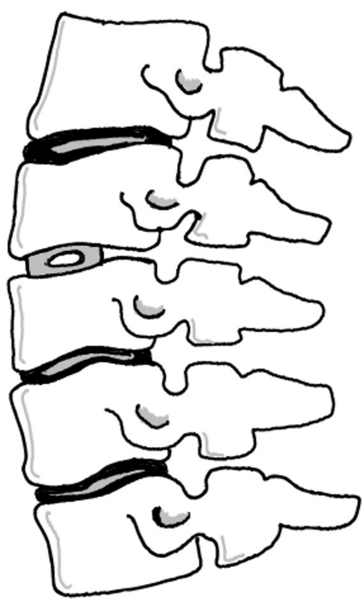

Figure 1. Cervical disc with a stand-alone cage. Illustration by Sauli Widbom (2023).

2.2.3 Effectiveness of surgery compared to conservative treatment

Although several long-term follow-up studies have suggested good overall outcomes for ACDF (Burkhardt et al., 2016; Faldini et al., 2010; Hamburger et al., 2001; Hermansen et al., 2023; Sugawara et al., 2009; Thorell et al., 1998), the effectiveness of surgery in comparison to conservative treatment for DCSD remains unaffirmed (Hermansen et al., 2013; Kotkansalo, Leinonen, et al., 2019). Both conservative and operative approaches have been considered successful treatments for cervical radiculopathy, but the optimal strategy for individual patients is uncertain (Kuijper et al., 2009; van Geest et al., 2014; Wainner & Gill, 2000). In addition, there is a lack of evidence supporting the superiority of any particular conservative treatment or surgical technique (Jacobs et al., 2011; Thoomes et al., 2013), and insufficient guidance for appropriate structured physiotherapy programs following surgery (Peolsson et al., 2014). Only a few randomized controlled trials (RCT) comparing surgery and conservative treatment exist, and the sample sizes of these trials are small.

The effectiveness of ACDF in reducing pain has been shown to range between 80% and 95% (van Geest et al., 2014). In a small RCT focusing on patients with radiculopathy, 81 patients were randomized to receive either physiotherapy, collar treatment or ACDF surgery (Persson et al., 1997). At three months, pain relief was superior in the surgery group, although this difference diminished at 12 months (Persson et al., 1997). Another small RCT also compared surgery and conservative treatment for DCM and found no statistically significant difference between its groups at two- and ten-year follow-ups (Kadaňka et al., 2011; Kadanka et al., 2000). However, a Cochrane review assessing the role of surgery in cervical spondylotic radiculomyelopathy in 2002 deemed both these RCTs unreliable for providing evidence on the effects of surgery for cervical spondylotic radiculopathy or myelopathy (Fouyas et al., 2002).

Engquist et al. randomized 63 patients with radiculopathy to receive either ACDF along with postoperative physiotherapy or physiotherapy alone (Engquist et al., 2013). In both groups, disability, neck pain, and arm pain had decreased significantly from that at baseline (Engquist et al., 2013). No notable differences were observed between the groups in terms of disability or arm pain, but the surgical group exhibited greater improvement in neck pain, which was sustained only until the 12-month mark (Engquist et al., 2013). However, during the follow-up period of five to eight years, surgery was more effective in reducing disability and neck pain than physiotherapy alone (Engquist et al., 2017).

The existing literature on the topic fails to provide sufficient evidence for determining when and for whom surgery should be recommended (Rhee et al., 2007). In their systematic review on the effectiveness and timing of surgery for radiculomyelopathy, Nikolaidis et al. concluded that the quality of the evidence that surgery may offer faster pain relief than physiotherapy or hard collar immobilization in patients with cervical radiculopathy was low (Nikolaidis et al., 2010). However, there was little or no difference in pain or sensory loss at one-year follow-up (Nikolaidis et al., 2010). The low quality of the available evidence suggests that the difference between the long-term functioning and quality of life of the individuals with mild myelopathy who had undergone surgery and those who had been treated conservatively may have been minimal or even nonexistent (Nikolaidis et al., 2010). It has been hypothesized that cervical spondylotic radiculomyelopathy comprises a heterogeneous condition, and that subgroups of patients may potentially benefit from surgery (Fouyas et al., 2002).

A prospective cohort study by Buttermann et al. (Buttermann, 2018) followed 159 patients across three distinct diagnostic groups (disc herniation, stenosis or advanced degenerative disease) for at least 10 years after ACDF (Buttermann, 2018). The results showed significant clinical improvements in all three diagnostic groups, and the positive outcomes persisted for up to a decade (Buttermann, 2018). However, a literature review in 2014 concluded that despite a trend toward expanding indications of ACDF due to its excellent treatment results, the significance of conservative treatments for DCSD should not be overlooked (Song & Choi, 2014).

2.3 Functioning and disability

2.3.1 Definitions

The definition of disability should be universally applicable to all individuals. It should avoid segregation, but still enable the comparison of levels of severity. It should also enable the description of the experience of disability across multiple areas of functioning (Leonardi et al., 2006).

Functioning has been defined as the dynamic interaction between the health condition of an individual, environmental factors, and personal attributes (WHO, 2013). Disability is a state of reduced functioning associated with disease, disorder, injury, or other health conditions (WHO, 2001). That said, disability relates to the adverse aspects of functioning and serves as the umbrella term for impairments (WHO, 2001). Within a specific environment, these adverse aspects of functioning can be perceived as an impairment, activity limitation, or restriction to participation (WHO, 2001). Disability is a continuous phenomenon, ranging from full functioning to some limitation and eventually the complete loss of functioning (Cieza et al., 2018).

To assess the effectiveness of health interventions at both the individual and population levels, it is important to have a clear approach to measuring disability. This enables comparison of the impact of different health conditions and the benefits of health interventions. (Cieza et al., 2018)

2.3.2 International Classification of Functioning, Disability and Health

In 2001, the World Health Organization (WHO) recommended the use of the International Classification of Functioning, Disability and Health (ICF) as a method of organizing the representation of functioning and disability in various health contexts and diverse populations (WHO, 2001). Serving as a common language and framework, the ICF describes and organizes information on functioning and disability (WHO, 2001). It consists of two parts, each of which has two components (WHO, 2001). The first part is *Functioning and Disability* and its components are *Body Functions and Structures* and *Activities and Participation* (WHO, 2001). The second part is *Contextual Factors*, which includes *Environmental factors* and *Personal factors* (WHO, 2001).

The primary use of the ICF in clinical settings has been for rehabilitation and evaluating its outcomes (Leonardi et al., 2022). The ICF has shown to be an essential tool for identifying and measuring the effectiveness of rehabilitation services, through both functional profiling and intervention targeting (Ustün et al., 2003). However, a few years after the initial publication of the ICF, it was acknowledged that the original format was impractical for everyday use, and core sets were developed (Castaneda et al., 2014). These core sets have two versions—the *comprehensive set* for research purposes and the *brief set* for clinical practice (Castaneda et al., 2014).

An ICF core set has been developed for low back pain (Cieza et al., 2004). During the formal consensus process, relevant ICF categories were identified, indicating that some areas of functioning may be more important than others. A modified Brief ICF Core Set profile has also been created for chronic widespread musculoskeletal pain, tailored to meet the demands of the clinical setting by providing a comprehensive overview of the patient's issues in a time-efficient manner (Löfgren et al., 2013). Such profiles or ICF core sets have not yet been developed for individuals with disorders of the cervical spine or for assessing the outcome of cervical spinal surgery.

Peolsson et al. have investigated the benefit of ACDF using an ICF-based assessment, and found improvements at all three levels of ICF (Peolsson, Vavruch, & Öberg, 2002). However, one third of patients had lingering disabilities in objective variables such as neck and arm strength and range of motion one year after surgery (Peolsson, Vavruch, & Öberg, 2002). Two thirds of the patients had residual problems in subjective variables including pain intensity and on the Neck Disability Index (NDI) (Peolsson, Vavruch, & Öberg, 2002).

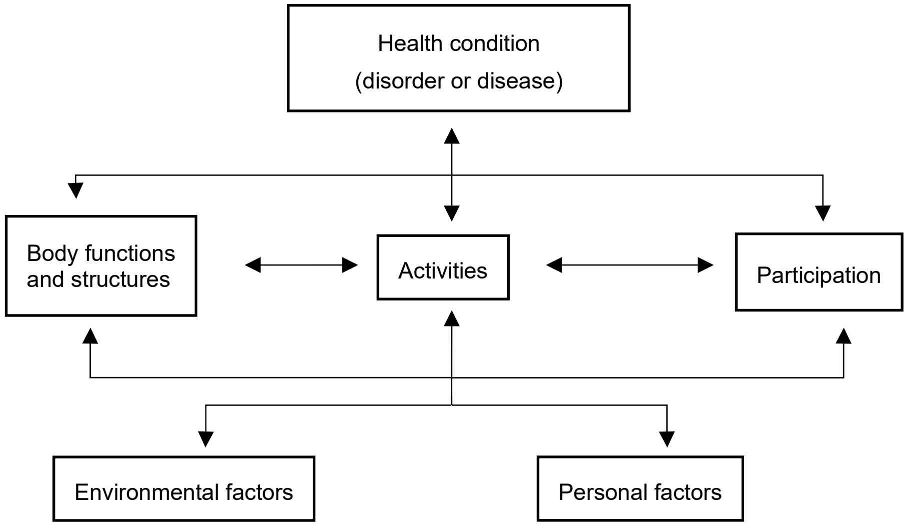

Figure 2. Interactions between ICF components. Modified from "International Classification of Functioning, Disability and Health". Geneva: WHO; 2001.

2.3.3 Patient-reported Outcome Measures and Neck Disability Index

Several different scales are used to measure neck pain and disability. These include the visual analog scale (VAS), the numeric rating scale (NRS), and the Neck Pain and Disability Scale (NPAD), which measures neck pain and related disability (Blozik et al., 2011) similarly to the Northwick Park Neck Pain Questionnaire and the Copenhagen Neck Functional Disability Scale. The Neck Bournemouth Questionnaire measures pain, physical functioning, social functioning, and psychological functioning in patients with nonspecific neck pain (Schellingerhout et al., 2012). Although not specific to the neck, the SF-36 and the Patient-reported Outcome Measurement Information System (PROMIS) are patient-reported outcome measures (PROMs) that have a physical functioning subscale. The Patient-Specific Functional Scale measures the physical functioning of patients with musculoskeletal disorders (Mathis et al., 2019). Several other scales assess the level of global improvement, for example, the Patient Global Impression of Change. One of the most widely validated neck-specific PROM is the NDI (Vernon, 2008).

The NDI is a version of the Oswestry Disability Index (ODI) modified by Dr. Howard Vernon in 1991 (Vernon, 2008). It is a standardized questionnaire consisting of ten domains: *pain intensity, personal care, lifting, reading, headaches, concentration, work, driving, sleeping*, and *recreation*. Over the years, the NDI has been extensively studied and used in various clinical and research settings to assess disability caused by neck pain, including situations in which the outcome of conservative or surgical treatment needs to be evaluated. Several dozens of publications have investigated the psychometric properties of the NDI (Vernon, 2008).

In a systematic review in 2002, Pietrobon et al. compared five different standardized neck pain scales (Pietrobon et al., 2002). They concluded that the NDI is the most extensively validated PROM across various populations with neck pain, which aligns with the comparison of 11 different measures by Resnick et al. in 2005 (Leveille et al., 2000). Another systematic review gathered data from 37 studies in 2008 and criticized previous reviews for not formally critically appraising the quality of individual studies (MacDermid et al., 2009). MacDermid et al. have confirmed that the NDI is a reliable and valid tool for evaluating disability caused by both acute and chronic neck pain (MacDermid et al., 2009).

Several studies have demonstrated the stable psychometric properties of the NDI (Howell, 2011), but concerns have been raised regarding its reliability, dimensionality and high floor effect (Hung et al., 2015; Schellingerhout et al., 2012). Hung et al. have reported multidimensionality using Rasch modeling, considered as a more modern method (Hung et al., 2015). Multidimensionality refers to a situation where a composite score of a scale describes more than one factor (e.g., disability), meaning the score is unreliable. Unidimensional scale measures only one factor, and the composite scores can be compared. Shortened versions have been offered as a solution for the problems with its dimensionality. Van der Velde et al. have removed *headaches* and *lifting*, creating the NDI-8 (van der Velde et al., 2009) and Walton and MacDermid have developed the NDI-5 by removing *pain intensity, headache, sleeping, reading,* and *lifting* (Walton & MacDermid, 2013).

In 2011, a systematic review critically appraised eight neck-specific questionnaires, and recommended the NDI for both practical and research use as the most comprehensively evaluated PROM, although concerns remained regarding its reliability, measurement error, and dimensionality (Schellingerhout et al., 2012). A recent meta-analysis on the psychometric properties of the NDI deemed that in most situations the NDI may be considered a unidimensional scale (Saltychev et al., 2024). It has been suggested that the performance of the NDI may vary depending on the characteristics of the studied population, such as the presence or absence of radicular symptoms (Young Ia Pt et al., 2019).

Looking back on the 17-year history of the NDI in 2008, Vernon noted that it has been employed as a primary outcome measure in 57 surgical trials (Vernon, 2008). Godil et al. compared six different PROMs among patients who had undergone ACDF for neck and arm pain and found the NDI to be the most valid and responsive measure for assessing postoperative improvement for pain and disability (Godil et al., 2015). Recently, Beighley et al. conducted a systematic review comparing commonly used PROMs for spine disease and spinal deformity (Beighley et al., 2022) and concluded that the NDI was valid and reliable and recommended it for use in cervicothoracic spine conditions (Beighley et al., 2022). Whitmore et al. examined correlations between five functional outcome measures among 103 patients who had undergone surgery due to myelopathy (Whitmore et al., 2013). Although all five measures were correlated, the NDI showed the greatest ability to differentiate favorable from adverse quality of life after surgery (Whitmore et al., 2013).

Donk et al. compared the NDI scores with patients' satisfaction with the surgical outcome for single-level degenerative disc herniation (Donk et al., 2016). An NDI score of seven or less points corresponded to a "good" outcome, as reported by the patients (Donk et al., 2016). However, Goyal et al. studied 118 patients with DCM after surgical intervention in order to determine whether improvements in the NDI score or specific domains were appropriate measures for tracking postoperative changes in this patient group (Goyal et al., 2020). All the outcome measures exhibited significant improvement after surgery (Goyal et al., 2020). Although *work*, *recreation*, and the NDI composite score have been significant predictors of change in physical functioning over time, the authors suggested that the NDI may not be a valid tool for determining changes in physical functioning in DCM patients after surgery, as only these two domains correlated with the SF-12 physical component score (Goyal et al., 2020). The NDI score at 12 months after elective surgery for radiculopathy has exhibited the strongest correlation with patient satisfaction when adjusted for other patient- and surgery-related factors (Khan et al., 2020).

Clinical guidelines employing the ICF framework recommend the NDI as the most extensively researched outcome measure of disability caused by neck pain (Blanpied et al., 2017). This aligns with the conclusions of previous evidence-based clinical guidelines for degenerative cervical radiculopathy (Bono et al., 2011). A systematic review studying the compatibility of neck pain scales with the ICF has stated that the NDI has a well-distributed set of items across the components of the ICF (Ferreira et al., 2010).

