Motion preservation in cervical prosthesis surgery: Implications for adjacent segment degeneration

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Chapter 8

Are Modic Vertebral Endplate Signal Changes Associated with Degeneration or Clinical Outcomes in the Cervical Spine?

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ABSTRACT

Objective

To report on the incidence of Modic changes (MCs) in patients with cervical radiculopathy due to a herniated disc. Presence of MCs was correlated to clinical outcomes and the presence of radiological degeneration.

Methods

Patients who underwent anterior discectomy for a cervical radiculopathy due to a herniated disc were analysed for the presence of MCs at baseline and at one-year follow-up after surgery. Neck disability index, physical component summary, mental component summary and visual analogue scale for neck pain and for arm pain were evaluated as clinical outcomes. The presence of radiological degeneration was defined by the method of Goffin.

Results

The prevalence of MCs was found at 18% at baseline and increased to 28% one year after surgery. Both at baseline and at one-year follow-up, the percentage of patients with and without MCs reporting neck pain was comparable. Likewise, both at baseline and at one-year follow-up, the percentage of patients with and without MCs reporting disabling arm pain was comparable. At baseline, the patients with MCs demonstrated more radiological degeneration than those without MCs (OR 2.40), but this difference disappeared at one year after surgery.

Conclusions

MCs were not associated with neck pain, nor with arm pain. Furthermore, there was a tendency for a correlation between the presence of MCs and radiological degeneration.

INTRODUCTION

Cervical radiculopathy is a frequently occurring problem with an annual incidence of about 80 per 100,000 people and a prevalence of 35 per 10,000 inhabitants[1,2]. Another recent study demonstrated an incidence of 1.79 per 1,000 person-years from 2000 to 2009[3]. Patients with cervical radiculopathy present with arm pain in a dermatomal pattern. Magnetic resonance imaging (MRI) of the cervical spine of these patients often demonstrates a bulging or herniated disc compressing the corresponding nerve root.

Frequently, additional neck pain is present. It is usually presumed that neck pain is multifactorial. One of the factors causing neck pain is deemed to be due to the muscle tension due to the continuous contraction of the muscles in response to the radicular pain. Since the spinal nerve root is specifically irritated on movements of the spinal column that narrow the neuroforamen, muscles are under constant tension to prevent these movements. Furthermore, neck pain can be due to general degenerative changes in the cervical spine that accompany the degeneration of the bulging or herniated disc[4]. However, changes in the endplates of the cervical spine, diagnosed as Modic changes (MCs) in the cervical vertebrae, also may be correlated to neck pain because these are associated with degeneration, inflammatory changes and bone marrow ischemia.

MCs or vertebral endplate signal changes can be visualized by MRI. In 1988, Modic et al.[5,6] described three types of signal changes in the bone marrow adjacent to the vertebral endplate. Type I lesions, hypointense on T1 weighted imaging (WI) and hyperintense on T2WI, represent marrow edema, and are associated with inflammatory changes and an acute process in the vertebral end-plate[5,7,8]. Type II lesions are the most common type and are associated with a chronic process, which increase signal on T1WI and isointense or slightly hyperintense signal on T2WI, and represent bone marrow ischemia with conversion of normal red hematopoietic bone marrow to yellow fatty marrow[5,9]. Type III lesions, hypointense both on T1WI and T2WI, are considered to represent sclerotic changes of the endplate[5,10]. Studies on the prevalence of cervical MCs are limited and incidences reported vary considerably ranging from 4.5% to 58%[11,12].

It is interesting to examine the association between MCs and cervical spine degeneration. Radiological signs of degeneration of the cervical spine can be scored on x-rays by the score of Goffin et al.[13], which was designed to score adjacent level degeneration in the cervical spine. There are, however, indications that spine degeneration is increased in by demographic factors[14]. The possible confounding factors will be examined.

It is furthermore interesting to explore whether MCs are associated with clinical parameters representing neck pain. Moreover, MCs have been reported to represent the inflammatory status of the vertebral body and the adjacent disc. This is hypothesized to influence the spinal root and thus influence pain in the arm[15,16]. Therefore, the correlation between MCs and arm pain also will be investigated.

For these research questions, we combined the data of two randomized double-blind trials, performed in the Netherlands, on patients treated by anterior cervical discectomy with or without interbody fusion and arthroplasty for cervical radiculopathy with a similar setup. The objective of this study is to investigate the prevalence of MCs in the cervical spine and its association to radiological degeneration and to correlate MCs to neck and arm pain.

