Review Article

Postoperative Modic Changes: What do we know?

Abstract :

Modic changes (MC), initially classified by Modic in 1988, consist of three types: MC1 (hyperintense on T2 weighted imaging T2WI), MC2 (hyperintense on T1 weighted imaging T1WI), and MC3 (hypointense on both T1WI and T2WI). These types are believed to represent different stages of the same disease, potentially resulting from persistent inflammation, altered healing, chronic inflammation, high bone turnover, and fibrosis.

In the postoperative setting, Modic changes can be influenced by different types of spinal surgeries such as lumbar spine fusion, lumbar disc surgery, cervical disc surgery, and scoliosis surgery. The impact of these surgical procedures on Modic changes varies depending on the specific technique employed.

Following lumbar disc surgery, the natural progression of Modic changes can be affected. It has been observed that certain surgical approaches, such as limited discectomy, may slow down the process of Modic changes. On the other hand, lumbar spine fusion, particularly posterior lumbar interbody fusion (PLIF), does not appear to prevent the development of Modic changes.

In the case of cervical disc surgery, the extent of disc resection and the surgical approach employed can have implications for Modic changes. Limited surgical techniques and approaches, which involve less extensive disc resection, have shown better outcomes in terms of Modic changes compared to broader disc resection procedures.

The surgical correction of scoliosis aims to restore spinal alignment and balance by fusing the vertebrae together. This fusion process can lead to changes in the adjacent vertebral segments, including the development of Modic changes. The altered biomechanics and stress patterns resulting from spinal fusion may contribute to the occurrence or progression of Modic changes in the postoperative period.

Overall, the impact of different spinal surgeries on Modic changes is complex and can vary depending on the specific procedure performed. Further research is needed to better understand the relationship between these surgical interventions and the development or progression of Modic changes in the postoperative period.

Keywords

Modic changes, post-operative, back pain, MRI.

Introduction

In 1987, de Roos and colleagues [1] were the first to describe vertebral endplate and subchondral marrow changes on MRI. The formal classification of these changes was established by Modic and colleagues [2], following an analysis of MR images from patients with low back pain (LBP).

Initially, two types of Modic changes (MC) were described, but a third type was added later (Modic et al, 1988) [2]:

- Type 1 (MC 1): hypointense on T1-weighted imaging (T1WI) and hyperintense on T2-weighted imaging (T2WI) (figure 1).
- Type 2 (MC 2): hyperintense on T1WI and isointense or slightly hyperintense on T2WI (figure 2).
- Type 3 (MC 3): hypointense on both T1WI and T2WI (figure 3).

Modic type 0 (MC 0) is the normal appearance of endplates on MRI.

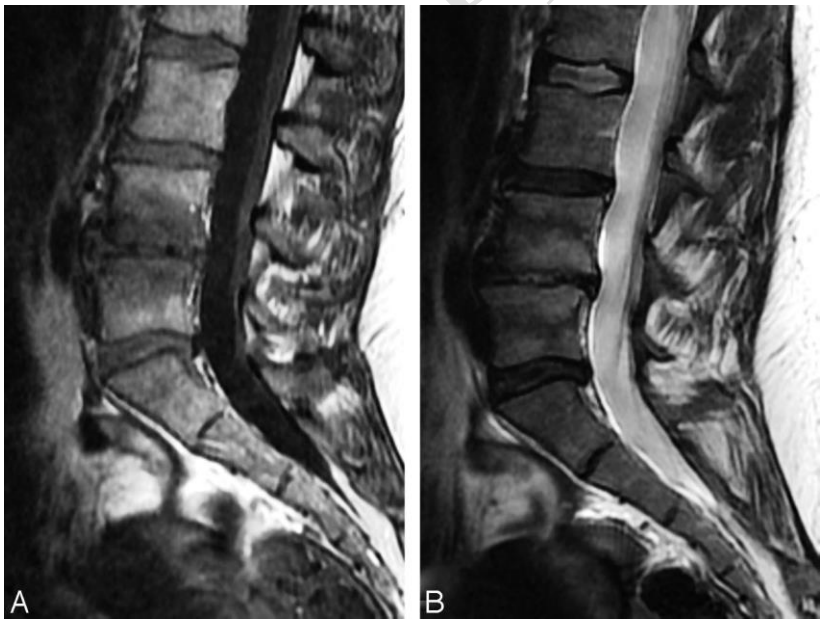

Figure 1: Modic type 1 changes: A: T1WI, B: T2WI (Rahme et al 2008) [3]