Despite being extensively studied, there is limited evidence regarding the reliability and validity of the NDI among patients undergoing cervical spinal surgery. The importance of the different domains of functioning defined by the ICF items, as well as the potential differential item functioning (DIF) of the NDI are not very well-known concepts. The potential DIF of the NDI means that different groups of respondents are not as likely to give particular responses, as they may overestimate or underestimate the severity of their disability. The composite NDI score may not reflect the different weights of individual items in dissimilar situations. This phenomenon might be seen indirectly in previous studies reporting variability in the structure of the NDI in factor analyses and the loadings of items (Croft et al., 2016; Gabel et al., 2016; van der Velde et al., 2009; Vernon & Mior, 1991).

NECK DISABILITY INDEX (NDI)

Section 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.

Section 2 – Personal care
0. I can look after myself normally without causing extra pain.
1. I can look after myself normally, but it causes extra pain.
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, I wash with difficulty and stay in bed.

Section 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, for example 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 lift very light weights.
5. I cannot lift or carry anything at all.

Section 4 – Work
0. I can do as much work as I want to.
1. I can do my usual work, but no more.
2. I can do most of my usual work, but no more.
3. I cannot do my usual work.
4. I can hardly do any work at all.
5. I cannot do any work at all.

Section 5 – Headaches
0. I have no headaches at all.
1. I have slight headaches that come infrequently.
2. I have moderate headaches which come infrequently.
3. I have moderate headaches which come frequently.
4. I have severe headaches which come frequently.
5. I have headaches almost all the time.

Section 6 – Concentration
0.I can concentrate fully when I want with no difficulty.
1.I can concentrate fully when I want with slight difficulty.
2.I have fair degree of difficulty in concentrating when I want to.
3.I have a lot of difficulty in concentrating when I want to.
4.I have a great deal of difficulty in concentrating when I want to.
5.I cannot concentrate at all.

Section 7 – Sleeping
0. I have no trouble sleeping.
1. My sleep is slightly disturbed for less than 1 hour.
2. My sleep is mildly disturbed for up to 1-2 hours.
3. My sleep is moderately disturbed for up to 2-3 hours.
4. My sleep is greatly disturbed for up to 3-5 hours.
5. My sleep is completely disturbed for up to 5-7 hours sleepless

Section 8 – Driving
0.I can drive my car without any neck pain.
1.I can drive my car as long as I want with slight neck pain.
2.I can drive my car as long as I want with moderate neck pain.
3.I cannot drive my car as long as I want because of moderate neck pain.
4.I can hardly drive at all because of severe neck pain.
5.I cannot drive my car at all because of neck pain.

Section 9 – Reading
0. I can read as much as I want with no pain in my neck.
1. I can read as much as I want with slight pain in my neck.
2. I can read as much as I want with moderate pain in my neck.
3. I cannot read as much as I want because of moderate pain in my neck.
4. I can hardly read at all because of severe pain in my neck.
5. I cannot read at all.

Section 10 – Recreation
0.I have no neck pain during all recreational activities.
1.I have some neck pain with all recreational activities.
2.I have some neck pain with a few recreational activities.
3.I have neck pain with most recreational activities.
4.I can hardly do recreational activities due to neck pain.
5.I can't do any recreational activities due to neck pain

Figure 3. Neck Disability Index. This figure is a modification of its original version. (Vernon & Mior, 1991)

2.4 Disability and pain after cervical spinal surgery

2.4.1 Overall changes in disability level after surgery

The outcome of an intervention is commonly evaluated by a difference between two measures. These measures may be pre- or post-estimates or the estimates observed in two groups (Carreon et al., 2010). The significance of the difference between the two estimates may be defined as either statistical or clinical. Especially in a large sample, the difference is often statistically significant even if the absolute magnitude of this difference is too small to be perceived by a person in reality. The concept of a minimal clinically important difference (MCID) has been introduced to represent the smallest change in an outcome measure that signifies a clinically meaningful change, in other words, a change perceivable by a person (Jaeschke et al., 1989; Parker et al., 2013). The MCID for the NDI after ACDF has been established as between 16 and 28 points (on an NDI scale of 0–100), depending on the calculation method used (Parker et al., 2013).

Two previous studies offer examples of the differences between statistical and clinical significance. Godil et al. studied 88 patients who had undergone primary ACDF due to neck and arm pain and radiographic evidence of cervical radiculopathy (Godil et al., 2015). The disability severity measured by the NDI had decreased by 25 points one year after surgery (Godil et al., 2015). In a heterogenous group of 505 patients who had undergone cervical fusion due to degenerative spine conditions, the NDI score declined by 13 points whereas the MCID was established as 15 points during the first year after surgery (Carreon et al., 2010). The difference between the pre- and post-estimates was both statistically and clinically significant in the first study, but the result of the later one was significant only statistically, as the estimate remained below the MCID level.

Mjåset et al. studied almost 3,000 patients who had undergone ACDF, a cervical foraminotomy or a cervical hemilaminectomy to establish the criteria for a successful outcome (Mjåset et al., 2020). Patients who reported having "completely recovered" or that their condition had "much improved" on the Global Perceived Effect scale were classified as having a successful outcome. The strongest indicators of successful outcome one year after surgery were an NDI score below 24 points (over 35% improvement from baseline) and neck pain below 2.5 out of 10 points on the NRS (over 47% improvement from baseline) at the end of follow-up (Mjåset et al., 2020).

Burkhart et al. followed 95 patients treated with ACDF for an average follow-up period of up to 28 years (Burkhardt et al., 2016). The study revealed excellent results in pain relief and functional outcome, as indicated by a mean NDI of 14 points (ranging from 2 to 44 points) (Burkhardt et al., 2016). Hirvonen et al. investigated the long-term outcome of ACDF among almost 300 young adults up to 28 years after surgery (Hirvonen et al., 2020). Over 90% of the patients were satisfied with the results of the surgery, as evaluated on a Likert scale. The patients demonstrated a low level of disability with a mean NDI of 18 points. (Hirvonen et al., 2020).

In a meta-analysis of almost 2,500 patients with radiculopathy, myelopathy or a combination of both, the NDI decreased by 33 points during a two-year follow-up (Oitment et al., 2020). Goedmakers et al. compared the outcome of fusion and prosthesis separately for patients with radiculopathy and for the mixed patient population, including patients with myelopathy with or without radiculopathy in their systematic review (Goedmakers et al., 2020). Six RCTs of 342 patients with radiculopathy reported a mean change of 28 NDI points after ACDF in a follow-up ranging from one to seven years (Goedmakers et al., 2020). Twenty-six RCTs reported a mean reduction of 31 NDI points among 2,189 patients with mixed pathology (Goedmakers et al., 2020). A meta-analysis of five studies comparing the clinical outcomes of minimally invasive posterior cervical foraminotomy and ACDF reported that a preoperative mean NDI value of 42 points improved to 25 points postoperatively in patients treated with ACDF during a two-year follow-up (Sahai et al., 2019).

Table 1 presents the average changes in disability level after ACDF reported by the RCTs and the register-based study, using a 100-point scale. Overall, the studies suggest that ACDF may effectively reduce disability in patients with cervical spine conditions. It seems that the effect may be long-lasting or even permanent (Hermansen et al., 2023).

Table 1. Changes in disability level after ACDF.

Study	Design	n	Follow-up, months	NDI[e]	
				Pre	Post
Engquist et al., 2013	RCT	31	24	change -14	
Gornet et al., 2018 [a]	RCT	137	84	54	23
Gornet et al., 2018 [b]	RCT	45	84	50	18
MacDowall, Skepholm, Lindhagen, et al., 2018	RCT	3794	60	42	25
MacDowall et al., 2019	Observational	3721	60	41	25
Nunley et al., 2009	RCT	66	16	44	23
Upadhyaya et al., 2012	RCT	592	24	53	21
Villavicencio et al., 2011	RCT	122	38	40[d]	22[d]
Vleggeert–Lankamp et al., 2019	RCT[c]	36	24	41	19

[a] Patients with radiculopathy; [b] Patients with combined myelopathy and radiculopathy; [c] Randomized Controlled Trial; [d] Reported NDI raw scores multiplied by two; [e] Neck Disability Index (0-100 points)

2.4.2 Factors affecting changes in functioning

Although previous studies have shown improvements in pain and reduced disability following ACDF (Lied et al., 2010; Löfgren et al., 2010; Zoëga et al., 2000), other evidence also suggests that some patients may continue to experience neck and arm pain along with associated disability after surgery (Peolsson, 2007; Peolsson, Vavruch, & Öberg, 2002; Ylinen et al., 2003). Consequently, it may be beneficial to identify the factors that can predict the outcomes after ACDF (Hermansen et al., 2013). This information could contribute to enhancing surgical inclusion criteria, managing patient expectations, and refining postoperative care and rehabilitation approaches (Hermansen et al., 2013). Several factors predicting surgical outcomes have been previously identified. Table 2 shows the common factors affecting changes in functioning.

Higher **preoperative disability** has been associated with worse postoperative disability (Mjåset et al., 2023; Peolsson & Peolsson, 2008). A differing postoperative clinical trajectory has been discovered among patients with severe preoperative disability (Jacob et al., 2022). While significant improvement in pain and disability was achieved in both groups, patients with severe preoperative disability presented with worse mean outcome scores for pain and disability up to two years after surgery compared to those with less severe preoperative disability (Cha et al., 2021; Jacob et al., 2022). Conversely, higher preoperative NDI has also been associated with overall clinical and NDI success (Anderson et al., 2009). The authors suggest that this finding may validate the possibility that an observable disability is a major indication for surgery in patients with both radiculopathy and myelopathy (Anderson et al., 2009). An alternative explanation might be related to statistical anomalies, for example, the ceiling effect of the NDI, that is that the worsening of the measure is limited when the initial scores are the maximum (Anderson et al., 2009). In a study of patients with severe to very severe DCM, the extent of the improvement in the NDI scores was greater in the very severe group, but one third of these patients had experienced residual symptoms for two years postoperatively (Kopjar et al., 2018). Similarly, in a study by Goh et al., 291 patients with myelopathy were stratified on the basis of the severity of their preoperative myelopathy symptoms (Goh et al., 2020). Although the patients with severe myelopathy demonstrated a significantly greater improvement in NDI and a higher portion achieved MCID for the NDI, their satisfaction, return-to-work and NDI scores were inferior at two-year follow-up to those of the patients with mild myelopathy (Goh et al., 2020).

Few studies have investigated the influence of **preoperative pain severity** on postoperative NDI and MCID achievement (Patel, Jacob, Nie, et al., 2022). Low preoperative pain intensity has been linked to an improved NDI (Peolsson et al., 2003), but substantial improvement has also been observed regardless of the presented pain levels (Patel et al., 2023; Patel, Jacob, Nie, et al., 2022; Patel, Jacob, Shah, et al., 2022). Patients with more severe preoperative neck pain intensity have exhibited greater MCID attainment in the NDI two years after surgery (Patel, Jacob, Nie, et al., 2022). Nonetheless, in this study, broader trends indicated that most patients achieving MCID for disability were likely to be those with lower preoperative neck pain (Patel, Jacob, Nie, et al., 2022). In a study by Devin et al., patients with predominant neck pain presented with a worse NDI score 12 months after surgery than the patients with predominant arm pain or equal preoperative pain localization (Devin et al., 2021). However, no significant differences were observed after one year (Devin et al., 2021). Similarly, higher preoperative arm pain appeared to diminish the chances of short-term NDI improvement (Patel et al., 2023).

The findings regarding the influence of **age** on postoperative NDI have been mixed, with some studies indicating that older age is associated with greater NDI improvement (Croci et al., 2022; Omidi-Kashani et al., 2014), while others have suggested that age has no significant impact on postoperative NDI (Chotai et al., 2017; Lee et al., 2020). At least one study has proposed that older age predicts lower NDI scores after surgery (Hartman et al., 2022). It has been observed that younger patients may initially exhibit poorer preoperative disability, but that surgical intervention may have a more pronounced overall effect on young patients, although the older cohort may still experience notable improvement (Hartman et al., 2022). In the context of surgical decision-making, age itself rarely influences the choice to opt for surgery; functional capacity and the specific medical condition being treated primarily more typically guide this decision. Older individuals may have a higher prevalence of coexisting medical conditions or comorbidities, which could potentially contribute to poorer functional outcomes postoperatively. The studies conducted may also have had participants with medical conditions for which recovery rates are consistent across different age groups, and thus age itself may not be the sole determinant of the surgical outcomes.

Although male **sex** has been identified as a positive predictor of good outcomes in spinal surgery (Hermansen et al., 2013; Scerrati et al., 2021; Strömqvist et al., 2008), and women may report worse preoperative back pain and disability (Kim et al., 2013), some reports have declared no significant differences between sexes in postoperative outcomes (Lim et al., 2020; Patel, Jacob, Parsons, et al., 2022). The dissimilarities observed may be attributed to variations in pain perception, with women perceiving pain as more severe due to increased pain-related distress (Paller et al., 2009), and men experiencing less widespread pain (Peolsson & Peolsson, 2008) combined with better neck muscle endurance (Peolsson et al., 2007). Other biological, psychological, and social factors may also contribute to these variations (Hermansen et al., 2013; Paller et al., 2009).

Obesity is a growing global epidemic, and elevated body mass index (BMI) has been linked to a higher incidence of degenerative spinal diseases requiring surgical intervention (Perez-Roman et al., 2021). ACDF requires sufficient tissue retraction of the longus colli muscles, the esophagus, and the trachea to access the anterior cervical column. Consequently, performing the procedure on obese patients with substantial subcutaneous tissue and a large corridor to the spine could result in more extensive and extended tissue retraction (Perez-Roman et al., 2021). However, the impact of obesity on the outcome of ACDF remains unclear. Some studies have suggested that obesity has no effect on the NDI (Sielatycki et al., 2016; Teo et al., 2021; Zhang et al., 2020), patient satisfaction (Sielatycki et al., 2016), or 30-day postsurgical complications (Buerba et al., 2014). In contrast, obesity has been associated with a higher likelihood of developing perioperative complications (Kalanithi et al., 2012; Perez-Roman et al., 2021), longer operative times, and mortality (Jiang et al., 2014). Furthermore, some evidence indicates a correlation between obesity and poorer NDI improvement (Stull et al., 2020), and increased pain six months after cervical spinal surgery (Auffinger et al., 2014).

The **duration of symptoms** has been documented as having a negative impact on the likelihood of recovery in patients with DCM (Kopjar et al., 2018). Likewise, longer duration of preoperative symptoms has been associated with poorer postoperative NDI scores in patients with radiculopathy, with varying symptom duration cutoffs (Hamburger et al., 2001; Mjåset et al., 2023; Shenoy et al., 2020; Tarazona et al., 2019). Some reports also indicate that symptom duration may not influence NDI improvement after surgery (Basques et al., 2019; Omidi-Kashani et al., 2014).

The **indication for surgery** may also have an impact on the outcome. Toci et al. compared the improvements in the PROMs of patients who had undergone ACDF for radiculopathy or myelopathy (Toci et al., 2023). Patients with myelopathy had a significantly lower preoperative NDI but showed less improvement in VAS-arm and NDI after surgery (Toci et al., 2023). It is well-established that patients who have undergone ACDF for radiculopathy can expect substantial improvement in physical functioning, arm pain, and neck disability (Toci et al., 2023). However, ACDF has traditionally been recommended for halting disease progression in myelopathic patients, so the expected improvement in PROMs is often more modest (Toci et al., 2023). Despite these differences in postoperative improvement, many studies tend to group together radiculopathy and myelopathy, which may introduce a significant confounding factor (Toci et al., 2023).

