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Preface

On behalf of the International Study Group on Spinal Degenerative Pathologies (ISSDP) (head Dr Alberto Alexandre) and the Committee for Peripheral Nerve Surgery of the World Federation of Neurosurgical Societies (head Dr Eduardo Fernandez) and sponsored by EU. N.I., European Neurosurgical Institute, the Sixth Symposium on Peripheral Nerve Microsurgery and Minimally Invasive Treatments for Spinal Diseases was held in Treviso with wide international participation.

The course was also supported by the European Association of Neurosurgical Societies and by the Latin-American Federation of Neurosurgery.

Peripheral nerve problems were discussed and problems concerning differential diagnosis were highlighted, i.e. differential diagnosis in special situations such as between radicular and peripheral nerve trunk lesions, pinpointing the significance of different diagnostic tools. Minimally invasive techniques, utilized nowadays to minimize bone demolition, scarring and risk of recurrence, were carefully analyzed. Microdiscectomy was compared with the results of intradiscal techniques, and new methods were discussed in the face of problems such as epidural fibrotisation, microinstability, osteoporotic or neoplastic or postraumatic vertebral lesions. The different minimally invasive methods were discussed with participation of radiologists, orthopedic and neurological surgeons as well as physical medicine specialists coming from different countries.

A new, exciting field of interest is the use of autologous blood elements in order to favor healing processes in spinal degenerative processes, where demolitive surgery tends to be substituted by nourishment of tissues and reorganisation of function.

Authors from different countries in the world have contributed to this volume, for which we express our thanks. This bespeaks the wide interest that exists in the matter of minimal invasiveness and shows how widely this philosophy of treating patients is entering into neurosurgery.

We are especially grateful to Prof. Armando Basso for his attentive, continuous intellectual support of our philosophy of work underlying the different clinical and surgical problems, and his contribution to building up a more physiological and anatomically-minded way of treatment.

Also, we thank Acta Neurochirurgica for having dedicated this special issue to the Course in Treviso. Once again this is a good opportunity for underlining the importance of a common understanding of peripheral-nerve and spinal surgery problems in order to obtain a more perfect differential diagnosis between problems so closely related and which have quite a similar physiopathology.

Treviso, Italy — Alberto Alexandre
Brasilia, Brazil — Marcos Masini
Firenze, Italy — Pier Maria Menchetti

Contents

Surgical Anatomy of the Sacral Hiatus for Caudal Access to the Spinal Canal

Andrea Porzionato, Veronica Macchi, Anna Parenti, and Raffaele De Caro

Abstract The sacral hiatus is used for access to the spinal canal in many neurosurgical and anesthesiologic procedures. The aim of the present paper is to give a review of its anatomical characteristics relevant to permit correct and uncomplicated accesses. The sacral hiatus is posteriorly closed by the superficial dorsal sacrococcygeal ligament (also called sacrococcygeal membrane) which has to be pierced in order to gain the sacral canal. The mean distance between the hiatal apex and the dural sac has been reported to be 45–60.5 mm in adults and 31.4 mm in children. The mean sacral space depth has been observed to be 4.6 mm in adults and 3.5 mm in infants. On the basis of anatomical measurements of the sacral hiatus, lower insertion angles have been suggested in infant with respect to adult subjects (21° vs. 58°).

Keywords Sacral hiatus · Sacral bone · Epidural injections

Introduction

The sacral hiatus is used as neurosurgical and anesthesiologic access to the spinal canal in many procedures such as myeloscopy/epiduroscopy [1–6], for both diagnostic and therapeutic (lysis of adhesions, local injection of anesthetics and steroids) purposes, and caudal epidural block (e.g., [7]). Knowledge of the anatomical characteristics and variations of the sacral hiatus is essential in order to permit a correct and uncomplicated access to the sacral canal. Nevertheless, to the best of our knowledge a review of the surgical anatomy of the sacral hiatus, with particular reference to the above procedures, is not yet present in the literature. The aim of the present study was to revise the literature about this topic in order to synthetise the useful anatomical information for access to the sacral canal through the sacral hiatus.