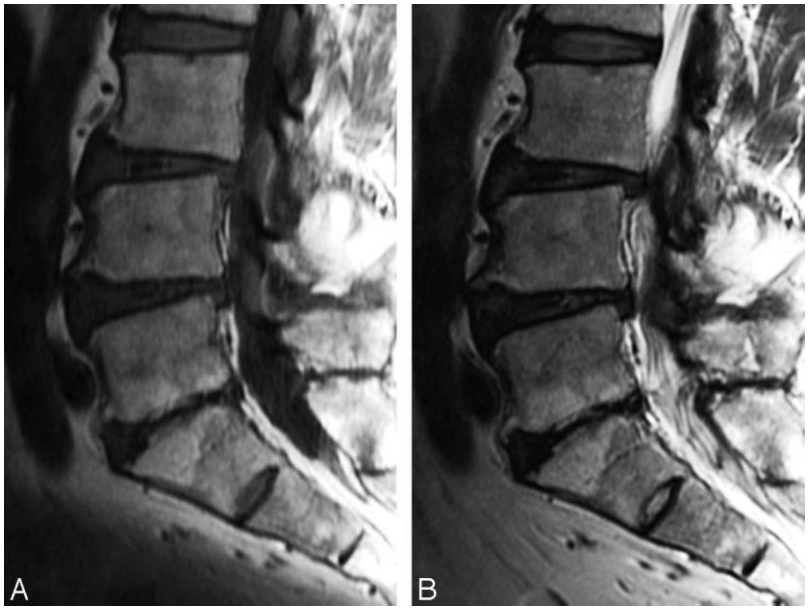

Figure 2: Modic type 2 changes: A: T1WI, B: T2WI (Rahme et al 2008) [3]

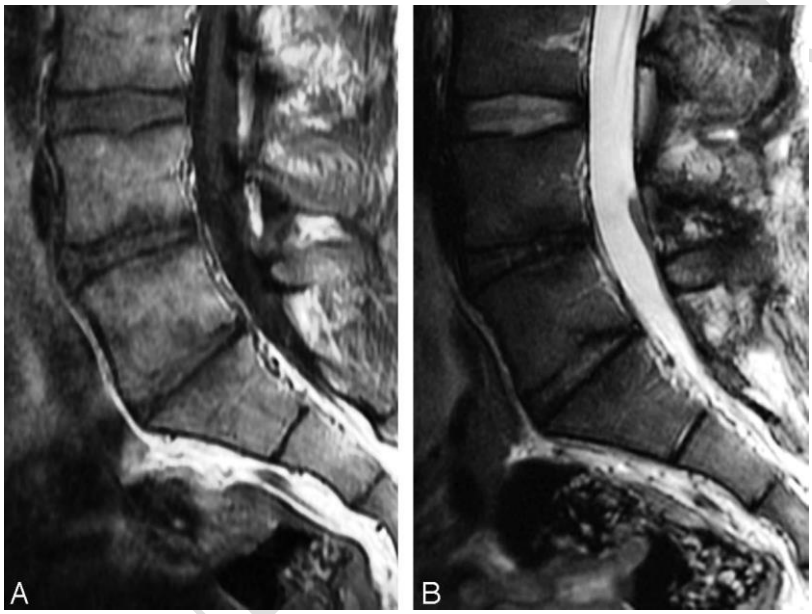

Figure 3: Modic type 3 changes: A: T1WI, B: T2WI (Rahme et al 2008) [3]

According to Braithwaite and colleagues (1998) [3], each type of Modic change is thought to be a different stage of the same pathological process. Modic type 1 is typically the first to appear, and it is associated with bone marrow edema and inflammation. Modic type 2 is characterized by bone ischemia and the conversion of hematopoietic marrow into yellow fatty marrow. Finally, Modic type 3 represents the end stage of the process, which is marked by subchondral bone sclerosis [1].

Modic changes (MC) are prevalent among symptomatic patients with degenerative disc disease, with reported prevalence rates ranging from 19% to 59%. The most frequently observed types of Modic changes are MC1 and 2, while mixed types and MC3 are relatively rare. Asymptomatic patients, on the other hand, have a much lower prevalence rate of MC, which is estimated to be around 9.6% .

It is important to talk about the role of Short Tau Inversion Recovery (STIR) MRI in evaluating Modic's lesions. In a recent study by Kristoffersen et al [4] the interpretation of STIR sequence signal hyper-intensity in Modic's lesions demonstrated reliable inter-observer agreement. This sequence is particularly sensitive to inflammation or edema. STIR's ability to highlight high water content areas, while suppressing fat signal, aids in identifying ongoing inflammatory processes within vertebral bodies. However, using STIR sequence to classify Modic changes is still controversial. We will limit our literature review to study that use T1 and T2 weighted images for the evaluation of pre and post operative Modic changes.

Natural history

Modic changes (MC) are believed to represent different stages of the same pathological process. Modic et al 1988 [2] followed a cohort of 16 patients longitudinally and found that most of the MC 1 lesions (5/6 patients) partially or totally converted to MC 2 within 14 months to 3 years. In contrast, MC 2 lesions were stable during the 2 to 3 years follow-up. Another study done by Mitra et al 2004 [5]showed that in patients with low back pain and sciatica, 92% of MC 1 converted to MC 2 or became more extensive, which suggests that type 1 is an unstable lesion. However, recent studies have shown that MC 2 lesions are less stable than previously reported. For instance, conversion from MC 2 to MC 1 is not a rare process, and it may occur in up to 80% of non-operated patients with sciatica [6]. These findings suggest that MC 2 lesions are not entirely stable and that a "reverse transformation" to MC 1 is possible.

MC and low back pain

The relationship between MC and LBP has been the subject of numerous studies, with some suggesting that such an association exists [7]. However, a recent systematic review and meta-analysis conducted by Herlin et al. (2018) [8] found a statistically significant positive

correlation between MC and LBP in only 50% of the studies reviewed (15 out of 30 studies). Among these 30 studies, 6, 4, and 1 reported a significant association between LBP and MC 1, MC 2, and MC 3, respectively. Notably, this review found no significant difference in the strength of association between Modic types 1 and 2 and LBP, and that the size of MC had no correlation with LBP. Additionally, the intensity of LBP was not found to be different between patients with or without MC. Therefore, it can be concluded that the association between LBP and MC is inconsistent, and no definitive conclusions can be drawn regarding this relationship.