The achievement of clinical improvement in pain and disability after surgery has been closely linked to patient satisfaction (Chotai et al., 2015). However, some patients who experience clinical improvement in disability and pain may still express dissatisfaction one year after spinal surgery (Sivaganesan et al., 2020). Modifiable factors, such as psychological distress, current smoking status, failure to return to work, and limited physical activity could contribute to this dissatisfaction (Sivaganesan et al., 2020).

Smoking has been linked to the development of surgically confirmed lumbar and cervical disc disease (An et al., 1994). Nonsmoking status has been associated with good outcomes in terms of arm pain (Mjåset et al., 2023; Peolsson, Vavruch, & Oberg, 2006), neck pain (Hermansen et al., 2013), and NDI three years after ACDF (Peolsson et al., 2003). However, in a review of smoking habits after lumbar spinal fusion, smoking had no influence on functional outcome, but increased the risk of nonunion (Andersen et al., 2001). Smoking cessation has shown to raise fusion rates to approximately those of nonsmokers (Andersen et al., 2001). Conversely, Gore et al. (Gore et al., 2006) failed to provide evidence that smoking played a causative role in the development of DCSD in asymptomatic people based on their radiographic examination. Peolsson et al. (Peolsson et al., 2004) studied the predictors of fusion after ACDF and found no correlation between smoking and pseudoarthrosis, suggesting that smoking might be associated with outcome by factors beyond strict biological effects.

Patients with **psychological disorders** have presented with a higher rate of spinal pain, postoperative complications and worse functional outcome (Jackson et al., 2019). Previous research has connected poor preoperative mental health with worse preoperative disability (Mayo et al., 2020), and a few studies have also observed this trend postoperatively (He et al., 2017; Skeppholm et al., 2017; Zong et al., 2014). Phan et al. proposed an inverse relationship between preoperative depression and functional outcome of ACDF (Phan et al., 2017). However, some studies have stated that despite experiencing more severe preoperative symptoms, individuals with preoperative mental health disorders exhibit substantial improvement in postoperative outcomes after ACDF (Berno et al., 2012; Mayo et al., 2020). Nonetheless, the strong link between mental health and disability after ACDF has prompted recommendations for the inclusion of mental health screening in preoperative assessments (Goedmakers et al., 2022).

Cognitive-behavioral factors have also been associated with chronic disability and pain after lumbar disc surgery (den Boer et al., 2006). Fear of movement, passive pain coping, and negative outcome expectations have independently predicted more disability and more severe pain after controlling for confounding variables (den Boer et al., 2006). Holly et al. in turn discovered that patients with cervical spondylosis experiencing neck disability exhibited significant changes in brain functional connectivity, which may lead to chronic pain and motor dysfunction (Holly et al., 2019). Furthermore, alterations in brain connectivity might persist even after treatment for the disease, potentially resulting in poorer postoperative physical functioning and pain outcomes (Holly et al., 2019). A degenerative cervical disease may induce long-term reorganization in the specific brain regions involved in pain modulation and sensory processing (Wang et al., 2021).

Table 2. Factors affecting changes in disability after ACDF.

Factor	Effect	Study
Male sex	👍	Hermansen et al., 2013; Scerrati et al., 2021
	👍/👎	Patel, Jacob, Parsons, et al., 2022
Older age	👍	Omidi–Kashani et al., 2014; Hartman et al., 2022
	👍/👎	Chotai et al., 2017; Lee et al., 2020; Croci et al., 2022
Higher BMI	👎	Stull et al., 2020
	👍/👎	Sielatycki et al., 2016; Zhang et al., 2020; Teo et al., 2021
Shorter preoperative duration of symptoms	👍	Hamburger et al., 2001; Tarazona et al., 2019; Shenoy et al., 2020; Mjåset et al., 2023
	👍/👎	Omidi–Kashani et al., 2014; Basques et al., 2019
Worse pain		Peolsson et al., 2003; Devin et al., 2021
	👍/👎	Patel, Jacob, Shah, et al.,2022; Patel, Jacob, Nie, et al. 2022; Patel et al., 2023
Worse disability	👍	Anderson et al., 2009
	👎	Peolsson & Peolsson, 2008; Cha et al., 2021; Jacob et al., 2022; Mjåset et al., 2023
Effect of pain localization	👎	Devin et al., 2021
	👍/👎	Massel et al., 2017; Goh et al., 2021; Patel, Jacob, Shah, et al., 2022
Nonsmoking	👍	Peolsson et al., 2003
Higher educational level	👍	Peolsson et al., 2003; Mjåset et al., 2023

2.4.3 Overall changes in pain severity

Evidence shows that ACDF leads to significant reduction in neck and arm pain (Landers et al., 2013; Massel et al., 2017). The severity of neck and arm pain is usually measured using VAS, which has a horizontal line of 100 mm / 10 cm, on which 0 on one end signifies no pain, and 100 / 10 on the other end signifies the worst possible pain (Bahreini et al., 2015). The scale can be presented in either format, based on the preference of the researchers or clinicians.

Knowledge of the VAS-MCID for the cervical spine is sparse but it has recently been studied by MacDowall et al., who found that the MCID for VAS-neck ranged from 4.6 to 21.4, and for VAS-arm from 1.1 to 29.1, when a VAS from 0 to 100 was used (MacDowall, Skeppholm, Robinson, et al., 2018). Parker et al. set out to determine the ACDF-specific MCID values using four different calculation methods and generated a range of MCID values on a scale of 0 to 100: VAS-neck pain was 26–40 and VAS-arm pain was 24–42 (Parker et al., 2013).

Long-term follow-up studies have also demonstrated sustained pain relief after ACDF. During a minimum of 10 years of follow-up, average VAS improved from a preoperative score of 70 (range 60–100) to 10 (range 0–40) at the last follow-up, when converted to a scale of 0 to100 (Faldini et al., 2010). Similarly, after a 22-year mean follow-up, pain relief continued at the end of the follow-up in 85% of patients (Noriega et al., 2013). A few months after surgery, pain intensity on a VAS scale of 0 to 100 was significantly lower (mean 16) than preoperatively (mean 89), and at the time of the last follow-up it remained low (mean 20) (Noriega et al., 2013).

A meta-analysis comparing the clinical outcome of minimally invasive posterior cervical foraminotomy and ACDF examined six studies of 246 patients reporting VAS-neck and seven studies of 294 patients reporting VAS-arm (Sahai et al., 2019). Neck pain decreased by 24 points and arm pain by 23 points after ACDF (Sahai et al., 2019). In their systematic analysis, Goedmakers et al. separated the neck pain outcome of patients with radiculopathy from that of the mixed patient population, comparing fusion and prosthesis (Goedmakers et al., 2020). Seven studies reported a mean reduction of 57 points among patients with radiculopathy after ACDF. Twenty-four studies reported a 46-point mean reduction for the mixed patient population (Goedmakers et al., 2020).

Table 3 provides an overview of the average changes in neck and arm pain intensity after ACDF reported by the RCTs and the register-based study. In addition, a few observational studies have reported changes in pain severity according to preoperative pain localization.

Table 3. Changes in pain intensity after ACDF.

Study	Design	n	Follow-up, months	Average reduction in VAS (0–100)	
				Neck	Arm
Engquist et al., 2013	RCT	31	24	32	18
Gornet et al., 2018[a]	RCT	137	84	50	49
Gornet et al., 2018[b]	RCT	45	84	57	57
MacDowall, Skeppholm, Lindhagen, et al., 2018	RCT	3794	60	26	28
MacDowall et al., 2019	Observational	3721	60	24	29
Nunley et al., 2009	RCT	66	16	33[c]	33[c]
Villavicencio et al., 2011	RCT	122	38	28	27
Vleggeert–Lankamp et al., 2019	RCT	36	24	30	42
Goh et al., 2021	Observational	102[d] 118[e] 83[f]	24	55[d] 47[e] 21[f]	62[d] 12[e] 59[f]
Massel et al., 2017	Observational	61[e] 28[f]	12	27[g] 35[e] 15[f]	31[g] 29[e] 37[f]
Patel, Jacob, Shah, et al. 2022	Observational	52[e] 58[f]	24	19[e] 10[f]	12[e] 25[f]

[a] Patients with radiculopathy; [b] Patients with combined myelopathy and radiculopathy; [c] Neck and/or upper extremity pain; [d] Equal pain predominance; [e] Predominant neck pain; [f] Predominant arm pain; [g] Average change

2.4.4 Factors affecting change in pain severity

A few studies have investigated the influence of **pain localization** on the recovery of patients who have undergone ACDF. In a study of almost 400 patients, predominant arm pain was the greatest contributor to achieving at least 50% reduction in upper body pain (Passias et al., 2018). Patients with predominant neck pain demonstrated less improvement in VAS-arm and VAS-neck scores, while MCID attainment was similar in the groups (Passias et al., 2018). In contrast, the patients seemed to experience significant improvements in both neck and arm pain regardless of preoperative presenting symptom (Goh et al., 2021; Massel et al., 2017; Patel, Jacob, Shah, et al., 2022).

Higher **preoperative disability** has been linked to weaker improvements in pain scores (Cha et al., 2021; Jacob et al., 2022; Mjåset et al., 2023; Peolsson et al., 2003; Peolsson & Peolsson, 2008). It has been speculated that when patients report high levels of preoperative pain, a substantial change score is required for them to perceive any relief following an intervention (Jensen et al., 2003). However, in a study of patients with mild, moderate and severe myelopathy, neck and arm pain scores were similar at all timepoints after ACDF during a two-year follow-up (Goh et al., 2020).

Higher **preoperative pain severity** has been associated with postoperative pain relief (Hermansen et al., 2013; Lied et al., 2010). However, an immediate high postoperative VAS-neck score has correlated with persistent neck pain 12 months after ACDF (Adogwa et al., 2018). More severe baseline pain intensity may result in worse pain scores at intermediate postoperative timepoints up to one year (Mjåset et al., 2023), but long-term pain outcome is more likely to be comparable (Patel et al., 2023; Patel, Jacob, Nie, et al., 2022).

A study by Stull et al. indicated that degenerative neck pain responded similarly to ACDF regardless of whether the patients had **radiculopathy, myelopathy, or both** (Stull et al., 2020). All three groups had experienced a significant reduction in VAS-neck pain postoperatively, with no significant differences between them (Stull et al., 2020). A meta-analysis by Oitment et al. concluded that patients with radiculopathy, myelopathy or a combination of both had significant relief in neck pain as early as six weeks postoperatively, with continued improvement beyond 48 months (Oitment et al., 2020).

Peolsson et al. found that patients obtaining **fusion** after ACDF reported less pain, although fusion did not affect functional outcome (Peolsson et al., 2004). Radiological factors explained only 4% of the variance in pain during the follow-up (Peolsson et al., 2004). The authors suggested that additional factors, such as indications for surgery and psychological aspects, may have had a more substantial impact on the outcome than radiological variables (Peolsson et al., 2004).

Table 4 summarizes the common factors influencing changes in pain after ACDF, aligning with those previously mentioned in relation to disability. Male **sex** has been associated with either pain reduction (Peolsson et al., 2003; Peolsson & Peolsson, 2008) or no significant impact on postoperative pain (Patel, Jacob, Parsons, et al., 2022). In contrast, Engquist et al. discovered that female sex was linked to better outcome from surgery than from nonsurgical treatment (Engquist et al., 2015). Older **age** either predicted pain reduction (Hartman et al., 2022; Peolsson et al., 2003) or showed no effect on outcome (Chotai et al., 2017; Croci et al., 2022; Lee et al., 2020). Age threshold varied from 49 to 65 years in the studies. Shorter **duration of symptoms** was linked to postoperative pain reduction (Burneikiene et al., 2015; Engquist et al., 2015; Mjåset et al., 2023; Tarazona et al., 2019) or to no effect on postoperative pain (Basques et al., 2019; Omidi-Kashani et al., 2014), with symptom duration cutoffs varying from 3 to 12 months.

Table 4. Factors affecting changes in pain after ACDF.

Factor	Effect	Study
Male sex	👍	Peolsson et al., 2003; Peolsson & Peolsson, 2008
	👎	Engquist et al., 2015
	👍/👎	Patel, Jacob, Parsons, et al., 2022
Older age	👍	Peolsson et al., 2003; Hartman et al., 2022 [a]
	👍/👎	Chotai et al., 2017; Lee et al., 2020; Croci et al., 2022 [a]
Higher BMI	👍/👎	Narain et al., 2018; Teo et al., 2021
Shorter preoperative duration of symptoms	👍	Burneikiene et al., 2015; Engquist et al., 2015; Tarazona et al., 2019; Mjåset et al., 2023
	👍/👎	Omidi–Kashani et al., 2014; Basques et al., 2019
Worse pain	👍	Lied et al., 2010; Hermansen et al., 2013; Wagner et al., 2020
	👎	Adogwa et al., 2017; Patel, Jacob, Nie, et al., 2022; Mjåset et al., 2023; Patel et al., 2023
Worse disability	👎	Peolsson et al., 2003; Peolsson & Peolsson, 2008; Cha et al., 2021; Jacob et al., 2022; Mjåset et al., 2023
Effect of pain localization	👍/👎	Massel et al., 2017; Goh et al., 2021; Patel, Jacob, Shah, et al., 2022
Nonsmoking	👍	Peolsson et al., 2003; Peolsson, Vavruch, & Oberg, 2006; Hermansen et al., 2013; Mjåset et al., 2023

[a] Patients treated with ACDF or TDR/posterior surgical approach.

2.5 Basic psychometric concepts

Whenever the assessment of a person's functioning is based on a questionnaire, the question arises – how reliably is the questionnaire capable of measuring what it is supposed to measure. When testing a new or old questionnaire, a wide variety of methods are commonly followed. There are big differences in the taxonomy of psychometric concepts, their definitions and statistical methods. So far, only one comprehensive system of recommendations concerning psychometrics has been proposed, a Dutch project COSMIN (*COSMIN Consensus-based Standards for the selection of health Measurement Instruments*). All basic psychometric concepts can be divided into three main categories:

1. Validity
2. Reliability
3. Clinical significance

Validity describes the suitability of the questionnaire for the task. To ensure that a questionnaire covers all relevant aspects of the measurable trait, the questionnaire items can be asked to judge by upcoming users (face validity) or by experts (content validity). Construct validity defines the factor structure of questionnaire. First, exploratory factor analysis is used to clarify if the questionnaire measures only one factor (e.g., disability) or many. If the questionnaire is unidimensional, then its composite score can be used with confidence. If the questionnaire is multidimensional (measuring more than one factor), then its composite score should not be used as two scores with equal points can potentially describe very different situations – one can be defined mostly by one factor and another by other factors. After the number of main factors has been established, confirmatory factor analysis can be performed on a sample drawn from the same population in order to describe the strength of correlations between individual items and the measurable factor.

Reliability describes the stability of results obtained by using a questionnaire. There are two most common measures of reliability – internal consistency and intra-rater reliability. Internal consistency (usually expressed as Cronbach's alpha) defines how well individual items included into a questionnaire correlate with each other. Certainly, the higher the internal consistency is the better. Another type of reliability is intra-rater reliability or the repeatability of questionnaire results over time. Same respondents answer to the same questionnaire at two time points assuming that no significant change in their situation has occurred between repeated measures. Intra-rater reliability is usually reported as intraclass correlation coefficient.