The anatomy of the sacral canal and hiatus have been studied in cadavers or dry sacral bones (e.g., [7–10]) and in the living, through magnetic resonance (e.g., [11, 12]) and ultrasound (e.g., [13]) imaging. The dorsal surface of the sacrum shows a raised median sacral crest made up of four (or three) spinous tubercles fused together. The fifth (or four and fifth) tubercle is not present but a communication with the sacral canal is visible, i.e., the sacral hiatus. This hiatus is due to failure of the laminae of the fifth (or sometimes also fourth) sacral vertebra to fuse in the median plane. Laterally to the median sacral crest and up to the sacral hiatus, the fused sacral laminae are visible. More laterally, the intermediate sacral crests are formed by four tubercles due to the fusion of the sacral articular processes. The inferior articular processes of the fifth sacral vertebra are free, project downwards at the sides of the sacral hiatus, are called sacral cornua and are connected to coccygeal cornua by means of intercornual ligaments. The sacral hiatus is closed by the superficial dorsal (or posterior) sacrococcygeal ligament (also called sacrococcygeal membrane), which runs from the free margin of the sacral hiatus to the dorsal surface of the coccyx and correspond to the ligamenta flava of the spine. Conversely, the deep dorsal (or posterior) sacrococcygeal ligament is the continuation of the posterior longitudinal ligament. It is localized inside the sacral canal going from the posterior aspect of the fifth sacral segment to the dorsal surface of the coccyx. The lateral sacrococcygeal ligaments complete the foramina for the fifth sacral nerve running from the rudimentary transverse processes of the first coccygeal vertebra to the lower lateral angle of the sacral bone [14]. The filum terminale emerges below the sacral hiatus, and after passing along the dorsal surface of the fifth sacral vertebra reaches the coccyx. The fifth sacral spinal nerves also emerge through the sacral hiatus, medially to the sacral cornua [15]. The sacral hiatus is covered by skin, subcutaneous fatty tissue and the sacrococcygeal membrane [16].

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Sacral Hiatus Measurements for Spinal Canal Access

The mean length of the sacral hiatus has been found to be 32.1 mm (range: 12–53) on adult dry sacral bones [7] and 22.6 mm (range: 11–36) on adult sacral bones studied through Magnetic Resonance Imaging (MRI) [12]. The width of the sacral hiatus at the level of the sacral cornua has been reported to be 10.2 mm (2.2–18.4) by Sekiguchi et al. [16] and 17.5 mm (7–28) by Senoglu et al. [7]. The distance between the hiatal apex and the tip of dural sac has been observed to be about 45 mm [17] or 60.5 mm (range: 34–80) [12]. Senoglu et al. [7] analysed the distance between the sacral hiatus and the level of S2 foramina as this is the most common level of the caudal extremity of the dural sac: the distances from the apex and base of the sacral hiatus to the S2 foramina were 35 mm (11–62) and 65 mm (39–85), respectively [7]. Moreover, it has been observed that the triangle formed between the superolateral sacral crests and the apex of the sacral hiatus is equilateral with mean length of the sides of 66.5–67.5 mm, these measurements being considered useful landmarks for localizing the apex of the sacral hiatus when ultrasonography or fluoroscopy are not possible [7]. The mean depth of the sacral hiatus at the level of its apex has been reported to be 6.0 (range: 1.9–11.4) by Sekiguchi et al. [16] and 4.5 mm (range: 1–7) by Senoglu et al. [7]. However, the anteroposterior (sagittal) diameter of the sacral canal at the level of the apex of the hiatus has been found to be 2 mm or less in 1–6.25% of cases [7, 16, 17]. On MRI, the maximum antero-posterior diameter of the sacral canal at an angle of 90°, corresponding to 4.6 mm (range: 1–8), has mainly been found in the upper third of the sacrococcygeal membrane [12]. Crighton et al. [12] on the basis of the above measurements identified the best fit angle to enter the sacral canal through the sacral hiatus in 57.9° (range: 40°–74°).

