The type of cervical disc herniation on MRI does not correlate to clinical outcomes

Yang, X.; Arts, M.P.; Bartels, R.H.M.A.; Vleggeert-Lankamp, C.L.A.

■ SPINE

The type of cervical disc herniation on MRI does not correlate to clinical outcomes

X. Yang,
M. P. Arts,
R. H. M. A. Bartels,
C. L. A. Vleggeert-Lankamp

From Leiden University Medical Centre, Leiden, the Netherlands

Aims

The aim of this study was to investigate whether the type of cervical disc herniation influences the severity of symptoms at the time of presentation, and the outcome after surgical treatment.

Methods

The type and extent of disc herniation at the time of presentation in 108 patients who underwent anterior discectomy for cervical radiculopathy were analyzed on MRI, using a four-point scale. These were dichotomized into disc bulge and disc herniation groups. Clinical outcomes were evaluated using the Neck Disability Index (NDI), 36-Item Short Form Survey (SF-36), and a visual analogue scale (VAS) for pain in the neck and arm at baseline and two years postoperatively. The perceived recovery was also assessed at this time.

Results

At baseline, 46 patients had a disc bulge and 62 had a herniation. There was no significant difference in the mean NDI and SF-36 between the two groups at baseline. Those in the disc bulge group had a mean NDI of 44.6 (SD 15.2) compared with 43.8 (SD 16.0) in the herniation group (p = 0.799), and a mean SF-36 of 59.2 (SD 6.9) compared with 59.4 (SD 7.7) (p = 0.895). Likewise, there was no significant difference in the incidence of disabling arm pain in the disc bulge and herniation groups (84% vs 73%; p = 0.163), and no significant difference in the incidence of disabling neck pain in the two groups (70.5% (n = 31) vs 63% (n = 39); p = 0.491). At two years after surgery, no significant difference was found in any of the clinical parameters between the two groups.

Conclusion

In patients with cervical radiculopathy, the type and extent of disc herniation measured on MRI prior to surgery correlated neither to the severity of the symptoms at presentation, nor to clinical outcomes at two years postoperatively.

Cite this article: *Bone Joint J* 2022;104-B(11):1242–1248.

Introduction

Cervical radiculopathy is a neurological disorder caused by compression and/or irritation of a cervical nerve root as it leaves the spinal cord, with an incidence of 1.79 per 1,000 person-years between 2000 and 2009 in the USA military.[1] It is characterized by pain in the arm in the distribution of the affected nerve root(s),[2] and is frequently associated with neck pain.[3] A common cause of cervical radiculopathy is a bulging or herniated disc compressing the corresponding nerve root.[4]

The diagnosis of cervical radiculopathy may be based on a thorough history and physical examination. Imaging of the cervical spine may reveal compression of a nerve root, for instance by a herniated disc. MRI, which is considered the procedure of choice in patients in whom cervical disc herniation is suspected, is widely used in the diagnosis and planning of treatment. MRI can provide a noninvasive morphological evaluation of the cervical spine and the discs, and reveal evidence of degenerative changes. The size and contour of disc herniations can be identified and measured, as can the size and proportions of the spinal canal,[5] possibly elucidating the aetiology of the clinically diagnosed cervical radiculopathy.

Correspondence should be sent to X. Yang; email: xy393@outlook.com

doi:10.1302/0301-620X.104B11.BJJ-2022-0657.R2 $2.00

Bone Joint J 2022;104-B(11):1242–1248.

Table I. Patient demographic details.

Variable	Bulge	Herniation	p-value
Total, n	46	62	
Mean age, yrs (SD)	47.1 (8.4)	46.4 (7.8)	0.685*
Mean BMI, kg/m² (SD)	26.9 (4.1)	26.6 (4.3)	0.714*
Male, n (%)	16 (34.8)	35 (56.5)	0.026†
Smoker, n (%)	17 (38.6)	27 (43.5)	0.613†
Mean duration of symptoms, wks (SD)	49.4 (69.0)	45.1 (76.3)	0.761*
Herniated level, n (%)			0.431†
C5–C6	25 (54.3)	31 (50)	
C6–C7	20 (43.5)	31 (50)	
C7–Th1	1 (2.2)	0	
Disabling neck pain, n (%)	31 (70.5)	39 (62.9)	0.491†
Disabling arm pain, n (%)	37 (84.1)	45 (72.6)	0.163†

*Independent-samples *t*-test.
†Chi-squared test.
SD, standard deviation.

However, bulging discs and/or degenerative changes on MRI are more frequently an incidental finding.[6,7] In 2015, Nakashima et al[8] reported that nearly 90% of asymptomatic subjects had disc bulging, defined as posterior protrusion of the disc by > 1 mm. Therefore, establishing the relationship between the size and shape of cervical disc herniation and symptoms is essential in order to understand the role of MRI findings in the diagnosis and treatment of this condition.

