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REVIEW

Schmorl's nodes: current pathophysiological, diagnostic, and therapeutic paradigms

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Abstract Schmorl's nodes were first described by the pathologist Christian Schmorl in 1927 as a herniation of the nucleus pulposus through the cartilaginous and bony endplate into the vertebral body. Although such lesions present most commonly as incidental findings in asymptomatic patients (or in patients with back or radicular pain due to other etiology), there have been several reports emphasizing the deleterious effects of the inflammatory response and endplate changes elicited by the herniation of for such reasons, Schmorl's nodes have been occasionally implicated in the etiology of chronic axial pain as well as in pathological osteoporotic fractures. In this article, a thorough literature review about the most relevant historical studies on Schmorl's nodes previously published is performed. Furthermore, the authors provide an overview about the recent advances in basic science research on the pathophysiology of such lesions, as well as on current diagnostic and therapeutic paradigms.

Keywords Schmorl's node · Back pain · Modic changes · Endplate changes · Osteoporotic fracture · Degenerative disc disease

Introduction

Schmorl's nodes were first described by the pathologist Christian Georg Schmorl in 1927 as a herniation of nucleus pulposus through the cartilaginous and bony endplate into the body of the adjacent vertebra. Most of the early studies in Schmorl's nodes focused on the epidemiological evaluation of such lesions as observed in x-rays, computed tomography (CT), and magnetic resonance imaging (MRI) as well as in the study of predisposing factors and possible relations with other diseases [16, 31, 40]. Moreover, some anatomo-pathological studies attempted to compare some postmortem histopathological samples with the observed radiological findings [8, 33, 50].

Preliminary epidemiological studies have identified a predominance of Schmorl's nodes in males (76 % of cases), as well as a correlation with disc degeneration in the T10–L1 region but not in the L2–L5 region. Another study did not identify any relationship between the number, location or size of Schmorl's nodes, and age or bone density [8]. A recent epidemiological analysis revealed that Schmorl's nodes occur more frequently in the thoracolumbar transition (T7–L1 region) and most commonly affect the inferior (rather than the superior) surface of the vertebral body (62.3 %). Additionally, it has already been demonstrated that in sagittal images, Schmorl's nodes are more commonly located at the middle portion of the vertebral bodies (63.7 %) [4].

A postmortem study which compared the histological findings with radiological characteristics of Schmorl's nodes found that in the peripheral regions of these lesions, where the vertebral bodies were in contact with the node, it was possible to observe growth of cartilaginous cells as well as thickened bone trabeculae, which made them detectable to plain x-rays [50]. According to early imaging studies, the height of the Schmorl's nodes ranges from 1 to 9 mm in lateral plain x-rays [30]. Such study has also suggested that, due to the local disruption of forces over the endplates, there would be a tendency of Schmorl's nodes to develop in a mirror fashion in adjacent vertebral bodies (Fig. 1). Interestingly, in a recent imaging study, Schmorl's nodes were found in up to 19 % lumbar MRIs of asymptomatic patients [10]. Other studies, which combined radiological and postmortem

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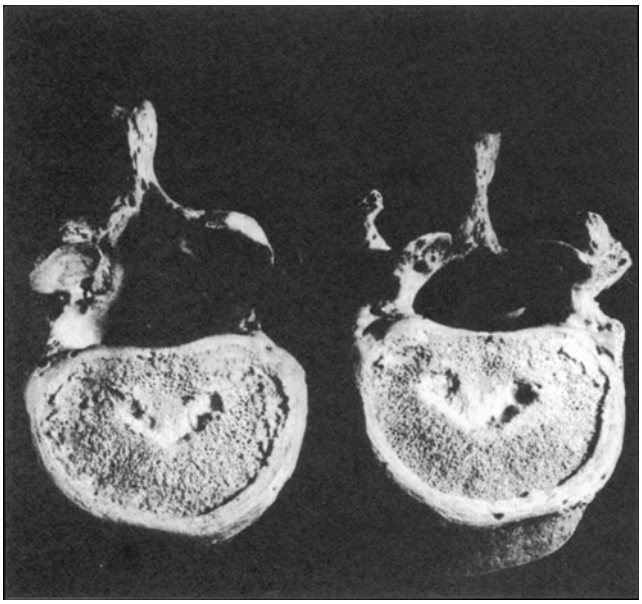

Fig. 1 Photograph of postmortem specimens showing two Schmorl's nodes on adjacent vertebral endplates. Note the mirror-like appearance with similar shape, size, and position of the nodes (reproduced with permission from Saluja et al. [37]

pathological analysis, have found that up to 73 % of the general population may present small herniations of the nucleus pulposus into the vertebral endplates [8, 41].