Clinical significance helps clinicians to interpret the results obtained from a questionnaire from the practical point of view. The most common forms of clinical interpretation are minimal detectable change (MDC), minimal clinically important difference (MCID), specificity, sensitivity, floor- and ceiling effects and responsiveness. MDC describes the minimal difference in responses, which can be detected by the questionnaire. In turn, MCID defines the smallest change in response, which can be perceived by a respondent as meaningful. Specificity and sensitivity define the amount of true positive and true negative responses and usually expressed by using area under the curve (AUC) statistic. Floor- and ceiling effects describes how sensitive is the questionnaire to detect the different levels of measurable construct at the lowest or the highest parts of the scale. It is usually agreed that if over 15% of responses are placed at the lowest part of the scale a floor effect is present. Respectively, if over 15% of responses are found at the highest possible score, then there is a significant ceiling effect. Responsiveness describes how well the change in a questionnaire score is able to reflect the small change in the status of respondent defined by some other test.

Item response theory (IRT) analysis stands a little aside of these three main categories, but it can be considered, with some reservations, to be a form of reliability. The idea behind IRT is that the score to a questionnaire item may depend on the intrinsic status of respondent. E.g., in some situations, people may over- or underestimate the perceived construct depending on its severity. In other situations, people may guess what score would be "better" or "worse". IRT analysis can be performed in three forms depending on the parameters that are taken into account. The simplest form is a 1-parameter model – the analysis describes how much more or less comparing to the average level (in this particular population) should a respondent experience the severity of measurable construct in order to mark a particular response out of two or more multiple choices. This first IRT parameter is called "difficulty". The next 2-parameter model adds another parameter "discrimination" to the previous model. Discrimination describes how well the item (or the entire multi-item questionnaire) is able to distinguish respondents with different severity of measurable construct at the different parts of scale. The third 3-parameter model is rarely used in medical science and it adds the third parameter of "pseudoguessing" to the previous model. For several decades there has been a debate of the differences between IRT and Rasch analysis. Roughly, Rasch analysis can be considered similar to 1-parameter IRT. However, supporters of the Rasch oppose such an idea. Taking a side in this heated debate was outside the scope of the present thesis.

2.6 Register-based study

The Finnish spine register (FinSpine) is an online, nationwide register developed to provide information about the number and type of surgical interventions on spine, long-term outcomes, and effectiveness of surgical treatment (Marjamaa et al., 2023). Introduced in 2016, FinSpine was inspired by other Nordic spinal registries, including Swedish SweSpine (Strömqvist et al., 2009) and Norwegian NorSpine (Austevoll et al., 2017). Today, more than 80% of public hospitals use the register, with a nationwide patient response-rate of 54-58% (Marjamaa et al., 2023). Hospitals with dedicated register coordinators achieve response rates of up to 90% preoperatively and 80% postoperatively (Marjamaa et al., 2023).

Data obtained from registries can help determine if care is in accordance with evidence-based guidelines and drive improvement in clinical practice (Ingebrigtsen et al., 2023). Aggregated outcome data may serve as a rough suggestion of possible outcomes for an individual patient after surgery (Fritzell et al., 2022). However, translating these group-level data, into individualized assessment of surgical success, may be challenging because several socio-demographic characteristics and other baseline variables, which are not always available, will impact the outcome (Fritzell et al., 2022). Large registries enable the observation of trends and changes over time, in addition to validation of new surgical techniques in general practice (Strömqvist et al., 2013).

Register-based studies have several limitations. These include potential gaps or inaccuracies in the register data, inconsistencies in coding practices across individuals and institutions, and lack of confounder information (Thygesen & Ersbøll, 2014). Registries represent large observational cohorts and are at risk for attrition bias (Ingebrigtsen et al., 2023). This means a systematic loss of study participants over time, due to various factors such as dropouts, loss to follow-up, or incomplete data collection. Loss of participants may skew the results of a study, as excluded participants may represent a subgroup, potentially leading to inaccurate conclusions about the studied population. To reduce bias in results, a 60-80% response-rate at 12 months follow-up has been recommended in a systematic review of evidence and practice in spine registries (van Hooff, Jacobs, et al., 2015). Patients lost to follow-up can be missing completely at random (respondents and non-respondents share similar baseline characteristics and clinical outcomes), at random (some baseline characteristics may be associated with being a non-respondent, but clinical outcomes remain similar), or not at random (being a non-respodent is associated with the outcome) (Kristman et al., 2004). In cohort studies, it seems that loss to follow-up rarely occurs randomly (Kristman et al., 2004). Those patients who are lost to follow-up in spine registries tend to be younger, male, smokers, and have lower socioeconomic status and anxiety disorder (Bisson et al., 2020; Højmark et al., 2016; Parai et al., 2020). Patients lost to follow-up in Swedish national spine register after degenerative lumbar spine surgery were predicted to have worse outcome (Parai et al., 2020).

However, a study examining a subset of NorSpine data for DCSD has found no differences in PROMs between respondents and non-respondents, whose outcomes were collected by telephone interviews (Ingebrigtsen et al., 2023). This suggests that if patient characteristics associated with attrition are appropriately controlled for, outcome analyses based on data from respondents may accurately represent the complete register cohort (Ingebrigtsen et al., 2023). Similar reports exist from Danish and Swedish national spine registries among lumbar spine surgery (Elkan et al., 2018; Højmark et al., 2016).

3 Aims

This thesis focused on the changes in the severity of pain and disability following cervical spinal surgery. The aims were:

1. To identify subgroups of patients with different development trajectories of postoperative pain and disability after surgery, and to identify predictors of probability of being classified to a particular group (V).
2. To evaluate the differences between age- and sex-related orders of importance of the different domains of functioning as reported by patients undergoing cervical spinal surgery (III).
3. To identify a potential sex-related differential item functioning of the Neck Disability Index among patients undergoing cervical spinal surgery (IV).
4. To explore the changes in functional profiles of patients undergoing cervical spinal surgery (II).
5. To validate the Neck Disability Index in the studied sample (I).

The hypotheses were:

1. Relatively large groups of patients can exhibit different changes in pain and disability after cervical spinal surgery.
2. Different domains of functioning can be perceived as more or less important by patients undergoing cervical spinal surgery.
3. Neck Disability Index can produce slightly different scores when applied to different sexes among patients undergoing cervical spinal surgery.
4. The magnitude of changes in different domains of functioning can be different among patients undergoing cervical spinal surgery.
5. The Neck Disability Index is a suitable scale to measure the severity of disability caused by neck pain in the studied sample of patients undergoing cervical spinal surgery.

4 Materials and Methods

4.1 Study cohort

The data for Studies I, II, III, and IV were collected from the register of patients who underwent any type of cervical spine surgery between 21 June 2018 and 17 August 2021 at the Turku University Hospital. Of these patients, all who had responded to an online survey at least once preoperatively were included. They were also included if they had undergone any of the following procedures: anterior fusion of cervical spine without fixation (NAG40), decompression of the cervical spinal cord (ABC60), anterior decompression of the cervical spine with insertion of interbody fixating implant (ABC21), anterior fusion of the cervical spine with fixation (NAG41), decompression of the cervical nerve roots (ABC30), microsurgical excision of cervical intervertebral disc displacement (ABC10), posterior fusion of the cervical spine with or without fixation (NAG42), or decompression of the cervical spinal canal and nerve roots (ABC50), according to the Nordic Classification of Surgical Procedures, version 1.15. For Study V, only patients with anterior fusion of the cervical spine without (NAG40) or with (NAG41) fixation, and anterior decompression of the cervical spine with insertion of interbody fixating implant (ABC21) were included, to enable focusing solely on anterior procedures. Patients who had undergone multiple procedures during the follow-up period were excluded from the analysis.

The patients responded to repeated surveys according to the FinSpine (Marjamaa et al., 2023) register during the two months before surgery, two to four months after the surgery, 11 to 13 months after surgery, and 23 to 25 months after surgery. The survey collected demographic information, as well as data on pain and disability. Data on NDI, VAS-neck, VAS-arm, smoking status, patient-reported height and weight, and pain duration leading up to the time of surgery (<6 weeks; 6–12 weeks; 3–12 months and >1 year) were obtained.

4.1.1 Variables used in the analyses

Age was determined in full years at the time of the surgery. BMI was calculated as body weight divided by the square of height and expressed in kg/m^2. Pain intensity was evaluated using a VAS ranging from 0 to 100 points, where 0 indicated *no pain* and 100 represented *the most severe pain possible*. Except for study V (which employed also arm pain), the severity of neck pain was analyzed. When needed for the sake of analysis, the preoperative duration of pain was dichotomized as <3 months vs. >=3 months, according to a commonly accepted cut-off for acute vs. chronic pain.

The Finnish version of the NDI (NDI-FI), which has previously been validated among Finnish patients (Salo et al., 2010), was used. The respondents rated the severity of their disability for each item on a Likert-type scale from zero to five with 0 indicating *no limitation* and 5 indicating *extreme limitation or an inability to function*, totaling a maximum score of 50 points. The total score of NDI can be expressed as a percentage calculated as a sum of all ten item scores, divided by 50 and multiplied by 100: Total score = (∑item scores/50) x 100. The total NDI score is interpreted as follows: 0–4 points (0–8%) = none; 5–14 points (10–28%) = mild; 15–24 points (30–48%) = moderate; 25–34 points (50–64%) = severe; and over 34 points (70–100%) = complete disability (Vernon, 2008). When the responses to one or more items were missing, the equation was adjusted accordingly. This study used a 100-point NDI scale, in which 50 points equaled 100 points. A score of 0 points indicated the highest level of functioning and independence, and a score of 100 points reflected the lowest level of functioning with complete dependence.

4.2 Data collection

Pre- and postoperative questionnaires have been created as a nationwide cooperative effort of committee of Finnish spine surgeons. In addition to demographics, numerous items (the NDI, pain VAS etc.) have been included if they had previously been found sufficiently reliable and valid and if they had been considered relevant for patients undergoing cervical spinal surgery. The register also included information extracted from the operation room data system like the duration of surgery, blood loss etc.(Marjamaa et al., 2023). All the patients, who were going to be operated in orthopaedic or neurosurgical clinics, received a link to an online-based questionnaire via text-message or email. The link to a preoperative questionnaire was sent at the time of scheduling a surgery, and the link was expired on the day of the operation. The links to a corresponding postoperative questionnaire were sent 30 days before each postoperative time point (three months, one year and two years), and the links were expired 30 days after each time point. Non-respondents received a reminder after 30 days.

4.3 Statistical analysis

4.3.1 Descriptive statistics

The descriptive characteristics of the sample were expressed as absolute numbers or percentages. Normally distributed data were presented as means and standard deviations. The level of statistical significance was set at 0.05. The average estimates were accompanied by 95% confidence intervals (95% CI) when appropriate. In Study III, two age groups were formed on the basis of the median age at the time of surgery. Independent t-tests and chi-square tests were employed to investigate the demographic differences between men and women.

The choice of psychometric statistical methods followed COSMIN recommendations (*COSMIN Consensus-based Standards for the selection of health Measurement Instruments*). In addition, the member of the research team who was responsible for the selection of psychometric methods acts as a leader in the ROVER project, which aims to create recommendations in collaboration with Cochrane Rehabilitation on, among other things, the selection of general psychometric tests.

4.3.2 Psychometric properties of Neck Disability Index (Study I)

This study used Cronbach's alpha to examine the internal consistency of NDI. Alpha describes how well the items of a scale correlate with each other. Alpha values of ≥ 0.9 were considered excellent, ≥ 0.8 good, ≥ 0.7 acceptable, ≥ 0.6 questionable, ≥ 0.5 poor, and values less than 0.5 were considered unacceptable. The sensitivity test was performed by excluding one item at a time. Item-test and item-rest correlations were assessed to evaluate the correlations between individual items and composite score with or without the item in question.

Both exploratory and confirmatory factor analyses were conducted. Exploratory and confirmatory analyses should be performed on separate samples drawn from the same population. In an ideal situation, the number of retained factors is determined by using exploratory factor analysis among a random sample drawn from the studied population. Then, confirmatory factor analysis can be applied, based on the established number of factors, to the random set consisted of different patients from the same population. Register-based design does not allow to follow this path. Thus, the available sample was randomly divided into two subsamples for conducting the two types of factor analysis, balancing sex and age.

Exploratory factor analysis estimated the underlying construct structure of the NDI. The objective was to determine whether the NDI measures had only one latent trait (e.g., disability) or whether other significant latent variables may affect the results. Exploratory factor analysis (principal factors) set a minimum eigenvalue for retention at >1.0 (Kaiser's rule) (Kaiser, 1960).

Confirmatory factor analysis was used to validate the construct structure of the NDI seen in the exploratory factor analysis. This extends the capabilities of exploratory factor analysis by incorporating a measurement error model. The estimation procedure used the maximum likelihood method considering covariances supplied as input being unbiased. The reported estimates were presented in a standardized form as correlation coefficients. Correlations below 0.2 were deemed poor, whereas those ranging from 0.21 to 0.4 were considered fair, from 0.41 to 0.6 moderate, from 0.61 to 0.8 substantial, and above 0.8 perfect.

To assess the degree of alignment between the model and the observed data, the root mean square error of approximation (RMSEA) was employed. Initially, the model fit was evaluated without assuming any covariances between unique factors. Thus, the modification indices provided by the software were utilized to introduce the covariances one at a time. Each covariance was tested to ensure that the lower 90% confidence limit (90% CL) of the RMSEA closely approximated 0.05 and the upper 90% CL approached 0.10. The probability of RMSEA being less than or equal to 0.05 was also reported. Every introduced covariance was considered acceptable if it made logical sense and did not violate the assumption that common and unique factors were uncorrelated. Once an appropriate RMSE value was achieved, no further covariances were added, and the overall goodness-of-fit was evaluated using a chi-square test to compare the used model with a saturated model (a model with a theoretically perfect fit). The results were further supported by Akaike's information criterion (AIC), the Bayesian information criterion (BIC), the comparative fit index, the Tucker–Lewis index, the standardized root mean squared residual, and the coefficient of determination.

4.3.3 Changes in functioning profile (Study II)

Linear mixed models contain both fixed effects and random effects. These models are a generalization of linear regression, allowing for the incorporation of random deviations or effects beyond those associated with the overall error term. Each patient demonstrates some linear trend in the change of NDI score and overall score measurements vary from patient to patient. The sample was treated as a random sample from a larger population, and the between-patient variability was modeled as a random effect, specifically a random-intercept at the patient level. The model was further expanded to include a random slope on the time of measurement, and a likelihood ratio test was utilized to compare a simpler model with only an intercept to a more complex model that also included a slope. Since the likelihood ratio test yielded a statistically significant result (*p* <0.05), the more complex model was adopted for the final analysis.

4.3.4 Effect of sex and age on importance of factors that determine disability (Study III)

Assuming unidimensionality (I), a comparison of confirmatory factor analysis models for sex and age groups was conducted (Brown GTL, 2017; Peugh, 2010; Ryu, 2014). The models were considered different if the likelihood ratio test resulted in a significance level of $p \leq 0.05$. The RMSE of approximation was evaluated, initially assuming no covariances between unique factors. Based on modification indices, covariances were incrementally added one at a time. Once an RMSE close to 0.05 was achieved, no further covariances were imputed. The loadings were presented as standardized values (correlation coefficients) and categorized as follows: 0.00–0.10, negligible correlation; 0.10–0.39, weak; 0.40–0.69, moderate; 0.70–0.89, strong; and 0.90–1.00, very strong correlation (Schober et al., 2018).