The aim of this study was to investigate the relationship between the type of cervical disc herniation and symptoms, and the response to surgical treatment.

Methods

The NEtherlands Cervical Kinetics trial (NECK trial; NTR1289) is a prospective, randomized, double-blind multicentre trial, aiming to compare patients with cervical radiculopathy caused by a single-level disc herniation between three groups, those treated by: anterior cervical discectomy with arthroplasty (ACDA; activC; Aesculap), with cervical fusion (ACDF; Cage standalone), and without fusion (ACD).

The inclusion criteria were: patients aged between 18 and 65 years, with radicular signs and symptoms in one or both arms (i.e. pain, paraesthesia, or partial paralysis in the distribution of a specific nerve root), who have received more than eight weeks of conservative treatment (i.e. physiotherapy, pain medication), with radiological evidence of cervical disc herniation with or without osteophyte formation at one level (between C3 to T1) as indicated by the clinical signs and symptoms, the ability and willingness to comply with requirements of the trial, and with written informed consent from the patient or their legally authorized representative.[9]

Exclusion criteria were: patients who had undergone previous surgery on the cervical spine (either anterior or posterior); those with no active motion of the target level on dynamic studies; those with increased anteroposterior translation of the target level by > 3 mm on dynamic studies; those with a fused or very narrow disc levels (central < 3 mm); severe segmental kyphosis of the involved disc level by > 3°; those with neck pain without radicular symptoms; evidence of myelopathy; infection; metabolic and bone diseases (such as osteoporosis and severe osteopenia); trauma or neoplasia of the cervical spine; a spinal anomaly (such as Klippel Feil syndrome,[10] ankylosing spondylitis,[11] or ossification of the posterior longitudinal ligament);[12] evidence of a psychiatric disorder; those who did not speak Dutch; or those who planned to leave the country in the year after inclusion.[9]

A randomized design with variable block sizes was used, with allocations stratified according to the institution in which treatment was undertaken. The study had ethical approval, including approval for randomization after the induction of anaesthesia. All patients gave informed consent. The design of the study and protocol have been previously reported.[13] The clinical outcomes between ACD, ACDF, and ACDA have also been reported previously.[14]

Patients. In the NECK trial, 111 patients were recruited and randomized into ACDA (35 patients), ACDF (38 patients), or ACD (38 patients). At the time of enrolment, MRI data were obtained from 108 patients. The initial characteristics of the patients are shown in Table I. Their mean age was 46.8 years (standard deviation (SD) 7.9; 27 to 70). There was no significant difference between the groups except for sex, with more female patients in the disc bulge group than in the disc herniation group (p = 0.026, chi-squared test).

The Neck Disability Index (NDI) is a patient-completed, condition-specific functional status questionnaire with ten items, including questions about pain, personal care, lifting, reading, headaches, concentration, work, driving, sleeping, and recreation.[15–17] It is a modification of the Oswestry Low Back Pain Index,[18] and has been shown to be reliable and valid for patients with cervical spinal pathology.[19] Each item is scored from 0 (no pain) to 5 (worst imaginable pain), and the total score ranges from 0 (best) to 50 (worst). Subsequently, the 50-point score is converted to a percentage (50 points = 100%, with 0% meaning no limitations of activity and 100% meaning complete limitation).

The 36-Item Short Form Survey questionnaire (SF-36) is a well-researched, coherent, and easily administered measurement of the quality of life.[20–22] The questionnaire includes 36 items which cover the physical and social status of the patient divided into eight domains. The questions are scored on a scale

Table II. Clinical outcomes at baseline, one-year, and two-year follow-up.

Outcome	Baseline	1-yr follow-up	2-yr follow-up
Mean NDI (SD)			
ACDA	47 (17)	18 (18)	20 (22)
ACDF	41 (13)	18 (17)	19 (18)
ACD	45 (16)	21 (16)	19 (15)
p-value	0.294*	0.711*	0.929*
Mean VAS arm pain (SD)			
ACDA	60 (24)	16 (19)	17 (30)
ACDF	57 (20)	18 (26)	15 (23)
ACD	64 (22)	24 (31)	18 (25)
p-value	0.331*	0.442*	0.880*
Mean VAS neck pain (SD)			
ACDA	50 (27)	17 (19)	23 (32)
ACDF	53 (26)	29 (28)	23 (27)
ACD	56 (31)	24 (27)	21 (23)
p-value	0.586*	0.140*	0.934*
Mean PCS (SD)			
ACDA	41 (14)	70 (21)	72 (27)
ACDF	45 (15)	72 (24)	76 (23)
ACD	41 (14)	70 (24)	68 (24)
p-value	0.745*	0.529*	0.622*
Mean MCS (SD)			
ACDA	55 (25)	76 (20)	74 (25)
ACDF	62 (22)	77 (23)	82 (19)
ACD	58 (21)	76 (21)	71 (23)
p-value	0.689*	0.643*	0.554*
Global health Likert, %			
ACDA	N/A	62	66
ACDF	N/A	77	68
ACD	N/A	53	63
p-value	N/A	0.125†	0.907†
Arm pain Likert, %			
ACDA	N/A	68	66
ACDF	N/A	77	74
ACD	N/A	59	69
p-value	N/A	0.298†	0.781†

