Occurrence, Risk Factors, and Time Trends for Late Reoperations due to Degenerative Cervical Spine Disease: A Finnish National Register Study of 19 377 Patients Operated on Between 1999 and 2015

BACKGROUND: Surgery for degenerative cervical spine disease has escalated since the 1990s. Fusion has become the mainstay of surgery despite concerns regarding adjacent segment degeneration. The patient-specific trends in reoperations have not been studied previously.

OBJECTIVE: To analyze the occurrence, risk factors, and trends in reoperations in a long-term follow-up of all the patients operated for degenerative cervical spine disease in Finland between 1999 and 2015.

METHODS: The patients were retrospectively identified from the Hospital Discharge Registry. Reoperations were traced individually; only reoperations occurring >365 d after the primary operation were included. Time trends in reoperations and the risk factors were analyzed by regression analysis.

RESULTS: Of the 19 377 identified patients, 9.2% underwent a late reoperation at a median of 3.6 yr after the primary operation. The annual risk of reoperation was 2.4% at 2 yr, 6.6% at 5 yr, 11.1% at 10 yr, and 14.2% at 15 yr. Seventy-five percent of the late reoperations occurred within 6.5 yr of the primary operation. Foraminal stenosis, the anterior cervical decompression and fusion (ACDF) technique, male gender, weak opioid use, and young age were the most important risk factors for reoperation. There was no increase in the risk of reoperations over the follow-up period.

CONCLUSION: The risk of reoperation was stable between 1999 and 2015. The reoperation risk was highest during the first 6 postoperative years and then declined. Patients with foraminal stenosis had the highest risk of reoperation, especially when ACDF was performed.

KEY WORDS: Cervical spine, Degeneration, Population-based, Register study, Reoperation, Risk factors

Surgery for degenerative cervical spine disease (DCSD), especially fusion surgery, has escalated in the United States (US), Norway, and Finland. Annual reoperation rates have varied from 2.3% to 2.9%. Anterior cervical decompression and fusion (ACDF) surgery especially has been suspected of increasing the risk of symptomatic degeneration in the adjacent levels (sASD). The increase in the incidence of revision cervical fusion surgery has been slightly higher compared to primary surgery in the US between 2002 and 2011.

ABBREVIATIONS: ACDF, anterior cervical decompression and fusion; ASD, adjacent segment disease; ATC, anatomical therapeutic chemical; COPD, chronic obstructive pulmonary disease; DCSD, degenerative cervical spine disease; FHDR, Finnish Hospital Discharge Register; HR, hazard ratio; IQR, interquartile range; PDF, posterior decompression and fusion; PIC, personal identity code; RA, rheumatoid arthritis; sASD, symptomatic adjacent segment disease; SI, social insurance institute; US, United States

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and 2009; beyond that, data on the trends in reoperations for DCSD are lacking.

The purpose of this study was to assess the occurrence, risk factors, and time trends of late reoperations covering every patient undergoing their first surgery for DCSD in Finland between 1999 and 2015. Only reoperations occurring more than 1 yr after the primary operation were included.

METHODS

Study Design and Data Sources

Every primary operation performed in Finland for degenerative or rheumatoid cervical spine disease between 1999 and 2015 was retrospectively identified based on the operative codes from the Finnish Hospital Discharge Register (FHDR). Figure 1 illustrates the construction of the database, which has been described in detail previously. The FHDR was subsequently queried for any reoperations using the personal identity codes (PIC), the operative and diagnosis codes, as well as separate complication codes (see Table, Supplemental Digital Content 1 for details). Data on comorbidities, prescription medicines, and deaths were acquired from the registries of the Social Insurance Institute (SII) of Finland and the Cause of Death Register.

The Ethics Committee of the National Institute for Health and Welfare approved the study and the creation of the database (THL 496/6.02.00/2011). The combining of the data was approved by the respective authorities. Informed consent was considered redundant as patients were not contacted and all the data were anonymized. The article...
TABLE 1. The Combinations of the Diagnosis (World Health Organization International Classification of Diseases, 10th revision) and Operative (Nordic Medico-Statistical Committee Classification of Surgical Procedures) Codes Used to Classify the Patients Into the Diagnosis and Technique Groups (Adapted From a Previous Publication)7

| Diagnosis group          | Diagnosis codes | Decompression | Anterior decompression and fusion or arthroplasty | Posterior decompression and fusion |
|--------------------------|----------------|---------------|--------------------------------------------------|-----------------------------------|
| Disc protrusion          | M50.0          | ABC01         | NAG40                                            |                                   |
|                          | M50.1          | ABC10         | NAG41                                            |                                   |
|                          | M50.2          | ABC20         | NAB92                                            |                                   |
|                          | M50.3          | ABC30         |                                                  |                                   |
|                          | M50.8          | ABC50         |                                                  |                                   |
|                          | M50.9          | ABC60         |                                                  |                                   |
|                          | G55.1          |               |                                                  |                                   |
| Foraminal stenosis       | M47.2          | ABC30         | NAG40                                            | NAG42                             |
|                          | G55.2          | ABC50         | NAG41                                            |                                   |
|                          | M99.6          | ABC99         |                                                  |                                   |
|                          | M99.7          |               |                                                  |                                   |
| Spinal canal stenosis    | M47.1          | ABC30[^a]     | ABC21                                            | NAG42                             |
|                          | M47.8          | ABC50         | NAG40                                            |                                   |
|                          | M47.9          | ABC60         | NAG41                                            |                                   |
|                          | M48.0          | ABC99         | NAG72                                            |                                   |
|                          | M99.2          |               |                                                  |                                   |
|                          | M99.3          |               |                                                  |                                   |
|                          | M99.4          |               |                                                  |                                   |
|                          | M99.5          |               |                                                  |                                   |
|                          | G95.2          |               |                                                  |                                   |
|                          | G99.2          |               |                                                  |                                   |

[^a] Six hundred eighty-eight cases with diagnosis codes consistent with spinal canal stenosis and the operative code ABC30 for foraminotomy, mostly from one hospital, were also included in the spinal canal stenosis group.

was constructed in accordance with the Strengthening the Reporting of Observational Studies in Epidemiology guidelines.

Study Setting and Patients

Only the patients operated for DCSD were included in this study. The operative and the diagnosis codes were cross-linked to classify the patients into 3 diagnostic groups (disc protrusion, foraminal stenosis, spinal canal stenosis) and 3 technique groups (decompression; ACDF; posterior decompression and fusion, PDF) (Table 1). Only reoperations occurring >365 d after the primary operation were included. Patients with a previous cervical spine operation between 1986 and 1998 were excluded. The other exclusion conditions were patients younger than 18 yr of age, not residing in mainland Finland or with cancer, inflammatory spondylitis, other secondary spondylarthropathies, osteoporotic fracture, congenital spinal deformity, osteochondrodysplasia, or trauma as the indication for surgery. The data on the comorbidities and the use of analgesics were collected from the FHDR and the registries of the SII utilizing the medication reimbursement codes and anatomical therapeutic chemical (ATC) codes (see Table, Supplemental Digital Content 2 for the classification of the analgesics and the ATC codes).[^7] The comorbidities were grouped into 8 groups (Table 2).

