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Corresponding Author: Dr. Jason Pui Yin Cheung, MBBS(HK), MMedSc

Corresponding Author's Institution: Queen Mary Hospital

First Author: Jason Pui Yin Cheung, MBBS (HK), MMedSc

Order of Authors: Jason Pui Yin Cheung, MBBS (HK), MMedSc; Hideki Shigematsu, M.D.; Kenneth Man Chee Cheung, M.D.

Abstract: Background Context: MRI is commonly used to assess patients with lumbar spinal stenosis. No single MRI sequence has been shown to be superior in spinal canal measurements. There are also cost concerns for the increased clinical and research use of MRI. Using only a single sequence may lower the financial burden however this requires spinal canal measurements in both T1 and T2 MRI to be reliable. Evidence for this is currently lacking.

Purpose: The aim of study is to determine the intra- and inter-reader reliability of MRI measurements of the lumbar spine and the reliability of measurements using T1 and T2 weighted MRI films.

Study Design/Setting: Retrospective study.

Patient Sample: Forty-two randomly selected patients who underwent spinal stenosis surgery.

Outcome Measures: Lumbar spinal canal measurements and reliability analysis between T1 and T2-weighted MRI.

Methods: Qualitative ratings of MRI features were performed according to previously published criteria by 2 independent readers (JC, HS). Measurements in axial scan included midline AP vertebral body diameter, mid-vertebral body width, midline AP spinal canal diameter, midline AP dural sac diameter, spinal canal width/interpedicular distance, pedicle width (right and left), and lamina angle. Measurements in the sagittal scan included midline AP body diameter, mid-vertebral body height and AP spinal canal diameter. Cronbach's alpha was used to characterize intra-

and inter-reader reliability for qualitative rating data. Similarly, T1 and T2 comparison were also performed in the same manner.

Results: Good to excellent intra- and interobserver reliability was obtained for all measurements. Reliability analysis of all T1 and T2 measurements were excellent.

Conclusions: Either T1 or T2 images can be used for measurements of spinal canal dimensions. These findings are of importance as not every patient undergoing preoperative MRI assessment will necessarily have both sequences performed and only a single sequence is required for research studies. Our findings are also of relevance in measurement of lumbar canal diameters.

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Verification of measurements of lumbar spinal dimensions in T1 and T2-weighted MRI sequences

Authors: Jason Pui-Yin Cheung[1], MBBS(HK), MMedSc

Hideki Shigematsu[2], M.D.

Kenneth Man-Chee Cheung[1], M.D.

Affiliations: [1]Department of Orthopaedics and Traumatology, Queen Mary Hospital, University of Hong Kong, Pokfulam, Hong Kong SAR, China

[2]Department of Orthopaedics Surgery, Nara Medical University, Kashihara, Nara, Japan

Corresponding author: Kenneth Man-Chee Cheung

Jessie Ho Professor in Spine Surgery

Head of Department and Chief of Service

Department of Orthopaedics & Traumatology

University of Hong Kong

Hong Kong SAR, China

Tel: (+852) 2255-4254

Fax: (+852) 2817-4392

Email: cheungmc@hku.hk

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Introduction

Magnetic resonance imaging (MRI) has become an irreplaceable tool in assessment of patients with spinal pathologies such as spinal stenosis. As a diagnostic imaging procedure, it can provide important morphological details of intervertebral disc abnormalities and canal stenosis.[1 2] With an aging population worldwide, lumbar spinal stenosis is becoming more commonly diagnosed. However, with all the available evidence regarding spinal stenosis measurements on MRI, information on how measurements should be carried out and whether T1 or T2-weighted MRI should be used is lacking.

MRI evaluation of patients with spinal stenosis requires examination of osteoarticular and ligamentous conditions in the spinal canal. Most MRI studies on spinal stenosis utilize variable

MRI sequences. Some use T2-weighted films only [3-5] while others use both T1 and T2-weighted films.[6-12] For surgical planning, T1-weighted films may be more important as it shows the thecal sac and epidural space more clearly. T2-weighted or fluid-sensitive sequences are more sensitive to water content and thus are superior in showing disc dessication.[13] T2-weighted sequences with fat saturation provide better visualization of potentially relevant degenerative processes such as facet joint pathology or marrow edema.[14] However, T2-weighted films often obscured lesions within the spinal canal due to the increase in cerebrospinal fluid signaling.[15]

With the limitations of both T1 and T2-weighted films, most clinicians rely on both sequences for assessment.[2 6 8-11] However, this may not reflect the real clinical situation since some patients may not have acquired complete sets of both T1 and T2-weight axial and sagittal MRI films for assessment. Without analysis of the interobserver reliability between these two sequences, it is uncertain as to whether measurements made on T1 sequences are equivalent to those made by T2-weighted films.

The cost of using MRI is also of concern. The consumption in clinical use is directly linked to the number of patients with spinal stenosis. One Japanese study reported the prevalence of symptomatic lumbar spinal stenosis was 9.3% in the general population.[4] Another Swedish study reported an incidence of 50/million person-years.[16] The number of MRI used for diagnosis and assessment of all these patients would be a great financial burden. Hisashige showed that the annual cost of MRI examinations were US$713,500.[17] A cost-effectiveness evaluation study showed that by a 60% reduction in MRI usage, annual savings of $777282 (Canadian dollars) can be obtained.[18] The use of MRI is also prominent in research studies. Costs can be lowered by limiting to a single sequence MRI. To do this, both sequences must be comparable to avoid reduced accuracy. Thus, the aim of this study is to assess the reliability of different measurement

parameters and the reliability of measurements in T1 and T2 MRI scans for spinal canal dimensions.

Materials and Methods

Ethics and Disclosures

This study was approved by a local institutional review board prior to conduction of the study. There was no funding received for this study and there was no conflict of interests.

Subjects

The subject group includes all patients who were operated on for lumbar spinal stenosis in the past 10 years. All patients were diagnosed with spinal stenosis clinically by a senior spine surgeon and were determined to be candidates for surgery after failed conservative treatment with vigorous physiotherapy and exercise training. All patients were diagnosed with spinal stenosis involving L4, L5 and/or S1 levels. These patients had both preoperative T1 and T2 axial and sagittal MRI scans. All patients with congenital deformities, previous infections, tumors or trauma were excluded.

Measurements

Measurement of MRI required images to be uploaded to an electronic viewing program. The program used was the Centricity Enterprise Web V3.0 (GE Medical Systems, 2006). The L1, L2, L3, L4, L5 and S1 vertebral levels were assessed for each patient. Two investigators (JC, HS) were involved in the measurements. Both investigators have over six years of experience in

treating spine conditions and reading MRIs of the spine. Both investigators were independent readers and were not involved in the management and follow-up of the included subjects. A consensus on the standardized methods of measurements was made with all authors prior to data collection.