*Independent-samples *t*-test.
†Chi-squared test.
ACD, anterior cervical discectomy; ACDA, anterior cervical discectomy with arthroplasty; ACDF, anterior cervical discectomy with fusion; MCS, 36-Item Short Form Survey mental component summary; N/A, not applicable; NDI, Neck Disability Index; PCS, 36-Item Short Form Survey physical component summary; SD, standard deviation; VAS, visual analogue scale.

of 0 (worst health) to 100 (ideal health). This questionnaire is widely used and has been validated for use in spinal surgery.[23,24] The physical component summary (PCS) and mental component summary (MCS) are derived from the SF-36 as summary scores for the Physical and Mental Quality of Life sections, respectively, which range from 0 to 100 with higher scores representing better self-reported health.

A visual analogue scale (VAS) for pain was used to assess the severity of pain during the week prior to the visit to the research nurse, with 0 being no pain and 100 being the worst pain imaginable. Patients scored the pain at the time of the visit to hospital and were not shown previous results. The reliability, validity, and responsiveness of the VAS for pain have been reported.[25] Disabling pain in the neck and arm were defined as a VAS > 40, as this cut-off value is regularly used when a VAS is categorized into a favourable or unfavourable outcome.[26,27]

Finally, patients were asked to judge their postoperative recovery ("perceived recovery") on a scale from "complete recovery" to "worse than ever" using a seven-point Likert scale. This has been used in previous evaluations of the treatment of spinal disorders and is regarded as valid and responsive to change.[28] "Complete recovery" and "almost complete recovery" are defined as a favourable result, which was used to dichotomize the data. An improvement in clinical outcome was defined as a positive difference between the findings at baseline and two years after surgery.

As previously reported, the clinical outcomes were comparable between the three surgical groups (Table II).[14] There was no significant difference in the proportion of patients with a disc bulge and disc herniation between the three groups (Table III).

MRIs were completed at each participating centre according to a standardized protocol tailored to a 1.5 or 3 Tesla scanner

Table III. The proportion of patients with disc bulge and disc herniation in the three groups.

Variable	ACDA	ACDF	ACD	p-value
Disc bulge, n (%)	10 (21.7)	19 (41.3)	17 (37.0)	0.134*
Disc herniation, n (%)	24 (38.7)	17 (27.4)	21 (33.9)	

*Chi-squared test.
ACD, anterior cervical discectomy; ACDA, anterior cervical discectomy with arthroplasty; ACDF, anterior cervical discectomy with fusion.

Table IV. Clinical outcomes at baseline, one-year, and two-year follow-up in the disc bulge and herniation groups.

Outcome	Baseline			1 yr follow-up			2 yr follow-up		
	Bulge	Herniation	p-value	Bulge	Herniation	p-value	Bulge	Herniation	p-value
Mean NDI (SD)	44.6 (15.2)	43.8 (16.0)	0.799*	20.0 (16.6)	18.9 (17.4)	0.840*	19.1 (16.4)	18.5 (19.6)	0.861*
Mean SF-36 (SD)	59.2 (6.9)	59.4 (7.7)	0.895*	69.3 (7.2)	68.8 (9.9)	0.760*	69.9 (9.0)	71.2 (9.9)	0.495*
Mean PCS (SD)	41.7 (13.5)	42.8 (15.1)	0.690*	71.8 (22.1)	70.7 (22.3)	0.823*	75.0 (20.8)	71.1 (25.8)	0.446*
Mean MCS (SD)	61.5 (21.9)	55.5 (23.2)	0.185*	77.7 (18.3)	75.2 (22.3)	0.553*	78.9 (17.1)	73.9 (25.7)	0.296*
Mean VAS neck pain (SD)	55.5 (24.7)	48.1 (27.7)	0.161*	24.0 (25.0)	20.7 (24.5)	0.520*	24.8 (27.3)	19.2 (26.8)	0.322*
Mean VAS arm pain (SD)	63.6 (20.6)	57.9 (23.0)	0.193*	14.8 (22.8)	21.8 (26.7)	0.168*	16.1 (24.3)	15.9 (6.2)	0.968*
Disabling neck pain, n (%)	31 (70.5)	39 (62.9)	0.491†	9 (22.0)	11 (19.0)	0.716†	9 (22.0)	11 (20.8)	0.888†
Disabling arm pain, n (%)	37 (84.1)	45 (72.6)	0.163†	6 (14.6)	15 (25.9)	0.178†	7 (17.1)	8 (15.1)	0.795†
Likert recovery, n (%)	N/A	N/A	N/A	26 (63.4)	38 (65.5)	0.829†	24 (58.5)	38 (70.4)	0.230†