Postoperative Modic changes

Materials and Methods

The aim of our study was to conduct a comprehensive narrative literature review examining the incidence and evolution of Modic changes post operatively among different types of spine surgeries using MRI T1 and T2 weighted images. To accomplish this, we utilized the PubMed search engine to find articles published in English since the emergence of the MODIC classification. The key search terms employed were "Modic changes," "postoperative," "back pain," "cervical pain," "signal abnormality," and "vertebral endplate(s)." Inclusion criteria required that each selected article include sections covering material and methods, study design, results, discussion, and conclusion. Our initial search yielded a total of 58 articles from PubMed. From these articles 18 satisfied our inclusion criteria and were relevant to the subject of our narrative literature review.

Lumbar disc surgery

Modic changes (MC) after lumbar disc surgery without fusion have been extensively studied. Weiner et al. (2015) [9] conducted a prospective study on 137 patients who underwent single-level lumbar discectomy and found that 30-40% of patients developed MC type 1 during the first year, with a decline in proportion during the 4th and 5th years. In contrast, a progressive increase in MC type 2 was observed over the years, with 80% of patients developing this type 5 years after surgery. The study found a significant association between loss of preoperative

disc height and MC type 1 one year after surgery, but no clinical correlation was observed between MC and functional and pain scores at any given time.

Another prospective study by Rahme et al. (2010) [10] on 41 patients reported that the prevalence of MC at the operated level increased from 46.3% to 78% 41 months after microdiscectomy. Preoperative MC was not correlated with patient outcome after surgery. The authors found that 59.1% of preoperatively normal endplates developed MC, with 18.2% of MC type 1 and 40.9% of MC type 2. None of the preoperative MC type 1 remained stable, with 40% progressing in depth and size, and 60% converting to MC type 2.

On the other hand, no preoperative MC type 2 converted to another type, but 74.1% progressed in size. No reverse conversion to MC type 0 was seen in patients with MC before surgery. Finally, conversion to MC type 2 after surgery was associated with lower rates of low back pain postoperatively (8.3%), compared to those who did not convert (37.9%) (p=0.0073).

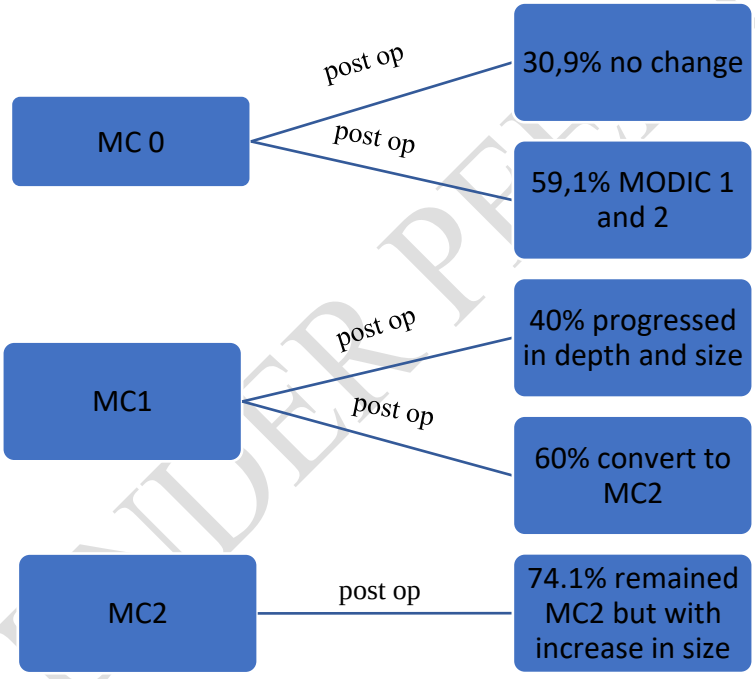

Chart 1 : the pattern of Modic changes 41 months after microdiscectomy. Rahme et al. 2010 [10]

When comparing sequestrectomy with total microdiscectomy in a study on 66 individuals, Barth et al. (2008) [11] found that postoperative endplate degeneration is more significant in the total discectomy group. The relative risk of developing MC was 0.474 in the latter group, versus 0.138 in the sequestrectomy group. This means that three patients need to

be treated by sequestrectomy to save one patient from progressive endplate changes. The authors demonstrated that among MRI findings, only endplate changes after surgery correlated with negative clinical outcome.

Similar results were found by Papanastasiou et al. (2019) (sample size = N= 61) [12], where a limited single-level microdiscectomy was performed without total removal of the disc. The study showed that only postoperative MC type 2 and 3 were correlated with a higher level of pain 36-60 months after surgery and lower physical and mental scores of SF-36 at 36 months postoperatively.

In another retrospective study, Barth et al. (2016) (N = 71) [13] compared postoperative outcomes between two groups: sequestrectomy alone or with the addition of an annulus closure device. The study found no significant difference in Modic staging before and after surgery, with a follow-up of 18 months (P=0.197).