Most measurements in this study were based upon those in published studies.[2 3 7 11 12 19-26] Measurements in axial scan **(Figure 1)** include: midline AP vertebral body diameter, mid-vertebral body width, midline AP spinal canal diameter, midline AP dural sac diameter, spinal canal width/interpedicular distance, pedicle width (right and left), and lamina angle (**Figure 2**). Measurements in the sagittal scan **(Figure 3)** include the midline AP body diameter, mid-vertebral body height and AP spinal canal diameter (from the most prominent tip of the spinous process, taking a perpendicular line to the vertebral body). The axial scan used for measurement is the MRI axial cut with the thickest pedicle diameter while the sagittal scan used is the mid-sagittal MRI cut with the most prominent spinous processes shown.

MRI protocol

The MRI machine used was the Signa Excite 1.5 T HD. For T2 weighted images, the repetition time (TR) was 3320ms and echo time (TE) was 85ms. No fat suppression was used for the T2 scans. Slice thickness was 5mm and slice spacing was 1mm. There were 11 slices per vertebral level.

Statistical Analysis

Ten random subjects retrieved from a cohort of normal individuals were used for intraobserver and interobserver reliability assessments between the two investigators (JC, HS).

This extra sample of 10 MRIs was not included in the 42 patients under study and were evaluated prior to the evaluation of the 42 patients and also reevaluated by each reader 1 month later to test for intraobserver reliability. Reliability analysis was also performed between T1 and T2 images for the sagittal and axial MRI scans. The Cronbach's alpha statistical tool was used to summarize intra-observer and inter-observer reliability. This tool was also used for comparison between T1 and T2 images. Every spinal canal measurement underwent normality testing by Shapiro-Wilk test followed by paired t-test to look for differences between T1 and T2 measurements.

Results

Forty-two patients were found to have both T1 and T2 axial or sagittal MRI scans loaded onto our electronic patient record system for measurement. There were 18 males (42.9%) and 24 females (57.1%). The mean age was 64.1 (SD 12.5) years. Besides the good interobserver reliability result of the sagittal canal width (0.881), all other inter and intraobserver reliability measurements (table 1) were excellent. Excellent reliability was also found between the T1 and T2 measurements (table 2).

Breakdown of the analysis of each vertebral level and each measurement variable is seen in table 3. Shapiro-Wilk test for normality showed that all measurement values for T1 and T2 were normally distributed. Using the paired t-test, no significant differences were found between the T1 and T2 measurements.

Mean values for axial vertebral body AP diameter, axial vertebral body width, interpedicular distance and both pedicle widths increased from cranially to caudally. Axial AP

spinal canal diameter, dural sac diameter and lamina angle decreased from cranially to caudally. The sagittal vertebral body width increased from L1 to L4, leveled at L5 then decreased to S1. The sagittal vertebral body height remained similar from L1 to L5 then increased to S1. The sagittal spinal canal width decreased caudally from L1 and levels at L4 and L5 before further decreasing to S1.

Discussion

Spinal stenosis is a syndrome caused by compression of the spinal canal leading to neurological symptoms in the lower extremity. Surgery to decompress the spinal canal will improve symptoms of spinal stenosis. Radiological assessment of spinal stenosis is important for confirmation of diagnosis and also for surgical planning.[27-29] Radiographs, myelogram, computed tomography and magnetic resonance imaging have all been used for assessment.[19 27 30] Historically, CT myelogram was the best at depicting the central spinal stenosis with compression of the dural sac and roots.[31] The spinal canal area is usually narrower on axial CT cuts than MRI as cortical bone is better discriminated from soft tissue (ligamentum flavum) on CT.[32] CT myelogram is also slightly superior to MRI in reproducibility of flavum thickness measurements but MRI may be better suited for measuring the severity of stenosis. Yet, CT myelogram is less used nowadays because it requires a lumbar puncture[33] and this leads to potential complications such as anaphylaxis to contrast material, headaches, arachnoiditis and infection.[34-36] There is also exposure to radiation and is more expensive than MRI.[28] Furthermore, in cases of severe stenosis, the contrast dye may be blocked leading to poor visibility.

MRI is useful for evaluating disc pathologies and has good visualizing capacities for soft tissues whilst avoiding ionizing radiation.[6 8 37-41] MRI has been shown to be superior in disc assessment especially those that could benefit from discectomy.[40] MRI of the lumbar spine is sensitive but likely not specific as large number of asymptomatic individuals have lumbar spine abnormalities.[6 8 38] Pneumaticos et al. reported 95% sensitivity and 95% specificity of the MRI measuring a herniated disc and leg symptoms.[41] Measuring disc height and overall lumbar spine length is also more sensitive using the MRI.[39] For disc degeneration, Benneker et al. compared 39 cadaveric lumbar discs morphologically with radiographs and MRI for T2-intensity loss, modic changes, endplate cartilage loss, DEBIT score (axial deformation of the disc/disc extension beyond the interspace), annular tears, osteophytes, nucleus pulposus shape and endplate integrity.[37] From this study, radiographs were able to distinguish different stages of degeneration better whereas the MRI can detect advanced stages of disc degeneration. All MRI parameters correlated significantly with morphological grade but modic changes, T2-intensity and osteophytes accounted for 83% of the variation in data.

In terms of the spinal canal measurements, the role of MRI is still controversial. Limited number of studies showed that MRI has a 68-87% sensitivity and 75-96% specificity for spinal stenosis.[42] Ogura et al. compared MRI and CT myelogram in lumbar spinal canal measurements and reproducibility.[43] This retrospective study of 189 patients showed that both investigations were very effective in objective analysis of the shape of the dural sac, thickness of the ligamentum flavum and subjective severity grading of spinal stenosis. CT myelogram was superior to MRI in distinguishing bone from soft tissue and MRI can distinguish the ligamentum flavum from the dural sac and fat. In more severe stenosis with deformation of dural sac, identifying the dural morphology was less clear on the MRI and there was some difficulty in

distinguishing fat and soft tissue from bone. The conclusion drawn from the study was that both investigations had equal ability for preoperative evaluation of spinal stenosis.

