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ORIGINAL ARTICLE

Correlations between sedimentation sign, dural sac cross-sectional area, and clinical symptoms of degenerative lumbar spinal stenosis

Sangbong Ko[1]

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Abstract
Purpose In this study, we addressed the correlation between the cross-sectional area (CSA) of the dural sac and the nerve root sedimentation sign (SedSign) and the correlation between the distance of claudication and the CSA of the dural sac or SedSign in patients with lumbar spinal stenosis. We also evaluated the reliability of clinical symptom prediction.
Methods We checked claudication distance using a questionnaire, and we gauged low back pain when standing, referred pain, and radiating pain using visual analog scale scores. Three observers measured the CSA of the dural sac and SedSign, and normal nerve root sedimentation was classified as negative (N) and the absence of nerve root sedimentation was positive (P). P was sub-classified as positive with room [P(+); empty space apparent in the dura] or positive without room [P(−); no empty space in the dura]. SedSign reflected ongoing sedimentation inside the spinal canal of the nerve roots. We demonstrated negative sedimentation for the nerve root except for exiting nerve roots that settled into more than half of the dorsal region of the spinal canal and positive sedimentation as compressed nerve roots or as distribution of nerve roots that conglomerated from the ventral to the dorsal part of the equator as nerve roots. We evaluated functional outcomes using the Oswestry Disability Index and Roland–Morris Disability Questionnaire. One-way ANOVAs, Chi square tests, and correlation analyses evaluated the correlation CSAs and SedSigns.
Results The total CSAs for the 716 sites were 98.63 ± 34.38 for N, 76.78 ± 28.78 for P(+), and 55.43 ± 27.77 for P(−), which were all statistically significant ($p = 0.01$). The correlations between pain and SedSign were not statistically significant ($p > 0.05$). There was no statistical significance in the correlations between the distance of the claudication and the CSA of the dura sac and the SedSign and between the functional score and the SedSign (both $p > 0.05$).
Conclusions Increasing severity of SedSign indicates progressively smaller dural sac CSA, but there is an inconsistent association with clinical symptoms. Therefore, it is reasonable to suggest that spinal stenosis is severe in patients with severe symptoms.

Keywords Lumbar spine · Spinal stenosis · Cross-sectional area · Sedimentation sign

Introduction

Lumbar spinal stenosis (LSS) is one of the most common reasons for spinal surgery [1, 2]. It is a degenerative disease of the spine characterized by narrowing of the spinal canal, compression of the dural sac, entrapment of nerve roots resulting in neurogenic claudication, and radiating pain and back pain [3–6]. Although LSS is common in elderly people, it is often difficult to diagnose because of the lack of clinical symptoms during rest, with pain, or with physical activity limitations. There are no standardized diagnostic criteria for LSS [3, 7], but it involves symptoms that arise from the narrowing of the spinal canal; thus, diagnosis is established by visualizing spinal canal narrowing on magnetic resonance image (MRI). Accurate diagnosis of LSS is made by evaluating the patient's medical history and the MRI-confirmed

✉ Sangbong Ko
bong@cu.ac.kr

[1] Daegu Catholic University Medical Center, 33, Duryugongwon-ro 17-gil, Nam-gu, Taegu 42472, Korea

clinical symptoms [8–10]. The cross-sectional area (CSA) of the dural sac is the most objective assessment of stenosis severity; CSA < 100 cm^2 is clinically diagnosed as LSS. However, CSA of the dural sac does not correlate with clinical symptoms. In cases that require surgical treatment, deciding on the exact level of the lesion may reduce the possibility of re-operation and affect the surgical outcomes. However, the relationship between spinal stenosis severity and symptoms is strongly debated [11, 12].

The nerve root sedimentation sign (SedSign) has been proposed as a means to facilitate the diagnosis of clinically significant stenosis [13]. Barz et al. [1] defined negative sedimentation as the posterior sedimentation of more than half of the nerve roots except the exiting nerve roots; when the nerve roots were being compressed or when they conglomerated from the ventral to the dorsal part of the equator, these findings were defined as positive sedimentation. Barz et al. [1] further described that both signs strongly correlated with symptoms of LSS, but the only study that has addressed the correlation between SedSign and CSA of the dural sac involved only patients who required surgical treatment [14]. No study has considered all LSS patients treated surgically or medically.