In patients with recurrent disc herniation after surgery, Abrishamkar et al. (2014) (N = 34) [14]found 100% of MC at the operated level 4.2 months postoperatively. The most common type was MC type 2 (50%), followed by MC type 3 (29.4%) and MC type 1 (20.6%). Furthermore, none of the preoperative MC type 2 converted to another type, but 71.4% progressed in depth. No regression to MC type 0 was observed in this study.

Hueftle et al (N = 30) [15] reported that 46% of patients with Failed back surgery syndrome had explicit Modic changes 1 and 2 after a minimum of 6 months follow-up after lumbar discectomy. However, it is important to note that this study was retrospective in nature and had a small sample size.

In a prospective study conducted by Ross et al in 1988 [2], 13 patients were followed with MRI in the immediate post-op period (1 to 10 days) and at 2 to 6 months after lumbar spine discectomy. The study found that 7 patients developed MODIC type 1 changes post-operatively, with 4 of them showing changes on the immediate post-op MRI and 3 on the late MRI.

In another prospective study done by Ross et al in 1996 [16]. 19 out of 94 patients who showed postoperative vertebral disc enhancement at 3 and 6 months after a unilateral first-time laminectomy/discectomy for symptomatic herniated lumbar disc were studied for Modic changes. Out of these, 5 patients developed type 2 changes, 3 patients showed

regression from type 2 to type 1, and 11 patients remained the same, with 3 having type 2 changes and 8 having no changes.

In a prospective study conducted by Bostelman et al in 2019 [17], which involved 278 individuals who underwent lumbar limited discectomy, the patients' postoperative progress was monitored using MRI T1 and T2 weighted sequences. These sequences were taken before the surgery, as well as at 1 and 2 years after the operation. Interestingly, the conversion of Modic changes type 2 to type 3 was only observed in 2% of cases one year after discectomy. However, a rather intriguing trend was observed regarding backward conversions of Modic changes. At the 1-year follow-up, approximately 33% of cases showed a conversion from Modic changes type 2 to type 1, and 7.4% converted from type 2 to type 0. Continuing into the 2-year follow-up, about 23% of cases displayed a conversion from Modic changes type 2 to type 1, while 9.9% converted from type 2 to type 0. These findings highlight the dynamic nature of Modic changes and the fact that limited discectomy may result in regression of the modic types over the course of 1 to 2 years. It is important to note that the findings of these studies should be interpreted with caution, as they have small sample sizes and their results may not be generalizable to a larger population. All data were summarized in table 1.

Table 1: summary of post-op modic changes after disc surgery

Authors	year	Type of the study	N	Type of surgery	Act done in the surgery	results	comments
Weiner et al.	2015	Prospective	137	Lumbar disc surgery	Single-level lumbar discectomy	30-40% developed MC1 during the first year 80% developed MC2 5 years after surgery	1-Significant association between **loss of preoperative disc height** and **MC type 1** one year after surgery. 2-No clinical correlation was observed between **MC** and f**unctional and pain scores** at any given time.

Rahme et al.	2010	Prospective	41	Lumbar disc surgery	Single-level lumbar microdiscectomy	MC increased from 46.3% pre op to 78% 41 months post op	1- 59.1% of MC0 preop developed MC 1 and 2 post op . 2-MC1 preop: 40% progressed in depth and size, 60% convert to MC2 3-MC2 preop remained MC2 post op but 74.1% progressed in size 4-Conversion from MC1 to MC2 was associated with lower rates of low back pain post op 8.3%
Barth et al.	2008	Prospective	66	Lumbar disc surgery	**Group D:** Total microdiscectomy Vs **Group S:** sequestrectomy	**Group D:** Prevalence of MC 1 and 2 increased from 21% to 42% after two years of operation. **Group S:** Prevalence of MC 1 and 2 increased from 28% to 34% after two years of operation.	Total microdiscectomy increases the chance of MC progression more than sequestrectomy
Papanastasiou et al.	2019	Prospective	61	Lumbar disc surgery	limited single-level microdiscectomy was performed without total removal of the disc		The study showed that only postoperative MC type 2 and 3 were correlated with a higher level of pain 36-60 months after surgery and lower physical and mental scores of SF-36 at 36 months postoperatively.
Barth et al	2016	Retrospective	71	Lumbar disc surgery	Sequestrectomy alone vs addition of annulus closure device	No significant difference was found between the groups, and both showed insignificant degree of progression	

Abrishamkar et al	2014	Prospective	34	Lumbar disc surgery	discectomy with hemilaminectomy, foraminotomy	percentage of MC before the disc operqtion : ● 41.2% MC1 ● 35.3% MC2 ● 23.5% MC3 Percentage of MC after recurrence of disc herniation: ● 20.6% MC1 ● 50% MC2 ● 29.4% MC 3	
Hueftle et al	1988	Retrospective	30	Lumbar disc surgery	Failed back surgery syndrome after discectomy/ laminectomy	MC present in 46% of patients (14/30) at the time of recurrence of symptoms	
Ross et al	1988	Prospective	13	Lumbar disc surgery	Lumbar discectomy	7 out of 13 patients developed MC 1 post op: ● 4 in the immediate post op period ● 3 after 2 to 6 months	
Ross et al	1996	Prospective	19	Lumbar disc surgery	First time laminectomy/ discectomy	● 5/19 developed MC2 ● 3/19 regression from MC2 to MC1 ● 11/19 remained the same (3 with MC2 and 8 with MC0)	MRI showed only in 19 patients postoperative vertebral disc enhancement at 3 and 6 months

Bostelmann et al	2019	prospective	278	Lumbar disc surgery	lumbar limited discectomy	modic changes type 2 are observed to convert to Type 3 at one year in only 2% of cases following discectomy however, a backward conversion of MC type 2 to type 1 and even to type 2 was seen at 1 and 2 years of follow up: at 1 year follow-up: 33% converted from type 2 to 1 and 7.4 % from type 2 to 0 at 2 years follow-up: 23% converted from type 2 to 1 and 9.9% from type 2 to type 0.	