Statistical Analyses

The Pearson χ² test was used to analyze differences in the reoperation rate between the groups. Differences in the follow-up time and the time to reoperation were analyzed using the Kruskal-Wallis independent samples test. P-value < .05 was considered statistically significant. Kaplan-Meier analysis was used to estimate the unadjusted rate of reoperations. For risk factor analysis and comparisons of reoperation risk between the groups, Cox regression analysis was used, with late reoperation as the dependent variable. Factors affecting the time to late reoperation were analyzed using the Cox regression model, with time to reoperation as the dependent variable. Patients were followed until the first reoperation, death or the end of the follow-up (December 31, 2017), and censored at death or at the end of the follow-up in the survival analysis. Statistical analyses were conducted using the IBM SPSS Statistics software version 26 (IBM Corporation, Armonk, New York).

RESULTS

Patients

From the FHDR, 19 377 patients with a primary operation for DCSD between 1999 and 2015 were identified. The follow-up data were complete for all the patients. The baseline
data are given in Table 3 (see Table, Supplemental Digital Content 3 for the granular comorbidity data).

Reoperation Data

During the follow-up, 2293 patients (11.8%) died. Altogether 2547 patients underwent a reoperation during the follow-up time of 0 to 19.4 yr; in 1777 patients (9.2%), the reoperation occurred over a year after the primary operation. The median follow-up times and the median time to reoperation varied between the diagnosis and the technique groups \((P < .001)\) (Table 4, Figure 2). The mean age at reoperation was 54.6 ± 9.6 (range 25.6-85.2) yr and 59.8% of the patients were male. During the follow-up, 233 patients (1.2%) had 2, 41 (0.2%) had 3, and 8 patients (0.04%) had 4 reoperations.

The distribution of the reoperation diagnoses and the reoperation rate in each diagnosis group are depicted in Table 5. Approximately 75.5% of the reoperations were done for radiculopathy and 23.9% for spinal cord compression. Foraminal stenosis accounted for 54.2% of the reoperations. The distribution of the primary and reoperation techniques is detailed in Table 6. ACDF was used in 67.6% of the primary operations and 63.8% of the reoperations. Reoperations because of pseudoarthrosis were rare, only 0.1% of the reoperations.

The Kaplan-Meier estimates for the cumulative risk of reoperation are depicted in Figure 3A for all the reoperations, in Figure 3B for reoperations after the first postoperative year, and in Table 7.

Risk Factors for Reoperation

Patients with radiculopathy underwent reoperations more frequently than those with myelopathy \((10.1\% \text{ vs } 6.9\%, \ P < .001)\). Figure 4 illustrates the reoperation rates within the diagnosis groups depending on the technique used. The rate of reoperations within the different groups is given in Table 8. Only 57 disc arthroplasty operations were identified \((0.4\% \text{ of the anterior operations); 14.0}\% of the arthroplasty patients and 9.8\% of the ACDF patients underwent a reoperation \((P = .280)\) during a mean follow-up time of 7.7 ± 2.2 and 7.2 ± 4.4 yr, respectively \((P = .134)\). Of the foraminotomy patients, 10.3\%, and 4.3\% of the laminectomy patients underwent a reoperation.

In the multivariate analysis, operation for foraminal stenosis, ACDF technique, a younger age, male gender, pulmonary comorbidity, an operation in a public hospital, and the use of weak opiates or muscle relaxants were all independent risk factors for reoperation (Table 8, Figure 5A-5E). The risk of reoperation was approximately 50% higher when ACDF was utilized for foraminal or spinal canal stenosis compared with decompression (Figure 6A-6C). Within the ACDF group, the risk of reoperation was significantly higher in foraminal and spinal canal stenosis patients compared to disc protrusion patients (Figure 7A and 7B). The only risk factors affecting the time to reoperation were the diagnosis group, the patient age group, and operation years (Figure 8A-8C).

Trends in Reoperation Rates

The crude reoperation rate for each consecutive year of primary operations remained fairly stable at around 11.5\% until 2008 (see Table, Supplemental Digital Content 4 for details). In the multivariate analysis, the risk of reoperation was higher at 2005-2007 and 2013-2015, but there were no other significant differences (Table 8). The time to reoperation decreased statistically significantly over time.

DISCUSSION

Key Results

Nine-point 2\% of the patients underwent a reoperation within a mean of 8.1 (range 0-19.4) yr follow-up. The estimated annual risk of reoperation increased up to 6 yr and decreased slightly thereafter; the estimated risk was 2.4% at 2 yr, 6.6% at 5 yr, 11.1% at 10 yr, and 14.2% at 15 yr. Seventy-five percent of the reoperations occurred within 1.0 to 6.5 yr after the primary operation. The median time to reoperation was 3.6 yr and varied depending on the diagnosis and the patient’s age, the shortest being in the foraminal stenosis group and the oldest patients. The operative technique did not affect the time to reoperation. Only 1.4% of the patients had more than one reoperation. Most reoperations
### TABLE 3. The Baseline Data on All the Patients Operated for Degenerative Cervical Spine Disease in Finland Between 1999 and 2015

| Diagnosis groups | Technique groups |
|------------------|------------------|
|                  | Decompression    | Anterior cervical decompression and fusion | Posterior decompression and fusion |
| All patients     | 19377            | 5998 (31.0%) | 571 (12.7%) | 280 (1.4%) |
| Male (%)         | 56.1             | 59.4 | 54.9 | 44.3 |
| Mean age (SD)    | 53.2 (11.4)      | 57.1 (12.7) | 51.1 (9.9) | 62.8 (11.5) |
| Comorbidity group (%) |                 |            |            |            |
| Rheumatoid arthritis | 4.1 | 4.5 | 4.5 | 4.5 |
| Metabolic syndrome | 40.5 | 44.3 | 38.4 | 61.4 |
| Cardiovascular | 44.8 | 20.1 | 12.0 | 28.2 |
| Pulmonary | 16.3 | 15.2 | 16.8 | 17.5 |
| Nervous system | 6.0 | 8.4 | 4.8 | 12.5 |
| Uremia or cancer | 5.1 | 7.0 | 4.1 | 11.4 |
| Psychiatric | 23.5 | 21.0 | 24.7 | 21.8 |
| Musculoskeletal | 10.6 | 10.0 | 10.7 | 18.6 |
| Preoperative pain medications (%) |                 |            |            |            |
| Antiepileptics | 30.3 | 18.0 | 36.0 | 30.7 |
| Duloxetine or amitriptyline | 12.1 | 9.2 | 13.4 | 10.4 |
| Weak opioid | 4.2 | 2.8 | 3.2 | 3.2 |
| Strong opioid | 3.3 | 1.8 | 2.5 | 6.1 |
| Muscle relaxants | 63.1 | 49.3 | 69.5 | 61.8 |
| Operations in a private hospital (%) | 4.9 | 7.7 | 3.7 | 0.7 |