*Independent-samples *t*-test.
†Chi-squared test.
MCS, 36-Item Short Form Survey mental component summary; N/A, not applicable; NDI, Neck Disability Index; PCS, 36-Item Short Form Survey physical component summary; SD, standard deviation; VAS, visual analogue scale.

Table V. The improvement of clinical outcomes at two-year follow-up.

Outcome	Bulge	Herniation	p-value*
Mean NDI (SD)	28.0 (15.4)	27.0 (14.3)	0.766
Mean SF-36 (SD)	11.1 (6.0)	15.4 (10.1)	0.144
Mean PCS (SD)	37.1 (16.1)	35.0 (17.4)	0.608
Mean MCS (SD)	16.6 (21.9)	19.2 (23.9)	0.613
Mean VAS neck pain (SD)	39.8 (24.4)	34.9 (23.1)	0.368
Mean VAS arm pain (SD)	54.8 (22.8)	47.7 (23.9)	0.169

*Independent-samples *t*-test.
MCS, 36-Item Short Form Survey mental component summary; NDI, Neck Disability Index; PCS, 36-Item Short Form Survey physical component summary; SD, standard deviation; VAS, visual analogue scale.

at baseline. Standard sagittal T1 and T2, and T2 axial images were obtained, using 3 mm contiguous slices in all directions and an in-plane resolution of 1 mm^2 or less. The type of disc herniation was evaluated at the operative level on both the left and right side, using a four-point scale: normal (completely normal); mild (slight bulging of the herniated disc); moderate (protrusion/extrusion < one-quarter of the foraminal canal); or severe (protrusion/extrusion > one-quarter of the foraminal canal) (Figure 1). The data were dichotomized into the disc bulge group for patients whose discs were normal or with mild herniation, and disc herniation for those with moderate or severe herniation. The MRIs were evaluated by neurosurgeons in the participating hospitals and independently confirmed by a senior neurosurgeon (CLAVL). If deemed necessary, a third reviewer (RHMAB, a professor of neurosurgery) was consulted.

Of the 108 patients, the discs were classified as normal in four, and the herniations as mild in 42, moderate in 59, and severe in three. Thus, 46 patients (43%) were included in the disc bulge group and 62 (57%) in the herniation group.

Statistical analysis. All data are presented as mean and SD. The independent-samples *t*-test was used to compare continuous data and chi-squared test for categorical data between groups. Differences between groups at all timepoints were analyzed using repeated measurement adjustment. Tests were two-tailed, and a p-value < 0.05 was considered significant. SPSS v. 25.0 was used in this study for all analyses (IBM, USA).

Results

At baseline, the disc bulge group had statistically comparable mean NDI (44.6 (SD 15.2) vs 43.8 (SD 16.0); p = 0.799, independent-samples *t*-test) and SF-36 (59.2 (SD 6.9) vs 59.4 (SD 7.7); p = 0.895, independent-samples *t*-test) values compared with the herniation group. In the disc bulge group, 37 patients (84.1%) had disabling pain in the arm, statistically similar to the 45 patients (72.6%) with disabling pain in the arm in the herniation group (p = 0.163, chi-squared test). The proportion of patients with disabling neck pain was also comparable (70.5% (n = 31) vs 62.9% (n = 39); p = 0.491, chi-squared test).