MRI imaging analysis on children (mean age: 134 months; range: 10–215) showed mean length of the sacral hiatus of 24.3 mm (range: 12.1–44.3) and maximum antero-posterior diameter of 4.92 mm (range: 2.0–10.0) [11]. The mean distance between the upper margin of the sacrococcygeal membrane and the dural sac was 31.4 mm (range: 13.6–57.1). Another study on children (median age: 19 months; range: 2–84) performed through ultrasound imaging showed median intercornual distance of 17.0 mm (range: 9.6–24.6) and sacral space depth of 3.5 mm (range: 1.0–8.0) [13]. In this children series, the optimal insertion angle was identified in 21° (range: 10°–38°).

The sacral hiatus may present some anatomical variations which can interfere with correct entrance in the caudal spinal canal. Agenesis of the hiatus has been found in mean percentages of 4–7.7% [7, 12, 17, 18]. The limitation in the access to the sacral hiatus due to cartilagineous tissue has been reported to be solved in two cases by mini-surgical approach consisting in dissection until the hiatus and removing of cartilagineous tissue with a Kerrison rongeur [3].

Cysts of the Sacral Canal

Some cyst types may also be present in the sacral canal, sometimes extending to the sacral hiatus. Although pathological entities and not anatomical variations, they are worthwhile to be considered due to their frequent asymptomatic presence, with possible complications of an access through the sacral hiatus. Nabors et al. [19] classified spinal meningeal cysts into three types: type I, spinal extradural meningeal cysts without spinal nerve root fibres; type II, spinal extradural meningeal cysts with spinal nerve root fibres; type III, spinal intradural meningeal cysts. According to Nabors et al. [19], cysts could show or not a communication with the subarachnoid space. Conversely, for Cilluffo et al. [20] the term "diverticula" is to be preferred if such a communication is present. Moreover, if the cyst wall is made up of arachnoid mater the term arachnoid cyst should be preferred, using the term meningeal cyst only if the cyst wall is constituted of dura mater [21]. Spinal arachnoid cysts are congenital lesions which are usually asymptomatic until patient's second decade of life [21]. Spinal arachnoid cysts without communication are rare and are more frequently located at spinal levels higher than L2 [18, 22, 23]. Only six genuine sacral epidural arachnoid cysts have been reported in the literature [24–28]. More frequent in the sacral canal are perineural or Tarlov cysts (Nabors type II), which form themselves between the perineurium and endoneurium of the spinal posterior nerve root sheath of the dorsal root ganglion and contain spinal nerve root fibres within the cyst wall or cavity [29–32]. These cysts are also mostly asymptomatic, show an incidence of 4–9% [29] and are more frequently found at the S2 or S3 levels [33]. Large Tarlov cysts may erode surrounding bone [31, 34].

Conflict of interest statement We declare that we have no conflict of interest.

References

1. Geurts JW, Kallewaard JW, Richardson J, Groen GJ (2002) Targeted methylprednisolone acetate/hyaluronidase/clonidine injection after diagnostic epiduroscopy for chronic sciatica: a prospective, 1-year follow-up study. Reg Anesth Pain Med 27:343–352
2. Heavner JE, Wyatt DE, Bosscher HA (2007) Lumbosacral epiduroscopy complicated by intravascular injection. Anesthesiology 107:347–350

