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## RESEARCH PAPER

# Does age affect surgical outcomes in patients with degenerative cervical myelopathy? Results from the prospective multicenter AOSpine International study on 479 patients

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**ABSTRACT**

**Background** In general, older patients with degenerative cervical myelopathy (DCM) are felt to have lower recovery potential following surgery due to increased degenerative pathology, comorbidities, reduced physiological reserves and age-related changes to the spinal cord. This study aims to determine whether age truly is an independent predictor of surgical outcome and to provide evidence to guide practice and decision-making.

**Methods** A total of 479 patients with DCM were prospectively enrolled in the CSM-International study at 16 centres. Our sample was divided into a younger group (<65 years) and an elderly (≥65 years) group. A mixed model analytic approach was used to evaluate differences in the modified Japanese Orthopaedic Association (mJOA), Nurick, Short Form-36 (SF-36) and Neck Disability Index (NDI) scores between groups. We first created an unadjusted model between age and surgical outcome and then developed two adjusted models that accounted for variations in (1) baseline characteristics and (2) both baseline and surgical factors. **Results** Of the 479 patients, 360 (75.16%) were <65 years and 119 (24.84%) were ≥65 years. Elderly patients had a worse preoperative health status ( $p < 0.0001$ ) and were functionally more severe ( $p < 0.0001$ ). The majority of younger patients (64.96%) underwent anterior surgery, whereas the preferred approach in the elderly group was posterior (58.62%,  $p < 0.0001$ ). Elderly patients had a greater number of decompressed levels than younger patients ( $p < 0.0001$ ). At 24 months after surgery, younger patients achieved a higher postoperative mJOA ( $p < 0.0001$ ) and a lower Nurick score ( $p < 0.0001$ ) than elderly patients. After adjustments for patient and surgical characteristics, these differences in postoperative outcome scores decreased but remained significant.

**Conclusions** Older age is an independent predictor of functional status in patients with DCM. However, patients over 65 with DCM still achieve functionally significant improvement after surgical decompression.

**INTRODUCTION**

Currently, the global population is experiencing a shift in its age structure. According to the WHO, the proportion of the population over 60 years of

age is projected to double from 11% in 2010 to 22% in 2050.<sup>1,2</sup> With this ageing of the population, clinicians worldwide will be required to manage an increasing number of spinal disorders related to advancing age, including degenerative cervical myelopathy (DCM).

DCM is a progressive, degenerative spine disease and the most common cause of spinal cord dysfunction in adults worldwide.<sup>3-6</sup> It is caused by age-related alterations to the spinal axis including (1) degeneration of the facet joints, intervertebral discs and/or vertebral bodies; (2) hypertrophy of the ligamentum flavum; and (3) ossification of the longitudinal ligament (OPLL), all of which may chronically compress the spinal cord. Of patients with evidence of spinal degeneration, approximately one-quarter will develop symptoms of neurological impairment due to mechanical compression of the neural elements.<sup>7-9</sup>

When patients present with symptomatic myelopathy, surgery is effective at halting further deterioration and improving neurological outcomes, functional status and quality of life.<sup>10-12</sup> However, there is controversy regarding whether surgical decompression is equally effective and safe in elderly patients as it is in younger patients.<sup>13-18</sup> Several studies to date have identified age as a significant predictor of surgical outcome, including the recent prospective multicenter AOSpine CSM-North America and CSM-International studies.<sup>5,17,19</sup> In general, older patients have reduced recovery potential following surgery due to comorbidities, diminished physiological reserves and age-related changes to the spinal cord, including a decrease in the number of myelinated fibres in the corticospinal tracts and posterior funiculus.<sup>20-23</sup> Furthermore, the elderly are likely to have more substantial degenerative pathology and may require a more complex surgery.