*The prevalence of psychiatric comorbidity is likely overestimated, as psychiatric comorbidity was recorded based on the International Classification of Diseases diagnosis codes from the Finnish Hospital Discharge Registry or the use of antidepressants. In this patient group, antidepressants can also be used for neuropathic pain.*
TABLE 4. The Follow-Up Time, Rate, and Timing of Late Reoperations (>365 Days After the Primary Operation) for all the Patients Operated for Degenerative Cervical Spine Disease in Finland Between 1999 and 2015 by Diagnosis and Technique Groups

| Diagnoses          | Techniques | All | Disc protrusion | Foraminal stenosis | Spinal canal stenosis | Decompression | ACDF | PDF |
|---------------------|------------|-----|-----------------|--------------------|----------------------|---------------|------|-----|
| Mean follow-up time (yr) (SD) | 8.1 (4.9) | 9.0 (5.1) | 7.6 (4.7) | 7.5 (4.8) | 10.1 (5.4) | 7.1 (4.4) | 6.1 (5.3) |
| Median follow-up time (yr) (IQR) | 7.2 (4.0,11.7) | 8.3 (4.6,13.2) | 6.8 (3.8,10.8) | 6.8 (3.7,10.9) | 11.1 (5.3,14.7) | 6.3 (3.8,9.8) | 5.3 (2.8,8.2) |
| Late reoperations % (N) | 9.1 (1777) | 9.2 (634) | 11.0 (756) | 6.9 (387) | 7.9 (476) | 9.8 (1282) | 6.8 (19) |
| Mean time to late reoperation (yr) (SD) | 4.7 (3.5) | 5.5 (3.9) | 4.2 (3.0) | 4.4 (3.3) | 5.8 (4.2) | 4.3 (3.0) | 4.4 (3.0) |
| Median time to late reoperation years (IQR) | 3.6 (2.0,6.5) | 4.2 (2.4,7.8) | 3.3 (1.8,5.8) | 3.3 (2.0,6.0) | 4.6 (2.3,8.4) | 3.4 (2.0,5.8) | 4.3 (1.5,7.0) |

ACDF, anterior cervical decompression and fusion; PDF, posterior decompression and fusion; SD, standard deviation; IQR, interquartile range.

*The follow-up time was defined as time until the first reoperation or death.

FIGURE 2. The distribution of the time to late reoperation (>365 d after the primary operation) in the individual patients primarily operated for degenerative cervical spine disease in Finland between 1999 and 2015. The median time to late reoperation was 3.6 yr in the entire cohort. Of the late reoperations, 75% occurred before 6.5 yr of the follow-up.

were done for radiculopathy and specifically foraminal stenosis. In the multivariate analysis, foraminal stenosis patients had a 38% higher risk of reoperation compared with the disc protrusion group. The risk of reoperation was approximately 50% higher in the foraminal and spinal stenosis patients after ACDF compared to decompression; there was no difference in the disc protrusion group. Male gender, young age, pulmonary system comorbidity, and the use of weak opioids also emerged as risk factors for reoperation. The risk of reoperation did not increase over the years, while the time to late reoperation was reduced.

Strengths and Limitations of the Study

The analysis included every primary operation for DCSD performed in Finland between 1999 and 2015. The reliable administrative records and PICs enable individual tracking of every patient; no patients were lost to the follow-up. Patients were excluded if the diagnosis and operative codes could not be matched, which probably occurred in a random manner.

However, the administrative records lack data on the specifics of the diagnoses or techniques, such as the curvature and the extent of degeneration in the cervical spine, the number of
### TABLE 5. The Rate and Indications for Late Reoperations (>365 Days After the Primary Operation) Within the Primary Diagnosis Groups on Patients Operated for Degenerative Cervical Spine Disease in Finland Between 1999 and 2015

| Reoperation indication       | Disc protrusion | Foraminal stenosis | Spinal canal stenosis | Proportion of all the reoperations % (N) |
|------------------------------|-----------------|--------------------|-----------------------|-----------------------------------------|
| Disc protrusion              | 3.3 (229)       | 1.5 (103)          | 0.9 (51)              | 21.6 (383)                              |
| Foraminal stenosis           | 4.2 (293)       | 7.9 (542)          | 2.3 (128)             | 54.2 (963)                              |
| Spinal canal stenosis        | 1.9 (110)       | 1.6 (107)          | 3.6 (203)             | 23.6 (420)                              |
| Mechanical problem           | 0.0 (2)         | 0                  | 0                     | 0.0 (2)                                 |
| Hematoma<sup>a</sup>         | 0               | 0                  | 2                     | 0.0 (2)                                 |
| Atlanto-axial subluxation    | 0               | 0.0 (4)            | 0.0 (3)               | 0.0 (7)                                 |
| Reoperations in primary diagnosis group % (N) | 9.2 (634)       | 11.0 (756)         | 6.9 (387)             | 1777                                    |

<sup>a</sup>Diagnosis based solely on the diagnosis code.

### TABLE 6. The Rate of Late Reoperations Within the Technique Groups and the Techniques Used in the Late Reoperations (>365 Days After the Primary Operation) on Patients Operated for Degenerative Cervical Spine Disease in Finland Between 1999 and 2015

| Reoperation technique       | Decompression | ACDF  | PDF  | Proportion of reoperations % (N) |
|------------------------------|---------------|-------|------|-----------------------------------|
| Decompression                | 3.3 (199)     | 2.9 (381) | 0.01 (4) | 32.9 (584)                           |
| ACDF                         | 4.3 (259)     | 6.6 (868) | 0.02 (6) | 63.3 (1133)                           |
| PDF                          | 0.2 (10)      | 0.2 (23) | 0.03 (8) | 2.3 (41)                               |
| Complication<sup>a</sup>     | 0.1 (8)       | 0.1 (10) | 0.0 (1) | 0.01 (19)                              |
| Reoperations in primary technique group % (N) | 7.9 (476)       | 9.8 (1282) | 0.07 (19) | 1777                                  |

ACDF, anterior cervical decompression and fusion; PDF posterior decompression and fusion.

<sup>a</sup>Based solely on the operative code. As per the operative codes, complications include 14 operations for hematoma, 2 operations for wound infection, 3 operations for “other postoperative complication” and 1 operation for “other wound complication.”