METHODS

Study design

NECK trial

A prospective, randomized double-blind multicentre trial among patients with cervical radiculopathy due to single-level disc herniation was conducted. Patients randomly were assigned into three groups: anterior cervical discectomy with arthroplasty (ACDA; activC, Aesculap AG, Tuttlingen, Germany), anterior cervical discectomy with fusion (ACDF; Cage standalone) and anterior cervical discectomy without fusion (ACD). A randomized design with variable block sizes was used, with allocations stratified according to centre. All patients gave informed consent.

The design and study protocol were published previously[17]. The two-year follow-up data revealed no differences in clinical outcomes nor in disc or adjacent segment degeneration diagnosed on x-rays and MRI[18].

PROCON trial

The trial design was a prospective, double blind, single-centre randomized study, with a three-arm parallel group. Patients were randomly allocated into three groups: ACDA (Bryan disc prosthesis, Sofamor Danek, Kerkrade, the Netherlands), ACDF (Cage standalone, DePuy Spine, Johnson and Johnson, Amersfoort, the Netherlands), and ACD.

The design and study protocol were published previously[19]. The follow-up data up to eight years post-surgery revealed no differences in clinical outcomes[20] nor in adjacent segment degeneration diagnosed on computed tomography or MRI[21].

Clinical outcomes

Neck disability index (NDI) is a 10-item questionnaire on three different aspects: pain intensity, daily work-related activities and nonwork-related activities. Each item is scored from 0 to 5 and the total score ranges from 0 (best score) to 50 (worst score). This 50 points score was converted to a percentage (50 points=100%). The NDI is a modification of the Oswestry Low Back Pain Index and has been shown to be reliable and valid for patients with cervical pathology[22-24]. To focus on neck pain specifically, additional neck pain was evaluated using the ‘neck pain intensity’ section of NDI questionnaire for all subjects, and disabling neck

pain was defined in the research group consensus meeting as at least 3 points (Table S1). Moreover, physical component summary (PCS) and mental component summary (MCS) were derived from the 36-Item Short Form Health Survey. The PCS and MCS range from 0 to 100, with greater scores representing better self-reported health.

In the NECK trial, patients were additionally assessed by means of the 100-mm visual analogue scale (VAS) for neck pain and for arm pain (with 0 represents no pain and 100 the worst pain ever experienced). Disabling neck pain and arm pain were defined as at least 40 mm since this cut-off value is regularly used when VAS is categorized into favourable and unfavourable outcome[25,26].

Demographic data also were scored for patients and included age, body mass index, sex, smoking, and alcohol use. Alcohol use was defined as no alcohol use and more than occasional drinker. These data were correlated to the presence of MCs and the presence of radiological degeneration at baseline.

Radiological outcomes

All patients underwent MRI at baseline and after one year. MR images were performed at each study centre using a standardized protocol tailored to a 1.5- or 3- Tesla scanner. 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. MCs were defined according to criteria of Modic et al.[5,6].

Standing lateral radiographs of the cervical spine were obtained with the patients in a neutral standing position and instructed to look straight ahead, with hips and knees extended. Radiological degeneration was defined based on the height of the discs and the presence and size of anterior osteophyte formation according to the classification reported by Goffin et al.[13] (Table S2). The radiographs were independently evaluated by one senior neurosurgeon dedicated to spine surgery. The reviewer was not provided with any clinical information of the included patients.

Statistical analysis

After we evaluated radiological degeneration using the method of Goffin et al.[13], subjects who assessed as *normal* for both superior and inferior level were defined as *non-radiological degeneration*, and the patients with either *mild*, *moderate* or *severe* degeneration at either superior or inferior level were defined as '*radiological degeneratio*n'. All the data are presented as mean ± standard deviation. Baseline and follow-up characteristics of the ACD, ACDF and ACDA treatment group were compared using analysis of variance for continuous data and chi-square test for categorical data. Logistic regression analysis was used to determine which factors were associated with the presence of MCs and radiological degeneration at baseline, and the correlation between MCs and radiological degeneration. The comparison on clinical parameters between MCs and non-MCs group was performed by means of the Student's *t*-test

for continuous data; chi-square test or Fisher's exact test were used for categorical data. Tests were two tailed, and a P value of < 0.05 was considered significant. SPSS software, version 23.0, was used for all statistical analyses (SPSS, Inc., Chicago, IL, USA).