There are several methodological limitations and knowledge gaps in the current body of literature. These include (1) a lack of multicentre prospective studies with large sample sizes; (2) insufficient evidence reporting the association between age and quality of life (QOL) outcomes such as the 36-Item Short Form Health Survey (SF-36); and (3) a lack of statistical analyses appropriately adjusting for differences in baseline characteristics and surgical factors.



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The objective of this study is to compare clinical, functional and QOL outcomes between two age groups ( $\geq 65$ ,  $< 65$  years) and to determine whether age is an independent predictor of outcome. In addition, this study aims to evaluate differences in demographics, comorbidities, management strategies and rates of perioperative complications between these two age groups. It is anticipated that these data will inform clinical decision-making older individuals with DCM.

## MATERIALS AND METHODS

### Subjects

Between October 2007 and January 2011, 479 patients with symptomatic DCM were prospectively enrolled in the AOSpine CSM-International study at 16 global institutions. Participating sites were either academic centres or high volume private practices and all had the resources necessary to conduct prospective clinical research, adequate subject availability and experienced research personnel. Investigators were orthopaedic surgeons or neurosurgeons who specialised in treating disorders of the spine.

Patients were asked to participate in this study if they were referred for surgical consultation and if they satisfied the following inclusion criteria: (1) aged 18 years or older; (2) presenting with symptomatic DCM with at least one clinical sign of myelopathy; (3) image-evidence of cervical spinal cord compression on MRI or CT; and (4) no previous cervical spine surgery. Patients were included in this study if they had myelopathy due to spondylosis, hypertrophy of the ligamentum flavum, OPLL, disc herniation, subluxation or a combination of these degenerative changes. Patients were excluded if they were asymptomatic or diagnosed with active infection, neoplastic disease, rheumatoid arthritis, ankylosing spondylitis or concomitant lumbar stenosis.

### Surgical techniques

At their respective sites, all patients underwent surgical decompression of the cervical spinal cord. For each case, the attending surgeon decided what approach to use, the number of levels to decompress and whether or not to use fusion or instrumentation. Anterior surgeries included cervical discectomy and/or corpectomy with or without fusion. Patients treated posteriorly underwent either laminectomy with or without fusion or laminoplasty. A minority of patients was treated with a two-stage circumferential surgery.

### Data collection

Extensive data were collected for each participating subject, including demographic information, disease causation, medical history and current comorbidities, symptomatology, surgical summary and level of impairment and disability. Each subject was neurologically examined at baseline and 24 months postoperatively and evaluated using a variety of functional and quality of life outcome measures, including the Neck Disability Index (NDI), SF-36, the Nurick and the modified Japanese Orthopaedic Association (mJOA) scales. In addition, each attending surgeon was required to record all adverse events throughout the study period. A central panel of investigators classified each event as related to surgery, related to myelopathy or unrelated. Perioperative complications were defined as surgery-related events occurring within 30 days of surgery.

### Quality assurance

External research monitors performed on-site evaluations to ensure that the data were accurate, reliable and complete and that the study was conducted in accordance with the protocol. All data were transcribed into an electronic data capture system

and were processed at the AOSpine clinical research network data management centre.

### Statistical analysis

Our sample was divided into two age groups: a younger group (patients  $< 65$  years old) and an elderly group (patients  $\geq 65$ ). Means  $\pm$  SDs were used to describe continuous variables and percentages were used to summarise categorical variables.

Patient demographics, baseline status and surgical factors were compared between the two age groups using an appropriate *t* test for continuous variables and a  $\chi^2$  test for categorical variables. Any variable that was significantly different ( $p < 0.05$ ) between the younger and elderly patients was controlled for in our multivariate analysis.

A mixed model analytic approach was used to compare patient outcomes between the younger and elderly groups. The independent variable of the model was age and the dependent variable was postoperative outcome at 24 months (mJOA, Nurick, NDI, SF-36 physical component summary (PCS) and mental component summary (MCS)). Cases with missing data were not included in the analyses.