The value of MRI largely depends on its role in clinical decisions regarding management of low back pain or sciatica and resulting outcomes. A considerable portion of patients may be incorrectly classified by MRI and may not be offered adequate management of low back pain. Currently, there is only evidence for diagnostic accuracy of MRI for lumbar disc herniation and spinal stenosis but the evidence is inconclusive. Thus, although MRI is the gold standard for assessing lumbar disc pathology, there is still no ideal investigation for the spinal canal.[44 45] Both CT myelogram and MRI have been considered gold standards for evaluation of spinal stenosis.[12]

This study focused on MRI assessment of spinal canal diameters in patients diagnosed with spinal stenosis. We found that the mean values for axial vertebral body AP diameter, axial vertebral body width, interpedicular distance and both pedicle widths increased from cranially to caudally. Axial AP spinal canal diameter, dural sac diameter and lamina angle decreased from cranially to caudally. The sagittal vertebral body width increased from L1 to L4, leveled at L5 then decreased to S1. The sagittal vertebral body height remained similar from L1 to L5 then increased to S1. The sagittal spinal canal width decreased caudally from L1 and levels at L4 and L5 before further decreasing to S1. These findings are similar to previously published studies.[3 11]

The spinal canal measurements from this study are useful for assessment of a patient with spinal stenosis. We obtained average measurements of the spinal canal of patients with spinal stenosis symptoms. Although these patients only had symptoms of L4, L5 and S1 nerve compression, these are the usual patients we come across in clinical practice and it is helpful to have a baseline measurement of their spinal canal dimensions. We do believe that the AP diameter measurements are more accurate because sagittal slices may not all cut the spinous

process at the same level. The axial scans in contrast are more consistent at the level of the pedicles. For spinal canal measurements on MRI, AP diameter measurements have higher sensitivity and specificity as compared to cross-sectional measurements and so AP diameter measurements are more superior for clinical application.[41] Both AP diameter and cross-sectional area of the dural sac can be used to differentiate symptomatic and asymptomatic individuals as they are smaller in symptomatic patients.

Obtaining accurate measurement of different variables is important for comparison within series and between series. Bony measurement variables of axial vertebral body AP diameter, width, pedicle widths and sagittal vertebral body width and height were easily reproduced as suggested by the results of the reliability analysis. There were some pitfalls during measurement that required special attention from readers. Osteophytes **(Figure 4)** were found on the edge of the vertebral bodies and could be differentiated on both T1 and T2 MRI scans as it was more hypointense than the bone in the vertebral body. This was possible with no fat suppression on the T2 MRI scans. The outer cortical diameter could be included in measurements of the vertebral body and pedicles and was defined by a hypointense lining **(Figure 4)** on the outer surface of the bone in both T1 and T2 MRI scans. This continuous lining could also be used to differentiate osteophytes from the main vertebral body. On sagittal views, the vertebral body height could be easily measured as the endplates were represented as a hypointense lining **(Figure 5)** on both T1 and T2 MRI scans. During assessment of the vertebral body and canal diameters, the posterior curvature **(Figure 6)** may affect the measurements. This posterior curvature must be taken into account during measuring to avoid overestimation of the vertebral body diameter and underestimation of the spinal canal diameter.

The dural sac was more easily measured on T1 than T2 since the hypointense contour of the dural sac could be differentiated from the hyperintense surrounding cerebrospinal fluid easily **(Figure 7)**. On T2 scans, the hypointense lining of the dura sac could be defined from the hyperintense surrounding cerebrospinal fluid and hyperintense dural sac content.

Inevitably, this study had some limitations. This included the discussion among authors prior to initiation of the study to standardize the measurement method. This led to a more structured assessment which was unlikely to be possible in clinical practice with individual clinicians of varying experience and expertise. Such a detailed and standardized assessment of the MRI may not be carried out by every clinician in practice. As such, the reliability outcomes from this study could be overestimated. In addition, although the clinical data on subjects in terms of age and gender were blinded during measurements, severity of spinal stenosis could be gauged by visualization of the MRI films during its measurement. How significant this assessment was in affecting the measurement results was unknown.

There is no standard for the type of MRI used for assessment of spinal canal dimensions. This study showed that results of different measurement variables are reliable regardless of the MRI sequence used for study. Occasionally, patients may have only acquired a single MRI sequence for assessment. In our study, either T1 or T2 sequence is adequate for study of the lumbar spinal canal. This result has important implications both in the clinical and the research setting in terms of cost.

In summary, the imaging characteristics of spinal stenosis assessed in this study showed good to excellent reliability between T1 and T2 MRI scans. This indicated that both T1 and T2 could be used to reliably measure different parameters of the spinal canal. Different parameters

to measure spinal stenosis were found to have excellent reliability. Future comparative studies of T1 and T2 spinal canal measurements in normal subjects would also be of interest.

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Figure Legends

Figure 1: Axial scan measurements: (A) midline AP vertebral body diameter; (B) mid-vertebral body width; (C) midline AP spinal canal diameter; (D) midline AP dural sac diameter; (E) spinal canal width/interpedicular distance; and (F) pedicle width (right and left).

Figure 2: Lamina angle (Made from two lines crossing the base of spinous process along the lamina to the base of the pedicles).

Figure 3: Sagittal scan measurements: (G) midline AP body diameter; (H) mid-vertebral body height; and (I) AP spinal canal diameter which is measured from the most prominent tip of the spinous process and taking a perpendicular line to the vertebral body.

Figure 4: Axial view of the lumbar vertebrae. Outer cortical surface of bone defined by a hypointense lining as indicated by the black arrow on T1 scan (left) and on T2 scan (right). This lining defines the border of the vertebral body and differentiates the vertebral body from surrounding osteophytes (white arrow).

Figure 5: Sagittal view of the lumbosacral spine. Vertebral body endplates represented by a hypointense lining (black arrow) on T1 scan (left) and T2 scan (right).

Figure 6: Sagittal view of two consecutive lumbar vertebras. Posterior concavity (black arrow) of the posterior wall of the lumbar vertebrae should be taken into account during measurement of the vertebral body width.

Figure 7: Axial view of the spinal canal. The hypointense lining defines the dura (black arrow) which can be seen clearly on the T1 scan (left) and T2 scan (right).

Table 1: Reliability analysis between T1 and T2 measurements

Measurement	**Cronbach's alpha**	**Mean (Variance)**
Axial vertebral body AP	0.905	31.8mm (0.003)
Axial body width	0.958	43.2mm (0.012)
Canal AP	0.951	17.6mm (0.031)
Dural sac AP	0.908	11.7mm (0.169)
Interpedicular distance	0.957	27mm (0)
Left pedicle width	0.977	10.9mm (0.071)
Right pedicle width	0.983	10.4mm (0)
Lamina angle	0.947	113° (1.576)
Sagittal body width	0.982	27.4mm (0.054)
Sagittal body height	0.977	22.7mm (0)
Sagittal canal width	0.957	14mm (0.049)