RESULTS

In the NECK trial, 111 patients were included and randomly assigned to ACD (38 patients), ACDF (38 patients) or ACDA (35 patients). At baseline, MRI data of 107 patients were available and at one-year follow-up, MRI data were available for 89 patients. X-ray data were available for 107 patients at baseline and for 98 patients at one-year follow-up.

In the PROCON trial, 142 patients were randomized into ACD (45 patients), ACDF (47 patients) or ACDA (50 patients). At baseline, MRI data of 116 subjects were available and at one-year follow-up, MRI data were available for only 31 patients. X-ray data were available for 121 patients at baseline and for 103 patients at one-year follow-up.

Demographics

Baseline characteristics are presented in Table 1. The mean age of the study population was 45.2 ± 7.3 years, ranging from 27 to 70 years. There was no difference regarding to baseline characteristics between treatment groups. Surgery was most frequent at levels C5-C6 and C6-C7.

Table 1 Patient demographics by treatment arm

		ACD	ACDF	ACDA	Total	P value
Population		83	85	85	253	
Age (years, Mean ± SD)		45.3 ± 6.7	45.6 ± 7.6	44.8 ± 7.7	45.2 ± 7.3	0.787
Body Mass Index (Mean ± SD)		26.2 ± 3.8	26.6 ± 4.7	26.7 ± 4.1	26.5 ± 4.2	0.726
Sex	Male	42	37	43	122	0.939
	Female	41	48	42	131	
Smoking	Yes	33	40	41	118	0.305
	No	50	43	44	133	
Alcohol	Yes	46	52	55	153	0.565
	No	37	31	30	98	
Herniated level						
C4-C5		1	2	0	3	
C5-C6		46	39	40	125	
C6-C7		36	43	45	124	
C7-Th1		0	1	0	1	

ACD: Anterior cervical discectomy
ACDF: Anterior cervical discectomy with fusion
ACDA: Anterior cervical discectomy with arthroplasty
SD: Standard deviation

Prevalence of Modic changes

At both baseline and one-year follow-up, there was no difference in the prevalence of MCs between the three treatment arms (total cervical spine: P=0.995 and P=0.190; the index level: P=0.731 and P=0.624, Table S3). Therefore, MCs was studied irrespective of the surgical method applied.

At baseline, MCs was observed in 17.9% of 223 patients: 31 patients had MCs at one level, six patients had MCs at two levels and three-level MCs was found in three patients. Regarding the type of MCs, 4.5% (ten patients) of the patients were found to have type I, 13% (29 patients) had type II and 0.4% (one patients) had both type I and type II. No type III MCs was observed. Focusing on the index level, 3.2% (7 patients) were detected to have type I, and 5.4% (12 patients) had type II MCs (Table 2). Of 1,337 evaluated segments in present study, MCs were observed in 3.9% (52 segments): type I in 0.8% (11 segments) and type II in 3.1% (41 segments) of cervical segments. MCs were the most frequently observed at C5 to C7 (Table S4).

Table 2 Modic changes at the index level

	None	Type I	Type II	Total
Preoperatively				
C4-C5	0	0	1	1
C5-C6	105	4 (3.5%)	5 (4.4%)	114
C6-C7	97	3 (2.8%)	6 (5.7%)	106
C7-Th1	1	0	0	1
Total	203	7 (3.2%)	12 (5.4%)	222
Postoperatively				
C4-C5	0	0	0	0
C5-C6	40	7 (13.2%)	6 (11.3%)	53
C6-C7	30	2 (5.3%)	6 (15.8%)	38
C7-Th1	1	0	0	1
Total	71	9 (9.8%)	12 (13.4%)	92

The number of MRIs available at one-year follow-up was small in the patients from the PROCON trial. At one-year follow-up, MCs was observed in 23.3% of 120 patients: 24 patients had one-level MCs and four patients had two-level MCs. Type II was the predominant type (14.2%, 17 patients). However, in the patients that received a prosthesis, it was not possible to evaluate MCs at the target level, due to scattering on MRI induced by the prosthesis. Therefore, the prevalence of MCs, one year after surgery is underestimated. The figures in Table S3 illustrate this: the percentage of MCs rises to circa 28% at one-year follow-up in the ACD and ACDF groups but decreases in the ACDA group to 13%. Therefore, we did additional analyses on correlations in which we omitted the ACDA results after one year. Focusing on the operated level, one year after surgery, we found that the percentage of seg-

ments with MCs increased to 9.8% (9 segments) for type I and 13.4% (12 segments) for type II, respectively (Table 2), but likewise, this will be underestimated numbers.