We first created an unadjusted model between age and surgical outcome (controlling for preoperative severity) and then developed two adjusted models that accounted for variations between the two age groups in (1) preoperative severity and other baseline characteristics and (2) both baseline demographics and surgical factors. These methods assessed whether any observed differences in outcome between the younger and elderly patients were due to other covariates or whether age is an independent predictor. Our adjusted models consisted of 6–8 predictors. As a rule of thumb, a well-powered statistical analysis requires 10 patients for each predictor evaluated. Our sample size of 479 patients (119 in elderly patients, 360 in younger patients) greatly exceeds the suggested criteria of 60–80 patients.

## RESULTS

From October 2007 to January 2011, 479 patients were enrolled in the CSM-International study at 16 global spine centres in four continents: 150 (31.32%) from the Asia-Pacific region, 126 (26.30%) from Europe, 123 (25.68%) from North America and 80 (16.70%) from Latin America. Of the 479 patients, 360 (75.16%) were less than 65 years of age and comprised the ‘younger’ group, while 119 (24.84%) were greater than or equal to 65 years and were placed in the ‘elderly’ group.

### Demographics

Patients in the elderly group were  $71.63 \pm 5.34$  years old (median 71 years), whereas those in the younger group were  $51.32 \pm 8.77$  years old (median 53 years) ( $p < 0.0001$ ; table 1). There were no significant differences in gender ( $p = 0.82$ ) or duration of symptoms ( $p = 0.82$ ) between the two age groups. The elderly patients had worse general preoperative health status as reflected by a significantly higher number of comorbidities ( $p < 0.0001$ ) and comorbidity score ( $p < 0.0001$ ). In addition, a greater percentage of elderly patients suffered from coexisting diabetes ( $p = 0.0004$ ), cardiovascular disease ( $p < 0.0001$ ) and rheumatological disorders ( $p < 0.001$ ). The frequency of psychiatric comorbidities, namely depression and bipolar disease, was higher in the younger group, although this relationship did not reach statistical significance ( $p = 0.08$ ). Elderly patients were functionally more impaired preoperatively based on the mJOA ( $p < 0.0001$ ) and Nurick ( $p < 0.0001$ ) scales and had a lower SF-36 PCS ( $p = 0.048$ ). There were no significant differences between age groups with respect to the NDI or SF-36 MCS.

**Table 1** Demographics and baseline severity scores of younger (<65 years) and elderly (≥65 years) patients

	Younger patients (<65 years)	Elderly patients (≥65 years)	p Value
<i>Demographics</i>			
Age (years)	51.32±8.77	71.63±5.34	<0.0001
Gender (%)	65.00 M, 35.00 F	63.87 M, 36.13 F	0.82
Duration of symptoms (months)	27.40±35.34	25.96±32.68	0.82
Smoker (%)	32.78 Y, 67.22 N	10.92 Y, 89.08 N	<0.0001
Comorbidities (%)	53.76 Y, 46.24 N	78.15 Y, 21.85 N	<0.0001
Comorbidity score	1.13±1.51	2.15±2.13	<0.0001
Number of comorbidities	1.00±1.25	1.74±1.31	<0.0001
Diabetes (%)	9.44 Y, 90.56 N	21.85 Y, 78.15 N	0.0004
Cardiovascular (%)	36.49 Y, 63.51 N	64.71 Y, 35.29 N	<0.0001
Respiratory (%)	7.54 Y, 92.46 N	12.61 Y, 87.39 N	0.09
Gastrointestinal (%)	15.08 Y, 84.92 N	15.13 Y, 84.87 N	0.99
Renal (%)	1.40 Y, 98.60 N	4.20 Y, 95.80 N	0.13
Psychiatric (%)	9.22 Y, 90.78 N	4.20 Y, 95.80 N	0.08
Rheumatological (%)	1.68 Y, 98.32 N	6.72 Y, 93.28 N	<0.001
Neurological (%)	3.63 Y, 96.37 N	6.72 Y, 93.28 N	0.15
<i>Baseline functional status</i>			
mJOA	12.86±2.76	11.41±2.89	<0.0001
Nurick	3.16±1.21	3.75±1.23	<0.0001
<i>Baseline quality of life</i>			
Neck Disability Index	37.52±19.59	39.15±22.31	0.70
SF36v2 Physical Functioning	32.51±11.94	28.47±12.18	<0.001
SF36v2 Role Limitation Physical	29.46±10.65	28.90±12.14	0.24
SF36v2 Bodily Pain	35.96±10.75	38.05±12.52	0.15
SF36v2 General Health	41.16±10.36	41.12±9.96	0.91
SF36v2 Emotional Well-being	38.35±12.93	40.95±12.78	0.06
SF36v2 Role Limitation Emotional	31.68±14.27	31.62±16.35	0.93
SF36v2 Social Functioning	35.98±12.86	34.89±13.00	0.41
SF36v2 Energy/Fatigue	42.59±11.09	43.56±11.16	0.38
SF36v2 Physical Component Score	34.69±9.03	32.90±8.91	0.048
SF36v2 Mental Component Score	38.94±13.10	40.79±12.94	0.16