Lumbar fusion

Few studies have investigated changes in vertebral endplates after lumbar fusion. In a prospective study by Vital et al (2003) (N = 17) [18], the evolution of MC1 at the fused level was studied 6 months after single level instrumented arthrodesis. All MC1 lesions evolved (100%), with 76.4% and 23.6% evolving to MC2 and MC0, respectively. All patients also showed clinical improvement.

In contrast, Ohtori et al (2010) (N = 33) [19] demonstrated that only 47.8% of preoperative MC1 lesions evolved at 11.5 months after laminectomy and posterior arthrodesis, with 39.1% evolving to MC2 and 8.7% to MC0. The remaining 52.2% remained as MC1 postoperatively. Only 16.6% of preoperative type 2 lesions evolved into MC 0 at 1 year postoperatively, with 83.4% remaining as type 2. Postoperative Modic changes were not correlated with low back pain scores at 24 months after surgery.

In a comparison between posterior lumbar fusion (PLF) and posterior lumbar interbody fusion (PLIF) by Farrokhi et al (2018) (N = 88) [20]. 89% of MC1 lesions in each group (PLF vs PLIF) converted to MC2 or MC0 at follow-up (24 months). Similarly, 73.8% and 68.2% of preoperative MC2 lesions converted to MC0 in PLF and PLIF groups, respectively. The authors demonstrated that the PLIF group had higher fusion rates, while the PLF group provided more decrease in MC1 and more increase in MC0 at any given time. This study revealed the non-superiority of PLIF over PLF in treating Modic changes, regarding the natural radiological history of this condition

In a 2022 retrospective study conducted by Mu et al [21], a total of 270 adults underwent surgery for lumbar degenerative disease using Microdiscectomy in 93 patients, Sequestrectomy in 60 patients, Micro decompression in 74 patients, and Transforaminal Interbody Lumbar Fusion TLIF in 43 patients. Preoperative, postoperative at 12- and 24-months MRI acquisitions were performed, and the results were displayed in the accompanying diagram (figure 4-6).

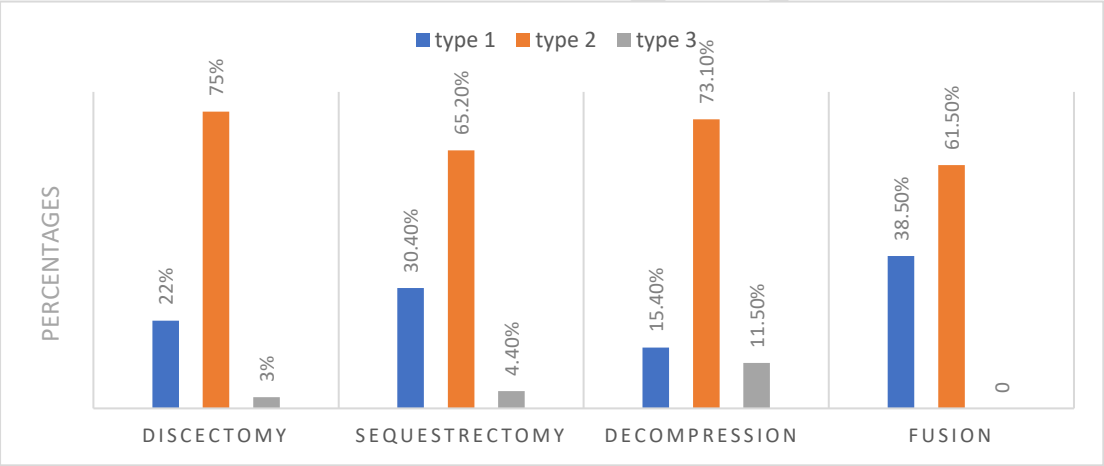

Figure 4: percentage of MODIC changes seen in the postoperative period (12 to 24 months) post discectomy, sequestrectomy, decompression and fusion.