For the present study, we examined the correlations between CSA of the dural sac, the conventional method of LSS diagnosis, and SedSign. As well, we sought to determine any correlations between distance of claudication among symptoms of spinal stenosis, CSA of the dural sac, and SedSign to determine which method was more helpful for predicting clinical symptoms.

Materials and methods

Patients

This study was approved by the relevant institutional review board (IRB no.: CR-16-167). We included in the study 522 patients who had been diagnosed with LSS and who had reported medical charts, MRI images, and clinical symptoms from January 1, 2008, to December 31, 2015, in our center. Spine specialists made the diagnoses of LSS based on clinical symptoms (back pain, claudication, referred pain, and radiating pain), MRI findings (CSA < 100 mm^2 ventral and dorsal dural canal diameter < 10 mm) and neurological examination (paraplegia, paresthesia). Clinical symptoms were back pain, neurogenic claudication, referred pain, and radiating pain. Stenosis on more than at least one level was identified by ligamentum flavum hypertrophy, facet joint osteoarthrosis, or disc herniation at lumbosacral levels 2–3, 3–4, or 4–5 on radiological findings and related symptoms or neurological disorders. We excluded patients with previous spine surgery; a main diagnosis that was not LSS; deformities including kyphosis, scoliosis, and isthmic spondylolisthesis in spinal stenosis; or presence of tumors, infections, deformities of nerve roots, and constitutional stenosis.

Outcome measurements

We determined symptoms of spinal stenosis by patient's self-reported common neurogenic claudication and self-reported visual analog scale score classified by back pain, referred pain, and radiating pain during MRI scanning. Patients rated each score from right and left separately, and we used the average right/left score for analysis. We also measured claudication severity as the mean of the shortest and farthest distances regardless of posture or use of walking aids such as cane or sticks. We measured the severity of stenosis on the midline of each lumbosacral level of 2–3, 3–4, and 4–5 on T2 sagittal MRI by CSA because of sagittal narrowing of the intervertebral canal [15]. As previously described for SedSign [13], normal nerve root sedimentation was classified as negative (N) and the absence of nerve root sedimentation as positive (P); P was sub-classified as positive with room [P(+); empty space apparent in the dura] or positive without room [P(−); no empty space in the dura; Fig. 1]. We

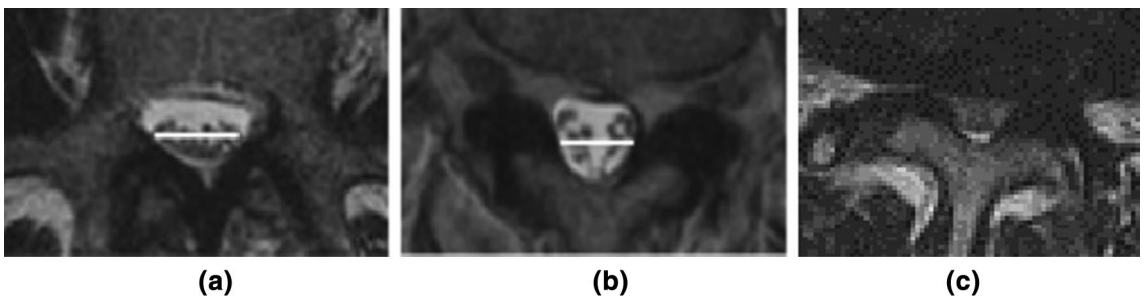

Fig. 1 Representative images from lumbar spine cases. **a** Image from a lumbar spine with a negative SedSign, level L4/5, and dural CSA of 120 mm^3; **b** image from a lumbar spinal stenosis with a positive SedSign, with room available for sedimentation, level L4/5, and dural CSA of 112 mm^3; **c** image from a lumbar spinal stenosis with a positive SedSign, with no room available for sedimentation, level L4/5, and dural CSA of 50 mm^3

evaluated the relationships between clinical symptoms and CSA and between clinical symptoms and SedSign, using the CSAs and the SedSigns from the levels with the most severe stenosis; in addition to symptoms, we based the correlations between CSA and SedSign on the two values measured at each level. Three observers measured each CSA, and we calculated a mean value, and three observers also measured SedSign, which was classified with agreement by at least two observers. The three observers were blinded to the patients' medical histories regarding previous surgeries, and they only evaluated the MRI findings and the functional outcomes. Functional outcomes were measured in all patients using the Oswestry Disability Index (ODI) and the Roland–Morris Disability Questionnaire (RMDQ).