Another interesting epidemiological study with 516 healthy female twins (150 monozygotic and 366 heterozygotic) demonstrated that Schmorl's nodes have a very high heritability (>70 %). Such study also found a positive correlation between Schmorl's nodes (especially when multiple) and degenerative disc disease (DDD), although the study was not able to demonstrate an independent association between Schmorl's nodes and low back pain [48]. A number of genes, which have been implicated in both DDD and Schmorl's nodes development, may be responsible for such heritability, including an aggrecan gene polymorphism [12], a vitamin D receptor [11], and matrix metalloproteinase-3 gene alleles [44], all of which are responsible for synthesis and breakdown of molecules related to maintenance of the disc anatomic integrity.

Schmorl's nodes and Modic endplate changes

The first description of the bone marrow changes adjacent to vertebral endplates in degenerated lumbar discs dates to 1987 from Ross. Nevertheless, it was Modic, in 1988, who popularized a classification of such abnormalities based on his analysis of more than 400 MRIs of the lumbar spine [22, 23]. According to Modic, these different types of MRi signals reflect a progressive spectrum of vertebral body marrow changes associated with degenerative disc disease.

There are basically three types of endplate (Modic) changes which can be characterized using T1- and T2-weighted images (T1W1 and T2WI, respectively) [22, 23] (Fig. 2). Type I changes are hypointense T1WI and hyperintense in T2WI and represent, at the histological level, bone marrow edema and inflammation [23]. Type 2 are hyperintense in both T1WI and T2WI and represent the conversion of normal red hemopoietic bone marrow into yellow fatty marrow as a result of ischemia [23]. Type 3 changes (a further division which was introduced by Modic in latter works) are hypointense on both T1WI and T2WI and are thought to represent a later stage of degeneration characterized by subchondral bone sclerosis. Modic 0 would represent the absence of any imaging signs of endplate degeneration.

In his original studies, Modic noted that the majority of patients with type 1 changes eventually had conversion to type 2 changes overtime, whereas patients with type 2 abnormalities usually displayed little change, occasionally progressing to type 3 after a long period [22]. Although there have been some recent reports of type 2 conversion to type 1 and type 1 to type 0 (normal MRI appearance of the endplates), this reverse pathway is rarely observed [9]. Therefore, it is common consent among the majority of experts that the progression of Modic type 1 to type 2 and type 3 represents the natural history of the endplate changes associated with degenerative disc disease, with type 1 representing the acute phase, type 2 the chronic phase, and type 3 the later sclerotic endstage.

Several previous studies have already demonstrated a significant correlation between Modic endplate changes and low back pain [13, 14, 16, 40]. For instance, a cross-sectional cohort study of a general population, which evaluated 412 individuals, found that Modic changes and anterolisthesis were the variables with the strongest association with axial back pain (odds ratio >4) [14]. Most experts on the issue understand axial pain in the presence of Modic endplate changes as a result of bone inflammation and instability. For example, a immunohistochemistry analysis of vertebral endplates harvested during surgery of patients with low back pain demonstrated that vertebral endplates from patients with Modic type 1 or type 2 had significantly more 'protein gene product 9.5'-immunoreactive nerve fibers and TNF-immunoreactive cells (two important markers of inflammation) than those samples obtained from patients with normal endplates appearance in the lumbar MRI [26].

Schmorl's nodes have already been correlated with degenerative disc disease, low back pain [8, 48], and Modic changes [26]. Nevertheless, the exact relationship between Modic changes and Schmorl's nodes is not completely elucidated. Previous studies have suggested that Modic endplate changes may either precede or follow intervertebral disc degeneration [35, 36]. There have also been suggestions that the occurrence of multiple Schmorl's nodes in early life may possibly lead to the appearance of Scheuermann's disease (juvenile kyphosis) [5]. Furthermore, several reports have already demonstrated that large Schmorl's node may present adjacent bone marrow