Conversion of Modic changes

At one-year follow-up, 13 MCs type II levels consisted of 11 newly developed and two maintained as type II. Of eight levels with MCs type I, seven were newly developed and one maintained as type I (Table 3). Moreover, 11 levels demonstrated MCs at another level than the target level. These data have to be interpreted with caution, since the number of MRIs is low and the index level in the ACDA group could not be evaluated for MCs.

Table 3 Conversion of Modic changes

	Postoperatively			
Preoperatively	None	Type I	Type II	Total
None	0	7	11	18
Type I	0	1	0	1
Type II	0	0	2	2
Total	0	8	13	21

Prevalence of radiological degeneration

There was no difference in the prevalence of radiological degeneration between the three treatment arms, neither at baseline nor at one-year follow-up (Table 4). Therefore, radiological degeneration was studied irrespective of the performed surgical method. At baseline, the prevalence of radiological degeneration was 34% (examined in 228 patients) and it increased to 47% (examined in 201 patients) at one year after surgery.

Table 4 Prevalence of radiological degeneration

	ACD	ACDF	ACDA	P value
Baseline	38% (27)	36% (29)	29% (22)	0.428
1-year follow-up	48% (31)	45% (28)	47% (35)	0.934

ACD: Anterior cervical discectomy
ACDF: Anterior cervical discectomy with fusion
ACDA: Anterior cervical discectomy with arthroplasty

Factors associated with the presence of Modic changes and radiological degeneration at baseline

The presence of MCs at baseline was slightly associated with increasing age (odds ratio [OR], 1.05; 95% confidence interval [CI], 1.00-1.10; P=0.052). Sex, body mass index, smoking, and drinking alcohol failed to reach a statistical association with the presence of MCs (Table 5). Regarding the presence of radiological degeneration, increasing age (OR, 1.12; 95% CI,

1.07-1.18; P<0.001) and alcohol use (OR, 1.82; 95% CI, 1.01-3.30; P=0.047) were found to be factors to be associated with radiological degeneration at baseline (Table 6).

Table 5 Factors associated with presence of Modic changes at baseline

		Univariate analysis		
	Comparison	OR	95% CI	P value
Age	Per additional year of age	1.05	1.00-1.10	0.052
BMI	Per additional unit	1.02	0.94-1.12	0.619
Sex	Male (107) vs. female (111)	0.93	0.47-1.84	0.825
Smoking	Yes (97) vs. no (122)	0.55	0.26-1.12	0.100
Alcohol	Yes (140) vs. no (79)	1.40	0.67-2.93	0.378

BMI: Body mass index
NDI: Neck disability index
OR: Odds ratio
CI: Confidence interval

Table 6 Factors associated with presence of radiological degeneration at baseline

		Univariate analysis		
	Comparison	OR	95% CI	P value
Age	Per additional year of age	1.12	1.07-1.18	<0.001
BMI	Per additional unit	1.02	0.95-1.01	0.534
Sex	Male (111) vs. female (112)	0.77	0.44-1.34	0.768
Smoking	Yes (101) vs. no (123)	0.58	0.33-1.02	0.059
Alcohol	Yes (140) vs. no (84)	1.82	1.01-3.30	0.047

BMI: Body mass index
NDI: Neck disability index
OR: Odds ratio
CI: Confidence interval

Association of Modic changes with clinical outcomes

Disabling neck pain (derived from the NDI score) was present in 61.6% of patients at baseline. There was no association with the presence of MCs: disabling neck pain was present in 70% of the patients with MCs, and in 62% of the patients without MCs (P=0.351). Similar results were found at one year after surgery: the proportion of patients with disabling neck pain in the MCs patients was comparable with that in the non-MCs group (33% versus 32%, P=0.877). After we omitted patients in the ACDA group at one-year follow-up, no association was found either (P=0.300).

Disabling neck pain derived from VAS neck pain was only available for the NECK trial, and was 70.6% at baseline. Disabling neck pain failed to correlate with radiological degeneration at baseline as well as at one-year follow-up (Table 7). Likewise, no correlation could be detected if the patients in the ACDA group at one-year follow-up were excluded (P=0.575).

The values for NDI, PCS and MCS in the patients with MCs were comparable with those in the patients who did not demonstrate MCs. Likewise, at one-year follow-up, these clinical outcome parameters were comparable in the patients with and without MCs (Table 7). The numbers of patients with MCs were too low to meaningfully correlate for type I and type II MCs separately.