Table 2: Inter and intraobserver reliability

Measurement	**Interobserver**	**Intraobserver (JC)**	**Intraobserver (HS)**
Axial vertebral body AP	0.953	0.979	0.970
Axial body width	0.904	0.988	0.945
Canal AP	0.950	0.987	0.941
Dural sac AP	0.953	0.990	0.967
Interpedicular distance	0.953	0.972	0.974
Left pedicle width	0.971	0.977	0.986
Right pedicle width	0.975	0.977	0.985
Lamina angle	0.955	0.995	0.980
Sagittal body width	0.961	0.980	0.948
Sagittal body height	0.916	0.944	0.939
Sagittal canal width	0.881	0.937	0.956

Table 3: Spinal Canal Measurements

Variable	Shapiro-Wilk T1	T1 measurement (mm): mean (range/SD)	Shapiro-Wilk T2	T2 measurement (mm): mean (range/SD)	Paired t-test (p-value)
Axial vertebral body AP diameter					
L1	**0.834**	**29 (24.2-36/3.57)**	**0.823**	**28.6 (22-35.3/3.94)**	**0.166**
L2	**0.849**	**30.5 (24.8-40.3/3.86)**	**0.700**	**30.3 (22.5-38.5/3.68)**	**0.318**
L3	**0.912**	**31.7 (25.2-38.5/3.46)**	**0.555**	**31.5 (24.3-41.7/3.71)**	**0.633**
L4	**0.663**	**31.5 (24.8-39.9/3.28)**	**0.914**	**31.8 (24.3-40/3.7)**	**0.398**
L5	**0.941**	**32 (25.9-38.6/3.25)**	**0.741**	**32.7 (25.9-48.2/4.38)**	**0.208**
S1	**0.701**	**33.9 (25.2-44.1/4.12)**	**0.443**	**33.6 (26.4-43.6/3.54)**	**0.469**
Axial vertebral body width					
L1	**0.407**	**37.1 (29.9-45.8/4.78)**	**0.976**	**37.4 (30.9-45.1/4.11)**	**0.465**
L2	**0.642**	**38 (30.3-**	**0.651**	**38.2 (29.8-**	**0.425**

		44.9/3.75)		**47.1/3.98)**	
L3	**0.867**	**39.2 (32.3-51/4.04)**	**0.921**	**39.6 (32.5-52.8/4.29)**	**0.053**
L4	**0.770**	**41.1 (34.1-52.9/3.74)**	**0.620**	**41.3 (28-51.1/4.1)**	**0.657**
L5	**0.967**	**47 (38.7-58.3/5.41)**	**0.917**	**46.2 (30.2-59.9/5.85)**	**0.238**
S1	**0.987**	**51.2 (42-59.8/4.5)**	**0.803**	**52 (42.6-60.4/4.67)**	**0.076**
Axial spinal canal AP diameter					
L1	**0.284**	**19.8 (15.8-23/2.28)**	**0.704**	**19.8 (16.1-22.8/2.27)**	**0.818**
L2	**0.244**	**19.9 (14.9-28/3.28)**	**0.832**	**19.8 (13.1-30.7/3.64)**	**0.703**
L3	**0.764**	**19.4 (12.4-25.5/3.61)**	**0.800**	**19.3 (12.2-26.1/3.35)**	**0.797**
L4	**0.124**	**17 (11-30/4.01)**	**0.827**	**16.5 (10.8-29.1/3.7)**	**0.112**
L5	**0.060**	**15.6 (10.0-25.4/3.05)**	**0.160**	**15.7 (10.2-25.4/3.09)**	**0.097**
S1	**0.127**	**16.4 (10.1-22/3.2)**	**0.528**	**16.1 (10.1-23.1/3.16)**	**0.314**
Axial dural sac AP diameter					

L1	**0.126**	**14.3 (11.7-16.4/1.58)**	**0.218**	**14.7 (10.3-16.6/1.76)**	**0.179**
L2	**0.335**	**13.5 (9.6-17.9/2.14)**	**0.853**	**13.9 (9.9-19.5/2.58)**	**0.246**
L3	**0.530**	**12.8 (9.6-17.8/2.14)**	**0.377**	**12.9 (7.8-18.6/2.31)**	**0.403**
L4	**0.922**	**10.5 (4.2-17.1/2.75)**	**0.175**	**10.9 (4.4-17.4/2.66)**	**0.059**
L5	**0.131**	**10.5 (3.5-19.2/2.92)**	**0.453**	**10.9 (4-18.3/2.72)**	**0.117**
S1	**0.303**	**9.6 (4.4-14.7/3.20)**	**0.146**	**9.9 (4.5-14.9/3.33)**	**0.106**
Interpedicular distance					
L1	**0.599**	**22.3 (18.3-26.9/2.01)**	**0.396**	**22.8 (20-27.4/2.04)**	**0.130**
L2	**0.745**	**22.5 (19.3-25.1/1.54)**	**0.786**	**22.6 (19.9-25.9/1.40)**	**0.255**
L3	**0.809**	**24 (17.2-29.1/2.35)**	**0.780**	**24.1 (20.4-27.7/1.82)**	**0.874**
L4	**0.102**	**25.8 (21.5-30.8/2.33)**	**0.612**	**25.1 (19.2-28.9/2.24)**	**0.053**
L5	**0.366**	**30.1 (24.8-37.6/3)**	**0.570**	**29.8 (23.8-37.1/3.02)**	**0.522**

S1	**0.928**	**32.8 (27.8-39.4/2.41)**	**0.645**	**33.1 (27.2-38.9/2.51)**	**0.248**
Left pedicle width					
L1	**0.270**	**5.7 (2.5-7.8/1.4)**	**0.842**	**5.5 (2.5-8/1.64)**	**0.334**
L2	**0.992**	**6.4 (2.8-9.7/1.63)**	**0.916**	**6.5 (3.9-9.5/1.56)**	**0.567**
L3	**0.078**	**7.2 (4.4-12.8/1.83)**	**0.908**	**7.7 (4.3-11/1.65)**	**0.058**
L4	**0.244**	**9.1 (5.6-12/1.72)**	**0.282**	**9.2 (5.5-11.9/1.74)**	**0.085**
L5	**0.326**	**12.9 (6.7-18.2/2.49)**	**0.135**	**13.4 (6.3-22/3.02)**	**0.144**
S1	**0.788**	**18.2 (10.2-23.5/3.06)**	**0.459**	**18.5 (9.4-25.6/3.06)**	**0.177**
Right pedicle width					
L1	**0.418**	**4.8 (2.7-7.5/1.35)**	**0.678**	**4.8 (3-7.6/1.4)**	**0.827**
L2	**0.370**	**5.9 (3.4-8.5/1.22)**	**0.552**	**5.6 (3.2-7.7/1.23)**	**0.088**
L3	**0.928**	**7.3 (3.5-10.6/1.57)**	**0.396**	**7 (3.6-9.9/1.4)**	**0.084**
L4	**0.867**	**8.4 (4.8-12.1/1.58)**	**0.411**	**8.8 (4.4-13.4/2.05)**	**0.166**