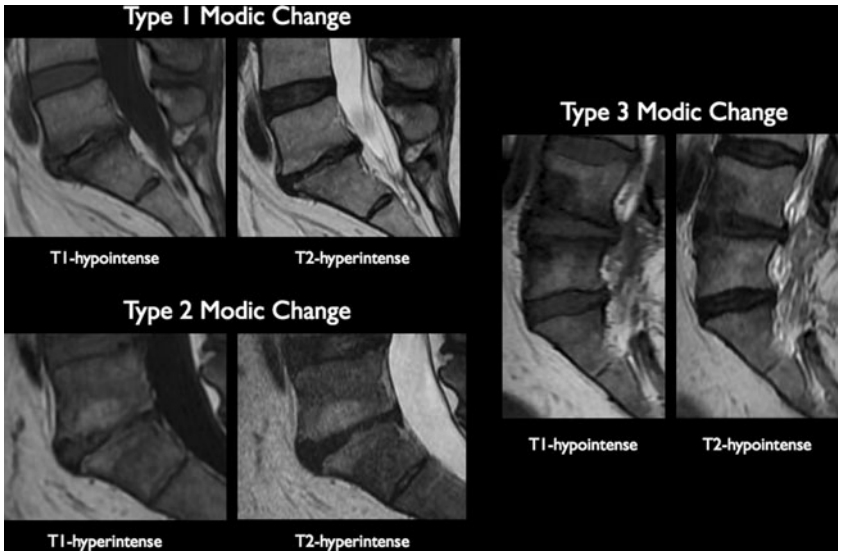

Fig. 2 Imaging classification of endplate degenerative changes as proposed by Modic: type 1, hypointense in T1WI and hyperintense T2WI; type 2, hyperintense in both T1WI and T2WI; type 3, hypointense on both T1WI and T2WI

changes which closely resembles Modic changes [2, 7, 43]. We have also observed in our clinical practice that progression in size of Schmorl's nodes is very often associated with increased signal changes in the adjacent bone marrow, and that the incidence of refractory low back in such patients seems to be much higher in comparison with the group without Schmorl's nodes of with those patients with stable lesions. (Fig. 3).

Most authors agree that there seems to exist a relationship between Modic changes and Schmorl's nodes, so that the herniation of the content of the *nucleus pulposus* would in some way explain the observed edema and the pathological bone marrow changes [24, 29, 33] Some authors have even hypothesized that Modic type III lesions and Schmorl's nodes may, in fact, be two different clinical manifestations of the same pathological process, so that Modic type III lesions would be the quiescent or incipient pathological phase of Schmorl's nodes. According to such hypothesis, the gradual degeneration of the intervertebral disc with aging would lead to progressive endplate changes from Modic type 1 to type 2 and type 3. Following such paradigm, the later stage of endplate degeneration (Modic type 3), when superimposed by external factor (such as trauma) or systemic ones (such as osteomalacia, developmental defects, infection, or Scheuermann's disease), would manifest itself as a complete disruption of the endplate cartilage, extravasation of the disc content into the vertebral body, and formation of Schmorl's nodes [44].

Pathophysiology of Schmorl's nodes

The pathophysiology of Schmorl's nodes development is still a matter of great debate. The classical hypothesis states that such lesions would be related to abnormalities of the vertebral blood vessels during development [21, 38]. It is known that, in the fetal period, the intervertebral discs are supplied by blood vessels which subsequently degenerate, so that the normal adult intervertebral disc is virtually avascular. According to such theory, the abnormal persistence of such vascular channels would weaken the vertebral endplate and, thereby, facilitate the herniation of the nucleus pulposus into the subchondral bone [39]. One support for such theory comes from the fact that previous postmortem studies of the adult lumbar spines found that such vascular channels penetrating the cartilaginous endplate occur mainly in the central region of the vertebral surface, the most common location of Schmorl's nodes [17, 25].

Other authors have suggested that Schmorl's nodes may be the final result of ischemic necrosis beneath the cartilaginous endplate, and that herniation of the nucleus pulposus into the vertebral body would be a secondary phenomenon. In support to such hypothesis, histological examinations of postmortem en-bloc slices through Schmorl's nodes suggested the presence of subchondral osteonecrosis [29]. In such study, it was possible to observe, beneath the cartilage endplate, the presence of fibrosis within the bone marrow cavities, with disappearance of both fat cells as well as of osteocytes within the bone trabeculae. According to such theory, there would be a close histological resemblance between the pathophysiology of Schmorl's nodes and that of avascular necrosis of the femoral head.