### TABLE 7. The Number of Reoperations and the Kaplan-Meier Estimates for the Rate of Reoperations for Adults Having Undergone a Primary Operation for Degenerative Cervical Spine Disease in Finland Between 1999 and 2015

| Follow-up (yr) | Patients at risk | Cumulative late reoperations | Estimated rate of late reoperations | SE of estimate |
|----------------|------------------|------------------------------|-------------------------------------|----------------|
| 2              | 17 865           | 441                          | 2.4                                 | 0.001          |
| 4              | 14 560           | 969                          | 5.5                                 | 0.002          |
| 6              | 11 378           | 1277                         | 7.7                                 | 0.002          |
| 8              | 8 725            | 1473                         | 9.5                                 | 0.002          |
| 10             | 6 447            | 1605                         | 11.1                                | 0.003          |
| 12             | 4 589            | 1695                         | 12.5                                | 0.003          |
| 14             | 2 996            | 1740                         | 13.6                                | 0.003          |
| 16             | 1 660            | 1765                         | 14.6                                | 0.004          |
| 18             | 501              | 1776                         | 15.7                                | 0.005          |

SE, standard error.
vertebral levels involved or operated, or the type of instrumentation used.\textsuperscript{10,14–18} Therefore, we cannot assess the effect of these potential risk factors or the anatomical relationship of the reoperation with the primary operation. The number of vertebral levels operated may explain at least partially the differences in the reoperation rates between the ACDF and decompression groups, especially since the risk of reoperation did not increase between 1999 and 2015 despite the change in the operative techniques from predominantly decompressive to ACDF\textsuperscript{19} Further limitations of the operative coding system have been discussed previously.\textsuperscript{7,19} Data on some potential confounding factors, especially smoking, are missing.\textsuperscript{13,17}

**Interpretation**

The reported reoperation rates have varied considerably (Table 9).\textsuperscript{9,15,20–29} In the 2 previous population-based studies, with short follow-up times, the reoperation rates were 5.6% in Washington state\textsuperscript{9} and 3.3% in Taiwan.\textsuperscript{20} A recent meta-analysis reported reoperation rates between 0% and 16.9%, with a pooled prevalence of 5.8% and an annual addition of 0.24% in the risk of reoperation for any technique;\textsuperscript{5} the reoperation rates after cervical fusion have varied between 1.6% and 4.2% annually.\textsuperscript{14} The long follow-up and the exclusion of the first postoperative year in our study may partly explain the differences in the reoperation rates, as the risk of reoperation declined after 6 yr. There may be differences in the operation indications, patient populations, diagnoses, and the techniques used.
TABLE 8. Risk Factors for Late (>365 Days After Primary Operation) Reoperation on all the Patients Operated for Degenerative Cervical Spine Disease in Finland Between 1999 and 2015 (Adjusted Cox Regression Analysis)

| Rate of reoperations, % | Hazard ratio of reoperations (CI) | Significance |
|-------------------------|-----------------------------------|--------------|
| Diagnosis group         |                                   |              |
| Disc protrusion          | 9.2                               | 1.0          |
| Foraminal stenosis       | 11.0                              | 1.33 (1.18-1.51) | <.001 |
| Spinal canal stenosis    | 6.9                               | 1.11 (0.96-1.27) | .436 |
| Technique group          |                                   |              |
| Decompression            | 7.9                               | 1.0          |
| Anterior decompression and fusion | 9.8 | 1.31 (0.82-2.09) | .253 |
| Posterior decompression and fusion | 6.8 | 1.33 (1.18-1.51) | <.001 |
| Gender                   |                                   |              |
| Male                     | 9.8                               | 1.0          |
| Female                   | 8.4                               | 0.79 (0.72-0.87) | .002 |
| Age group                |                                   |              |
| 18-44                    | 11.5                              | 1.0          |
| 45-60                    | 9.8                               | 0.84 (0.75-0.94) | .002 |
| 61-75                    | 6.2                               | 0.68 (0.57-0.81) | <.001 |
| Over 75                  | 2.1                               | 0.33 (0.20-0.55) | <.001 |
| Comorbidity group        |                                   |              |
| Rheumatoid arthritis     | 8.3                               | 1.10 (0.86-1.41) | .436 |
| Metabolic syndrome       | 8.2                               | 1.01 (0.91-1.13) | .801 |
| Pulmonary                | 10.4                              | 1.30 (1.15-1.47) | <.001 |
| Nervous system           | 7.3                               | 1.00 (0.80-1.25) | .979 |
| Uremia or cancer         | 5.3                               | 0.80 (0.61-1.06) | .125 |
| Psychiatric              | 9.4                               | 1.03 (0.91-1.16) | .609 |
| Musculoskeletal degeneration | 9.1   | 1.16 (0.99-1.36) | .060 |
| Cardiovascular           | 6.3                               | 0.84 (0.72-0.99) | .037 |
| Hospital type            |                                   |              |
| Public                   | 9.3                               | 1.57 (1.19-2.07) | .001 |
| Private                  | 3.0                               | 1.0          |
| Preoperative medication  |                                   |              |
| Antiepileptic drugs      | 8.9                               | 1.10 (0.98-1.24) | .095 |
| Amitriptyline or duloxetine | 9.8 | 1.08 (0.92-1.27) | .332 |
| Weak opiates             | 10.1                              | 1.40 (1.11-1.77) | .005 |
| Strong opiates           | 9.2                               | 1.01 (0.77-1.32) | .959 |
| Muscle relaxants         | 9.6                               | 1.19 (1.07-1.32) | .001 |
| Operation years          |                                   |              |
| 1999-2001                | 10.6                              | 1.0          |
| 2002-2004                | 11.1                              | 1.11 (0.94-1.32) | .227 |
| 2005-2007                | 11.8                              | 1.26 (1.06-1.50) | .008 |
| 2008-2010                | 9.9                               | 1.16 (0.96-1.39) | .125 |
| 2011-2012                | 8.1                               | 1.20 (0.98-1.48) | .085 |
| 2013-2015                | 5.3                               | 1.24 (1.00-1.54) | .046 |

CI, confidence interval.