3. Helm S 2nd, Gross JD, Varley KG (2004) Mini-surgical approach for spinal endoscopy in the presence of stenosis of the sacral hiatus. Pain Physician 7:323–325
4. Igarashi T, Hirabayashi Y, Seo N, Saitoh K, Fukuda H, Suzuki H (2004) Lysis of adhesions and epidural injection of steroid/local anaesthetic during epiduroscopy potentially alleviate low back and leg pain in elderly patients with lumbar spinal stenosis. Br J Anaesth 93:181–187
5. Richardson J, McGurgan P, Cheema S, Prasad R, Gupta S (2001) Spinal endoscopy in chronic low back pain with radiculopathy. A prospective case series. Anaesthesia 56:454–460
6. Saberski LR, Kitahata LM (1995) Direct visualization of the lumbosacral epidural space through the sacral hiatus. Anesth Analg 80:839–840
7. Senoglu N, Senoglu M, Oksuz H, Gumusalan Y, Yuksel KZ, Zencirci B, Ezberci M, Kizilkanat E (2005) Landmarks of the sacral hiatus for caudal epidural block: an anatomical study. Br J Anaesth 95:692–695
8. Edwards WB, Hingson RA (1942) Continuous caudal anesthesia in obstetrics. Am J Surg 57:459–464
9. Lanier VS, McKnight HE, Trotter M (1944) Caudal analgesia: an experimental and anatomical study. Am J Obstet Gynecol 47:633–641
10. Trotter M, Lanier PF (1945) Hiatus canalis sacralis in American whites and Negros. Hum Biol 17:368–381
11. Adewale L, Dearlove O, Wilson B, Hindle K, Robinson DN (2000) The caudal canal in children: a study using magnetic resonance imaging. Paediatric Anaesth 10:137–141
12. Crighton IM, Barry BP, Hobbs GJ (1997) A study of the anatomy of the caudal space using magnetic resonance imaging. Br J Anaesth 78:391–395
13. Park JH, Koo BN, Kim JY, Cho JE, Kim WO, Kil HK (2006) Determination of the optimal angle for needle insertion during caudal block in children using ultrasound imaging. Anaesthesia 61:946–949
14. Morris Craig E (2005) Low back syndrome: integrated clinical management. McGraw-Hill, Milan
15. Standring S (2008) Gray's anatomy – the anatomical basis of clinical practice. Churchill Livingstone, London
16. Sekiguchi M, Yabuki S, Satoh K, Kikuchi S (2004) An anatomic study of the sacral hiatus: a basis for successful caudal epidural block. Clin J Pain 20:51–54
17. Waldman SD (2004) Caudal epidural nerve block: prone position. In: Atlas of interventional pain management, 2nd edn. Saunders, Philadelphia, pp 380–392
18. Hatashita S, Kondo A, Shimizu T, Kurosu A, Ueno H (2001) Spinal extradural arachnoid cyst – case report. Neurol Med Chir (Tokyo) 41:318–321
19. Nabors MW, Pait TG, Byrd EB, Karim NO, Davis DO, Kobrine AI, Rizzoli HV (1988) Updated assessment and current classification of spinal meningeal cysts. J Neurosurg 68:366–377
20. Cilluffo JM, Gomez MR, Reese DF, Onofrio BM, Miller RH (1981) Idiopathic ("congenital") spinal arachnoid diverticula. Clinical diagnosis and surgical results. Mayo Clin Proc 56: 93–101
21. Sakellaridis N, Panagopoulos D, Mahera H (2007) Sacral epidural noncommunicating arachnoid cyst. Case report and review of the literature. J Neurosurg Spine 6:473–478
22. Krings T, Lukas R, Reul J, Spetzger U, Reinges MH, Gilsbach JM, Thron A (2001) Diagnostic and therapeutic management of spinal arachnoid cysts. Acta Neurochir (Wien) 143:227–235
23. Kulkarni AG, Goel A, Thiruppathy SP, Desai K (2004) Extradural arachnoid cysts: a study of seven cases. Br J Neurosurg 18:484–488
24. Muthukumar N (2002) Sacral extradural arachnoid cyst: a rare cause of low back and perineal pain. Eur Spine J 11:162–166
25. Myles LM, Gupta N, Armstrong D, Rutka JT (1999) Multiple extradural arachnoid cysts as a cause of spinal cord compression in a child. Case report. J Neurosurg 91(1 Suppl):116–120
26. Nakagawa A, Kusaka Y, Jokura H, Shirane R, Tominaga T (2004) Usefulness of constructive interference in steady state (CISS) imaging for the diagnosis and treatment of a large extradural spinal arachnoid cyst. Minim Invasive Neurosurg 47:369–372
27. Rabb CH, McComb JG, Raffel C, Kennedy JG (1992) Spinal arachnoid cysts in the pediatric age group: an association with neural tube defects. J Neurosurg 77:369–372
28. Rengachary SS, Watanabe I (1981) Ultrastructure and pathogenesis of intracranial arachnoid cysts. J Neuropathol Exp Neurol 40:61–83
29. Acosta FL Jr, Quinones-Hinojosa A, Schmidt MH, Weinstein PR (2003) Diagnosis and management of sacral Tarlov cysts. Case report and review of the literature. Neurosurg Focus 15:E15
30. Goyal RN, Russell NA, Benoit BG, Belanger JM (1987) Intraspinal cysts: a classification and literature review. Spine 12:209–213
31. Hefti M, Landolt H (2006) Presacral mass consisting of a meningocele and a Tarlov cyst: successful surgical treatment based on pathogenic hypothesis. Acta Neurochir (Wien) 148: 479–483
32. Tarlov IM (1938) Spinal perineural cysts. Arch Neurol/Psychiat 40:1067–1074
33. Voyadzis JM, Bhargava P, Henderson FC (2001) Tarlov cysts: a study of 10 cases with review of the literature. J Neurosurg 95(1 Suppl):25–32
34. Dastur HM (1963) The radiological appearances of spinal extradural arachnoid cysts. J Neurol Neurosurg Psychiatry 26:231–235