L5	**0.097**	**13 (7.4-16.5/2.49)**	**0.900**	**13 (7.7-19.1/2.58)**	**0.857**
S1	**0.787**	**18.2 (10.4-25.6/3.78)**	**0.507**	**18.3 (10.5-25.2/3.43)**	**0.838**
Axial lamina angle					
L1	**0.617**	**121.5° (108-134.8/7.38)**	**0.448**	**121.8° (106.6-135.7/7.84)**	**0.781**
L2	**0.455**	**122.1° (89.5-139.1/11.77)**	**0.889**	**120.6° (86.1-140.8/12.72)**	**0.065**
L3	**0.224**	**124.1° (98.6-145.2/11.62)**	**0.543**	**122.7° (101.9-136.8/10.04)**	**0.194**
L4	**0.945**	**111.8° (92.1-128.8/7.69)**	**0.894**	**109.6° (81.9-125.8/9.42)**	**0.245**
L5	**0.062**	**97.6° (73.3-118.5/10)**	**0.354**	**96.1° (70.1-115.9/9.73)**	**0.149**
Sagittal vertebral body width					
L1	**0.479**	**26.7 (20.4-34.4/3.37)**	**0.752**	**26.3 (19-31.9/3.31)**	**0.071**
L2	**0.647**	**27.6 (19.1-35.3/3.83)**	**0.372**	**27.5 (19.2-35.3/3.83)**	**0.512**
L3	**0.538**	**29.7 (21.2-39.6/4.3)**	**0.790**	**29.6 (21.3-39.5/4.27)**	**0.191**
L4	**0.548**	**30 (22.6-**	**0.054**	**29.7 (22.5-**	**0.233**

		37.7/3.16)		**38.5/3.54)**	
L5	**0.288**	**29.3 (22.9-35.3/2.82)**	**0.708**	**29.2 (22.9-35.7/2.91)**	**0.055**
S1	**0.499**	**22.3 (15.2-29/3.14)**	**0.120**	**22 (15.1-29.8/3.18)**	**0.112**
Sagittal vertebral body height					
L1	**0.453**	**22.7 (18.9-26.8/1.89)**	**0.310**	**22.5 (18.8-26.4/1.84)**	**0.100**
L2	**0.930**	**23.2 (16.2-26.9/2.06)**	**0.824**	**23.1 (15.1-26.9/2.22)**	**0.093**
L3	**0.483**	**22.8 (19.4-26.6/1.83)**	**0.586**	**22.7 (19.3-26.2/1.74)**	**0.397**
L4	**0.373**	**22 (13.7-26.5/2.61)**	**0.135**	**22 (13.5-26.5/2.42)**	**0.825**
L5	**0.990**	**21.5 (15.4-25.8/2.22)**	**0.884**	**21.7 (16.1-25.7/2.19)**	**0.157**
S1	**0.614**	**24.1 (17.9-30.1/2.53)**	**0.370**	**24.2 (18.2-30.2/2.3)**	**0.161**
Sagittal spinal canal width					
L1	**0.789**	**15.3 (11.1-19.9/2.00)**	**0.634**	**15.5 (11.8-19.5/1.85)**	**0.059**
L2	**0.272**	**14.6 (9.2-17.7/1.91)**	**0.721**	**14.7 (10.5-17.6/1.93)**	**0.304**

L3	**0.202**	**13.7 (10-17.4/1.94)**	**0.422**	**13.8 (9.1-17.4/2.14)**	**0.240**
L4	**0.710**	**13.5 (8.1-17.9/2.45)**	**0.758**	**13.9 (7.9-18.7/2.41)**	**0.084**
L5	**0.481**	**14.1 (7.2-27.7/3.58)**	**0.697**	**14.2 (8.7-27.7/3.4)**	**0.677**
S1	**0.463**	**11.9 (7.1-19.4/2.46)**	**0.358**	**12.1 (7.3-19.6/2.58)**	**0.091**

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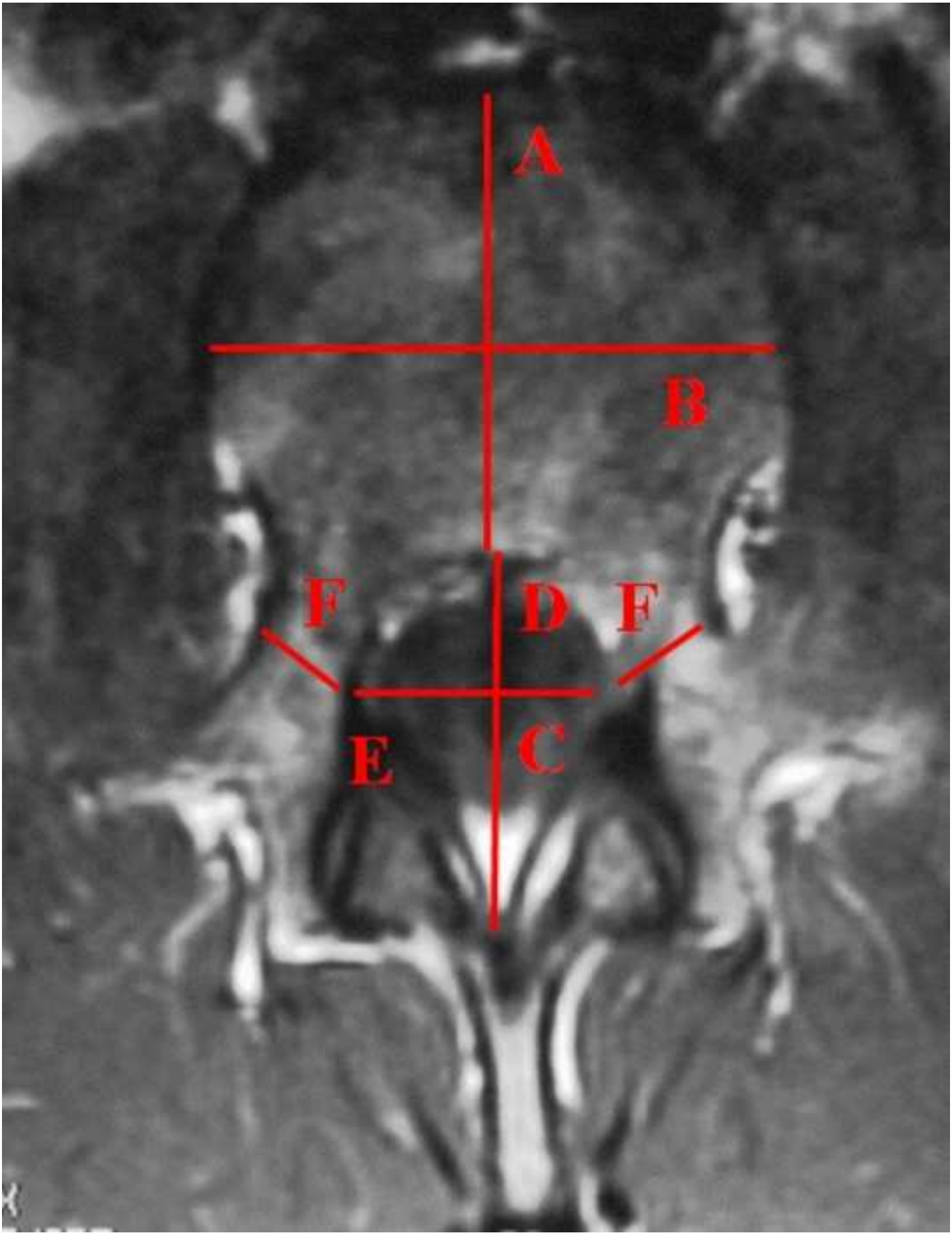