4.3.5 Sex-related differential item functioning of Neck Disability Index (Study IV)

DIF, a subroutine of the IRT, was used to examine whether NDI items behave differently depending on whether the disability level is measured among men or among women. The IRT enables the characterization of two main psychometric properties of a questionnaire: discrimination and difficulty parameters.

Discrimination measures the sensitivity of a test to differentiate the severity levels of symptoms, represented by a regression curve. The steeper the curve, the more discriminative the test is. Ideally, the steepest interval aligns with an average disability level in the studied population. In this study, the discrimination values were categorized as *none* (0.01–0.24), *low* (0.25–0.64), *moderate* (0.65–1.34), *high* (1.35–1.69), and *perfect* (discrimination >1.7) (Baker, 2001). Difficulty, on the other hand, describes how much more or less a respondent should perceive disability than the average level in the studied population, in order to attain a 0.5 probability of providing a particular answer. Ideally, zero difficulty is located in the middle of the scale. In an ideal NDI case (a six-level grading system from zero to five) zero difficulty would be situated at a response of 2 or 3. This means that difficulty estimates for 0 or 1 would carry a minus sign, indicating less severe disability, and responses of 4 and 5 would be positive, indicating more severe disability than on average.

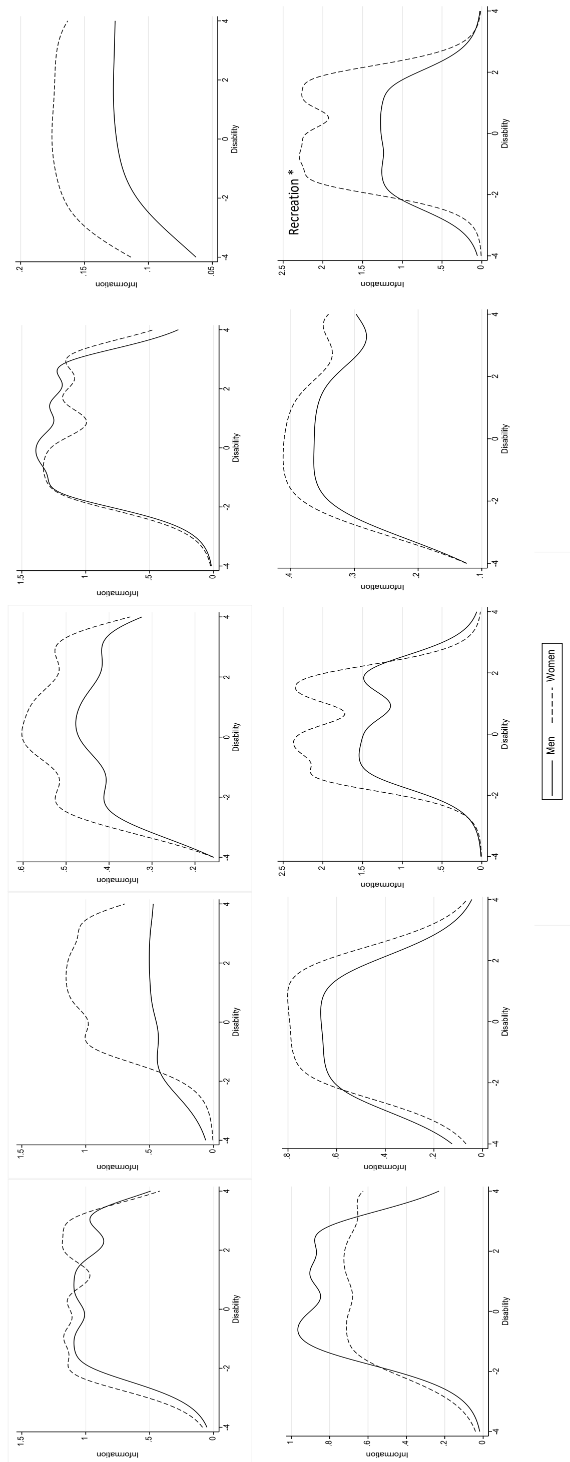

Figure 4. Test information functions for the NDI items by sex. Test information is an inverse variance representing the preciseness of the scores. * Statistically significant difference between sexes (*p* <=0.005). Reproduced with the permission of the copyright holders from original Study IV (2023).

Probit logistic regression was used to test whether an item exhibited uniform or nonuniform DIF in the two sexes (De Boeck, 2004; Swaminathan H, 1990). Uniform DIF occurs when the difference between groups remains the same across the entire scale, while nonuniform DIF is observed when the direction of difference varies at different levels of functioning limitation (e.g., when men perform better up to a midpoint and worse than women after that). The significance level for DIF was set at $p < 0.05$. The results of the analysis are presented and evaluated graphically using item characteristic curves based on the graded response model (GRM) of IRT, as illustrated in Figure 4.

4.3.6 Changes in disability level and pain severity (Study V)

The determination of the number of clusters and the order of regression involved testing all possible combinations from one to four clusters and from first-order (linear) to third-order (cubic) regression models. The highest order (1st, 2nd, or 3rd) with a significant p-value of <0.05 was retained. The goodness-of-fit for the retained model was verified using the BIC and the AIC, with a preference for estimates closest to zero. Additionally, the average posterior probability (APP) cutoff was set at 0.7, and the minimum size for a cluster was set at 10%.

Trajectory analysis was separately repeated for the NDI, severity of neck pain, and arm pain (both measured using VAS). For the changes in NDI score and neck pain, three-trajectory models were selected, as the four-trajectory models resulted in groups below a pre-agreed threshold of 10% of the sample size. A two-trajectory model was retained for changes in arm pain.

Once the clusters were identified, the probability of group membership was calculated on the basis of sex, the duration of pain before surgery, and BMI. These probabilities were expressed as relative risk ratios (RRR) with 95% CI. Figure 5 shows the path for the group-based trajectory analysis (GBTA) in this study.

All analyses were conducted using Stata/IC Statistical Software: Releases 16 and 17, College Station (StataCorp LP, TX, USA).

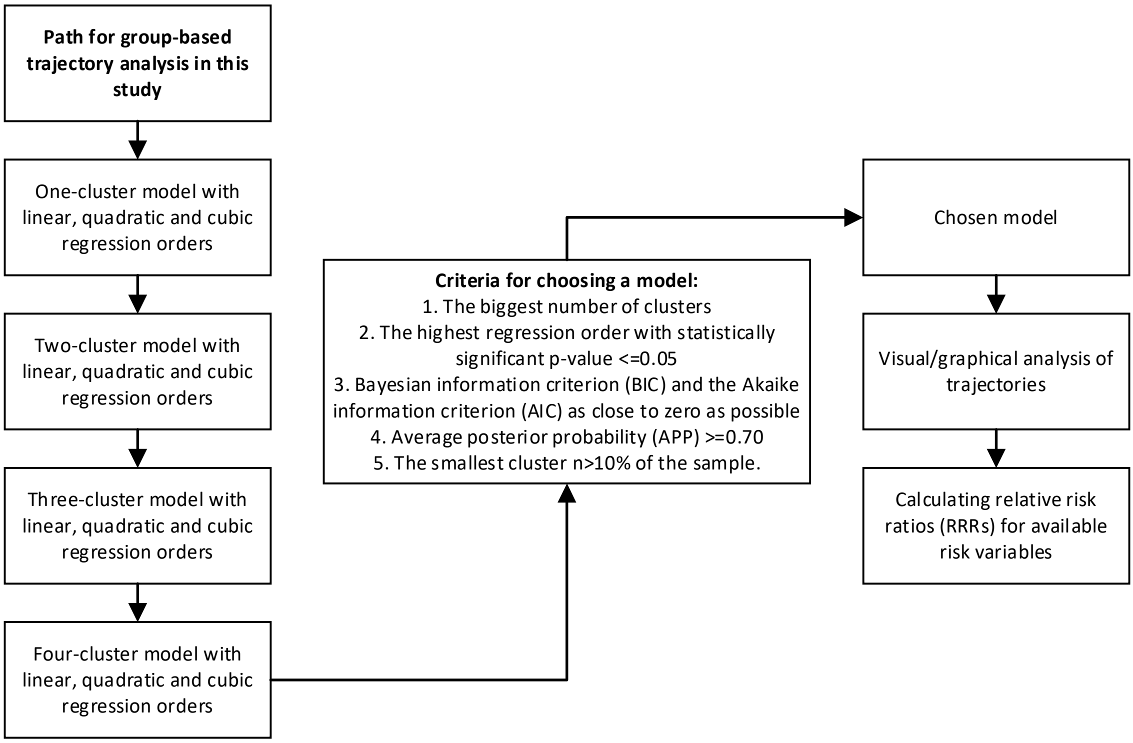

Figure 5. Path for group-based trajectory analysis. Reproduced with the permission of the copyright holders from the original study V.

5 Results

5.1 Descriptive participant characteristics

5.1.1 Studies I–IV

A total of 392 patients were included in Studies I–IV, with 52% being women and 48% men. The average age was 54.9 (SD 11.3) years. In Study III, the average age in Group 1 was 46.1 years (SD 6.9) and in Group 2 it was 64.1 years (SD 6.8). The mean BMI was 28.2 (SD 5.5) kg/m^2. Of the 392 patients, 21 (6%) had experienced neck pain for less than 6 weeks, 36 (10%) for 6 to 12 weeks, 128 (35%) for 3 to 12 months, and 184 (50%) for over one year. Preoperatively, the average NDI was 44.3 (SD 17) points and pain intensity 53.8 (SD 28.5) points. Out of 392 procedures, 294 (70%) were anterior fusion of the cervical spine without fixation (NAG40). The primary reasons for surgery were *M50 Cervical disc disorders* (38%) and *M47 Spondylosis* (34%), according to the International Statistical Classification of Diseases and Related Health Problems, 10th Revision (ICD-10).

5.1.2 Study V

The sample in Study V consisted of 318 patients. The mean age was 52.8 (SD 10.3) years, and the average BMI was 28.3 (SD 5.7) kg/m^2. Of the patients, 49 (16%) had experienced neck pain for less than three months, and 253 (84%) for more than three months. The average NDI score before surgery was 44.9 (SD 16.9) points. Preoperatively, average neck pain was 55.3 (SD 28.0) points and average arm pain 54.8 (SD 28.9) points. The most common surgical technique used was ACDF without fixation, accounting for 86% of the cases. The primary reasons for surgery were *M50 Cervical disc disorders* (43%) and *M47 Spondylosis* (35%). Table 5 shows the descriptive characteristics of the study participants.

Table 5. Descriptive participant characteristics in Studies I–V.

Characteristic	Studies I–IV		Study V	
	Mean (SD)	**N**	**Mean (SD)**	**N**
Age, years	54.9 (11.3)	392	52.8 (10.3)	318
Body mass index, kg/m^2	28.2 (5.5)	392	28.3 (5.7)	318
Arm pain intensity at baseline, points	54.0 (29.0)	214	54.8 (28.9)	177
Neck pain intensity, points				
Baseline	53.8 (28.59)	215	55.3 (28.0)	176
3 months	30.1 (26)	171	29.3 (25.0)	140
1 year	32.5 (27.8)	208	32.5 (28.0)	166
2 years	39.5 (26.9)	103	38.6 (27.5)	86
Neck Disability Index score, points				
Baseline	44.3 (17)	338	44.9 (16.9)	279
3 months	26.8 (18.4)	163	26.1 (18.1)	135
1 year	27 (19)	202	25.1 (18.8)	161
2 years	29.2 (19.3)	93	28.1 (19.4)	81
Pain duration before surgery		N (%)		N (%)
<6 weeks		21 (6)		16 (5)
6–12 weeks		36 (10)		33 (11)
3–12 months		128 (35)		112 (37)
>1 year		184 (50)		141 (47)
<3 months				49 (16)
>=3 months				253 (84)
Surgery codes				
NAG40 Anterior fusion of cervical spine without fixation		274 (70)		274 (86)
ABC21 Anterior cervical decompression with insertion of interbody fixating implant		30 (8)		30 (9)
NAG41 Anterior fusion of cervical spine with fixation		14 (4)		14 (4)
ABC60 Decompression of cervical spinal cord		45 (11)		-
ABC30 Decompression of cervical nerve roots		12 (3)		-
ABC10 Microsurgical excision of cervical disc displacement		8 (2)		-
NAG42 Posterior fusion of cervical spine with or without fixation		7 (2)		-
ABC50 Decompression of cervical spinal canal and nerve roots		2 (1)		-
Main diagnoses				
M50 Cervical disc disorders		147 (38)		136 (43)
M47 Spondylosis		134 (34)		111 (35)
G99 Other disorders of nervous system		59 (15)		35 (11)
G55 Nerve root and plexus compressions		18 (5)		14 (4)
M48 Spondylopathies		14 (4)		13 (4)
M51 Intervertebral disc disorders		14 (4)		4 (1)
Other		6 (2)		5 (2)

5.2 Psychometric properties of Neck Disability Index (Study I)

Cronbach's alpha was determined as good at 0.86 (lower 95% CL 0.84). All the items exhibited good item-test and item-rest correlations. Excluding one item at a time did not contribute to an improvement in the alpha.

The exploratory factor analysis confirmed the unidimensionality of the NDI, as a single factor retained an eigenvalue of 5.31. Satisfactory item loadings were observed for all ten items on this factor.

The confirmatory factor analysis indicated an acceptable fit for the one-factor model. To enhance model accuracy, covariances of measurement errors were imputed for items 2, 3, 7, and 10. The correlations between the main factor of *disability* and the individual items ranged from moderate (0.51) to substantial (0.78). The highest correlations were observed for items 1. *pain intensity*, 4. *reading*, 8. *driving*, and 10. *recreation*, suggesting that these items are particularly relevant when assessing disability.

5.3 Changes in functioning profile (Study II)

During the follow-up period of 23–25 months, statistically significant improvements were observed in all the NDI items and the total score (p <0.001). The NDI total score decreased from 44 to 27 points within the first year after surgery, with a slight trend toward worsening to 30 points at the end of follow-up. Similarly, the individual NDI items showed significant postoperative improvements, with a slight decline between one and two years after surgery. However, overall, the observed improvement persisted throughout the follow-up period.

At the final measurement, the scores of the NDI domains of *sleeping*, *reading*, and *driving* exhibited a greater increase, indicating a worsening of functioning. In comparison to baseline levels, the improvements at the end of follow-up ranged from 20% (e.g., *sleeping* and *headache*) to 40% (e.g., *pain intensity*, *personal care*, *lifting*, and *recreation*). For the other items and the overall composite score, this improvement was approximately 30%. Table 6 presents the changes in the NDI scores. To provide a more comprehensive view of the postoperative changes, the functioning profile based on the NDI is presented as a bar chart in Figure 6, and as a radar chart in Figure 7.

Table 6. Neck Disability Index (NDI) scores at different timepoints. Reproduced with permission of copyright holders of original Study II (2023).