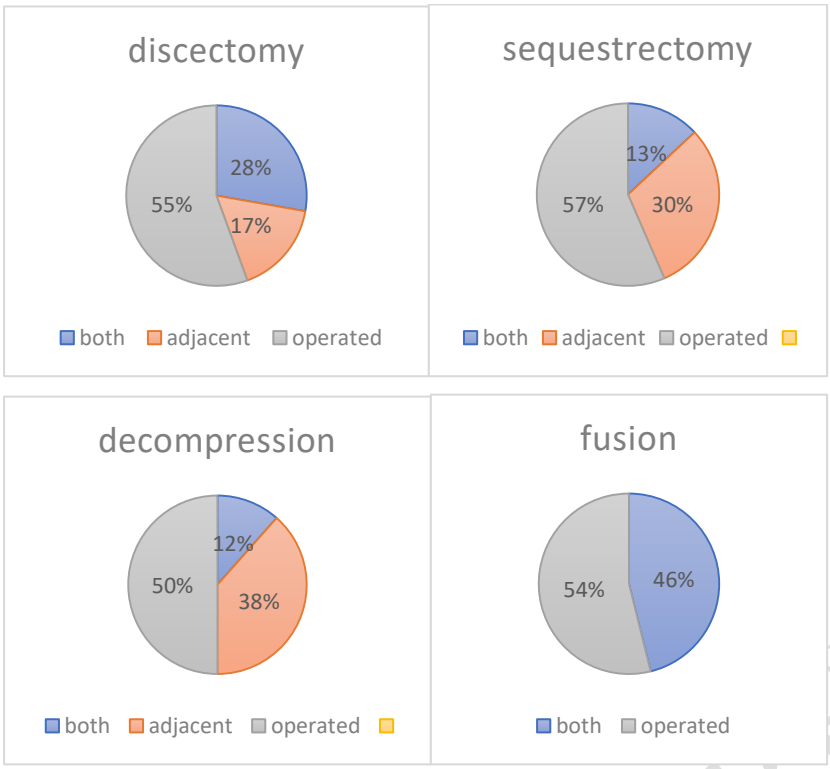

Figure 5: Distribution of affected lumbar levels (operated, adjacent and both levels) of new Modic changes after lumbar surgical procedures (discectomy, sequestrectomy, decompression, fusion)

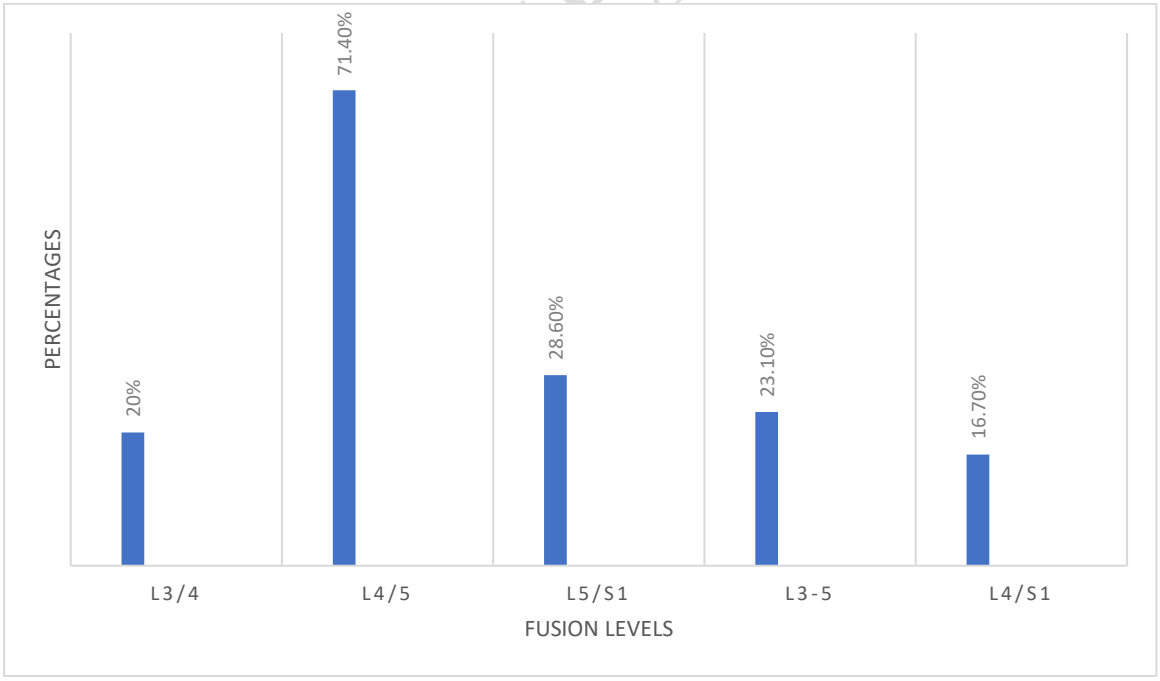

Figure 6: Percentages of new Modic changes in the lumbar spine after fusion of the different spinal levels.

The comparison between pre- and postoperative progression of MC revealed that in the first three groups (Microdiscectomy, Sequestrectomy, and Micro decompression), the postoperative volumes of MC were significantly larger than the preoperative volumes ($P<0.01$). These procedures may aggravate the lesions of the endplates and their adjacent bone marrow. On the other hand, in the lumbar fusion group, no significant difference was found between pre- and postoperative volumes of MC changes ($P>0.05$).

The occurrence of MC could be observed at any phase after lumbar surgery, and the incidence of new MC changes has shown a declining trend over time, with the first postoperative year being the most active phase for the development of new MC changes.All data were summarized in table 2.