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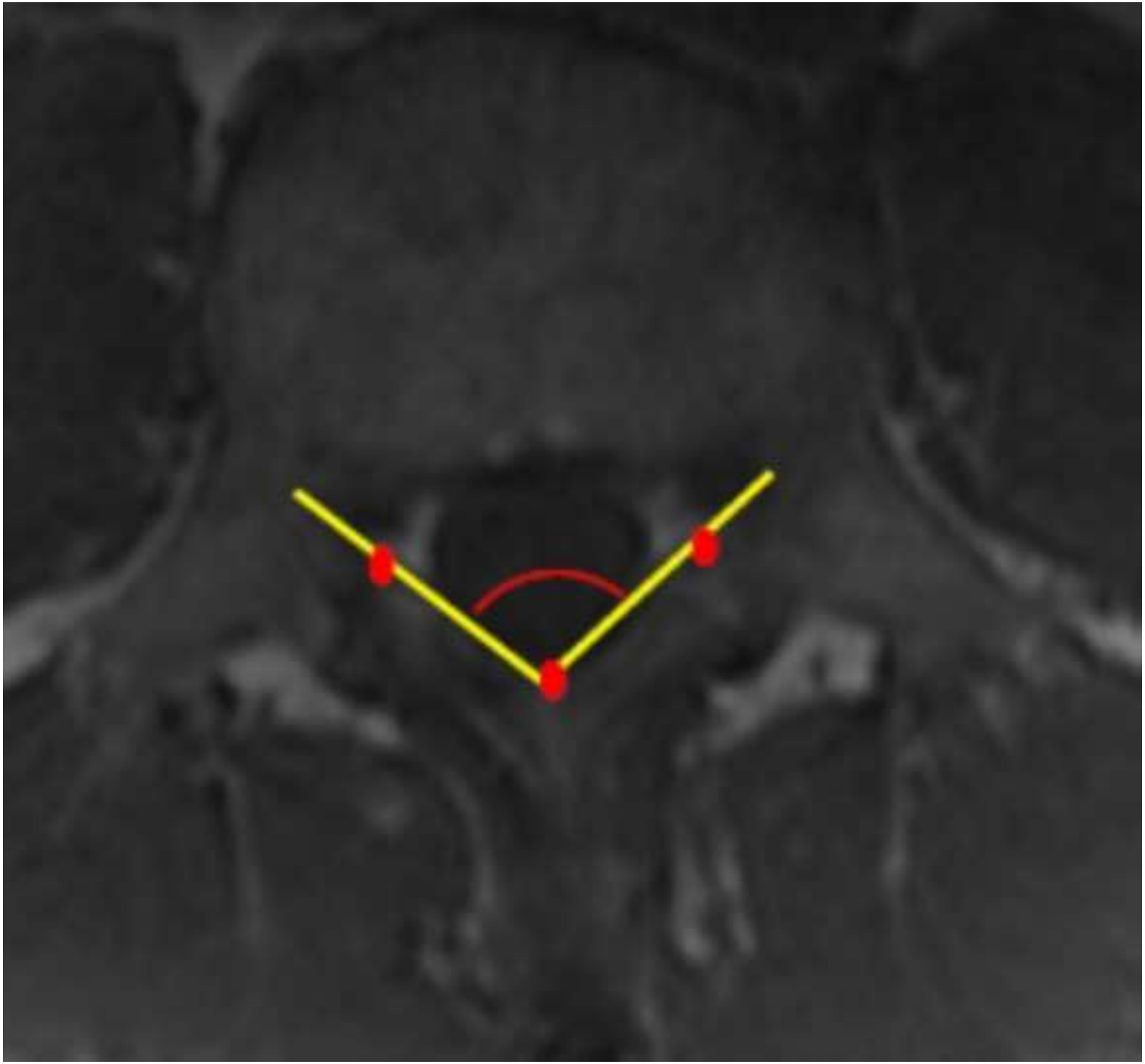

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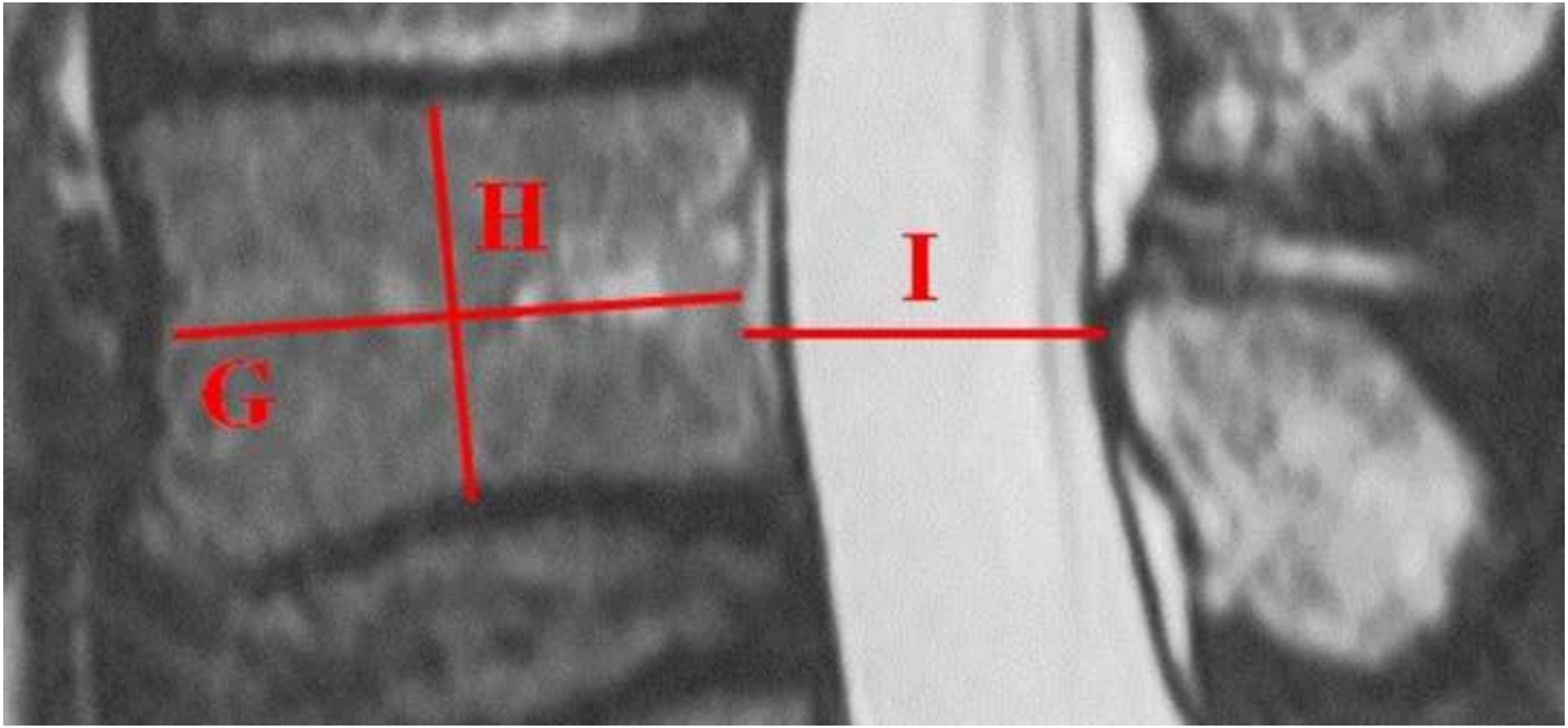