Clinical presentation

Schmorl's nodes and low back pain

Although some epidemiological studies have previously suggested that patients with Schmorl's nodes may present a higher incidence of low back pain in comparison to the normal population [45], this finding is not unanimous in the literature [48]. In fact, there seems to be a small specific subgroup of

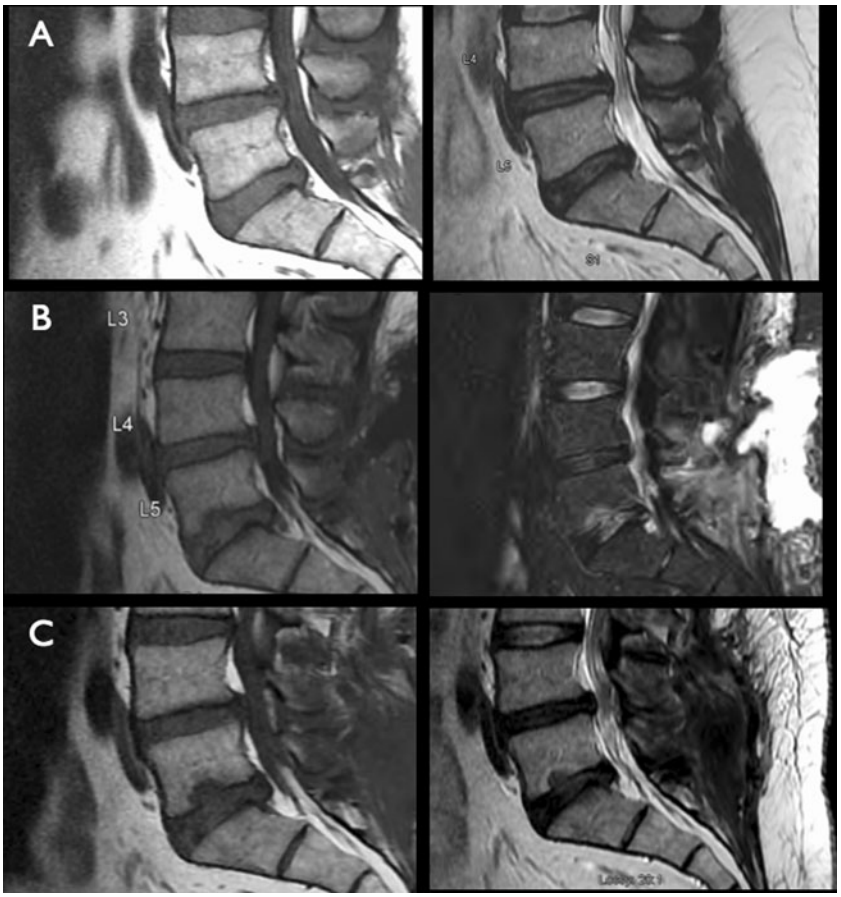

Fig. 3 MRI of the lumbar spine demonstrating that endplate degeneration caused by traumatic external factors may lead to formation of Schmorl's nodes which may increase in size and progress with adjacent bone marrow edema. **a** Initial sagittal MRI (T1WI on the *left* and T2WI on the *right*) in a patient with clear left radicular pain and a L5/S1 disc protrusion. **b** The patient was submitted to a left L5/S1 microdiscectomy and presented complete resolution of the radicular pain. Nevertheless, 3 months later, he returned to follow-up with low back pain. The new MRI demonstrated a small fluid collection in the paraspinal soft tissue as well as signs of initial degeneration of the superior endplate (hypointense in T1WI—*left*, and hyperintense in short TI inversion recovery—right). Clinically, there was no sign of acute infection and the wound was clean **c** Control MRI 6 months later demonstrating progression of the endplate changes with a typical concentric ring abnormality similar to a Modic type 1 change (hypointense in T1WI—*left*, and hyperintense in T2WI—*right*) as well as formation of a new Schmorl's node not present in previous exams

patients with Schmorl's nodes which tend to present with low back pain. It has been suggested that such group can identified as those patients whose MRI of the lumbar spine presents low signal intensity on T1WI and high signal intensity on T2WI in the vertebral body surrounding the Schmorl's node. Such findings, which would indicate the presence of inflammation and edema in the bone marrow, seem to have a high sensitivity and specificity for identifying such subgroup of patients with so-called painful Schmorl's nodes [43].