Statistical analyses

We conducted one-way ANOVA, Chi square, and correlation analyses to evaluate the correlations between CSA and SedSign and performed the statistical analyses using SPSS version 19.0 (IBM Corp., Chicago, IL, USA). We considered $p \leq 0.05$ statistically significant.

Result

Epidemiologic findings

We included a total of 522 patients in the current study (165 males, 357 females) of mean age 67.3 ± 7.86 years (range 50–87). We measured dural sacs at a total of 716 levels. Stenosis was most severe at L2–3 in 33 patients, at L3–4 in 199, and at L4–5 in 290. Of those, 169 patients had decompression surgery, and 353 had conservative treatments including medication and nerve root blocks (Table 1).

Table 1 Epidemiological result

Variable	
Sex	
Male	165
Female	357
Mean age (year)	67.3 ± 7.86
Treatment	
Surgical treatment	169
Conservative treatment	353
Most stenotic level	
L2–3	33
L3–4	199
L4–5	290

Correlation between CSA of the dural sac and SedSign

Measurements of the 716 levels revealed CSAs of 98.63 ± 34.38 in N, 76.78 ± 28.78 in P(+), and 55.43 ± 27.77 in P(−); all were statistically significant ($p = 0.01$). As the SedSign worsened [i.e., N to P(−)], the CSA of the dural sac decreased ($p = 0.01$).

Correlations between symptoms of spinal stenosis, CSA, and SedSign

Correlation between pain and SedSign

The results are presented in Table 2. The correlations for back pain and SedSign were 4.25 ± 3.16 in N, 3.94 ± 2.98 in P(+), and 4.14 ± 2.97 in P(−), but these were not statistically significant ($p > 0.05$). The correlations for SedSign and referred pain were 4.73 ± 3.18, 4.08 ± 3.27, and 4.43 ± 3.22 in N, P(+), and P(−), respectively, but these were also not statistically significant ($p > 0.05$). The correlations for radiating pain were 4.96 ± 3.30, 4.62 ± 3.17, and 5.12 ± 3.22 in N, P(+), and P(−), respectively, but these correlations with SedSign were not statistically significant ($p > 0.05$).

Correlations among level of claudication, CSA of the dural sac, and SedSign

The results are presented in Table 3. There were no correlations between distance of claudication and CSA of the dural sac (= −0.072, $p = 0.393$) or between claudication distance

Table 2 Correlation between pain and SedSign

Variable	SedSign, mean (SD)			*p* value
	N	P(+)	P(−)	
Back pain	4.25 (3.16)	3.94 (2.98)	4.14 (2.97)	0.440
Referred pain	4.73 (3.18)	4.08 (3.27)	4.43 (3.22)	0.166
Radiating pain	4.99 (3.30)	4.62 (3.17)	5.12 (3.22)	0.311

SedSign sedimentation sign, *N* negative, *P(+)* positive with room, *P(−)* positive without room

Table 3 Correlation between the distance of claudication and SedSign

Variable	SedSign, mean (SD)			*p* value
	N	P(+)	P(−)	
Claudication (m)	49.17 (62.71)	43.72 (57.36)	39.76 (31.06)	0.553

SedSign sedimentation sign, *N* negative, *P(+)* positive with room, *P(−)* positive without room

and SedSign [49.17 ± 62.71 m in N, 43.72 ± 57.36 m in P(+), and 39.76 ± 31.06 m in P(−); $p > 0.05$].

Correlations between functional outcomes and SedSign

The results are presented in Table 4. ODI scores were 22.64 ± 11.04 in N, 22 ± 9.43 in P(+), and 23.02 ± 8.34 in P(−), with no correlation evident ($p > 0.05$). There was also no correlation between RMDQ and SedSign: 1.27 ± 5.42 in N, 9.68 ± 5.70 in P(+), and 11.33 ± 5.84 in P(−); $p > 0.05$.