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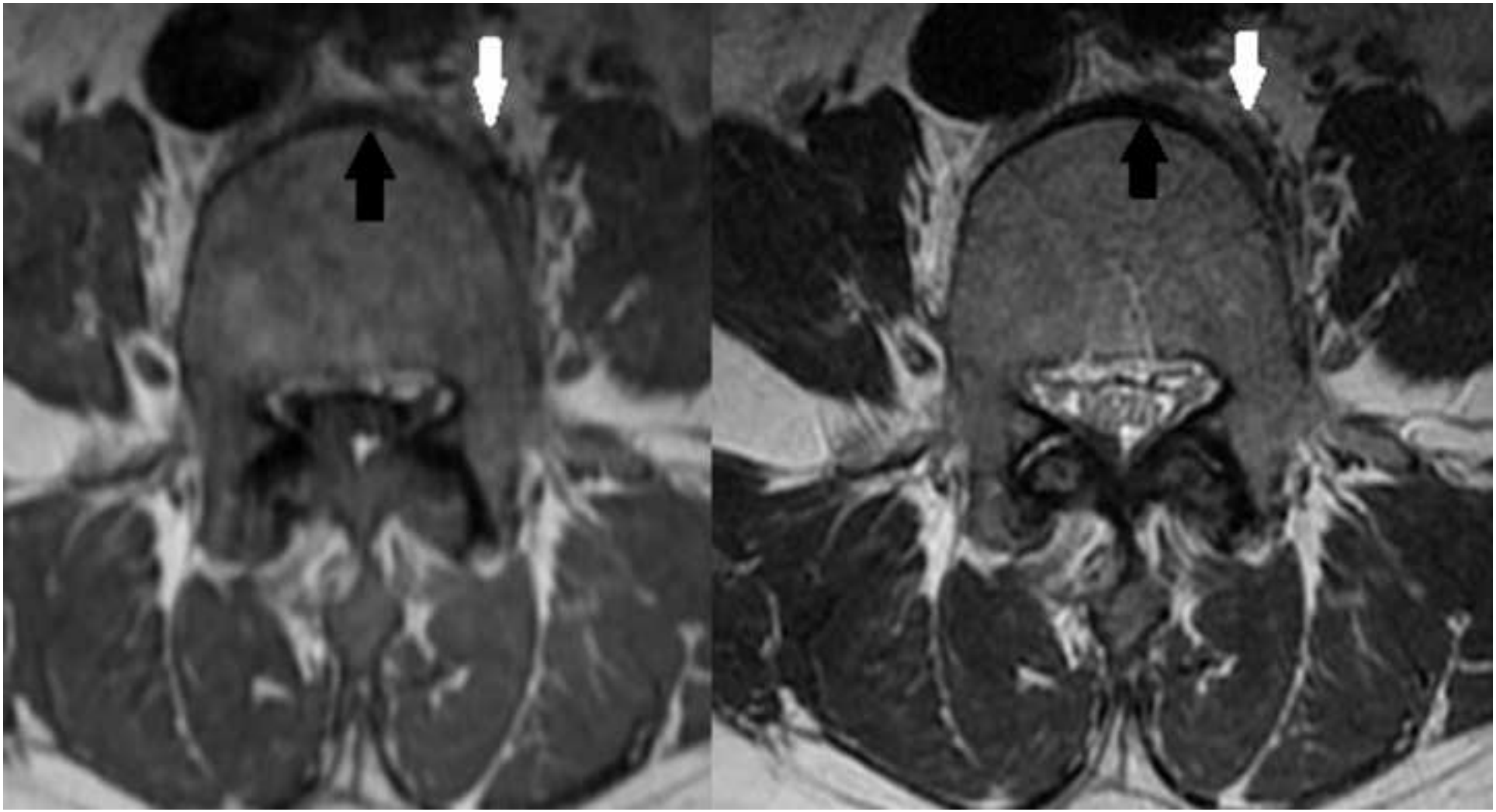