Table 2: summary table of post-op modic changes in lumbar spine fusion

Authors	year	Type of the study	N	Type of surgery	Act done in the surgery	results	comments
vital et al	2003	prospective	17	Lumbar fusion	Single level instrumented arthrodesis + bone graft	All patients had MODIC changes type 1 preop **Post op:** a-76.4% progressed to MC2 (13 patients) b-23.6% regressed to MC0 (4 patients)	All patients showed clinical improvement.
Ohtori et al	2010	prospective cohort	33	Lumbar fusion	Decompression + PLF for spinal stenosis	Pre op, 21 patients had MC1: a-12 stayed MC1 b-9 progress to MC2 c-2 regress to MC0 Preop, 12 patients had MC2: a- 0 regressed to type 1 b- 2 regressed to MC0	Postoperative Modic changes were not correlated with low back pain scores at 24 months after surgery

						c- 10 stayed MC2	
Farrokhi et al	2018	Randomized prospective controlled study	88	Lumbar fusion	comparison between posterior lumbar fusion (PLF) and posterior lumbar interbody fusion (PLIF)	PLIF group had higher fusion rates, while the PLF group provided more decrease in MC1 and more increase in MC0 at any given time	There is no superiority of PLF over PLIF in treating MODIC changes, both techniques demonstrated positive outcomes.
Mu et al	2022	retrospective study	270	surgery for lumbar degenerative disc disease	microdiscectomy (N=93), sequestrectomy (N=60), microdecompression (N= 74) and transfora;inal interbody fusion(TLLIF) (N = 43)	in the post-operative period patients how did discectomy, sequestrecto my and decompressio n had higher percentage fo type 2 and type 3 modic changes compared to patients how did TLIF	Patients who did microdiscecto; y, sequesttrqtion and micro decompression had increase in the postoperative MC volume, however in the lumbar fusion group no significant difference was seen betwen pre and post-operative volumes of MC changes.

Cervical Disc Surgery

In a retrospective study conducted by Ross et al. (1987) [22], vertebral postoperative endplate changes were examined prior to the original classification by Modic. The study included 73 patients who underwent surgery for cervical radiculopathy or myelopathy, and they were evaluated using MRI in the postoperative period.

Among the six patients who were examined between 12 days and 1 month after the surgery, three of them did not exhibit any Modic changes (Modic type 0), while the remaining three patients showed a decrease in signal intensity on T1 and hyperintense or iso-signal intensity on T2 (Modic type 1 changes).

Furthermore, nine patients who underwent anterior disc fusion (ADF) were evaluated between 7 and 24 months after the surgery. In these cases, the vertebral bodies demonstrated a decrease in signal intensity on T1 and iso or increased signal intensity on T2 (Modic type 1).

For the remaining patients who underwent ADF, MRI evaluations were performed at 2 years or more postoperatively, but the study did not mention the T1 and T2 findings on the adjacent vertebral endplates.

Additionally, four patients who underwent corpectomy were evaluated using MRI between 6 months and 4 years after the surgery. Among these patients, three out of four showed low signal intensity on T1 and high or iso-signal intensity on T2 (Modic type 1), while one patient exhibited high signal intensity on both T1 and T2 imaging.

In a recent retrospective study conducted by Nakamura et al. (2018) [23], patients who underwent endoscopic cervical discectomy (PECD) for cervical disc disease were followed up. The study included 43 patients who underwent MRI examinations at 3 to 12 months after the surgery. The patients were categorized into four groups based on the location of the hernia and the surgical approach employed.

Group C (n = 18) consisted of patients with unilateral hernia who were treated using the contralateral approach. Group I (n = 15) included individuals with unilateral hernia who underwent surgery using the ipsilateral approach. Group B (n = 5) comprised patients with broad and bilateral disc herniation, and Group M (n = 4) consisted of patients with midline hernia.

Modic changes were defined as a transition from Modic type 0 to any other type of Modic. The incidence of Modic changes in the different groups was as follows: Group C = 72.2% (13/18), Group I = 26.7% (4/15), Group M = 25% (1/4), and Group B = 80% (4/5). The study did not find a significant difference between patients who underwent PECD with the use of an electric drill and those who did not use a drill, in terms of the occurrence of Modic changes.

Additionally, the mean visual analog score (VAS), which was used to assess postoperative neck and shoulder pain, was found to be higher in patients with Modic changes compared to those without Modic changes. However, this difference did not reach statistical significance (p value = 0.09).All data were summarized in table 3.

Table 3: summary of studies describing MC changes post cervical surgery

Authors	***year***	***Type of the study***	***N***	***Type of surgery***	***Act done in the surgery***	***results***	***comments***
Ross et al	1987	retrospective	73	**ADF** (anterior discectomy and fusion) **Corpectomy**	**ADF**: removal of intervertebral disc and fusion using plate and screws	**ADF** group: a- 3/6 patient did not show MC b- 3/6 showed MC1 **Corpectomy** group: 3/4 showed MC2	none
Nakamura et al	2018	retrospective	43	PECD (percutaneous endoscopic cervical discectomy)	Endoscopic spinal cord and nerve root decompression 1-GroupC: unilateral hernia who were treated using the contralateral approach. 2-GroupI: unilateral hernia who underwent surgery using the ipsilateral approach. 3-GroupB: broad and bilateral disc herniation GroupM: midline hernia.	incidence of Modic changes was as follows: Group C = 72.2% (13/8), Group I = 26.7% (4/15), Group M = 25%, (1/4), and Group B = 80% (4/5)	a-No significant difference was seen between patients operated using an electric drill versus those that did PECD without using a drill. b- neck and shoulder pain post-op was higher in patients that had Modic changes than in those without Modic changes