At two-year follow-up, patients in the disc bulge group reported statistically comparable NDIs (Figure 2; p = 0.091, repeated measurement adjustment) and SF-36 scores (Figure 3; p = 0.427, repeated measurement adjustment)

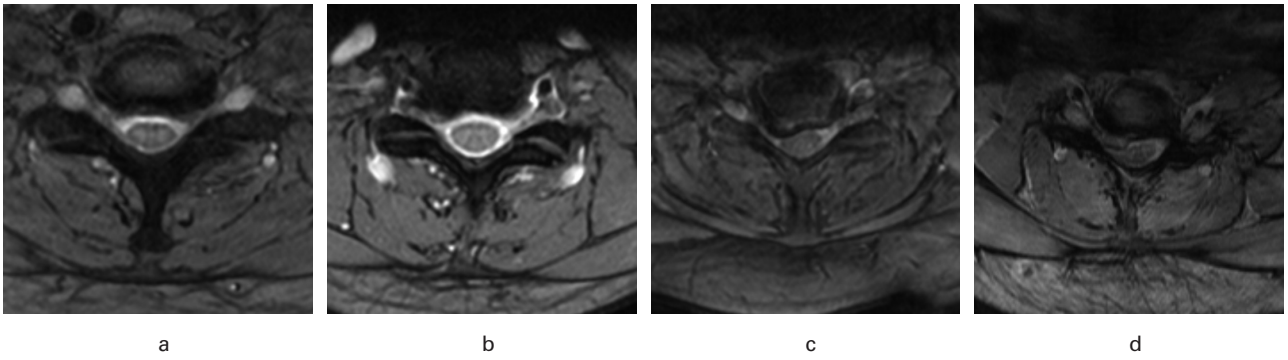

Fig. 1

Classification of cervical disc herniation. a) Normal, b) mild, c) moderate, and d) severe.

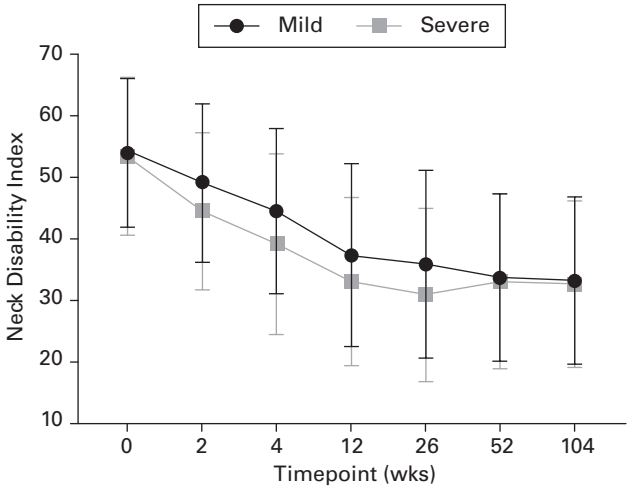

Fig. 2

Neck Disability Index results.

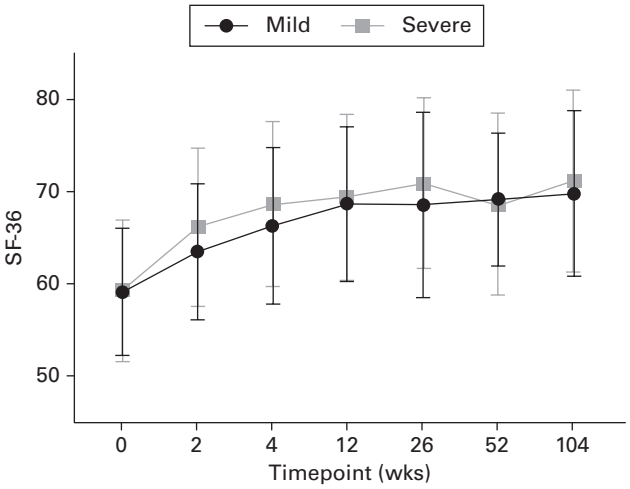

Fig. 3

36-Item Short Form Survey questionnaire (SF-36) results.

compared with those in the herniation group. Overall, seven patients (17.1%) in the disc bulge group reported disabling pain in the arm, which is similar to eight patients (15%) in the herniation group (p = 0.795, chi-squared test). A statistically similar proportion of patients in both groups (22% vs 21%; p = 0.888, chi-squared test) also had disabling neck pain. Additionally, 24 patients (59%) in the disc bulge group reported a favourable outcome which was statistically similar to 38 patients (70%) in the herniation group (p = 0.230, chi-squared test) (Table IV).

There was no significant difference in the improvement in the clinical outcomes between the two groups (Table V).

Discussion

In this study of patients with cervical radiculopathy due to disc herniation who underwent anterior cervical discectomy, the type of disc herniation recorded on MRI did not correlate to clinical outcomes at baseline or at two years after surgery.

MRI is indicated in patients with cervical radiculopathy who have persistent or progressive neurological symptoms despite routine conservative treatment,[29–33] or if malignancy is suspected. It is deemed not to be helpful in most patients with cervical radiculopathy due to the high rates of false-negative and false-positive MRI findings. Teresi et al[34] reported that 57% (24/42) of patients aged > 64 years have evidence of disc herniation without symptoms. Nakashima et al[8] found that 88% of 1,211 asymptomatic volunteers had significant disc bulging, being defined as protrusion > 1 mm. However, the presence of disc extrusion is associated with symptoms, as reported by Beattie et al.[35] In contrast to these studies, we explored the relationship between the amount of disc herniation and symptoms and the response to surgery, in patients with symptomatic cervical radiculopathy.