We have found in our clinical practice that Schmorl's nodes which present progression in size and significant T2 signal alteration in the adjacent vertebral bone, present a higher risk of fracture due to disruption of the integrity of the vertebral body (Fig. 4). As it will be discussed in the sequence, this subgroup of patients may specifically benefit from surgical intervention in the presence of refractory low back pain and compatible imaging findings. In fact, a previous imaging study found that, although most of the Schmorl's nodes tend to be stable in size in follow-up imaging exams (in an average follow-up of 17 months), around 26 % of the patients will present an increase in the node's size and 13 % will demonstrate increased T2 signal in the adjacent vertebrae [49]. According to this study, the incidence of fractures may increase to 10 % in such subgroup of patients.

The pain observed in the presence of Schmorl's nodes is thought to be related to inflammatory changes and cell infiltration induced by the presence of intraspongious disc components in contact with the vertebral bone marrow [1], as well as to occult trabecular bone fractures which may further aggravate inflammation and edema [45]. In addition to the surrounding edema, it has already been demonstrated that a significant proportion of such 'painful' Schmorl's nodes may present contrast enhancement after gadolinium administration, suggesting the presence of increased vascularization in such tissue in comparison with control lesions in asymptomatic patients [42]. Such study demonstrated that contrast-

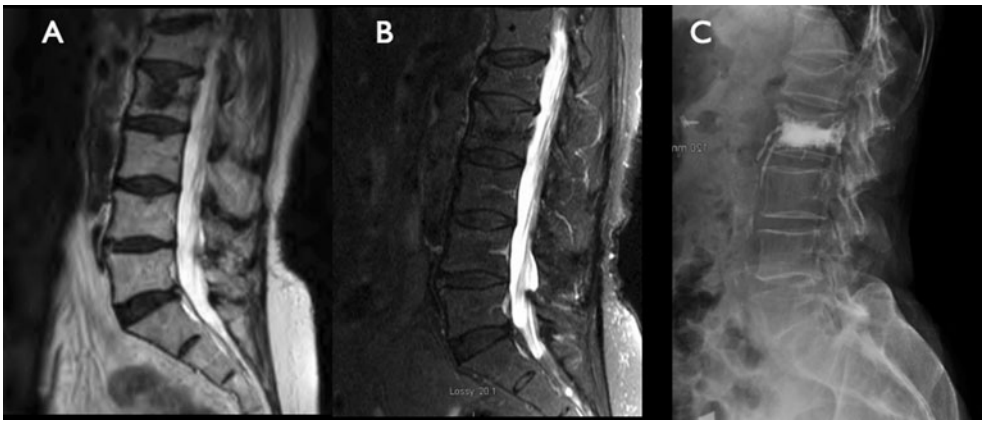

Fig. 4 Patient with a giant Schmorl's node in the L2 vertebral body (**a** sagittal T1WI; **b** sagittal T2WI fat suppression). The patient presented with acute axial back pain after a minor fall and imaging exams compatible with an acute fracture which was treated with vertebroplasty with complete resolution of the pain (**c** lateral x-ray post-vertebroplasty)

enhancing Schmorl's nodes were larger than the non-contrast-enhancing ones and more frequently associated with bone marrow edema [42]. Furthermore, some studies have also demonstrated that Schmorl's nodes may present focal increased uptake of fluorodeoxyglucose at positron emission tomography (PET/CT), suggesting the presence of an active inflammatory process [2]. Although there are very few studies in the literature on the topic [20], in our personal clinical practice, bone scan scintigraphy has proven to be a valuable diagnostic tool in order to reveal the inflammatory changes related to endplate degeneration which may be significantly increased in Schmorl's nodes and, therefore, to identify the patients which might benefit from additional interventional procedures. Finally, although the great majority of patients with symptomatic Schmorl's nodes will present only axial back pain, there have been reports of Schmorl's nodes which extravasate posteriorly to the spinal canal and neural foramen causing significant radicular pain [3].

Schmorl's nodes and osteoporotic fractures

Although several observational studies [6, 19, 24] have observed an association between Schmorl's nodes and osteoporotic fractures, the exact relationship between these two pathological entities is still not clear.

An imaging study, for example, demonstrated that neurologically asymptomatic patients with stable vertebral fractures in childhood present a higher incidence of Schmorl's nodes at the fracture level in comparison with the normal pediatric population, suggesting that trauma may also be an important etiological factor for development of Schmorl's nodes [24]. Other authors contest such traumatic hypothesis for the formation of Schmorl's nodes, defending that such lesions would be rather associated with the development of spinal vertebrae during early life, a period during which the nucleus pulposus would exert pressure on the weakest portion of the adjacent vertebrae and ending up producing small micro-herniations, which would increase in size with further biomechanical stress later in life, especially after torsional spine movements [4]. Such theory is supported by the fact that Schmorl's nodes are more commonly found in the inferior half of the vertebral body. According to these authors, this finding can be explained by the fact that during the embryological period and early life, the inferior half of the vertebrae is mechanically weaker than the superior half [4].