Previous studies have discovered higher rates of reoperation for myelopathy compared with radiculopathy,9,23 which may reflect differences in the number of vertebral levels operated. The risk of reoperation has been found to be smaller in longer fusions.10,14,15 The degenerative changes are more diffuse at the spondylosis stage,30 possibly predisposing foraminal stenosis patients to the development of sASD. Further, the progression of especially foraminal stenosis has been linked to radicular pain.30 The longer follow-up time may also explain this difference, as 2 small series of ACDF operations with an over 20-yr follow-up found reoperations in 23% of disc protrusion patients31 and 11% of spondylotic myelopathy patients.32 The operative indications in Finland may also favor foraminal stenosis: the incidence of primary surgery has increased most in this diagnosis group.7
### TABLE 9. Literature Review of Population-Based Series Describing Rates of Late Reoperations for Degenerative Cervical Spine Disease

| Author                  | Patients and data source                                                                 | Years, follow-up                          | Diagnoses and techniques                                                                 | Reoperation rates                                                                 | Risk factors for reoperation                                                                 |
|-------------------------|------------------------------------------------------------------------------------------|-------------------------------------------|------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------|
| King et al, 2009         | 12,338 patients with degenerative cervical spine disease from Washington SID                 | 1998-2002, median follow-up 2.3 yr (0.99 mo) | Degenerative cervical spine disease Any technique: 82% ventral, 14% dorsal, 4% combined, 0% unspecified Fusion in 87% of the surgeries 100% of the ventral surgeries and 11% of the dorsal surgeries | 5.6% reoperations; 2.9% yr Ventral surgery: RR 0.67; fusion: RR 0.65 Reoperation diagnoses: disc displacement 32%, spondylosis 20%, stenosis 12%, mechanical complication 11% | Higher risk: male gender (RR 1.17), younger age, herniated disc with myelopathy (RR 1.32) Lower risk: ventral surgery (RR 0.82), fusion surgery (RR 0.95) |
| Park et al, 2016         | 9071 patients with cervical radiculopathy or myelopathy; discectomy with anterior fusion, corpectomy (ACDF) or PCD for cervical spondylotic myelopathy; Medicare database from the PearlDiver Patient Records Database | Primary operation in 2009, followed until June 30, 2014, follow-up of 3.5 to 4.5 yr | Cervical radiculopathy or myelopathy ACDF 89.77%, laminectomy with fusion 3.92%, laminoplasty 4.3% | Reoperation rate 3.3% Laminectomy with or without fusion: 10.48% Laminoplasty: 7.93% Discectomy or corpectomy with fusion: 2.48% | Higher risk: laminoplasty (HR 2.4, CI 1.6-3.5), laminectomy with fusion (HR 4.7, CI 2.4-6.2), comorbidity, hospital type Low risk: female gender (HR 0.5, CI 0.34-0.61) Age not a significant risk factor |
| Puvanesarajah et al, 2017 | 55,446 patients undergoing ACDF, corpectomy (ACDF) or PCD for cervical spondylotic myelopathy; Medicare database from the PearlDiver Patient Records Database | 2005-2012, follow-up up to 5 yr | 1-2-level ACDF, 1-2 level ACCE, 1-2 level PCF, 3 or more levels PCF 63.0% ACDF, 78.7% ACCF, 11.0% 1-2 level PCD 18.2% 3 + level PCF; the distribution was different between the patients aged 65 to 64 and younger than 65 yr | Younger age group: 1-2 level ACDF 11.8%, 1-2 level PCF 11.8%, 1-2 level ACCF 16.7%, 3 + level PCD 11.3% Elderly (65 yr or older): ACDF 9.4%, 1-2 level PCF 9.9%, 1-2 level PCD 9.6% | Higher risk in the younger age group (<65 yr): ACDF OR 1.56 or ACCF OR 1.75 Both age groups: ACCF No significant difference between ACDF and PCD in either age group |
| Kelly et al, 2018         | 52,395 patients with single-level degenerative disc disease undergoing ACDF or TDR from OSHPD | 2003-2010, follow-up up to 5 yr | ACDF or TDR 97.2% ACDF 2.8% TDR | Overall late reoperation rate 2.7/100 patient years No significant difference between ACDF and TDR (HR TDR versus ACDF) 0.86 (95% CI, 0.60-1.23) | Older age, HR 1.10; African-American, HR 1.27 Lower risk: female gender, HR 0.68 Worker’s compensation, HR 0.78 |
| Park et al, 2016         | 7948 patients operated by ACDF technique for cervical radiculopathy or myelopathy, identified from Korean HIRA national database | Primary operation in 2009, followed until June 30, 2014, minimum follow-up period 4.92 yr | Cervical radiculopathy or myelopathy 82.28% radiculopathy, 17.72% myelopathy | Reoperation rate 2.45%; 3.69% in patients with myelopathy; 2.19% in patients with radiculopathy | Higher risk: myelopathy, HR 1.43; diabetes, HR 1.54; hospital type, comorbidity, HR 1.39 Lower risk: female gender, HR 0.40 Age not a significant risk factor |
| Veeravagu et al, 2014     | 12,744 patients undergoing single- or multilevel ACDF for any indication, from the MarketScan research Database | 2006-2010, minimum follow-up 2 yr, mean follow-up 3.2 (single-level) and 3.1 (multilevel) yr | Any indication | 91% revisions in single-level and 107% revisions in multilevel ACDFs | Multilevel operation, OR 11 Greater than 2 level operation, OR 1.27 Hypertension, OR 11 Osteoporosis, OR 12 Age (10 yr group), OR 0.90 |
| Wu et al, 2017           | 19,385 ACDF surgeries; from the National Health Insurance Research Database (NHIRD) of Taiwan | 1997-2007, minimum follow-up 1 yr | ACDF | 2nd ACDF 2.9%, 3rd ACDF 0.15% Incidence of secondary ACDF 76.1/1000 patient-years (0.8%/yr) | Male gender, HR 1.27 Young age 15- to 39-yr-olds, HR 1.45 40- to 59-yr-olds, HR 1.41 compared to patients aged 60 yr or older |
| Author                  | Patients and data source                                                                 | Years, follow-up          | Diagnoses and techniques                                      | Reoperation rates                          | Risk factors for reoperation |
|------------------------|------------------------------------------------------------------------------------------|---------------------------|----------------------------------------------------------------|-------------------------------------------|-------------------------------|
| Wu et al, 2019         | 38,149 ACFD surgeries; from the National Health Insurance Research Database (NHIRD) of Taiwan | 1998-2013; follow-up until the end of 2013, mean follow-up 6.2 ± 3.9 yr | ACFD                                                        | 2nd ACFD, 2.9% at the mean of 4.7 yr incidence 4.64/1000 person-years | Male gender, HR 1.18; Younger age; risk diminishes by each progressively older age group Depression, HR 1.42; Psychoses, HR 1.45 |
| Posterior decompression |                                                                                          |                           |                                                                |                                           |                               |
| Sayari et al, 2017      | 6527 patients undergoing single-level posterior foraminotomy from the PearlDiver database | 2007-2011; follow-up of 1, 2 or 4 yr | Posterior cervical foraminotomy                                  | 8.3% reoperations within 1 yr; 9.8% reoperations within 2 yr and 10.5% within 4 yr | Age under 65 yr; highest in the 50- to 54-yr age group No significant gender difference but a trend towards higher incidence of reoperations in females Regional differences in reoperation rates from 9.5% to 20.8% reoperations at 4yr follow-up |
| Veeavagu et al, 2018    | 2613 patients undergoing cervical laminoplasty from the Thomson Reuters MarketScan Commercial Claims and Encounters and Medicare Supplemental and Coordination of Benefits databases | 2007-2014; mean follow-up 2.2 yr | 52.4% cervical spondyloitic myelopathy, 19.3% cervical spinal stenosis, 10.4% disc disorder with myelopathy, 4.7% spondylisis without myelopathy, 1.9% disc displacement without myelopathy, 1.3% disc degeneration | 10.9% reoperations; 4.2% after the first postoperative year Reoperations in 8.9% within first 2 yr 0.2% laminoplasty; 4.5% laminectomy, 4.9% fusion, 0.3% re-fusion | Not analyzed                      |
| Anterior versus posterior operation |                                                                                          |                           |                                                                |                                           |                               |
| Lin et al, 2016         | 8833 patients undergoing multilevel ACFD or LMP for cervical degenerative disease; from Taiwan National Health Insurance Research Database | 2001-2011; follow-up 1-10 yr | 80.7% ACFD, 19.3% LMP                                           | Incidence of reoperations after 1 yr in the LMP group 0.06/1000 person months and in the ACFD group 0.04/1000 person months Reoperation rate 0.48%/yr in the ACFD group No significant difference in risk of reoperation after 1 yr | Higher risk; history of osteoarthritis, HR 2.07 in the ACFD group but not in the LMP group; diabetes in the LMP group, HR 3.27 Low risk; age 65 yr or older in the ACFD group (HR 0.43), 95% CI 0.24-0.77, not in the LMP group |
| Cervical fusion for any indication |                                                                                          |                           |                                                                |                                           |                               |
| Derman et al, 2016      | 87,042 patients undergoing isolated primary subaxial arthrodesis from New York Department of Health’s Statewide Planning and Research Cooperative System database | 1997-2012; median follow-up 75 mos, IQR 28-120 mos | All subaxial cervical arthrodeses                                | Revision rate 7.7%; probability of revision at 16 yr follow-up 12.6% (95% CI, 12.2-13.1%) | Risk factors for revision: age group 35-49 yr or under; Workers’ Compensation or Medicare; white or black ethnicity; spinal stenosis HR 1.12, spondylisis HR 1.12, deformity HR 1.32, neoplasm HR 1.61 Anterior approach 13.4%, HR 1.0; posterior approach 7.4%, HR 0.76; circumferential approach 5.2%; HR 0.53 Higher revision risk in longer (3 or more vertebral levels) arthrodesis, HR 1.18; significant only in anterior arthrodesis, HR 1.25 |