Between about 80% and 88% of patients with this condition will improve with four weeks of conservative treatment.[30,36] If severe symptoms persist, spinal surgery may be considered and the outcome could be anticipated if it correlated to the extent of the herniation. Our results, however, did not confirm this. Thus, not only is the presence of disc herniation on MRI

not specific for cervical radiculopathy, the type of herniation does not determine the severity of the symptoms.

In a recent systematic review, Hill et al[37] failed to draw a definitive conclusion about the relationship between the appearance of the cervical spine on MRI and the development of neck pain in the future due to the limited number of patients and their heterogeneity in the studies dealing with this issue. Moreover, none of the studies considered the outcomes of surgical treatment. In the present study, we were unable to show that the type of disc herniation predicted the outcome. However, we were able to show that patients with a disc bulge can have an excellent outcome following anterior cervical discectomy, as also seen in patients with severe herniation. This finding is clinically significant since patients, surgeons, and insurers may overlook a diagnosis of degenerative cervical radiculopathy and/or the role of surgery in the treatment of a minor disc bulge as opposed to a large one.

In the lumbar spine, there is also no association between the size of a disc herniation and outcomes. El Barzouhi et al[38] reported that the MRI at baseline did not distinguish between patients who did and those who did not undergo delayed surgery, and the size of disc herniation prior to surgery did not predict the outcome of lumbar disectomy one year postoperatively.[39] They had previously shown that the MRI appearances one year after surgery did not distinguish between those with a favourable outcome and those with an unfavourable outcome.[40] In the current study, as one-year follow-up MRIs were not available, this correlation could not be investigated.

The study has limitations, one being the sample size. One may doubt from post hoc analysis that there is an increased risk of a type II error. However, a power analysis showed that the power of this study was > 85%. Another limitation is the variation in the duration of symptoms before surgery between patients. The time to surgery may have influenced the severity of symptoms at baseline. Finally, clinical outcomes were only available for one- and two-year follow-up and similar results may not have been found at other timepoints.

In conclusion, in patients with cervical radiculopathy, the type of disc herniation prior to surgery does not correlate to the severity of the symptoms and does not allow the outcome at two years after surgical treatment to be predicted.

Take home message

- The presence of a disc herniation, compared with the presence of a simple disc bulge without explicit protrusion or extrusion of disc materials, did not significantly change the presenting characteristics of the patients (all had similar severe symptoms as assessed by Neck Disability Index, 36-Item Short-Form Health Survey questionnaire, and disabling arm/neck pain).
- Therefore, disc bulges can produce severe symptoms, especially for those patients with herniation of the nucleus pulposus.
- Furthermore, these patients with disc bulges can achieve excellent clinical outcomes following anterior cervical discectomy, which are equivalent in magnitude to those seen in patients with severe herniation.