Radiologic Anatomy of the Sacral Canal

Veronica Macchi, Andrea Porzionato, Aldo Morra, Carla Stecco, and Raffaele De Caro

Abstract The extradural space is currently investigated through fluoroscopy and ultrasound for surgical approach, whereas magnetic resonance imaging has been used to provide detailed information. The aim of the present paper is to describe the radiologic anatomy of the sacral canal through a review of its appearance in the different radiologic techniques. CT is able to visualise also the sacrum and the content of the sacral canal, triangular in shape in the transverse images, being able to establish the measurement of the transverse area of the dural sac and of the canal diameter. On the sagittal CT scans, the sacrococcygeal membrane appears as a hypodense structure, between the posterior end of the sacral vertebra and the posterior tip of the coccyx. In magnetic resonance imaging, on T2-sagittal plane images, the sacral canal appears hyperintense, due to the presence of the liquor. The dural sac appears as a hypointense band and its termination as hypointense cul de sac in the context of the hyperintensity of the sacral canal. The sacrococcygeal membrane appears as a hypointense band between the posterior end of the sacral vertebra and the posterior tip of the coccyx. On ultrasound imaging, in the transverse sonographic view, two hyperechoic reversed U-shaped structures correspond to the two bony prominences of sacral cornua, between which there were two hyperechoic band-like structures. The band-like structure on top is the sacrococcygeal ligament. The band-like structure at the bottom is the dorsal surface of the sacrum. The sacral hiatus corresponds to the hypoechoic region observed between the two hyperechoic band-like structures.

Keywords Sacral hiatus · Sacral canal · Extradural space

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Introduction

Spina bifida occulta is a condition where there is incomplete fusion of the neural arch of the vertebra, usually in the lumbosacral region [1]. When this condition occurs in the sacrum, the level of non-closure of the lamina of the sacral bodies is variable [2]. Many sacra have S5 or also S4 open, exposing the dorsal surface of the fifth sacral body [3]. Many radiological studies have investigated the prevalence of this condition in the sacrum in various populations, also analysing X-rays that were originally taken for other diagnostic purposes [4], or combined X-ray and computed tomography to determine the level of sacral crest closure [5], raising the question as to whether a standard frontal X-ray image of the whole of the sacrum gives a clear enough image to confidently diagnose spina bifida occulta at all levels [6].

The extradural space has also been investigated through fluoroscopy [7] or ultrasound [8–14] for surgical approach, whereas magnetic resonance imaging has been used to provide detailed information on the anatomy of the extradural space in living subjects [15].

The aim of the present study is to describe the radiologic anatomy of the sacral canal through a review of its appearance in the different radiologic techniques.

X-Rays

In an antero-posterior projection of the pelvis, the sacrum appears as a large, triangular bone, derived from the fusion of five vertebrae; its blunted, caudal apex articulates with the coccyx. In the lateral radiograph, the sacrum shows its pelvic concavity, opened infero-anteriorly, which continues with the supero-anteriorly opened concavity of the coccyx [16]. Thus, the sacrum does not lie in the coronal plane, because of the sharp lumbosacral angle. Moreover, the bone is more vertical in males than in females and the female sacrum is more curved, especially in the lower half of the bone [17].