NDI items	Mean (0.95 % CI)	N	NDI items	Mean (0.95 % CI)	N
Pain intensity			Concentration		
Before surgery	2.27 (2.16–2.37)	392	Before surgery	1.71 (1.61–1.82)	389
2 months	1.27 (1.13–1.41)	191	2 months	1.05 (0.91–1.19)	189
12 months	1.34 (1.21–1.48)	217	12 months	1.11 (0.98–1.25)	217
2 years	1.47 (1.28–1.65)	105	2 years	1.19 (1.01–1.37)	105
Personal care			Work		
Before surgery	1.41 (1.30–1.51)	391	Before surgery	2.75 (2.60–2.91)	371
2 months	0.82 (0.68–0.96)	191	2 months	1.85 (1.65–2.05)	186
12 months	0.74 (0.61–0.87)	219	12 months	1.75 (1.56–1.93)	218
2 years	0.81 (0.63–0.98)	105	2 years	1.92 (1.67–2.17)	103
Lifting			Driving		
Before surgery	2.35 (2.21–2.49)	390	Before surgery	2.36 (2.22–2.49)	361
2 months	1.72 (1.53–1.90)	189	2 months	1.29 (1.11–1.47)	179
12 months	1.43 (1.25–1.60)	218	12 months	1.32 (1.15–1.49)	209
2 years	1.44 (1.21–1.68)	104	2 years	1.60 (1.37–1.84)	98
Reading			Sleeping		
Before surgery	2.21 (2.08–2.33)	388	Before surgery	2.32 (2.19–2.45)	390
2 months	1.36 (1.19–1.52)	188	2 months	1.48 (1.31–1.65)	189
12 months	1.35 (1.19–1.50)	218	12 months	1.53 (1.37–1.69)	218
2 years	1.61 (1.40–1.82)	104	2 years	1.89 (1.67–2.11)	104
Headaches			Recreation		
Before surgery	1.81 (1.69–1.94)		Before surgery	2.77 (2.63–2.90)	376
2 months	1.25 (1.08–1.41)	392	2 months	1.68 (1.49–1.87)	185
12 months	1.37 (1.22–1.53)	192	12 months	1.65 (1.47–1.82)	216
2 years	1.48 (1.27–1.69)	219	2 years	1.73 (1.48–1.98)	100
Total score		104			
Before surgery	44.17 (42.27–46.06)	338			
2 months	27.06 (24.60–29.52)	163			
12 months	27.09 (24.82–29.36)	202			
2 years	30.30 (27.21–33.38)	93			

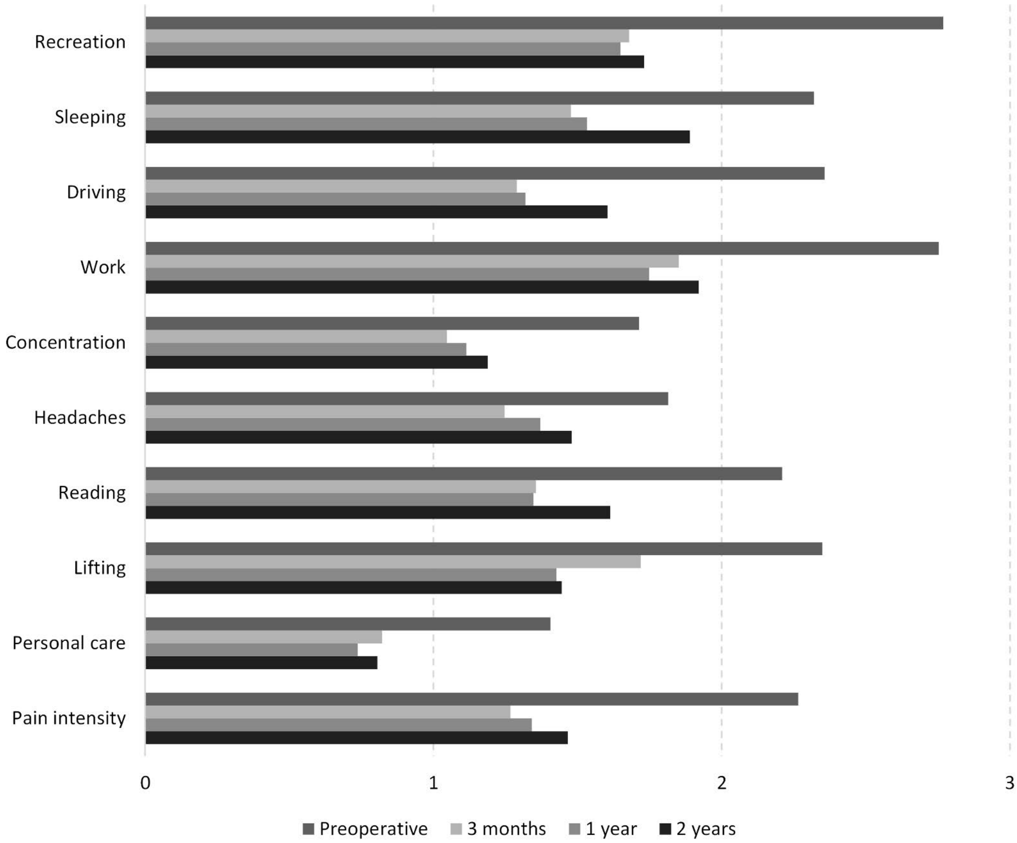

Figure 6. Change in functioning profile, presented as bar chart. Reproduced with permission of copyright holders of original Study II (2023).

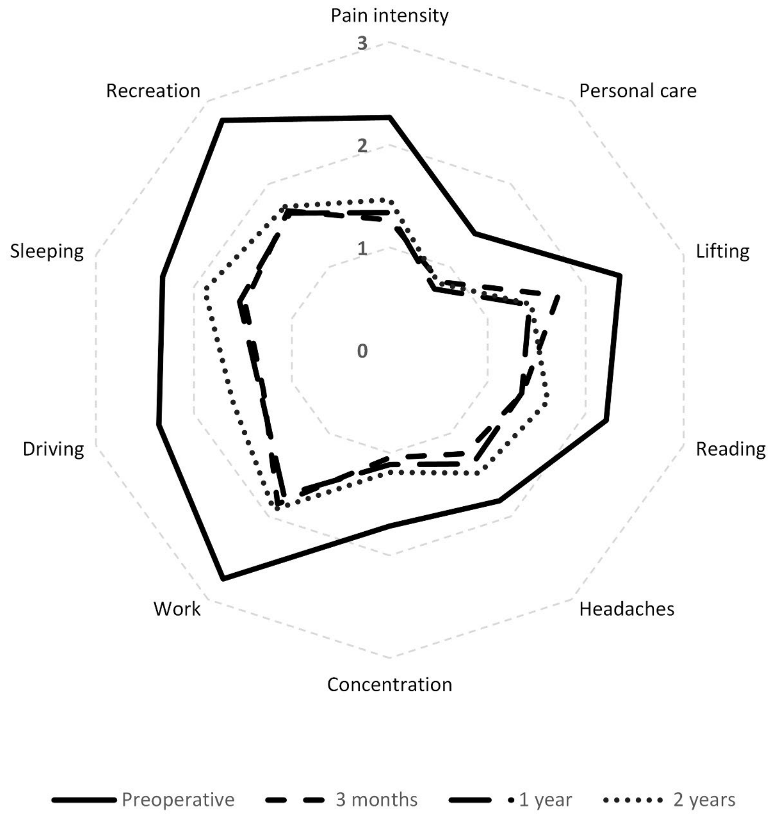

Figure 7. Change in profile of functioning presented as radar chart. Reproduced with permission of copyright holders of original Study II (2023).

5.4 Effect of sex and age on importance of factors that determine disability (Study III)

Before surgery, the women reported higher levels of pain than the men: 58.7 (SD 27.9) vs. 48.5 (SD 28.1) points, and this difference was statistically significant (p = 0.0083). Additionally, the composite NDI score was slightly higher among the women: 47.2 (SD 16.8) vs. 41.3 (SD 16.7) points (p = 0.0013). However, other differences between the sexes were not statistically significant.

Confirmatory factor analysis models for sexes and age groups were compared, and the likelihood ratio test demonstrated a significant result, with p <0.0001, indicating the presence of a common factor in both groups. Most loadings were positive and at least moderate. *Reading* and *driving* were strongly associated with a common factor for all groups, as were *pain intensity* and *recreational activity*. *Headaches*, *lifting*, and *sleeping* were of lesser importance.

Among the men, *reading* and *pain intensity* had higher loadings, whereas *recreational activity* and *driving* had higher loadings among the women. *Reading* and *work* were more significant for the younger respondents, and *recreational activity* was more important for the older respondents. Based on the lower confidence limits, five items showed a strong correlation of >0.70: *reading* among men, *recreational activity* and *driving* among women, *reading* among the younger respondents; and *driving* among the older respondents. Additionally, five items demonstrated only weak loadings: *headaches*, *personal care,* and *lifting* among men, and *headaches* among women and older respondents. The covariance structure was complex and showed no evident patterns, except among the younger respondents, where most of the covariances were connected to *work*. Table 7 presents the loadings of the NDI items by age groups and sex.

Table 7. Loadings of the NDI items by group sorted from high to low. Strong loadings are bolded. Reproduced with permission of copyright holders of original Study III (2023).

ITEMS	LOADING (95% CI)	ITEMS	LOADING (95% CI)
Men		**Women**	
Reading	**0.79 (0.72 to 0.86)**	**Recreation**	**0.84 (0.77 to 0.90)**
Pain intensity	**0.76 (0.68 to 0.83)**	**Driving**	**0.79 (0.72 to 0.85)**
Driving	**0.74 (0.66 to 0.82)**	**Reading**	**0.73 (0.65 to 0.81)**
Concentration	**0.73 (0.65 to 0.81)**	Pain intensity	0.69 (0.61 to 0.77)
Recreation	0.60 (0.50 to 0.71)	Personal care	0.64 (0.55 to 0.74)
Sleeping	0.50 (0.38 to 0.62)	Work	0.64 (0.55 to 0.73)
Work	0.46 (0.34 to 0.59)	Concentration	0.59 (0.49 to 0.69)
Headaches	0.41 (0.28 to 0.54)	Lifting	0.54 (0.43 to 0.65)
Personal care	0.38 (0.25 to 0.52)	Sleeping	0.48 (0.37 to 0.60)
Lifting	0.37 (0.23 to 0.50)	Headaches	0.30 (0.17 to 0.44)
Age group 46.1 (6.9) years		**Age group 64.1 (6.8) years**	
Reading	**0.80 (0.73 to 0.86)**	**Driving**	**0.82 (0.76 to 0.89)**
Work	**0.77 (0.68 to 0.86)**	**Recreation**	**0.73 (0.65 to 0.81)**
Driving	**0.71 (0.64 to 0.79)**	**Reading**	**0.72 (0.64 to 0.80)**
Pain intensity	0.69 (0.60 to 0.77)	**Pain intensity**	**0.71 (0.63 to 0.79)**
Recreation	0.68 (0.60 to 0.76)	Concentration	0.67 (0.58 to 0.76)
Concentration	0.63 (0.53 to 0.72)	Work	0.62 (0.52 to 0.72)
Personal care	0.55 (0.45 to 0.65)	Personal care	0.57 (0.46 to 0.68)
Lifting	0.53 (0.43 to 0.63)	Sleeping	0.51 (0.40 to 0.63)
Sleeping	0.46 (0.34 to 0.57)	Lifting	0.47 (0.35 to 0.59)
Headaches	0.43 (0.31 to 0.55)	Headaches	0.26 (0.11 to 0.40)

5.5 Sex-related differential item functioning of Neck Disability Index (Study IV)

The difficulty estimates for the majority of the NDI items reflected an ideal scenario, with zero centered around responses of 2 and 3, negative values for responses below 2, and positive estimates for responses above 3. Only the *personal care* item slightly deviated from this ideal situation, as responses of 0 and 1 were negative. This indicates that for this particular item, the respondents with severe restrictions to functioning might perceive their disability as milder than the actual level compared to the sample average.

Seven out of ten NDI items demonstrated high or perfect discrimination ability. The *lifting* (1.32 [95% CI 1.05–1.60]), *headaches* (0.71 [95% CI 0.50–0.93]) and *sleeping* (1.12 [95% CI 0.87–1.37]) items showed only moderate discrimination abilities. All the difficulty and discrimination estimates were statistically significant with 95% CI not including zero.

Although differences between sexes were apparent in all ten items, only three items demonstrated statistically significant DIF: *pain intensity*, *headaches*, and *recreation*. The DIF curves for *headaches* were uniform and remained consistent across the spectrum of disability variance. In contrast, the DIF for *pain intensity* and *recreation* was nonuniform, and the men's and women's curves crossed each other at different levels of disability. However, these deviations were only minor. The *headaches* item was significantly more precise among the women than the men, whereas the discrimination ability of the *recreation* item was better among the women than the men. Although the other seven items did not show statistically significant DIFs, a trend of better discrimination could be graphically observed among the women in *personal care*, *lifting*, *work*, *driving*, and *sleeping*. The only item with a steeper DIF curve among the men was *concentration*.

5.6 Group-based trajectory analysis of changes in disability level and pain severity after surgery (Study V)

Three trajectory groups were identified on the basis of the changes in disability level following surgery: *Steadily good functioning*, *Improved functioning*, and *Steadily poor functioning* (Figure 8). Within the *Steadily good functioning* group, the baseline NDI score of 26.5 points decreased to 8.1 points during the first year after surgery, slightly increased to 13.2 points after two years but then fell below the baseline level. In the *Improved functioning* group, the high initial NDI score of 48.0 points decreased to 20.5 points during the first postoperative year and rose slightly to 24.2 points by the end of the follow-up, settling at an average of approximately 50% of the preoperative value. Conversely, the *Steadily poor* *functioning* group maintained a nearly constant NDI score throughout the two-year follow-up: fluctuating between 56.3 points at baseline, 49.3 points after one year, and 53.2 points after two years.

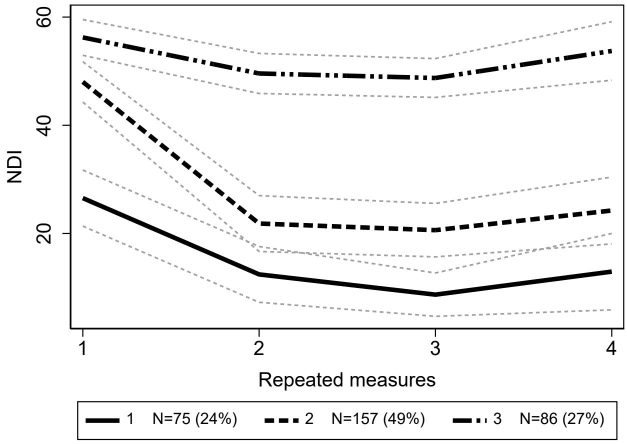

Figure 8. Group trajectories based on changes in functioning. Reproduced with the permission of the copyright holders from the original study V. Group 1=*Steadily good functioning*, group 2=*Improved functioning*, group 3=*Steadily poor functioning*. On the X-axis timepoints #1= two months before surgery, #2=two to four months after surgery, #3=11-13 months after surgery and #4=23-25 months after surgery. The light grey dashed lines represent the 95% CI.

Three distinct trajectories emerged for neck pain severity (Figure 9). The *Worsened neck pain* group showed mild pre- and post-surgery pain (21.5 and 19.5 points), which significantly escalated to 49.7 points at two-year follow-up. The *Relieved neck pain* group displayed a decrease from severe pain at 64.8 points to 12.1 points after one year, settling at 12.6 points at the end of two years; and the *Steadily severe pain* group maintained a relatively consistent range of severe pain at 60–70 points over the two-year period.