Means were compared using the appropriate t test and frequencies were compared using the  $\chi^2$  test.  
mJOA, modified Japanese Orthopaedic Association scale.

### Surgical factors

The majority of younger patients (64.96%) underwent anterior surgery, whereas the preferred approach in the elderly group was posterior (58.62%) ( $p<0.0001$ ; table 2). Of patients treated anteriorly, a greater percentage of elderly patients

received a combined anterior discectomy and corpectomy (27.66%) compared to younger patients (12.83%;  $p=0.01$ ). A similar percentage of patients in both age groups were treated with a two-stage anteroposterior surgery (younger: 2.23%, elderly: 2.52%,  $p=1.00$ ). Elderly patients, on average, had a

**Table 2** Differences in surgical factors between younger and elderly patients

	Younger patients (<65 years)	Elderly patients (≥65 years)	p Value
Operative duration (min)	176.21±80.45	183.75±79.48	0.17
Number of operated levels	3.50±1.23	4.14±1.30	<0.0001
Surgical approach (%) (Anterior, Posterior)	64.96, 35.04	41.38, 58.62	<0.0001
Anterior surgeries (%)			0.01*
Discectomy	85.84	70.21	
Corpectomy	1.33	2.13	
Discectomy and corpectomy	12.83	27.66	
Posterior surgeries (%)			0.96†
Laminectomy without fusion	6.50	11.76	
Laminectomy with fusion	58.54	52.94	
Laminoplasty	34.96	35.29	
Number of stages (%) (single or multiple)	97.77, 2.23	97.48, 2.52	1.00

Means were compared using the appropriate t test and frequencies were compared using the  $\chi^2$  test.  
\* $\chi^2$  test comparing discectomy or corpectomy with discectomy and corpectomy.  
† $\chi^2$  test comparing laminectomy with/without fusion with laminoplasty.

greater number of decompressed levels (which most likely accounts for the increased rate of posterior surgery;  $4.14 \pm 1.30$ ) than younger patients ( $3.50 \pm 1.23$ ) ( $p < 0.0001$ ) but a similar operative duration (younger:  $176.21 \pm 80.45$  min, elderly:  $183.75 \pm 79.48$  min,  $p = 0.17$ ).

### Outcomes

Three hundred and eighty-nine patients (81.21%) attended their 24-month follow-up appointment and were assessed using the mJOA ( $n = 385$  for SF-36 PCS and MCS,  $n = 389$  for Nurick,  $n = 324$  for NDI; table 3). The remaining 90 patients (18.79%) withdrew from this study (1.25%), did not attend their scheduled appointment (15.87%) or died prior to their 24-month postoperative visit (1.67%).