aSID, Washington State Inpatient Database.
bIRR, incidence rate ratio.
cHIRA, Korean Health Insurance Review and Assessment Service.
dACDF, anterior cervical decompression and fusion.
eHR, hazard ratio.
fCI, confidence interval.
gACCF, anterior cervical corpectomy and fusion.
hPCF, posterior cervical foraminotomy.
iOR, odds ratio.
jTDR, total disc replacement.
kOSHPD, California’s Office of Statewide Health Planning and Development Database.
lLMP laminoplasty.
FIGURE 5. The risk of reoperation within the diagnosis A, technique B, gender C, age D, and primary operation year E groups. The adjusted multistep hazard curves illustrating the risk of reoperation for the patients primarily operated for degenerative cervical spine disease in Finland between 1999 and 2015 within the diagnosis groups A, within the technique groups B, between the genders C, within the age groups D, and within the primary operation year groups E. The risk of reoperation was 38% higher in the foraminal stenosis group compared with the disc protrusion group (P < .001), while the difference between the spinal canal stenosis and disc protrusion groups was not significant. The anterior cervical decompression and fusion patients (ACDF) had a 33% higher risk of reoperation compared with decompression patients (P < .001), while the difference between the posterior decompression and fusion (PDF) and decompression groups was not significant. Female patients had a 27% lower risk of reoperation compared with male patients (P < .001). The risk of reoperation was the highest in the youngest age group and lower with each consecutive age group. The risk of reoperation in the oldest age group was only 33% of the risk in the youngest age group. Compared to the years 1999-2001, the risk of reoperation was significantly higher between 2005-2007 and 2013-2015 only. The preoperative use of weak opioids (codeine or tramadol) increased the risk of reoperation by 40%, while the use of strong opioids (morphine, hydromorphone, oxycodone or fentanyl) did not influence the reoperation risk. Patients taking muscle relaxants preoperatively had a 19% higher risk of reoperation compared to those not taking muscle relaxants. Patients with pulmonary comorbidities had a higher and patient with cardiovascular comorbidities a lower risk of reoperation.
The risk of reoperation for the disc protrusion A, foraminal stenosis B, and spinal canal stenosis C groups depending on the technique used. The adjusted, multistep hazard curves illustrating the risk of reoperation for the patients primarily operated for degenerative cervical spine in Finland between 1999 and 2015 in the disc protrusion A, foraminal stenosis B, and spinal canal stenosis C groups depending on the operative technique. The risk of reoperation did not differ between the decompression and the anterior cervical decompression and fusion (ACDF) patients in the disc protrusion group, but in the foraminal stenosis group the hazard ratio (HR) of reoperation was 1.53 (95% CI 1.24-1.89, P < .001) in the ACDF patients compared to decompression and in the spinal canal stenosis group the HR of reoperation in the ACDF patients was 1.48 (95% CI 1.18-1.86, P = .001) compared to decompression. The HR of reoperation in the posterior decompression and fusion (PDF) technique group was not statistically different from decompression in either diagnosis group.

between the techniques appear to increase with time. A 16-yr follow-up of cervical fusion patients found a higher probability of revision in anterior versus posterior arthrodesis. The increased risk of reoperation after ACDF compared to decompression in foraminal and spinal stenosis, but not disc protrusion patients, may stem from differences in the extent of decompression, as the posterior approach may cover more segments than ACDF or yield a better decompression of the foramen. There may also be differences in the patient populations that were not controlled for, eg, the curvature of the cervical spine, which would influence both the choice of technique and risk of reoperation. A recent meta-analysis, with relatively short follow-up times, found greater improvement of radicular symptoms after foraminotomy, yet no difference in the reoperation rates between foraminotomy and ACDF.

Most series have detected a higher risk of reoperation in males. The degenerative changes progress more in asymptomatic men than in women and become more prevalent in men compared to women with increasing age. Younger age has consistently been identified as a risk factor, which probably represents differences in the stage of the degeneration and possibly patient selection. The smoking data for our patients were unavailable; smoking might explain the increased reoperation risk in the patients with pulmonary comorbidities, as the group included chronic obstructive pulmonary disease. Higher complication risk and patient selection may explain the lower reoperation risk in the patients with cardiovascular comorbidities. Kalakoti et al also found 21% higher odds of reoperation in patients with preoperative opioid use. The increased risk of reoperation in the patients taking muscle relaxants preoperatively is a novel finding.