A tilt of the X-ray beam 10–15° [17] or 20° [18] cephalad allows the best possible view of this bone, and the angle may need to be increased if there is a greater posterior tilt of the sacrum, for example in a female patient [17]. In a comparative study between X-ray and cadavers dissection, Albrecht et al. [6] found that a single antero-posterior view with 10–15° cephalad angulation provided the clearest image of the whole sacrum.

In an antero-posterior (Fig. 1) X-ray of the sacrum, the sacral hiatus appears as a more radiotransparent zone at the lower end of the sacrum, due to the presence of the inverted U- or V-shaped foramen, formed by the failure of the vertebral arch at fifth sacral vertebra to meet in the median plane. The sacral hiatus is covered by fibrous tissue (sacrococcyx membrane) [3]. A complicating factor in diagnosing images of this area is the presence of intestinal gas, fecal matter, and the full urinary bladder overlying the sacrum. This can make it difficult to see the sacrum and hence make it difficult to diagnose. For this reason, radiography positioning texts [17–19] recommend that the patient both empties the bladder and has a cleaning enema before a sacral X-ray. This rarely occurs in practice, especially if the X-rays are not specifically requested for the sacrum.

Fluoroscopy is most commonly used in interventional spine procedures [20] and is frequently used in confirming the location of caudal epidural needle. It has been advocated that caudal epidural needle placement should be confirmed by fluoroscopy alone or by epidurography [7]. Radiographic contrast administration can confirm the location of the caudal epidural needle with the Christmas tree-like appearance, due to the bath of the contrast dye of the external aspect of the dura mater and nerve roots [8]. Radiation exposure is the major concern when obtaining fluoroscopic images; actually pulsed imaging is preferred during fluoroscopy because it can reduce overall exposure by 20–75% [7].

Although myelography has been replaced in large part by MR imaging, it remains indicated in some instances (for instance the presence of metal hardware that precludes examination of the spinal canal and cord by magnetic resonance imaging or computed tomography). Subarachnoid contrast agent for myelography is most commonly introduced by a lumbar approach and in these cases lateral fluoroscopy can be helpful in determining an entry site on the skin slightly caudal to the hiatus at about the S5 level, allowing for alignment of the needle nearly parallel to the posterior aspect of the upper sacral vertebral bodies [21].

Computed Tomography

Computed tomography (CT), with its cross-sectional scan provides the capability to visualize the sacral canal, formed by sacral vertebral foramina, and appears triangular in axial images. Its caudal opening is the sacral hiatus. In the sagittal CT images, the sacrococcygeal membrane appears as a hypodense structure, between the posterior end of the sacral vertebra and the posterior tip of the coccyx (Fig. 2). CT is able to visualise also the content of the sacral canal, being able to establish the measurement of the transverse area of the dural sac and of the canal diameter [22]. Solomon et al [23] studied the opening of the sacral canal in 2 population groups: born 1940 to 1950 and 1980 to 1990 and have reported that the individuals born later have significantly more open sacral arches when compared with those born 40 years earlier, especially in the midsacral region. Also,