In both age groups, patients demonstrated significant improvements across all outcome measures. Younger patients, however, achieved a higher postoperative mJOA (15.45, 95% CI 15.18 to 15.72) and a lower Nurick score (1.64, 95% CI 1.48 to 1.81) than elderly patients (mJOA: 14.08, 95% CI 13.61 to 14.56,  $p < 0.0001$ ; Nurick: 2.44, 95% CI 2.15 to 2.73,  $p < 0.0001$ ). SF-36 PCS scores were also significantly higher in the younger group (41.87, 95% CI 40.73 to 43.00) than in the elderly group (39.36, 95% CI 37.38 to 41.36,  $p = 0.033$ ). There were no significant differences in postoperative NDI or SF-36 MCS between age groups after controlling for preoperative severity.

Adjusted models were run to compare postoperative Nurick and mJOA scores between the two age groups, while controlling for differences in patient characteristics (preoperative severity, diabetes, cardiovascular disease, rheumatological disorders and comorbidity score). After adjustment, the differences in mJOA and Nurick scores between age groups remained significant (mJOA:  $p < 0.0001$ ; Nurick:  $p = 0.0002$ ). The differences in SF-36 PCS between age groups became insignificant ( $p = 0.08$ ).

A second set of adjusted models was created to further control for differences in surgical features between age groups, such as the approach (anterior, posterior or combined) and number of decompressed segments. Even after this adjustment, functional differences between the elderly and younger groups remained statistically significant (mJOA:  $p < 0.0001$ , Nurick:  $p = 0.0006$ ), although the difference between mean outcome scores across age groups decreased (Nurick: unadjusted =  $-0.80$  ( $-1.13$  to  $-0.46$ ), adjusted =  $-0.63$  (95% CI  $-0.99$  to  $-0.27$ ); mJOA: unadjusted =  $1.36$  (95% CI  $0.81$  to  $1.92$ ), adjusted:  $1.25$  (95% CI  $0.68$  to  $1.82$ ).

### Complications

On average, elderly patients had a significantly longer length of postoperative hospital stay ( $12.99 \pm 13.56$  days) than younger patients ( $9.53 \pm 8.67$  days) ( $p = 0.0086$ ; table 4). There were no significant differences between the two age groups with respect to rates of perioperative complications ( $p = 0.47$ ), C5 nerve root palsy ( $p = 0.58$ ), superficial ( $p = 1.00$ ) or deep ( $p = 0.15$ ) infection, dysphagia ( $p = 0.80$ ) or dural tear ( $p = 0.76$ ). A greater percentage of elderly patients (2.52%) experienced screw malposition in the perioperative period compared to younger patients (0%;  $p = 0.015$ ). Rates of progression and perioperative worsening of myelopathy were similar across the two age groups.

### DISCUSSION

This study represents the largest prospective analysis of the relative efficacy and safety of surgical decompression in younger and elderly patients. On the basis of our findings, younger patients have superior functional status and clinical outcomes at 24 months following surgery based on the mJOA and Nurick scales. This indicates that the elderly may not be able to translate neurological improvements into functional recovery as effectively as younger patients. Potential explanations for this