References

1. **Schoenfeld AJ**, **George AA**, **Bader JO**, **Caram PM**. Incidence and epidemiology of cervical radiculopathy in the United States military: 2000 to 2009. *J Spinal Disord Tech.* 2012;25(1):17–22.
2. **Bogduk N**. The anatomy and pathophysiology of neck pain. *Phys Med Rehabil Clin N Am.* 2011;22(3):367–382.
3. **Childress MA**, **Becker BA**. Nonoperative management of cervical radiculopathy. *Am Fam Physician.* 2016;93(9):746–754.
4. **Radhakrishnan K**, **Litchy WJ**, **O'Fallon WM**, **Kurland LT**. Epidemiology of cervical radiculopathy. A population-based study from Rochester, Minnesota, 1976 through 1990. *Brain.* 1994;117 (Pt 2):325–335.
5. **Carragee EJ**, **Kim DH**. A prospective analysis of magnetic resonance imaging findings in patients with sciatica and lumbar disc herniation. Correlation of outcomes with disc fragment and canal morphology. *Spine (Phila Pa 1976).* 1997;22(14):1650–1660.
6. **Matsumoto M**, **Fujimura Y**, **Suzuki N**, **et al**. MRI of cervical intervertebral discs in asymptomatic subjects. *J Bone Joint Surg Br.* 1998;80-B(1):19–24.
7. **Nagata K**, **Yoshimura N**, **Muraki S**, **et al**. Prevalence of cervical cord compression and its association with physical performance in a population-based cohort in Japan: the Wakayama Spine Study. *Spine (Phila Pa 1976).* 2012;37(22):1892–1898.
8. **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.
9. **Yang X**, **Bartels R**, **Donk R**, **Arts MP**, **Goedmakers CMW**, **Vleggeert-Lankamp CLA**. The association of cervical sagittal alignment with adjacent segment degeneration. *Eur Spine J.* 2020;29(11):2655–2664.
10. **Litrenta J**, **Bi AS**, **Dryer JW**. Klippel-Feil syndrome: pathogenesis, diagnosis, and management. *J Am Acad Orthop Surg.* 2021;29(22):951–960.
11. **Longo DL**, **Taurog JD**, **Chhabra A**, **Colbert RA**. Ankylosing spondylitis and axial spondyloarthritis. *N Engl J Med.* 2016;374(26):2563–2574.
12. **Saetia K**, **Cho D**, **Lee S**, **Kim DH**, **Kim SD**. Ossification of the posterior longitudinal ligament: a review. *FOC.* 2011;30(3):E1.
13. **Arts MP**, **Brand R**, **van den Akker E**, **Koes BW**, **Peul WC**. The NEtherlands Cervical Kinematics (NECK) trial. Cost-effectiveness of anterior cervical discectomy with or without interbody fusion and arthroplasty in the treatment of cervical disc herniation; a double-blind randomised multicenter study. *BMC Musculoskelet Disord.* 2010;11:122.
14. **Vleggeert-Lankamp CLA**, **Janssen TMH**, **van Zwet E**, **et al**. The NECK trial: Effectiveness of anterior cervical discectomy with or without interbody fusion and arthroplasty in the treatment of cervical disc herniation; a double-blinded randomized controlled trial. *Spine J.* 2019;19(6):965–975.
15. **Vernon H**, **Mior S**. The Neck Disability Index: a study of reliability and validity. *J Manipulative Physiol Ther.* 1991;14(7):409–415.
16. **Vos CJ**, **Verhagen AP**, **Koes BW**. Reliability and responsiveness of the Dutch version of the Neck Disability Index in patients with acute neck pain in general practice. *Eur Spine J.* 2006;15(11):1729–1736.
17. **Pietrobon R**, **Coeytaux RR**, **Carey TS**, **Richardson WJ**, **DeVellis RF**. Standard scales for measurement of functional outcome for cervical pain or dysfunction: A systematic review. *Spine (Phila Pa 1976).* 2002;27(5):515–522.
18. **Fairbank JCT**, **Pynsent PB**. The Oswestry Disability Index. *Spine.* 2000;25(22):2940–2953.
19. **Owen RJ**, **Khan AZ**, **McAnany SJ**, **Peters C**, **Zebala LP**. PROMIS correlation with NDI and VAS measurements of physical function and pain in surgical patients with cervical disc herniations and radiculopathy. *J Neurosurg Spine.* 2019;1–6.
20. **Stansfeld SA**, **Roberts R**, **Foot SP**. Assessing the validity of the SF-36 General Health Survey. *Qual Life Res.* 1997;6(3):217–224.
21. **Brazier JE**, **Harper R**, **Jones NM**, **et al**. Validating the SF-36 health survey questionnaire: new outcome measure for primary care. *BMJ.* 1992;305(6846):160–164.
22. **McHorney CA**, **Ware JE**, **Lu JF**, **Sherbourne CD**. The MOS 36-item Short-Form Health Survey (SF-36): III. Tests of data quality, scaling assumptions, and reliability across diverse patient groups. *Med Care.* 1994;32(1):40–66.
23. **Yang X**, **Donk R**, **Bartels R**, **Arts MP**, **Depreitere B**, **Vleggeert-Lankamp CLA**. Comparing heterotopic ossification in two cervical disc prostheses. *Spine (Phila Pa 1976).* 2020;45(19):1329–1334.
24. **Ghogawala Z**, **Dziura J**, **Butler WE**, **et al**. Laminectomy plus fusion versus laminectomy alone for lumbar spondylolisthesis. *N Engl J Med.* 2016;374(15):1424–1434.
25. **Carlsson AM**. Assessment of chronic pain. I. Aspects of the reliability and validity of the visual analogue scale. *Pain.* 1983;16(1):87–101.
26. **Peters ML**, **Sommer M**, **de Rijke JM**, **et al**. Somatic and psychologic predictors of long-term unfavorable outcome after surgical intervention. *Ann Surg.* 2007;245(3):487–494.
27. **Yamashita K**, **Ohzono K**, **Hiroshima K**. Patient satisfaction as an outcome measure after surgical treatment for lumbar spinal stenosis: testing the validity and