Discussion

Despite extensive study, little if any correlation has been found between the severity of stenosis and clinical symptoms [2, 12, 16–23]. One study reported a lack of correlation between CSA and lower leg radiating pain, referred pain, back pain, walking distance, ODI, and SF-36, and those authors suggested that stenosis severity on MRI and clinical symptoms should be used in limited cases [18]. However, many physicians still perceive that the more severe the degree of stenosis, the more severe the clinical symptoms. In most cases, however, stenosis severity is determined by the CSA of the dural sac on MRI.

It has been proposed that nerve roots normally sediment under the influence of gravity to the dorsal part of the dural sac on axial MRI, which was defined as negative SedSign [13]; the authors of that study reported that positive SedSign corresponded to nerve roots packed in the middle of the dural sac and, thus, SedSign could be a precise tool in diagnosis of LSS [13]. Subsequent studies established the relevance of this classification method and walking distance on the treadmill, claiming that a patient's claudication distance could be evaluated by SedSign [24, 25], and other authors claimed that the SedSign can be used for decision making concerning the type and extent of surgery [26, 27]. The latter studies were limited in that the surveys involved patients with severe symptoms and stenosis. We conducted interviews and physical examinations for all patients admitted to our institution for the past 8 years. Specifically, we retrospectively reviewed the patients who underwent MRI and in whom we diagnosed as having spinal stenosis.

CSA and positive SedSign have been reported to be correlated [14], and they were also correlated in the present study. The earlier study was biased toward patient choice in that the study focused on finding conformity of clinical symptoms with SedSign in patients who had had surgery; those patients needed surgery and so had severe stenosis and, thus, they were more likely to have severe CSA as well. A more recent study had a different view on the diagnosis of LSS; although the authors contended that symptom severity and CSA level were correlated, SedSign was not correlated with clinical symptoms among all LSS patients [28]. However, SedSign correlated with clinical symptoms and was helpful in determining surgery type and extent when the symptoms were severe enough to require surgery [14]. In short, when spinal stenosis patients are admitted, a severe SedSign does not mean that they have severe clinical symptoms, and it is not correct to confirm a surgery based only on severe SedSign. It is better to exclude the range of surgery based on negative SedSign rather than deciding range of surgery based on positive SedSign [27].

The outcome of a spinal stenosis patient following decompression surgery cannot be predicted based on the SedSign [26]. However, authors have claimed that there was limited improvement in spinal stenosis symptoms in patients with positive SedSign; in other words, it is not correct to determine spinal stenosis severity by SedSign. Also, the CSA of the dural sac is small and the conformity with symptoms is low in patients with only positive SedSign. Thus, for patients with severe symptoms and positive SedSign who would likely have small CSA of the dural sac, it is considered better to diagnose LSS and proceed with further treatment. The present study has some limitations. SedSign could only diagnose central stenosis but not foraminal or lateral recess stenosis and, thus, further study on stenosis of intervertebral foramen is recommended. Second, we did not compare need for surgery or range of surgery with SedSign. Third, for walking distance, we used patients' self-reports rather than using a treadmill, but it has long been known that there is no clear correlation between stenosis severity on imaging study and its clinical manifestations. Fourth, the MRI signs are commonly measured in the supine position, which is not the clinically relevant one: Functional flexion–extension, sitting and standing, up-right MRI investigations show changes of CSA and SedSign. This study was large: We analyzed 522 patients and MRI images at 716 levels, and this is the first report of a relationship between dural sac cross-sectional area and SedSign.

Table 4 Correlation between functional outcome and SedSign

Variable	SedSign, mean (SD)			*p* value
	N	P(+)	P(−)	
ODI	22.64 (11.04)	22 (9.43)	23.02 (8.34)	0.561
RMDQ	11.27 (5.42)	9.68 (5.70)	11.33 (5.84)	0.422

SedSign sedimentation sign, *ODI* Oswestry Disability Index, *RMDQ* Roland–Morris Disability Questionnaire

*Statistically significant with $p < 0.05$

Conclusions

As SedSign worsened [i.e., N to P(−)], the CSA of the dural sac decreased. However, typical clinical LSS symptoms including claudication, radiating pain, referred pain, and back pain were not relevant to SedSign. Furthermore, there was no correlation between SedSign and functional spine outcomes such as ODI or RMDQ score. Therefore, SedSign is not an absolute criterion for deciding whether severe lumbar spinal canal stenosis requires a surgical procedure.

Compliance with ethical standards

Conflict of interest The authors declare no competing financial interest.

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