**Table 3** Functional status and quality of life at 24 months following surgery

Outcome	Younger patients (<65 years)	Elderly patients ( $\geq 65$ years)	Difference	p Value
Unadjusted*				
mJOA	15.45 (15.18, 15.72)	14.08 (13.61, 14.56)	1.36 (0.81, 1.92)	<0.0001
Nurick	1.64 (1.48, 1.81)	2.44 (2.15, 2.73)	-0.80 (-1.13, -0.46)	<0.0001
NDI	23.83 (21.76, 25.90)	23.99 (20.51, 27.46)	-0.16 (-4.20, 3.89)	0.94
SF-36v2 PCS	41.87 (40.73, 43.00)	39.36 (37.38, 41.36)	2.50 (0.21, 4.80)	0.033
SF-36v2 MCS	47.34 (45.96, 48.72)	46.72 (44.31, 49.13)	1.41 (-2.16, 3.40)	0.66
Adjustment Model 1†				
mJOA	14.02 (13.23)	12.72 (11.86, 13.58)	1.31 (0.73, 1.87)	<0.0001
Nurick	2.52 (2.02, 3.01)	3.20 (2.67, 3.74)	-0.69 (-1.04, -0.33)	0.0002
NDI	30.63 (24.16, 37.10)	29.61 (22.52, 36.70)	1.02 (-3.96, 6.01)	0.69
SF-36v2 PCS	38.02 (34.41, 41.63)	35.90 (31.96, 39.83)	1.21 (-0.25, 4.50)	0.080
SF-36v2 MCS	46.70 (41.87, 51.54)	47.71 (42.45, 52.97)	-1.01 (-4.19, 2.17)	0.53
Adjustment Model 2‡				
mJOA	13.80 (12.86, 14.74)	12.55 (11.55, 13.55)	1.25 (0.68, 1.82)	<0.0001
Nurick	2.58 (2.00, 3.17)	3.22 (2.59, 3.85)	-0.63 (-0.99, -0.27)	0.0006
NDI	27.79 (20.16, 35.42)	26.84 (18.60, 35.07)	0.95 (-4.08, 5.99)	0.71
SF-36v2 PCS	38.87 (34.64, 43.10)	36.91 (32.37, 41.44)	1.96 (-0.48, 4.40)	0.16
SF-36v2 MCS	48.64 (43.01, 54.26)	48.92 (42.89, 54.96)	-0.29 (-3.54, 2.96)	0.86

\*Adjusted for preoperative severity.

†Adjusted for differences in patient characteristics between age groups ( $p < 0.05$  in univariate analysis, table 1): baseline severity score, smoking status, comorbidity score, diabetes, cardiovascular disease and rheumatological disorders.

‡Adjusted for differences in patient and surgical characteristics ( $p < 0.05$  in univariate analysis, tables 1 and 2): all clinical factors from adjustment model 1 and surgical approach and number of decompressed levels.

NDI, Neck Disability Index; mJOA, modified Japanese Orthopaedic Association; MCS, mental component summary; PCS, physical component summary; SF-36, Short Form-36.

**Table 4** Length of hospital stay and perioperative complications

	Younger patients (<65 years)	Elderly patients (≥65 years)	p Value
Length of hospital stay (days)	9.53±8.67	12.99±13.56	<0.01
Perioperative complications (%)	15.56	18.49	NS
Pseudoarthrosis (%)	0.28	0.84	NS
Hardware failure (%)	0.28	–	NS
Screw malposition (%)	–	2.52	0.015
Graft dislodgement (%)	0.28	–	NS
Graft pain (%)	0.28	–	NS
C5 palsy (%)	1.11	–	NS
New neck pain (%)	0.28	0.84	NS
Dural tear (%)	2.78	3.36	NS
Superficial infection (%)	2.22	1.68	NS
Deep infection (%)	0.28	1.68	NS
Dysphagia (%)	4.17	5.04	NS
Dysphonia (%)	0.56	0.84	NS
Perioperative worsening of myelopathy (%)	0.83	–	NS
Progression of myelopathy (%)	0.28	–	NS
New radiculopathy (%)	0.28	1.68	NS
Cardiopulmonary (%)	0.56	–	NS
DVT (%)	–	0.84	NS
Other (%)	2.22	5.04	NS

Means were compared using the appropriate t test and frequencies were compared using the  $\chi^2$  test.