discriminative ability in terms of symptoms and functional status. *Spine (Phila Pa 1976).* 2006;31(22):2602–2608.
28. **Bombardier C**. Outcome assessments in the evaluation of treatment of spinal disorders: summary and general recommendations. *Spine (Phila Pa 1976).* 2000;25(24):3100–3103.
29. **Bono CM**, **Ghiselli G**, **Gilbert TJ**, **et al**. An evidence-based clinical guideline for the diagnosis and treatment of cervical radiculopathy from degenerative disorders. *Spine J.* 2011;11(1):64–72.
30. **SPURLING RG**, **SEGERBERG LH**. Lateral intervertebral disk lesions in the lower cervical region. *J Am Med Assoc.* 1953;151(5):354–359.
31. **Gross A**, **Kay TM**, **Paquin J-P**, **et al**. Exercises for mechanical neck disorders. *Cochrane Database Syst Rev.* 2015;1:CD004250.
32. **Kuijper B**, **Tans JTJ**, **Beelen A**, **Nollet F**, **de Visser M**. Cervical collar or physiotherapy versus wait and see policy for recent onset cervical radiculopathy: randomised trial. *BMJ.* 2009;339:b3883.
33. **Takenaka S**, **Kashii M**, **Iwasaki M**, **Makino T**, **Sakai Y**, **Kaito T**. Risk factor analysis of surgery-related complications in primary cervical spine surgery for degenerative diseases using a surgeon-maintained database. *Bone Joint J.* 2021;103-B(1):157–163.
34. **Teresi LM**, **Lufkin RB**, **Reicher MA**, **et al**. Asymptomatic degenerative disk disease and spondylosis of the cervical spine: MR imaging. *Radiology.* 1987;164(1):83–88.
35. **Beattie PF**, **Meyers SP**, **Stratford P**, **Millard RW**, **Hollenberg GM**. Associations between patient report of symptoms and anatomic impairment visible on lumbar magnetic resonance imaging. *Spine (Phila Pa 1976).* 2000;25(7):819–828.
36. **Honet JC**, **Puri K**. Cervical radiculitis: treatment and results in 82 patients. *Arch Phys Med Rehabil.* 1976;57(1):12–16.
37. **Hill L**, **Aboud D**, **Elliott J**, **et al**. Do findings identified on magnetic resonance imaging predict future neck pain? A systematic review. *Spine J.* 2018;18(5):880–891.
38. **el Barzouhi A**, **Vleggeert-Lankamp CLAM**, **Lycklama à Nijeholt GJ**, **et al**. Predictive value of MRI in decision making for disc surgery for sciatica. *J Neurosurg Spine.* 2013;19(6):678–687.
39. **El Barzouhi A**, **Verwoerd AJH**, **Peul WC**, **et al**. Prognostic value of magnetic resonance imaging findings in patients with sciatica. *J Neurosurg Spine.* 2016;24(6):978–985.
40. **el Barzouhi A**, **Vleggeert-Lankamp CLAM**, **Lycklama à Nijeholt GJ**, **et al**. Magnetic resonance imaging in follow-up assessment of sciatica. *N Engl J Med.* 2013;368(11):999–1007.

Author information:
X. Yang, MD, PhD, Research Fellow
C. L. A. Vleggeert-Lankamp, MD, PhD, Neurosurgeon
Department of Neurosurgery, Leiden University Medical Centre, Leiden, the Netherlands.

M. P. Arts, MD, PhD, Neurosurgeon, Department of Neurosurgery, Haaglanden Medical Centre, The Hague, the Netherlands.

R. H. M. A. Bartels, MD, PhD, Professor and Neurosurgeon, Department of Neurosurgery, Radboud University Medical Centre, Nijmegen, the Netherlands.

Author contributions:
X. Yang: Conceptualization, Methodology, Data curation, Formal analysis, Writing – original draft.
M. P. Arts: Conceptualization, Methodology, Investigation, Writing – review & editing.
R. H. Bartels: Conceptualization, Methodology, Investigation, Writing – review & editing.
C. L. A. Vleggeert-Lankamp: Conceptualization, Methodology, Investigation, Writing – review & editing.

Funding statement:
The authors disclose receipt of the following financial or material support for the research, authorship, and/or publication of this article: this work was supported by China Scholarship Council and the Department of Neurosurgery, Leiden University Medical Centre, the Netherlands. X. Yang received support from both funding agencies. The NECK trial was sponsored by B. Braun Medical and the Department of Neurosurgery, Leiden University Medical Centre, the Netherlands.

Acknowledgements:
We would like to express our gratitude to Mr Benjamin Davies (Department of Clinical Neurosciences, University of Cambridge, UK) for proofreading the article.

Trial registration number:
NECK trial, Dutch Trial Register Number: NTR1289.

This article was primary edited by J. Scott.