Scoliosis surgery

In a case-control study conducted by Akazawa et al. (2018) [23], 26 individuals with adolescent idiopathic scoliosis (AIS group) who underwent spinal fusion using Harrington instrumentation were compared to a control group of 29 individuals. The objective of the study was to evaluate Modic changes in the non-fused segment of AIS patients who underwent surgical fusion. The participants underwent MRI follow-up at an average of 36.1 years after the operation. The AIS group had a higher percentage of Modic changes (57.7%) compared to the control group (13.8%). Among the AIS group, 61.9% of the patients with Modic changes had them located on the concave side of the curvature. The AIS group also exhibited significantly worse SRS-22 scores for function and higher ODI scores. Within the AIS group, patients were further divided into two subgroups: those with Modic changes (Modic [+], 15 patients) and those without Modic changes on MRI follow-up (Modic [-], 11 patients). The Modic [+] group had a larger lumbar coronal curvature (mean 32.7 degrees) and greater thoracolumbar kyphosis (15.5 degrees) compared to the Modic [-] group (mean lumbar coronal curvature: 19.7 degrees and mean thoracolumbar kyphosis: 4.8 degrees). A weakness of this study was the long follow-up time and a low follow-up rate, with only 26 out of 194 patients included in the analysis.

In a prospective study by Akazawa et al. (2017) [23], 35 participants who underwent Harrington spinal instrumentation for AIS were followed up for a mean period of 35.1 years. The participants were divided into two groups based on the level of vertebral instrumentation: Group H (n = 27, lowest fused vertebrae at L3 and above) and Group L (n = 8, lowest fused vertebrae at L4 or below). Modic changes were observed in 57.1% of the participants, with 42.8% having Modic changes in one segment, 5.7% in two segments, and 8.5% in three segments. Group H had a higher percentage of Modic changes (75%) compared to Group L (51.9%), but this difference was not statistically significant (p value = 0.24). The study had limitations including the very long follow-up period and a high number of patients lost to follow-up, with more than half of the participants not included in the analysis.

Kelly et al. (2010) [24] investigated the X-ray and MRI findings of patients treated with anterior thoracolumbar instrumentation and fusion for AIS. The study included 28 patients with an average follow-up period of 16.97 years. However, only six patients underwent follow-up X-rays and MRI. Among these six patients, two had Modic changes below the instrumented levels (on either side of the disc). No correlation was found between

the SRS-30 or ODI scores and disc degeneration or Modic changes. The study's limitations included the small sample size and the fact that it was a retrospective study.All data were summarized in table 4.

Table 4: summary of modic changes post scoliosis surgery

Authors (scoliosis)	year	Type of the study	popuation	Type of surgery	Act done in the surgery	results	comments
Akazawa et al	2017	case control study	29 patients	harrington instrumentation for AIS	posterior spinal fusion for treatment of AIS	Higher percentage of Modic changes was seen in the AIS group (57.7%) versus the control group	MC being seen in the concave side of the curvature in 61.9% of patients with AIS group treated with instrumentation.
Akazawa et al	2016	prospective	35	harrington spinal instrumentation	posterior spinal fusion for treatment of AIS	MC was seen in 20 patients (57.1%). 15 individuals (42.8%) had MC in one segment, 2 individuals (5.7%) had MC involving 2 segments and 3 individuals (8.5%) showed MC in 3 segments	Patients in Group H had higher percentage of MC (75%) compared to Group L (51.9%) however this difference was not statistically significant (p value = 0.24).
Kelly et al	2010	retrospective	28	anterior thoracolumbar instrumentation	anterior spinal fusion	2 out of 6 patients that had MRI follow up developed MC below instrumented levels (on either sides of the disc).	

Conclusion

In conclusion, Modic changes (MC) in the vertebral endplates and adjacent bone marrow have been extensively studied, but there is still much to learn about their etiology, natural history, and relationship with low back pain (LBP) as well as their behavior in the postoperative setting.

In the postoperative setting, lumbar disc surgery can influence the natural history of MC. Studies have shown that lumbar discectomy may accelerate the radiological changes in vertebral endplates, with a higher prevalence of MC type 1 in the early postoperative period and a progressive increase in MC type 2 over time. Limited discectomy techniques may slow down this process. The use of posterior lumbar interbody fusion (PLIF) does not appear to prevent MC when compared to posterior spinal fusion.

In cervical discectomy, a limited surgical technique and approach may yield better results in terms of Modic changes when compared to broader disc resection. However, more research is needed to understand the impact of surgery on MC in the cervical spine.

It is important to note that the relationship between Modic changes and scoliosis has not been extensively explored in the literature. While scoliosis is a complex spinal deformity that involves structural abnormalities, the specific association with Modic changes remains uncertain. Future studies should investigate the prevalence and impact of Modic changes in individuals with scoliosis, including the potential influence on pain and functional outcomes.

Overall, Modic changes continue to be an area of active research and investigation. While progress has been made in understanding their classification and potential associations, there is still much to uncover about their etiology, natural history, and clinical implications. Further studies with larger sample sizes and long-term follow-up are needed to provide more definitive conclusions and guide clinical decision-making.

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