There has also been some suggestion in the literature that Schmorl's nodes may represent an early stage of endplate osteoporotic fracture. For example, a cadaveric study demonstrated that cyclical axial compression in segments with normal discs lead to appearance of Schmorl's nodes, while in moderated degenerated discs it leads to central endplate fractures (type II). In such study, burst fractures were observed whenever such specimens presented failure in the first loading cycle and were submitted to a second cycle [6]. Another study, which aimed to evaluate the normal ranges for vertebral body wedging at the thoracolumbar junction in asymptomatic healthy subjects, demonstrated that the height of the vertebral body in patients with Schmorl's nodes was significantly lower than in patients without. Such findings corroborate the supposition that Schmorl's nodes may represent an early stage of endplate osteoporotic fracture, which, at the long term might lead to loss in vertebral body height and increased vertebral wedging [19].

Additionally, an animal experiment has already demonstrated that repetitive mechanical stresses on the vertebral body may induce the formation of Schmorl's nodes [34]. Another study, which attempted to unveil the possible relation of Schmorl's nodes and traumatic injuries demonstrated that around 57 % of these lesions could be traced to episodes of significant, sudden-onset, localized, non-radiating back pain, and tenderness for which the MRI showed a Schmorl's node surrounded by vertebral body marrow edema. Interestingly, in 43 % of the patients in which no Schmorl's node were identified but the bone marrow immediately adjacent to the endplate demonstrated signs of edema, developed asymptomatic Schmorl's nodes in follow-up MRIs [46]. With basis on such results, the authors of such study defend that both symptomatic and asymptomatic Schmorl's nodes could be ultimately traced to a traumatic triggering

episode. Finally, there have also been reports of new formation of Schmorl's node after discography for evaluation of degenerative disease [32].

According to such evidence, it is important to have in mind the possible relationship between Schmorl's nodes and spinal fractures, especially in the elderly population. In our practice, old patients (especially postmenopausal women) presenting with Schmorl's nodes receive a routine assessment of bone mineral density measurements through dual energy x-ray absorptiometry (DEXA scan) for investigation of osteoporosis [28]. In the case of positive with DEXA scan results, in order to rule secondary causes, a basic metabolic investigation is performed, including total serum and ionized calcium, complete blood count, 25-hydroxyvitamin D, T_3, T_4, and thyroid stimulating hormone and, eventually serum protein electrophoresis for those patients with vertebral fractures in which multiple myeloma is suspected.

Treatment of Schmorl's nodes

As already mentioned, the majority of patients with Schmorl's nodes will be asymptomatic or will present with low back pain from another etiology. Nevertheless, a small subgroup of patients with refractory low back pain (and in whom the MRI findings demonstrate a Schmorl's node of significant dimension and adjacent bone edema), may benefit from some form of intervention. Several different treatment paradigms have been proposed for the management of Schmorl's nodes depending on the viewpoint through which they are approached: either as a variant of vertebral body fractures or a form of endplate change associated with degenerative disc disease.

Vertebroplasty

As previous studies have shown that Schmorl's nodes may represent an early stage of vertebral body fracture [6, 19], and clinical studies have demonstrated a significant clinical benefit of vertebroplasty with polymethylmethacrylate (PMMA) in patients with osteoporotic fractures [15], some groups have proposed the use of vertebroplasty as a therapeutic strategy in patients with chronic low back pain and Schmorl's nodes which demonstrate significant signs of local edema and inflammation in imaging exams [18, 47].

In fact, some studies have reported very high success rates (up to 80 %) of back pain relief after vertebroplasty with PMMA in patients with large Schmorl's nodes [18, 47]. It is important to remember that the authors of such studies emphasize that, for a Schmorl's node to be considered symptomatic or active, the MRI must demonstrate T1 and T2 MRi signal changes typical of inflammation. Moreover, it has also been suggested that the cement injection should specifically target the edematous rim around the node (as seen on MRI) and which has been implicated as the main source of pain [46]. In such studies, it has been reported that the injected PMMA tends to distribute according to the limits of the Schmorl's nodes, covering the observed hyperintense area in the T2 and STIR sequences, without surpassing the vertebral body margins and, surprisingly, with very low rates of extravasation toward the intervertebral disc space.