The risk of reoperation did not increase between 1999 and 2015, even though the age- and sex-adjusted rate of primary operations for DCSD increased by 36% and the use of ACDF...
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FIGURE 7. The risk of reoperation in the decompression A and anterior cervical decompression and fusion B and groups depending on the diagnosis. The adjusted, multi-step hazard curves illustrating the risk of reoperation for the patients primarily operated for degenerative cervical spine disease in Finland between 1999 and 2015 across the technique groups depending on the diagnosis: the decompression patients A and anterior cervical decompression and fusion (ACDF) patients B. In the ACDF group, the risk of reoperation was significantly higher in both the foraminal stenosis patients (HR 1.52, 95% CI 1.34–1.72, P < .001) and spinal canal stenosis patients (HR 1.23, 95% CI 1.03–1.45, P = .019) compared to disc protrusion patients. In the decompression and PDF group, the risk of reoperation was not statistically significantly different between the diagnosis groups (there were only 19 reoperations in the PDF group, hazard curve not shown). Note the difference in scaling to Figures 5 and 6.

FIGURE 8. The factors affecting the time to reoperation: diagnosis A, age group B, and operation year C. The adjusted, multistep hazard curves illustrating the time to late reoperation for the patients primarily operated for degenerative cervical spine disease in Finland between 1999 and 2015 by diagnosis group A, patient age group B, and operation year range C. The time to late reoperation decreased from the youngest to the oldest age group and from the earlier to the later time periods. Foraminal stenosis patients and spinal canal stenosis patients underwent reoperations at an earlier time point compared to disc protrusion patients. The operative technique did not affect the time to late reoperation in the multivariate analysis.
increased to over 80% of the primary operations during the same period.7,10 As most of the reoperations occurred within the first 6 postoperative years, we presume that the follow-up was sufficiently long to analyze the trends in the reoperations. Such patient-level time trends in reoperations have not been assessed previously. In the US, the incidence of cervical spine fusion reoperations has increased more rapidly than the incidence of primary operations.13

**Generalizability**

The healthcare system in Finland is tax funded; the decision to operate and the technique are decided solely by the surgeon and the patient. The surgeons’ salary is independent of the number or type of operations they perform. Over 90% of the operations occurred in teaching hospitals. These factors may influence the reoperation rates. There may be differences between populations in the prevalence of DCSD or the progression of the degenerative changes.

**CONCLUSION**

We assessed the occurrence, risk factors and the time trends of late reoperations in a longitudinal population-based survey of every patient operated for DCSD in Finland between 1999 and 2015. The principal findings were that the annual reoperation risk increased up to 6 yr and declined thereafter and that the patients operated for foraminal stenosis were especially likely to undergoing a reoperation. ACDF technique increased the risk of reoperation by 50% compared with decompression in spondylotic patients, which may be explained by differences in the number of vertebral levels operated. The risk of reoperation developed differently depending on the technique with extending follow-up. These findings underline the importance of a long follow-up for a comparison between the techniques relative to ASD as well as for estimating the overall risk of reoperation. In spondylotic patients, with diffuse degeneration, the high rate of reoperations should be considered when deciding on the technique and the extent of decompression.