In addition, VAS arm pain was studied in patients from the NECK trial. The patients with MCs reported disabling arm pain in comparable proportion with those patients without MCs, both at baseline and at one-year follow-up (Table 7). If only the patients with ACD and ACDF at one-year follow-up were considered, the result was similar (P=0.526).

Table 7 Comparison of Modic changes with clinical outcomes

	VAS neck	VAS arm	NDI	PCS	MCS
Baseline					
MCs	81%	71%	40.7 ± 15.9	43.6 ± 14.1	63.7 ± 19.6
Non- MCs	67%	79%	39.3 ± 15.4	44.0 ± 13.5	58.4 ± 22.0
P value	0.203	0.563	0.603	0.891	0.201
1-year follow-up					
MCs	27%	33%	24.0 ± 20.1	64.9 ± 25.9	70.2 ± 23.1
Non- MCs	24%	19%	17.3 ± 14.3	71.3 ± 20.3	78.0 ± 17.8
P value	1.00	0.293	0.158	0.208	0.081

VAS: Visual analogue scale
NDI: Neck disability index
PCS: Physical-component summary
MCS: Mental-component summary
MCs: Modic changes

Association of Modic changes with radiological degeneration

At baseline, in 73 of 77 patients with radiological degeneration MRI data were available. 51% of 37 patients with MCs were found to have radiological degeneration, which was significantly greater than 31% (out of 177 patients) without MCs (OR, 2.40; 95% CI, 1.171-4.938; P=0.017). At one-year follow-up, MRI data were available for 52 patients with radiological degeneration, and the association disappeared. It was shown that 39% of 26 patients with MCs were demonstrated to have radiological degeneration compared with 52% of 81 patients without MCs (P=0.235). After we excluded patients with ACDA, no association was demonstrated as well (P=0.211) (Table 8).

Considering associations between radiological degeneration and MCs at the index level, at baseline, 42% of 19 patients with MCs were found to have radiological degeneration compared with 34% of 194 patients without MCs (P=0.451). After one year, it was found that 35% of 20 patients with MCs at the index level had radiological degeneration, compared with 46.8% of 62 patients in non-MCs group (P=0.356). With exclusion of patients with ACDA, a similar result was shown (P=0.282) (Table 8).

Table 8 Association of Modic changes with radiological degeneration

Radiological degeneration	Time point	OR	95% CI	P value
Total cervical spine	Baseline	2.40	0.203-0.854	0.017
	1-year follow-up	1.72	0.699-4.248	0.237
	1-year follow-up, without ACDA group	1.98	0.679-5.766	0.211
The index level	Baseline	0.69	0.266-1.806	0.453
	1-year follow-up	1.97	0.665-5.837	0.221
	1-year follow-up, without ACDA group	1.94	0.582-6.443	0.282

OR: Odds ratio
CI: Confidence interval
ACDA: Anterior cervical discectomy with arthroplasty

In addition, it was demonstrated that alcohol was a factor that significantly associated with radiological degeneration. Therefore, this was added to the statistical analysis as a covariate. It was demonstrated that a similar correlation was found between MCs and radiological degeneration (OR, 2.38; 95% CI, 1.144-4.945; P=0.020).

DISCUSSION

In patients with cervical radiculopathy due to a herniated disc, one fifth of patients were detected to have MCs, being predominantly type II. One year after cervical discectomy, the prevalence of MCs increased to circa 30%, and remains predominantly type II. If observing MCs around the level with the bulging cervical disc, 9% of patients had MCs at the target level preoperatively, which increased to 23% at one-year follow-up. MCs is most prevalent in the most frequently operated levels from C5 to C7 at both baseline and follow-up, in accordance with literature[27-29]. Our results on the prevalence of MCs in patients with cervical radiculopathy are in agreement with the results of Kressig et al.[30], who also studied patients with cervical radiculopathy. Kressig et al.[30] reported that 29.5% of patients were found to have MCs and that this was 27.5% at one-year follow-up after undergoing manipulative therapy.

It was hypothesized that MCs were associated with neck pain in the cervical spine. This hypothesis could not be affirmed. Other studies reported, contrary to our results, that neck pain was more prevalent in patients with MCs in the cervical spine[27,31,32]. However, information on the scoring method for neck pain was absent in these papers. In our study, with the use of an accurate and representative measures for neck pain, it was shown both at baseline and at one year after surgery, that patients with and without MCs reported disabling neck pain in a comparable proportion. Our results are in agreement with Matsumoto et al.[11] who demonstrated the absence of a correlation between neck pain and cervical MCs in 223 asymptomatic healthy volunteers.