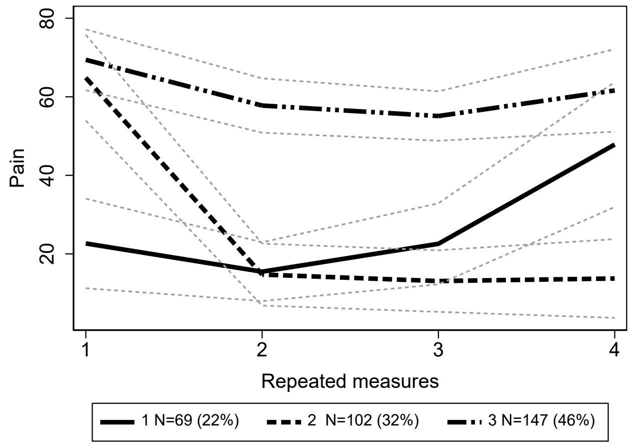

Figure 9. Group trajectories based on changes in neck pain. Reproduced with the permission of the copyright holders from the original study V. Group 1=*Worsened neck pain*, group 2=*Relieved neck pain*, group 3=*Steadily severe neck pain*. On the X-axis timepoints #1= two months before surgery, #2=two to four months after surgery, #3=11-13 months after surgery and #4=23-25 months after surgery. The light grey dashed lines represent the 95% CI.

Two trajectories were identified for arm pain (Figure 10). The *Decreased arm pain* group saw a moderate pain decline from 40.4 points at baseline to 15.4 points after one year, then increased slightly to 19.6 points at the two-year mark. In contrast, the *Severe arm pain with only short-term relief* group had baseline arm pain severity of 70.6 points, which decreased to 47.9 points after one year, but then increased again to 61.0 points after two years.

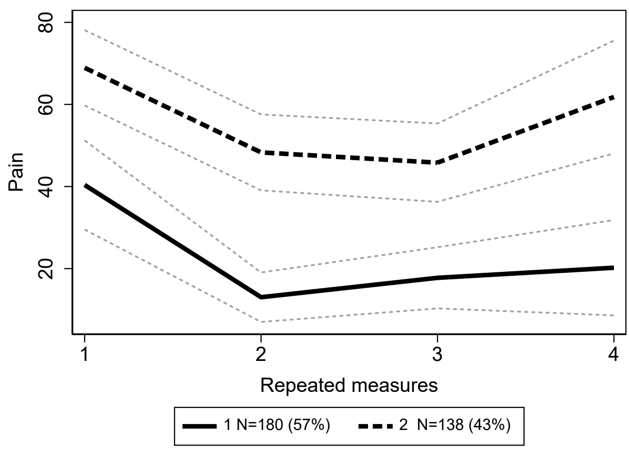

Figure 10. Group trajectories based on changes in arm pain. Reproduced with the permission of the copyright holders from the original study V. Group 1=*Decreased arm pain*, group 2=*Severe arm pain with only short-term relief*. On the X-axis timepoints #1= two months before surgery, #2=two to four months after surgery, #3=11-13 months after surgery and #4=23-25 months after surgery. The light grey dashed lines represent the 95% CI.

No significant associations were found between sex, preoperative pain duration, or body weight and the likelihood of being classified into a specific disability trajectory group. However, female sex increased the likelihood of being classified into the severe neck pain group (RRR 1.78). Longer history of preoperative pain was associated with a higher probability of being categorized into a group with steadily severe neck pain than into any of the other two groups (RRR 2.31 and 2.68). Furthermore, a longer preoperative pain history was linked to an increased likelihood of being classified into the group with severe arm pain with only short-term relief (RRR 2.68). BMI had no significant impact on any of the probabilities.

6 Discussion

6.1 Key results

This thesis used register-based data on all the patients who had undergone cervical spine surgery of any kind in the Hospital District of South-West Finland. When identifying trajectory groups, the data were limited to ACDF surgery only. The main result was that changes in disability and pain after surgery are quite heterogenous and that several relatively large groups of patients demonstrate very different patterns in these changes. These groups can be identified, and in some specific situations the probability of being classified into a particular group may be predicted by very basic factors. Another result was that different domains of functioning may change after surgery with different magnitudes and speeds, and patients perceive different order of these domains' importance.

In general, functional ability had improved at two-year follow-up after surgery. For the majority of patients (over 75%), this was a rapid improvement within the first three months, after which the improvement either slowed down or gently turned in the other direction. Deviating from this general trend, this change for the better did not occur in about a quarter of the patients, for whom disability remained more or less uniformly high.

The changes in upper extremity pain after surgery were different. At three months, arm pain was either at most moderate or had almost disappeared since the initial measurement. At the end of two-year follow-up, arm pain substantially eased among patients with initially mild pain, while pain remained moderate among patients with moderate arm pain at the baseline.

The change in neck pain was considerably more heterogeneous. In about half of the patients, severe neck pain remained at the same level throughout follow-up. On the other hand, in one third of the patients, the very severe pain before surgery decreased rapidly and dramatically during the first three months and remained at this low level for up to two years after surgery. In about 20% of the patients, mild pain before surgery significantly worsened during the follow-up.

In summary, after the operation, the majority of patients felt that their ability to function had improved, even though pain often worsened or remained unchanged at the same time. While the exact reason for such a disproportion is not known, it could be speculated that pain is just one dimension in a very complex concept of functioning, and the imbalance between pain severity and disability level has been often reported before. Another explanation could be that patients with chronic pain can get used to the pain and adjust the demands of their environment and their own activities according to the pain. Sex, preoperative pain duration, and body weight were not associated with the differences in disability level improvements. Instead, female sex and longer duration of preoperative pain correlated with more severe neck and arm pain after surgery.

Individual domains of functioning also underwent different changes after surgery. For example, *pain intensity*, *personal care*, *lifting*, and *recreation* improved more noticeably than *sleeping* or *headache* compared to the initial scores. This result was supported by examining the importance of different NDI items by confirmatory factor analysis. The respondents perceived *headache*, *lifting,* and *sleeping* as the least important domains, and *pain intensity* and *reading* as the most important. This order of importance also varied according to sex and age group. The NDI was used as the main outcome measure of disability caused by neck pain. Its applicability for the task was confirmed by testing its psychometric properties in the studied population.

6.2 Changes in disability level after cervical spinal surgery

Although functioning improved after surgery for most of the patients, this change for the better did not occur for about a quarter of the patients, whose disability remained more or less uniformly high. This is in line with previous studies on the topic that have reported that despite improvements observed at the overall group level, some individuals continued to experience persistent or recurring disability and pain in both the short and long term after surgery (Hermansen et al., 2023). After ACDF, two thirds of patients reported ≥20% disability on the NDI, which was set as the cutoff point for deficit (Peolsson, Vavruch, & Öberg, 2002). Similarly, improvement in the NDI was seen in only about 20% of the patients six years postoperatively (Peolsson, 2007). In a ten-year follow-up after ACDF, pain intensity improved more than disability, indicating a potential need for early postoperative rehabilitation to further improve physical functioning (Hermansen et al., 2011). A study by Hermansen et al. with an over 20-year follow-up showed that 40% of participants experienced a decrease of 20 percentage units in disability, which has been defined as a clinically relevant improvement (Hermansen et al., 2023). Hirvonen et al. followed almost 500 young adults for a median duration of 17.5 years after ACDF, and over 90% of the 281 responding patients remained satisfied with their surgical outcome, despite almost half reporting neck pain associated with disability (Hirvonen et al., 2020).

The novelty of the findings of this thesis is that whereas most previous research has focused on average change in disability, this study attempted to define substantially large groups of patients with different trajectories of changes in disability level. Only a few previous studies have employed similar approaches. They have reported varying postsurgical recovery trajectories among patients with DCM, as the majority of patients have shown significant improvement, although a smaller group has shown no improvement or even declined functional capacity (Jaja et al., 2023). Hébert et al. identified three trajectory subgroups for neck pain-related disability after ACDF in their study, with 45% of the patients categorized as belonging to the excellent subgroup, 39% to the fair subgroup, and 15% to the poor subgroup (Hébert et al., 2023). Among lumbar spinal surgery patients, Yang et al. discovered four distinct functional trajectories following adult spinal deformity surgery, and that individuals with moderate-to-low disability may achieve more favorable functional outcomes (Yang et al., 2020). In addition, Wang et al. identified unique trajectories of pain and disability among lumbar radiculopathy patients following lumbar discectomy surgery, using latent class analysis (Wang et al., 2022). They found three trajectories based on disability (excellent = 60%, fair = 35%, poor = 5%) (Wang et al., 2022). Although a minority of the patients experienced poor disability outcomes, a notable portion, approximately one third, reported persistent back or leg pain after surgery (Wang et al., 2022). These subgroups differed from those previously described by Hébert et al. in their study of patients who had undergone surgery for lumbar spinal stenosis (Hebert et al., 2019), which suggested that recovery patterns vary depending on the clinical characteristics of the overall population under study (Wang et al., 2022).

Sex, preoperative pain duration, and body weight were not associated with differences in improvement in disability level. This is in line with previous studies that have found that sex has little value in clinically meaningful recovery, as women and men have reported similar levels of postoperative disability after ACDF (Patel, Jacob, Parsons, et al., 2022) and minimally invasive lumbar fusion (Lim et al., 2020). In line with the findings of this thesis, a few previous studies have reported that neither symptom duration (Basques et al., 2019; Omidi-Kashani et al., 2014) nor obesity (Sielatycki et al., 2016; Teo et al., 2021; Zhang et al., 2020) have any influence on postsurgical NDI.

In contrast, other previous studies have found some correlations between male sex and greater improvement in disability level after surgery (Hermansen et al., 2013; Scerrati et al., 2021). In a study of patients who had undergone lumbar fusion, women reported significantly greater disability across all domains of ODI, but inferior disability did not translate into poorer quality of life, as measured by health-related quality of life (Ungureanu et al., 2018). Longer duration of symptoms (Hamburger et al., 2001; Mjåset et al., 2023; Shenoy et al., 2020; Tarazona et al.,

2019) and obesity (Stull et al., 2020) have shown to correlate with worse postoperative functioning level. The differences in these results might be explained by previous knowledge on the impact of sex on postsurgical outcomes possibly being compromised by publication bias, as insignificant results are often left unpublished (Patel, Jacob, Parsons, et al., 2022). Inconsistencies in the impact of symptom duration might be explained by the use of different symptom duration cutoff points, as some studies use a three-month (Hamburger et al., 2001; Mjåset et al., 2023) or six-month cutoff (Burneikiene et al., 2015; Omidi-Kashani et al., 2014; Peolsson & Peolsson, 2008) whereas others use 12 months or more (Engquist et al., 2015; Shenoy et al., 2020; Tarazona et al., 2019). It has been proposed that a statistically and clinically significant effect on outcomes may require a longer duration of symptoms, although the chronicity of the pathology could potentially result in permanent neurologic damage (Shenoy et al., 2020). The variability in the literature regarding the impact of obesity may be attributed to limited data availability, small sample sizes, short postoperative follow-ups, and differences in study design (Perez-Roman et al., 2021). Obesity may not diminish the advantages of surgical intervention (Narain et al., 2018; Scerrati et al., 2021; Sielatycki et al., 2016; Teo et al., 2021; Zhang et al., 2020); however, it could elevate the risk of postoperative complications (Jiang et al., 2014; Kalanithi et al., 2012; Perez-Roman et al., 2021; Qi et al., 2020).

In this thesis, belonging to a “nonimproved” group was associated with only an exceptionally severe disability level before surgery. This is in line with previous research results that suggest that patients with more severe preoperative disability demonstrate significantly worse postoperative outcomes (Cha et al., 2021; Jacob et al., 2022; Mjåset et al., 2023; Peolsson et al., 2003; Peolsson & Peolsson, 2008). It could indicate that patients with more severe preoperative disability might have natural restrictions to how much they can recover after surgery due to biological changes in the central nervous system (Cha et al., 2021).

6.3 Changes in neck pain severity after cervical spinal surgery

In about half of the patients, severe neck pain remained at the same level throughout the follow-up. In one third of the patients, the very severe pain before surgery decreased rapidly and dramatically during the first three months and remained at this low level for up to two years. Unexpectedly, in about 20% of the patients, the mild pain before surgery significantly worsened during the follow-up. Female sex and longer duration of preoperative pain were correlated with worse neck pain after surgery. This is in line with previous research that has reported that male sex predicts pain reduction, although pain location was not specified in these studies (Peolsson et al., 2003; Peolsson & Peolsson, 2008). It has been proposed that catastrophizing (Sullivan et al., 2001), differences in pain perception (Paller et al., 2009) and several biological and psychosocial factors (Fillingim et al., 2009), including gonadal hormones, endogenous pain modulatory systems, and sex roles, might explain the higher pain ratings among women. Symptom duration of less than six months has been previously associated with greater neck pain improvement (Tarazona et al., 2019). In contrast, Basques et al. discovered that despite more severe preoperative neck pain in patients with symptom duration of less than six months, there were no significant differences in neck pain during follow-up (Basques et al., 2019). They suggested that the previous study was limited, as the authors lacked precise information on the symptom duration of each patient and relied on questionnaires with broad timeframes (Basques et al., 2019). However, in their narrative review of recent studies on cervical radiculopathy outcomes, Zuckerman et al. concluded that a longer duration of symptoms was associated with a lower likelihood of meaningful improvement (Zuckerman & Devin, 2020).

Only a few studies have attempted to distinguish large groups of patients who have undergone cervical spinal surgery with different trajectories of changes in neck pain. They have reported that individuals with higher baseline neck pain have demonstrated worse neck pain postoperatively for up to six months, despite no differences in neck pain scores at one year and beyond (Patel, Jacob, Nie, et al., 2022). Massel et al. categorized patients on the basis of whether they presented with predominant preoperative arm or neck pain localization (Massel et al., 2017). Although both groups experienced a significant decrease in both arm and neck pain, the reduction in pain was more pronounced among patients aligning with their predominant presenting pain (Massel et al., 2017). Similarly to the present study, a latent class analysis by Hébert et al. (Hébert et al., 2023) revealed that 23% of patients followed a poor neck pain trajectory. The predictors of an unfavorable neck pain outcome included moderate to severe depression, worker's compensation or other preoperative insurance claims, smoking, longer waiting times for surgery, and longer procedure durations (Hébert et al., 2023). The duration of symptoms and sex showed no association with the outcome of neck pain in their study (Hébert et al., 2023).

The differences between the findings of Hébert et al. and the current findings may be explained by variations in the cutoff points for symptom duration, as their study categorized patients on the basis of complaints lasting less than one year, one to two years, or more than two years. The insignificance of sex in comparison to the present study is not properly understood.

6.4 Changes in arm pain severity after cervical spinal surgery

At three months, arm pain was either at most moderate or had almost disappeared since initial measurement. The level of upper extremity pain two years after surgery either substantially eased or was similar to the level of pain before surgery. Other studies have also found this arm pain persistence. A recent investigation on recurrent symptoms after ACDF reported left upper limb numbness in 26% and right upper limb numbness in 21% of its patients (Alzahrani et al., 2023). Patel et al. studied the influence of baseline arm pain severity on the outcome after ACFD and found that mean neck and arm pain scores were higher two years after surgery, although no significant difference was noted at six months (Patel et al., 2023). The authors suggested that the restricted sample size due to losses during follow-up might have been the reason behind the statistical insignificance (Patel et al., 2023). A higher baseline ratio of arm pain to neck pain has been associated with a greater likelihood of postoperative arm pain improvement, which has significantly influenced whether patients achieve at least a 50% improvement in their upper body pain score (Passias et al., 2018). One study reported that for 31% of patients, shoulder symptoms did not improve after ACDF, and that a rotator cuff tear was the major MRI finding among these patients, suggesting the possibility of dual pathologies (Khan et al., 2021). In the two-year clinical outcome trajectories of Hébert et al., 23% of the patients followed a poor outcome trajectory for arm pain (Hébert et al., 2023). Potential explanations for the persistence of symptoms after surgery include inadequate patient selection, the influence of measurement methods on outcomes, and a lack of understanding of the effects of different complementary rehabilitation forms (Peolsson et al., 2003).