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**REFERENCES**

1. Lad SP, Patil CG, Berta S, Santarelli JG, Ho C, Bouky M. National trends in spinal fusion for cervical spondylotic myelopathy. *Surg Neurol*. 2009;71(1):66-69; discussion 69.
2. Liu CY, Zygoourakis CC, Yoon S, et al. Trends in utilization and cost of cervical spine surgery using the National Inpatient Sample database, 2001 to 2013. *Spine*. 2017;42(15):E906-E913.
3. Marquez-Lara A, Nandyala SV, Fineberg SJ, Singh K. Current trends in demographics, practice, and in-hospital outcomes in cervical spine surgery: a national database analysis between 2002 and 2011. *Spine*. 2014;39(6):476-481.
4. Salzmann SN, Derman PB, Lampe LP, et al. Cervical spinal fusion: 16-Year trends in epidemiology, indications, and in-hospital outcomes by surgical approach. *World Neurosurg*. 2018;113:4280-4295.
5. Patil PG, Turner DA, Pietrobon R. National trends in surgical procedures for degenerative cervical spine disease: 1990-2000. *Neurosurgery*. 2005;57(4):753-758.
6. Kristiansen J, Balteskard L, Slettebo H, et al. The use of surgery for cervical degenerative disease in Norway in the period 2008-2014: a population-based study of 6511 procedures. *Acta Neurochir (Wien)*. 2016;158(5):909-974.
7. Kotkansalo A, Leinonen V, Korajoki M, Salmenkivi J, Korhonen K, Malmivaara A. Surgery for degenerative cervical spine disease in Finland, 1999-2015. *Acta Neurochir*. 2019;161(10):2147-2159.
8. Kong L, Cao J, Wang L, Shen Y. Prevalence of adjacent segment disease following cervical spine surgery: a PRISMA-compliant systematic review and meta-analysis. *Medicine*. 2016;95(27):e1471.
9. King JT, Abbed KM, Gould GC, Bae HW. Cervical spine reoperation rates and hospital resource utilization after initial surgery for degenerative cervical spine disease in 12,338 patients in Washington state. *Neurosurgery*. 2009;65(6):1011-1023.
10. Hilibrand AS, Carlson GD, Palumbo MA, Jones PK, Bohlman HH. Radiculopathy and myelopathy at segments adjacent to the site of a previous anterior cervical arthrodesis. *J Bone Joint Surg Am*. 1999;81(4):519-528.
11. Lee JC, Lee S, Peters C, Riew KD. Risk-factor analysis of adjacent-segment pathology requiring surgery following anterior, posterior, fusion, and nonfusion cervical spine surgery: survivorship analysis of 1358 patients. *J Bone Joint Surg Am*. 2014;96(21):1761-1767.
12. Helgeson MD, Bevevino AJ, Hilibrand AS. Update on the evidence for adjacent segment degeneration and disease. *Spine*. 2013;38(3):342-351.
13. Rajaei SS, Kanim LEA, Bae HW. National trends in revision spinal fusion in the USA: patient characteristics and complications. *Bone Joint J*. 2014;96-B(6):807-816.
14. Lawrence BD, Hilibrand AS, Brodt ED, Dettori JR, Brodke DS. Predicting the risk of adjacent segment pathology in the cervical spine: a systematic review. *Spine*. 2012;37(22 Suppl):S52-S64.
15. Derman PB, Lampe LP, Hughes AP, et al. Demographic, clinical, and operative factors affecting long-term revision rates after cervical spine arthrodesis. *J Bone Joint Surg Am*. 2013;95(18):1533-1540.
16. Faldini C, Miscione MT, Acri F, et al. Single level cervical fusion by an anterior approach using autologous bone graft influences the adjacent levels degenerative changes: clinical and radiographic results at 10-year minimum follow-up. *Eur Spine J*. 2012;21(Suppl 1):S90-S93.
17. Lee JC, Lee SH, Peters C, Riew KD. Adjacent segment pathology requiring reoperation after anterior cervical arthrodesis: the influence of smoking, sex, and number of operated levels. *Spine (Phila Pa 1976)*. 2015;40(10):E571-E577.
18. Chen Y, Wang X, Lu X, et al. Comparison of titanium and polyetheretherketone (PEEK) cages in the surgical treatment of multilevel cervical spondylotic myelopathy: a prospective, randomized, control study with over 7-year follow-up. *Eur Spine J*. 2015;24(7):1539-1546.
19. Kotkansalo A, Malmivaara A, Korajoki M, Korhonen K, Leinonen V. Surgical techniques for degenerative cervical spine in Finland from 1999 to 2015. *Acta Neurochir (Wien)*. 2019;161(10):2161-2173.
20. Park MS, Ju Y, Moon S, et al. Reoperation rates after surgery for degenerative cervical spine disease according to different surgical procedures: national population-based cohort study. *Spine*. 2016;41(19):1484-1492.
21. Puvanesarajah V, Jain A, Cancienne JM, et al. Complication and reoperation rates following surgical management of cervical spondylotic myelopathy in Medicare beneficiaries. *Spine*. 2017;42(1):1-7.
22. Kelly M, Eliaescu C, Riley M, Ajiboye R, SooHoo N. Reoperation and complications after anterior cervical discectomy and fusion and cervical disc arthroplasty: a study of 52,395 cases. *Eur Spine J*. 2018;27(6):1432-1439.
23. Park MS, Ju Y, Moon S, et al. Reoperation rates after anterior cervical discectomy and fusion for cervical spondylotic radiculopathy and myelopathy: a national population-based study. *Spine*. 2016;41(20):1593-1599.
24. Veeravagu A, Cole T, Jiang B, Ratilff JK. Revision rates and complication incidence in single- and multilevel anterior cervical discectomy and fusion procedures: an administrative database study. *Spine*. 2014;39(7):1125-1131.
25. Wu J, Liu L, Huang W, et al. The incidence of adjacent segment disease requiring surgery after anterior cervical discectomy and fusion: estimation using an 11-Year comprehensive nationwide database in Taiwan. *Neurosurgery*. 2012;70(3):594-601.
26. Sayar AJ, Tuchman A, Cohen JR, Hsieh PC, Buser Z, Wang JC. Risk and cost of reoperation after single-level posterior cervical foraminotomy: a large database study. *Global Spine J*. 2017;7(2):116-122.
27. Veeravagu A, Azad TD, Zhang M, et al. Outcomes of cervical laminoplasty—population-level analysis of a national longitudinal database. *J Clin Neurosci*. 2018;48:66-70.
28. Lin J, Chien L, Tsai W, Chen L, Hsieh Y, Chiang Y-H. Reoperation rates of anterior cervical discectomy and fusion versus posterior laminoplasty for multilevel cervical degenerative diseases: a population-based cohort study in Taiwan. *Spine J*. 2016;16(12):1428-1436.
29. Wu J, Chang H, Huang W, Chen Y. Risk factors of second surgery for adjacent segment disease following anterior cervical discectomy and fusion: a 16-year cohort study. *Int J Surg*. 2019;68:48-55.
30. Daimon K, Fujikawa H, Nishiwaki Y, et al. A 20-year prospective longitudinal study of degeneration of the cervical spine in a volunteer cohort assessed using MRI: follow-up of a cross-sectional study. *J Bone Joint Surg Am*. 2018;100(10):843-849.
31. Burkhardt B, Brielmaier M, Schwerdtfeger K, Oertel J. Clinical outcome following anterior cervical discectomy and fusion with and without anterior cervical plating for the treatment of cervical disc herniation—a 25-year follow-up study. *Neurosurg Rev*. 2018;41(2):473-482.
32. Burkhardt B, Brielmaier M, Schwerdtfeger K, Sharif S, Oertel J. Smith-Robinson procedure with and without Caspar plating as a treatment for cervical spondylotic myelopathy: a 26-year follow-up of 23 patients. *Eur Spine J*. 2017;26(4):1246-1253.
33. Asher AL, Devin CJ, Kerezoudis P, et al. Comparison of outcomes following anterior vs posterior fusion surgery for patients with degenerative cervical myelopathy: an analysis from quality outcomes database. *Neurosurgery*. 2019;84(4):919-926.
34. Sahai N, Changoor S, Dunn CJ, et al. Minimally invasive posterior cervical foraminotomy as an alternative to anterior cervical discectomy and fusion for unilateral cervical radiculopathy: a systematic review and meta-analysis. *Spine (Phila Pa 1976)*. 2019;44(24):1751-1739.
35. Okada E, Matsutomo M, Ichihara D, et al. Aging of the cervical spine in healthy volunteers: a 10-year longitudinal magnetic resonance imaging study. *Spine (Phila Pa 1976)*. 2009;34(7):706-712.
36. Nakashima H, Yukawa Y, Suda K, Yamagata M, Ueta T, Kato F. Abnormal findings on magnetic resonance images of the cervical spines in 1211 asymptomatic subjects. *Spine (Phila Pa 1976)*. 2015;40(6):392-398.
37. Eisner MD, Anthonisen N, Cote J, et al. An official American Thoracic Society public policy statement: novel risk factors and the global burden of chronic obstructive pulmonary disease. *Am J Respir Crit Care Med*. 2010;182(5):693-718.
38. Kalakoti P, Volkmar A, Bedard N, Eisenberg J, Hendrickson N, Pugely A. Preoperative chronic opioid therapy negatively impacts long-term outcomes following cervical fusion surgery. *Spine (Phila Pa 1976)*. 2019;44(18):1279-1286.

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**Supplemental Digital Content 1. Table.** The diagnosis (the 10th revision of the World Health Organization International Classification of Diseases) and operative (Nordic Medico-Statistical Committee classification of surgical procedures) codes used to identify complications from the Finnish Hospital Discharge Register.

**Supplemental Digital Content 2. Table.** The Social Insurance Institute special medication reimbursement codes and anatomical therapeutic chemical codes used to record the use of prescription medications.

**Supplemental Digital Content 3. Table.** The comorbidity data on all the patients operated for degenerative cervical spine disease in Finland between 1999 and 2015.

**Supplemental Digital Content 4. Table.** The rate of late reoperations among patients operated each consecutive year for degenerative cervical spine disease in Finland between 1999 and 2015.