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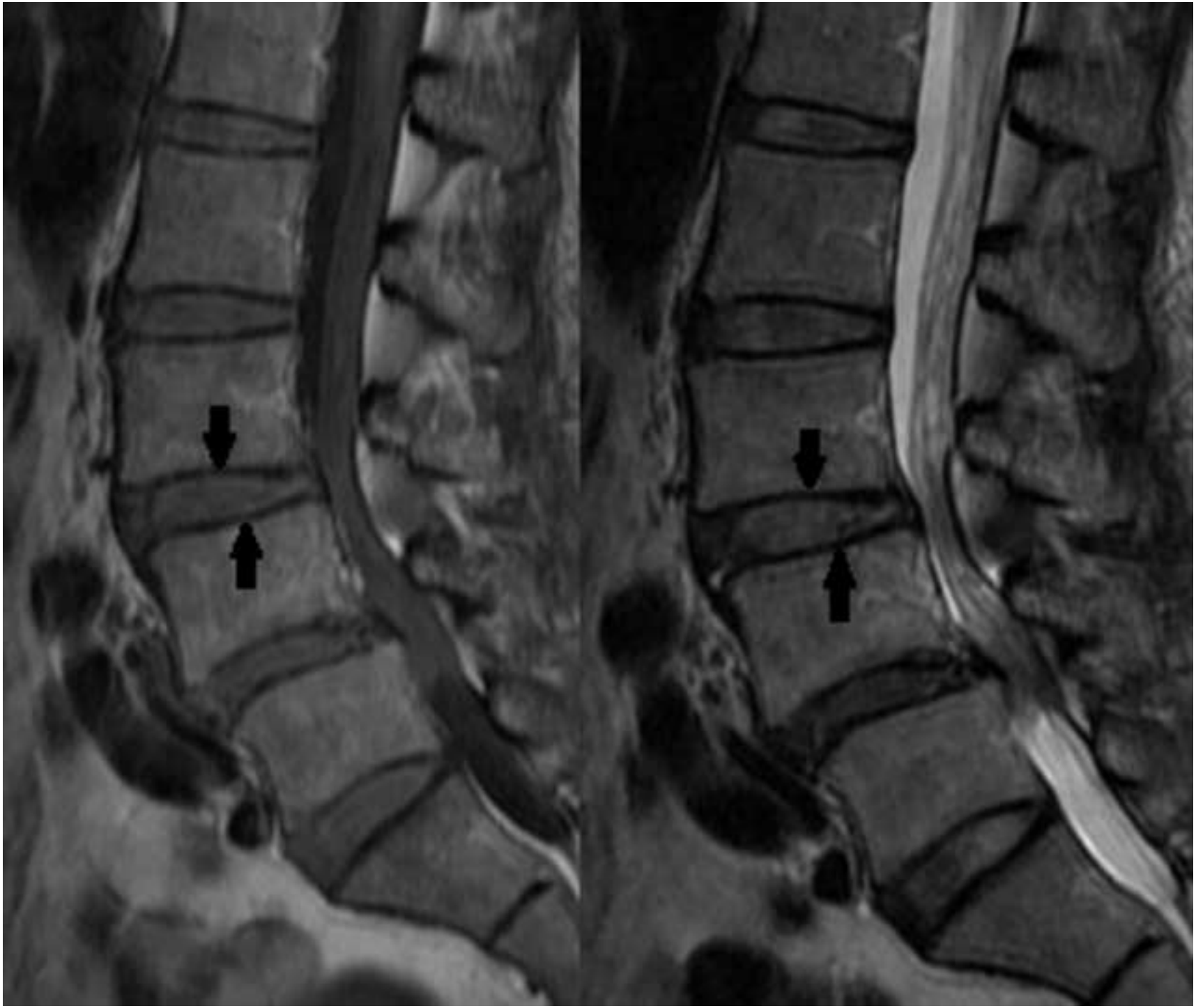

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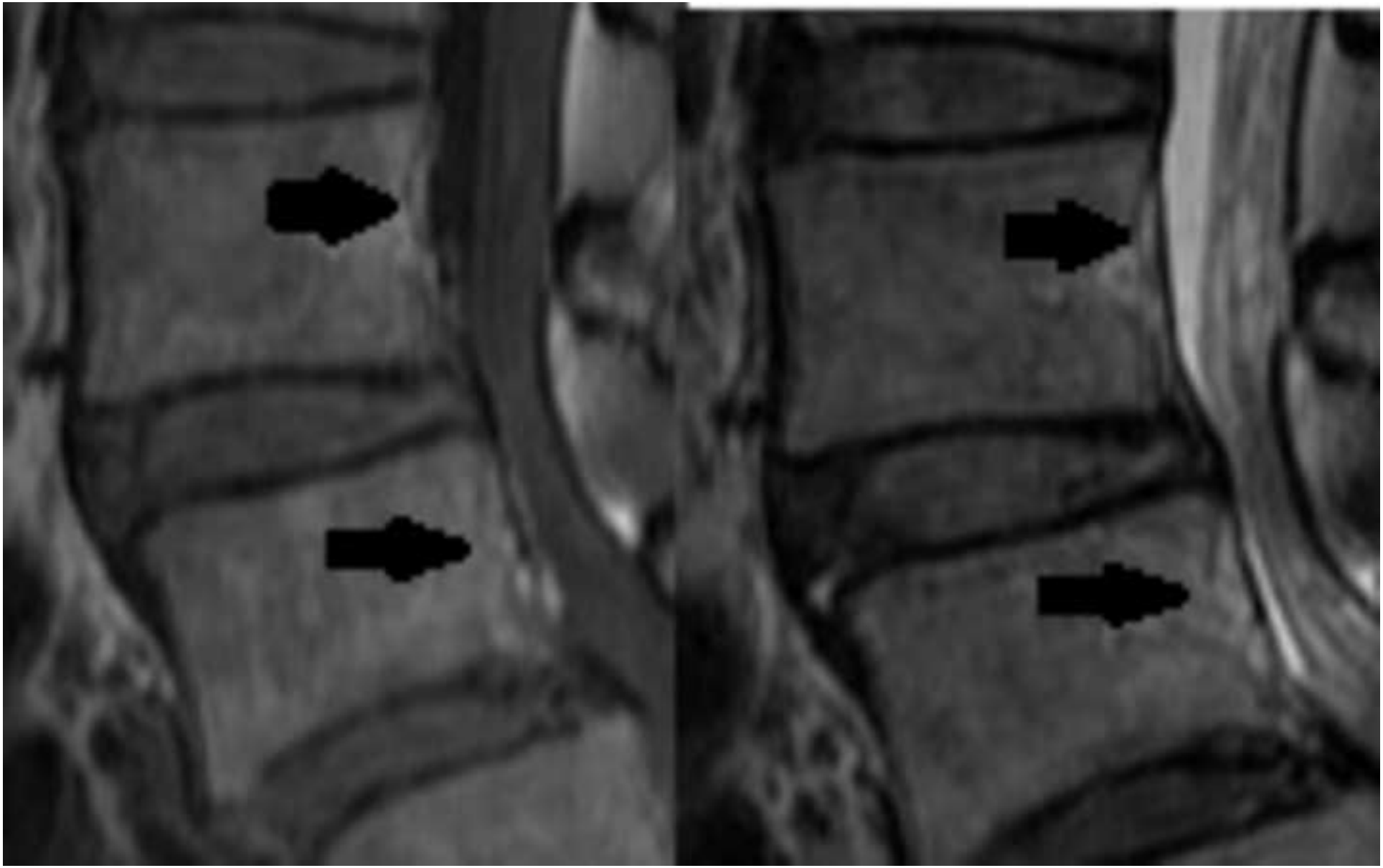

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