DVT, deep vein thrombosis; NS: not significant.

discrepancy between age groups include that the elderly (1) experience age-related changes in their spinal cord, including a decrease in  $\gamma$ -motor neurons, synaptic and dendritic elements, number of anterior horn cells and number of myelinated fibres in the corticospinal tract and posterior funiculus;<sup>20–21</sup> (2) may have unassociated comorbidities that may impede their ability to perform the simple tasks required for the mJOA, such as locomotor diseases (hip and knee osteoarthritis), sarcopenia, diabetic neuropathy or urinary incontinence due to benign prostatic hypertrophy;<sup>16–24</sup> (3) have reduced physiological reserves and, as a result, are less tolerant to physical assault such as that represented by surgery;<sup>25–26</sup> and (4) may have substantial degenerative pathology that may require greater decompression and a more complex surgery. Surgeons, however, should not discriminate on the basis of age but should rather use this information during the surgical consent discussion to manage their patients' expectations and explain the relative risks and benefits of the procedure.

Interestingly, there were no significant differences in patient-reported outcomes (NDI and SF-36) between age groups. This result indicates that a lower functional status translates to equivalent QOL in the elderly compared to younger patients. This finding is significant as cost-utility analyses typically explore the effectiveness of an intervention in terms of SF-6D utility values derived from SF-36 scores.<sup>27</sup> In addition, there were no significant differences in rates of overall perioperative or neurological complications between age groups.

This study also evaluated differences in baseline demographics and surgical strategies between age groups as these factors could also influence outcome. Unsurprisingly, elderly patients not only had more severe functional impairment preoperatively, but also had a higher comorbidity score and an increased frequency of diabetes, cardiovascular and rheumatological disorders. With

respect to surgical factors, the elderly had a greater number of decompressed levels, were more often treated posteriorly and, if operated on anteriorly, were more likely to receive a combined discectomy and corpectomy. These differences confirm that the elderly may have more substantial degenerative pathology and may require a more extensive surgery. All of these factors could potentially explain the discrepancies in recovery potential between the younger and elderly patients as hypothesised earlier; however, after adjustment for these characteristics, differences in functional outcomes between the age groups were still significant. This allows us to conclude that age is an independent predictor of neurological outcome and that the elderly most likely have reduced recovery due to alterations in the composition of their spinal cord and diminished physiological reserves. However, given that (1) the absolute change in mJOA was still substantial and in excess of the MCID;<sup>28</sup> (2) the quality of life between the elderly and younger patients was not significantly different; and (3) complication rates were similar between age groups despite worse preoperative health status in the elderly, surgery remains an effective treatment option for patients at an advanced age.

Our results must be interpreted in the context of the existing literature. We conducted a literature search to identify studies that examined the predictive value of age using a well-powered multivariate analysis. Results differed depending on what measurement was used to evaluate outcome.

### JOA recovery rate

Fourteen studies evaluated the association between a patient's JOA recovery rate and his/her age. Recovery rate was calculated using the following equation developed by Hirabayashi: (postoperative JOA-preoperative JOA)/(17-preoperative JOA)×100%.<sup>29</sup> Three studies dichotomised the recovery rate and defined an 'excellent' outcome as a recovery rate ≥50% and a 'fair' outcome as a recovery rate <50%.<sup>14–30–31</sup> Yamazaki *et al*<sup>14</sup> and Naruse *et al*<sup>31</sup> reported no significant difference in age between patients who achieved an excellent outcome and those who did not. In the study by Kim *et al*,<sup>30</sup> however, the interaction of diabetes and old age increased the patient's risk of a poor surgical outcome (OR 2.21, 1.15 to 4.23).

Seven studies reported that older patients had a less favourable surgical outcome based on the JOA recovery rate.<sup>5–32–37</sup> Chen *et al*<sup>31</sup> aimed to examine the impact of T2-SI on surgical prognosis and identified a significant association between patient age and recovery rate ( $p=0.037$ ). Fujimura *et al*<sup>5</sup> and Kato *et al*<sup>33</sup> explored predictors of recovery at the short-term (1 year) and long-term follow-up: age was a significant predictor of outcome at 5 years postoperative in both studies. In a study by Koyanagi *et al*,<sup>34</sup> patients were divided into three groups depending on whether their primary diagnosis was CSM, OPLL or disc herniation. On the basis of univariate analysis, age was significantly correlated with the JOA recovery rate in patients with OPLL and cervical disc herniation but not in patients with CSM. However, in multivariate analysis, age was deemed an insignificant predictor of recovery rate in all three forms of DCM. Finally, three studies developed linear regression equations relating a combination of significant clinical and imaging variables to recovery rate. All three equations included age as a predictor.<sup>35–37</sup> In contrast, four studies could not identify a significant association between age and JOA recovery rate.<sup>38–41</sup>