In contrast, some previous studies have reported substantial improvement in arm pain after cervical spine surgery (Hirvonen et al., 2020; Srikhande et al., 2019; Vleggeert-Lankamp et al., 2019). In one study, during short-term follow-up, ACDF demonstrated a significant impact on radicular pain among young adults, reducing the prevalence from 90% preoperatively to only 10% postoperatively (Hirvonen et al., 2020). The cervical spine literature has focused on identifying the predictive factors of a favorable surgical outcome to improve patient selection (Passias et al., 2018; Peolsson, Vavruch, & Oberg, 2006). Factors such as nonsmoking status, low pain frequency, and a normal rating in the Distress and Risk Assessment Method (DRAM) have demonstrated significant associations with low arm pain after ACDF (Peolsson, Vavruch, & Öberg, 2006). Latent class analysis has revealed lower physical and mental health, a moderate to severe risk of depression, and longer surgical waiting and procedure times to predict poor postoperative arm pain (Hébert et al., 2023). However, previously reported predictive factors vary, likely due to the use of different outcome measures, small sample sizes, and diverse statistical analyses (Hébert et al., 2023; Peolsson et al., 2003).

Also, in cases of arm pain trajectories, longer duration of preoperative pain has correlated with more severe arm pain after surgery. This is in line with the findings of previous studies that have reported higher reduction in arm pain when symptom duration has been shorter (Burneikiene et al., 2015; Mjåset et al., 2023; Tarazona et al., 2019) .

6.5 Changes in different functioning domains after cervical spinal surgery

The different functioning domains demonstrated more or less diverse magnitudes of improvement after surgery. For example, *pain intensity*, *personal care*, *lifting*, and *recreation* improved more noticeably than *sleeping* or *headache* compared to the initial scores. This is in line with previous research reporting that the functional *pain intensity*, *personal care*, *lifting*, *driving*, and *recreation* domains have exhibited significant improvement after ACDF (Peolsson, Vavruch, & Öberg, 2002). Steinhaus et al. found that the *recreation*, *sleeping* and *pain intensity* domains demonstrated the most significant absolute improvement after cervical spinal surgery (Steinhaus et al., 2019). A study of only DCM patients saw the greatest improvements in the *recreation*, *sleeping* and *work* items (Goyal et al., 2020). Differences in the level of improvement in the different items after surgical intervention have also been seen when using the ODI (Djurasovic et al., 2012; Murphy et al., 2018).

Variations in the extent of score improvement among the items suggested that distinct aspects of functioning might respond differently to surgical intervention. While the composite score of NDI offers an overall description of functioning, it is formed by different sets of scores obtained from individual items. In addition, the composite score may represent different functional situations for individual patients. This study presented a novel approach of using functioning profile to offer a more informative description of postoperative changes.

The varying levels of change in the functional domains of the NDI may be attributed to the fact that the present study exclusively examined surgically treated patients. Not all patients experiencing neck pain can be treated operatively; rather, the decision to undergo surgery is typically based on imaging results and symptoms. Consequently, the process of selecting patients for surgery may involve factors that inherently influence changes in disability. Understanding these variances in the extent of improvement across different items may be valuable in treatment planning and rehabilitation strategies.

6.6 Psychometric properties of Neck Disability Index among patients who have undergone cervical spinal surgery

The unidimensional structure of the NDI showed a good fit when the CFA was employed. There were some age- and sex-related differences in the respondents' perceived order of importance of the different areas of functioning. Women prioritized *recreational activity* and *driving*, while *reading* and *pain intensity* had higher loadings in men. Among younger respondents, *reading* and *work* were of greater importance, whereas *recreational activity* was more important to older individuals. However, for both sexes and all age groups, *headache*, *lifting* and *sleeping* were the least important domains, and *pain intensity* and *reading* were the most important. In any case, it seemed that the NDI may behave slightly differently depending on the sex of the respondents. Specifically, *pain intensity, headaches and recreational activity* were more accurate and more sensitive in detecting functional limitations in women than in men.

These findings are in line with those of previous studies that have supported a one-factor structure (Croft et al., 2016; Hains et al., 1998; MacDermid et al., 2009). Although the importance of the different domains of functioning has not been previously examined, the results indirectly align with earlier reports on varying item loadings in different situations (Croft et al., 2016). Due to their limited impact, *headaches* and *lifting* have been removed from the NDI-8 version (van der Velde et al., 2009) and *pain intensity*, *headache*, *sleeping*, *reading,* and *lifting* have been removed to form a brief five-item version (Walton & MacDermid, 2013). Greater improvement in the domains of functioning perceived as more important by the patient may have an impact on satisfaction with treatment. Further analysis of this finding could provide additional insights into the concept of patient satisfaction. Although very little studied, the *reading* item has shown to exhibit uniform sex-related DIF for each sex (Walton & MacDermid, 2013). Significant DIF has also been observed for the *headaches* item, with women scoring lower than men at similar levels of disability (Ailliet et al., 2013). The finding that several items of the NDI may be more precise and more sensitive among women than among men when restrictions in functioning are being examined adds knowledge on gender disparities following spinal surgery, a key issue for more personalized treatment (Salamanna et al., 2022).

In contrast to the findings of this study, some previous research has reported multidimensionality in the NDI (Ailliet et al., 2013; Hung et al., 2015; van der Velde et al., 2009), like for the ODI. These differences may be explained by different psychometric behavior across diverse populations. It has been suggested that the potential reason for either a one-factor or two-factor structure might be connected to the different influence that pain and disability have on various pathologies and samples (MacDermid et al., 2009). However, as several studies have agreed that only one factor—disability—is present for both NDI (Cook et al., 2006; Hains et al., 1998; Salo et al., 2010; Saltychev et al., 2018) and ODI (Gabel et al., 2017; Monticone et al., 2009; van Hooff, Spruit, et al., 2015), it may be reasonable to assume that the NDI exhibits a one-factor structure in the studied population.

The validation of the Finnish version of the NDI among patients undergoing cervical spinal surgery will be valuable for future national spine register studies. The repeatability of previous findings in different study populations —now in the Finnish population, in publicly funded healthcare system, and among operatively treated patients —strengthens the reliability of earlier findings in other contexts.

6.7 Strengths and weaknesses of the study

The strengths of this study are its relatively large dataset of almost 400 patients, consecutive cases, and its wide age and sex distribution. The application of advanced statistical methods enhanced its methodological strength. Real-life register-based data can provide valuable additional information to the knowledge obtained from more evidence-based robust research like controlled trials.

However, the study has several limitations. It must be taken into account that the sample size at baseline was significantly larger than the groups that answered the surveys during the follow-up. Unfortunately, non-response in the middle of the follow-up could not be taken into account in the analyzes due to the available register data. The register did not include data on missing responses. Thus, there was no information about the reasons for non-responding or the situation among patients with missing responses. Missing data could affect the results and this fact should be taken into account when making conclusions. The generalizability of the results can be affected by the fact that the register covered responses obtained from the patients of single hospital district. The drawback of using real-life data lies in the absence of information on the type and extent of conservative treatments provided before surgery, if any. The characteristic weakness of register-based study is that the register includes only those patients operated for whom the surgeon has recorded detailed information about the procedure. For this reason, it was not possible to obtain accurate information about all patients operated during the entire study period. Due to register-based design, the patient data were characteristically heterogeneous. The diagnoses that led to the surgery were described at a general level. It was not possible to find out more precise diagnoses from the patient data (register), e.g. how many patients had radicular symptoms and how many had myelopathy symptoms/findings. It was unknown did the preoperative diagnosis influence the results. The goals of surgery in patients with myelopathy and patients with radicular pain are different. Similar to the present one, an analysis based on diagnosis groups could be an interesting topic for further research.

The trajectory analysis considered only a limited set of potential explanatory variables, such as sex, BMI, and pain duration. Hence, certain significant factors that influence developmental curves might not have been fully recognized. Previously identified factors include greater kyphosis at the operated level, increased neck mobility in right rotation, greater right handgrip strength and increased flexion mobility (Peolsson et al., 2003), worker's compensation, the use of weak narcotics, normal sensory function (Anderson et al., 2009), pain control, catastrophizing (Hermansen et al., 2013), and postoperative collar use (Scerrati et al., 2021), in addition to the previously mentioned factors of age, smoking status, educational level, and both mental and general health (Jackson et al., 2019; Kjellman et al., 2002; Peolsson et al., 2003).

6.8 Suggestions for future research

Functioning profiles and postoperative changes in pain severity and disability level could be investigated among more precisely defined diagnostic groups and with a certain type of surgery. Comparative studies of effectiveness are needed to determine whether the observed changes in pain severity and disability level are due to surgical intervention or coincident. It would be worth planning long-term studies with a longer follow-up period to further investigate postoperative changes more than two years after surgery, and to determine whether the observed differences between the pain outcomes of men and women stabilize after two years. Different rehabilitation programs pre- and postoperatively could be investigated to see whether they speed up or prolong positive changes after surgery.

It might also be useful to study the effect of customized rehabilitation plans on patients with severe and prolonged pain before surgery. Identification of the factors that predict slower recovery may enable addressing these factors through closer monitoring, enhanced pain management, or individual rehabilitation. The results of trajectory analysis could be broadened, using a wider set of explanatory variables including mental health, educational level, and smoking. Spine register-based studies with other spine clinics would offer a more representative sample and produce more generalizable results. In future, it should be examined whether there are differences in baseline characteristics and clinical outcomes between respondents and non-respondents among the FinSpine cohort of patients operated for DCSD.

6.9 Clinical implications

The changes in pain and disability after cervical spine surgery has been the subject of many previous studies. The topic has previously been studied mostly in terms of the average change of the whole sample. In other words, most of the previous research treated the population of operated patients as a homogeneous population. The main contribution of this study to the already existing research knowledge is the evidence of the heterogeneous nature of these changes. Pain and disability change at different rates and in different directions in different patient groups. Changes in different areas of functioning may be different in different groups. Similarly, different patient groups may experience the degree of importance of these areas differently. In addition, this study has shown that a measure of disability commonly used in neck surgery patients (even if it has been found to be valid and reliable) can produce slightly different results in different patient groups.

Clinicians should be prepared for varying degrees and speeds of recovery among patients who have undergone cervical spinal surgery. Based on the presented findings, it seems that some patient groups demonstrate better and others worse surgery results. In some cases, these different paths of postoperative recovery may be predicted by basic factors such as sex, age, or duration of preoperative pain. Moreover, improvements in functioning may not always be followed by pain relief. The changes in functioning may not be homogenous and may show greater or lesser improvements in certain functioning domains. Patients may also consider changes in some particular functioning domains more important than in others. The observed variability in the changes in pain and disability after cervical spinal surgery indicates a need for a more individualized approach when planning and executing the procedure and when planning pre- and postoperative rehabilitation.

7 Conclusions

This thesis ended up with the following conclusions:

1. The changes in disability and pain after cervical spinal surgery can be heterogenous and relatively large groups of patients can demonstrate very different patterns of these changes. These groups can be identified, and in some specific situations the probability of being classified into a particular group may be predicted.
2. Different areas of functioning show different magnitude and speed of changes after cervical spinal surgery.
3. The order of importance of changes in different domains of functioning may vary between sexes and age groups among patients undergoing cervical spinal surgery.
4. Neck Disability Index was found to be an accurate measure of disability among patients undergoing cervical spinal surgery.
5. Neck Disability Index may behave slightly differently in different groups.

Acknowledgements

This work was carried out on the Doctoral Programme in Clinical Research at the University of Turku in 2022–2024, and received financial support from the Finnish government research funding.

I am privileged to acknowledge Professor Mikhail Saltychev and Katri Pernaa as my supervisors. Professor Saltychev, you have made an extensive contribution to this research project and fostered my growth as a scientist. I have always been able to rely on your guidance, linguistic skills, and analytical thinking. Katri, your expertise and positivity have encouraged me throughout this journey. You inspire me as a surgeon and as a scientist. Thank you both for generously sharing your time and knowledge with me.

I extend my sincere appreciation to my reviewers, Adjunct professor Kati Kyrölä and Adjunct professor Teija Lund, for their dedicated commitment and pivotal role in enhancing the quality and depth of my work. Thank you, Professor Ville Leinonen, for accepting the invitation to be my esteemed opponent.

I want to thank my co-authors, Roosa Lintuaho and Anna Kotkansalo, for their collaborative spirit and valuable insights.

Thank you, Alice Lehtinen (Altexta), for revising the English language of this thesis.

I have been blessed with some exceptionally wonderful women in my life. To my amazing, multitalented friend Veera—words cannot express how grateful I am to have you as my best friend since childhood. Katri, I am so thankful that our paths crossed in the early days of medical school. Your readiness to listen to my worries and your ability to always offer the right words in every situation amazes me every time. Jarna, I will forever cherish all the fabulous, fun memories we have shared together. Ellis, thank you for making high school such a happy period in my life. I am forever grateful for your enduring friendship!

To my excellent colleagues in the Satasairaala surgical department, thank you for providing such an enriching, supportive work environment. Especially, I want to thank my dear friend Sofia, firstly for your friendship, as well as for your wonderful support, tips, dresses, and shoes. Thank you, Vesa Pihlajaniemi, for being my mentor in the wonderful field of surgery, into which I am just beginning my journey.

My gratitude also goes to my parents Kari and Säde, for their support and belief in my capabilities. Mom, thank you for taking care of our children and thus providing time for these studies, and for keeping our family in your prayers. Pirjo, I consider you a kind of godmother, and I am grateful for your prayers and commitment to our family.

To my incredible in-laws, Ari and Tarja, thank you for the constant love, time, and support you have given our family; we are truly fortunate to have you!

My brothers Sauli and Samuel, it was you who inspired me to apply to medical school. Thank you for sharing your thoughts on medicine, clinical work, and life in general. My extra thanks go to Sauli for the artwork in this thesis.

I wish to express my deepest, loving gratitude to Juuso, my husband, my best friend, and the fantastic father of our children. I am immensely grateful to have already spent half of my 30-year-long life with you: thank you for all our past adventures, and I look forward to our future ones. Thank you for being there for me every step of the way. I could not have completed this project without you. I am humbled by your endless patience and support, which have given me the strength to rise when I have felt like giving up. You bring out the absolute best in life. Finally, I am eternally grateful for my amazing children Mikael, Mila, and Magnus. Little Magnus, you were the best company when I was writing this thesis. You three are a gift from God beyond measure, the reason behind my smile, my greatest achievement, my everything.

"Commit to the LORD whatever you do, and your plans will succeed"
Proverbs 16:3.

May 2024
Sara Widbom-Kolhanen

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TURUN
YLIOPISTO
UNIVERSITY
OF TURKU

Painosalama, Turku, Finland 2024

ISBN 978-951-29-9745-9 (PRINT)
ISBN 978-951-29-9746-6 (PDF)
ISSN 0355-9483 (Print)
ISSN 2343-3213 (Online)