Fusion

Another therapeutic approach which has been proposed to Schmorl's nodes relies on the interpretation of them as endplate lesions which may be associated with variable degrees of intervertebral disc degeneration and discogenic pain. The management protocols based on such paradigm recommend that patients with Schmorl's nodes and chronic low back pain, especially those in the young population and which present also MRI findings suggestive of advanced disc degeneration in the respective level, should be submitted to provocative discography and, in the case of a positive response, to fusion of the involved segment.

In a retrospective evaluation of 21 patients with Schmorl's nodes, refractory chronic back pain, positive discography, and which were submitted to lumbar fusion (either through anterior or posterior approaches), the authors found, in a mean follow-up of 3.5 months, a statistically significant improvements in the VAS and ODI scores [30]. In fact, 20 of the 21 patients reported complete disappearance or marked alleviation of the low back pain and a definite improvement in physical function after the surgical procedure.

According to the authors of such study, Schmorl's nodes may induce mechanical pain (i.e., movement-related pain) through the production of inflammatory mediators and cytokines, such as bradykinin, prostaglandin E2, and IL-1, which are generated due to endplate osteonecrosis [29], sensitizing the silent nociceptors which usually do not respond to mechanical stimulation.

However, it is important to remember that, as previous clinical observational studies have demonstrated an incidence of almost 30 % of Schmorl's nodes in the general asymptomatic population [46], such groups strongly rely on provocative discography in order to select those patients which might significantly benefit from surgical fusion of the affected level.

Alternative treatments

As previous animal models have demonstrated that tumor necrosis factor alpha (TNF-α) may be implicated in radicular pain generated by nucleus pulposus herniation, and that TNF-α blockade may be effective in preventing nucleus pulposus-induced functional and structural nerve root injury in animal models [27], some authors have tested the use of a

TNF-α inhibitor (infliximab) for treatment of painful Schmorl's nodes refractory to medical therapy. Such treatment consisted in infliximab infusions at a dose of 3 mg/kg at weeks 0, 2, 6, and 14. Both patients treated according to such pilot protocol presented a remarkable clinical response in terms of back pain as measured by VAS (decrease from VAS=90 to VAS=0 and VAS 85 to VAS=7) as well MRI imaging changes which revealed complete disappearance of the contrast enhancement of the Schmorl's nodes and of the adjacent bone marrow edema. Finally, there is also a report of improvement of back pain after *ramus communicans* nerve blocking in a patient with a large and painful Schmorl's node.

Conclusions

Although Schmorl's nodes most commonly present as an incidental finding in asymptomatic patients (or in patients with low back or radicular pain due to another etiology), there have been several reports of the deleterious effect of the inflammatory response in the adjacent bone elicited by the herniation of the nucleus pulposus, which may lead, in some cases, to a significantly impairment of the anatomical integrity of the vertebral body and its associated load-sharing capacity, incurring in chronic axial pain and even pathological fractures.

It is important for the neurosurgeon to be able to recognize such subgroup of patients by combining both clinical and specific imaging findings, as such population might benefit from further interventional procedures (such as vertebroplasty or fusion) which have already been demonstrated to provide significant sustained clinical improvement at the long-term follow-up in selected cases.

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Comments

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In this article, the author discussed the debate of the clinical/radiological significance of Schmorl's nodules. The authors performed a nice review of literature making this article a good reference for further reading in this topic. Although this article appears academically nice, its impact in clinical practice, according to our opinion, is limited. The debate is not solved. It would be better if the authors had added their own series and discussed their own finding.

It would be great if the authors use this knowledge for a future clinical study.

Noel I Perin, New York, USA

This is an interesting article researching a common finding on routine MRI studies, which may be relevant in patients with back pain symptoms. The pathophysiology of these lesions and their association with adjacent disc degeneration is an important observation. Patients presenting with back pain symptoms and large Schmorl's nodes with type 1 Modic changes may well be candidates for surgical treatment when conservative treatment measures fail. Additionally, osteoporotic patients with large Schmorl's nodes may benefit from early vertebroplasty to prevent fractures. The authors should be congratulated for this interesting paper on an entity thought of as an incidental finding on MRI studies and reminds us to observe these lesions more closely.