### Postoperative mJOA/JOA score

Seven studies used postoperative mJOA or JOA as the primary outcome measure. Of these, five reported an insignificant

association between age and surgical outcome.<sup>11 24 38 42 43</sup> In a study by Furlan *et al*,<sup>44</sup> age was significantly correlated with mJOA score at 6 months ( $R^2=0.287$ ,  $p<0.0001$ ) and 12 months ( $R^2=0.185$ ,  $p=0.0003$ ) postoperatively. In multivariate analysis, age was also a significant predictor of mJOA at 1 year ( $p=0.01$ ). Morio *et al*<sup>37</sup> constructed a regression model using a continuous JOA score as the outcome variable and included age as a predictor.

### Nurick scale

In three studies, the Nurick score was dichotomised: a 'poor' neurological outcome was defined as either no change or a decrease in the Nurick grade, and a 'good' neurological outcome as an increase of at least one Nurick grade.<sup>45–47</sup> In studies by Choi *et al*<sup>45</sup> and Rajshekar and Kumar,<sup>46</sup> age was not a significant predictor of outcome. However, according to Suri *et al*,<sup>47</sup> patients in the <40 age group were 2.17 times more likely to exhibit improvement on the Nurick scale than patients aged 40–60 years ( $p<0.001$ ). In a fourth study, Furlan *et al*<sup>44</sup> identified a significant association between the Nurick score at 1 year and age ( $p=0.015$ ).

It is evident that there is controversy in the literature as to whether age is a significant predictor of outcome. This study helps to confirm that, although surgery is effective for the elderly, these patients are less effective at translating neurological improvements to functional recovery. Given that our study is a prospective cohort study with a  $\geq 80\%$  follow-up rate, these results should be considered as a strong contribution to the overall body of evidence.

### Strengths and limitations

Since patients were prospectively enrolled at 16 global sites, the findings of this study are likely to be more generalisable and externally valid than findings from single-centre studies. The large number of recruitment sites allowed us to evaluate outcomes for approximately 500 patients. Of these, 119 were over 65 years of age and categorised as 'elderly'; this reflects a cohort size that is larger than the majority of previous studies. In addition, we evaluated outcome using four different measurement tools, allowing for a complete and comprehensive assessment of surgical outcomes in patients with DCM.

This study has several limitations. First, a 16% attrition rate was observed at the 12-month time point. Second, a standardised surgical protocol was not utilised across centres and the approach, number of decompressed levels and whether or not to use instrumentation and fusion was left to the discretion of the attending surgeon. However, the same goal of spinal cord decompression was achieved in all cases. Finally, we arbitrarily defined 65 as the cut-off between the younger and elderly patients. However, in support of the chosen cut-off, in a survey of AOSpine International members, 65 years was deemed as the threshold age above which there is a significant negative impact on surgical outcome.<sup>48</sup> Furthermore, 65 is recognised as the retirement age and has also been used as a cut-off in previous DCM studies.<sup>14 49 50</sup>

### CONCLUSION

Our findings indicate that surgical decompression results in superior functional status in younger patients compared with elderly patients and confirms that the elderly are less effective at translating neurological recovery into functional improvements. In contrast, there were no differences in quality of life outcomes between age groups, indicating that the elderly and younger patients have similar perceptions of their disability despite significant differences in functional status. After adjustment of key demographic

characteristics and surgical factors, the association between age and functional outcomes was still statistically significant; age is therefore an independent predictor of surgical outcome.

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