MCs are hypothesized to represent an inflammatory process involving low virulent anaerobic bacteria[16], which may influence the spinal root and thus influence pain in the arm. The correlation of MCs with disabling arm pain was, however, not confirmed in the present study. This result is consistent with previous research reported by Kressig et al.[30]. El Barzouhi et al.[33] could not demonstrate a correlation between back pain and MCs. But Djuric et al.[15] did find a MCs dependent correlation between back pain/leg pain and the presence of macrophages in disc tissue in patients operated for sciatica due to a herniated disc. Nevertheless, these studies were conducted on data from the lumbar spine, and the value of these findings for the cervical spine remain unclear. Additional research is needed.

Radiological degeneration is present at baseline in one third of patients, and we demonstrated that it tends to be associated with MCs (OR 2.40). The only correlation that was convincing was the correlation between MCs (considering the global cervical spine) and radiological degeneration at baseline. However, since this correlation could not be confirmed in the analysis considering only the target level and disappeared at one year after surgery, we softened the conclusion to 'tending to correlate'. The absence of a correlation at one year after surgery may be due to the lower number of MRIs that were available. A limitation of this study is that MRI studies and x-rays were not available for all patients. Furthermore, it would have led to stronger results if the VAS neck pain was assessed for the patients in the PROCON study, too. Finally, the prosthesis lacks proper evaluation of MCs at the adjacent levels, which lowered the number of patients in which MCs could be studied even more. Future studies are needed to investigate the change of the prevalence of MCs between the pre- and post-operative condition. A large series of such patients is also need in order to compare neck and arm pain as well as radiological degeneration between different types of MCs.

CONCLUSIONS

The prevalence of MCs was found at 18% at baseline and increased to 28% at follow-up. MCs were not correlated to neck pain, but tended to be correlated to radiological degeneration in the cervical spine.

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Table S1 Neck pain intensity

Score	Pain intensity
0	No pain at the moment.
1	The pain is very mild at the moment.
2	The pain is moderate at the moment.
3	The pain is fairly severe at the moment.
4	The pain is very severe at the moment.
5	The pain is the worst imaginable at the moment.

Table S2 The classification of radiological degeneration

	Disc height	Anterior osteophyte formation
Normal	Same as adjacent disc	No anterior osteophyte
Mild	75-100% of normal disc	Just detectable anterior osteophyte
Moderate	50-75% of normal disc	Clear anterior osteophyte <25% of AP diameter of corresponding vertebral body
Severe	<50% of normal disc	Clear anterior osteophyte >25% of AP diameter of corresponding vertebral body

Table S3 Prevalence of Modic changes in subgroups

	Total cervical spine		The index level	
	Baseline	1-year follow-up	Baseline	1-year follow-up
ACD	13 (17.6%)	12 (27.3%)	6 (8.1%)	10 (23.8%)
ACDF	14 (18.2%)	11 (28.9%)	8 (9.8%)	8 (26.7%)
ACDA	13 (18.1%)	5 (13.2%)	5 (6.9%)	3 (15.0%)
P value	0.995	0.190	0.731	0.624
Total	40 (17.9%)	28 (23.3%)	19 (8.6%)	21 (22.8%)

ACD: Anterior cervical discectomy
ACDF: Anterior cervical discectomy with fusion
ACDA: Anterior cervical discectomy with arthroplasty

Table S4 Modic changes on cervical segments

	None	Type I	Type II	Total
Preoperatively				
C2-C3	213	1 (0.4%)	9 (4%)	223
C3-C4	219	0	4 (1.8%)	223
C4-C5	219	0	4 (1.8%)	223
C5-C6	208	4 (1.8%)	11 (4.9)	223
C6-C7	205	5 (2.3%)	12 (5.4%)	222
C7-Th1	221	1 (0.4%)	1 (0.4%)	223
Total	1285	11 (0.8%)	41 (3.1%)	1337
Postoperatively				
C2-C3	116	1 (0.8%)	3 (2.5%)	120
C3-C4	119	0	1 (0.8%)	120
C4-C5	118	0	1 (0.8%)	119
C5-C6	91	7 (6.7%)	7 (6.7%)	105
C6-C7	91	2 (2%)	8 (7.9%)	101
C7-Th1	115	1 (9%)	1 (0.9%)	117
Total	650	11 (1.6%)	21 (3.1%)	682