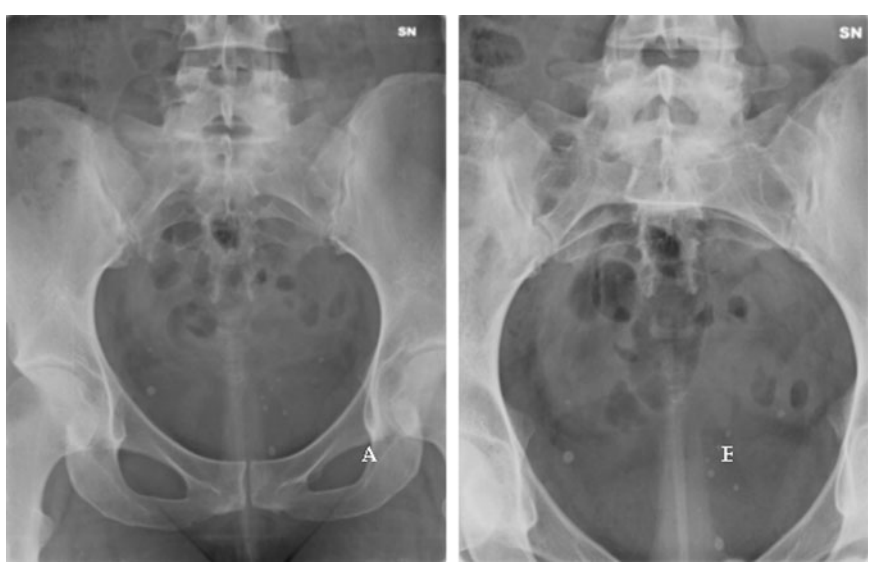

Fig. 1 Antero-posterior radiograph of the sacrum showing the sacral hiatus

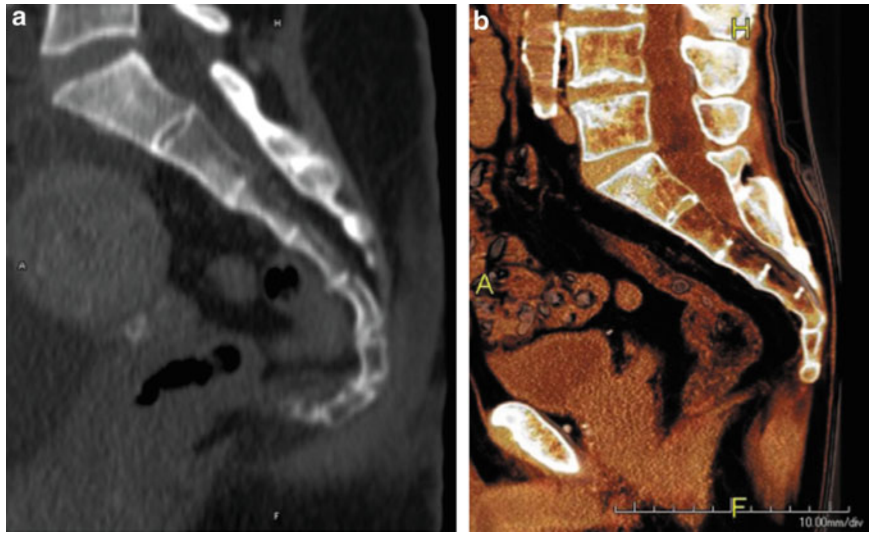

Fig. 2 CT sagittal image (**a**) and volume rendering reconstruction (**b**), showing the caudal space, the sacrococcygeal membrane appears hypodense (*asterisk*)

males have open sacral arches in the rostral segments of the sacrum more than females. CT can be used as guide for sacroplasty for the proper cannula placement prior to cement injection [24]. CT is able also to show with great details the soft tissues and on in vivo CT studies, Scapinelli [25] documented the appearance of the lumbo-sacral meningo-vertebral ligaments, most commonly on transverse images, as a median sagittal septum, easily identifiable when the extradural fat that it crosses is abundant.

Magnetic Resonance Imaging

Magnetic resonance (MR) imaging offers a detailed representation of the sacral canal and of its content (cauda equina and the filum terminale, and the spinal meninges) with a high quality tissue contrast and on multiple planes. Opposite the middle of the sacrum, the subarachnoid and subdural spaces close: the lower sacral spinal roots and filum terminale pierce the arachnoid and dura mater at that level [3]. The images of the sacrum have been obtained on sagittal and transverse planes. It can also be visualised whole or in part during the exams of the lumbar vertebral columns. Usually a phase array spine coil is used and the patient is in the supine position. The relevant anatomy of the sacral canal is demonstrated by the T2-sagittal plane images [15, 26, 27], in which the sacral canal appears hyperintense, due to the presence of the liquor. The dural sac appears as a hypointense band and its termination as hypointense cul de sac in the context of the hyperintensity of the sacral canal. The sacrococcygeal membrane appears as an hypointense band between the posterior end of the sacral vertebra and the posterior tip of the coccyx (Fig. 2). McDonald et al. [15] reported that the median level of termination of the dural sac is located at the level of the middle one third of the S2, extending from the upper border of S1 to the upper border of S4. The mean level for males was also the upper one-third of S2 and for females the middle one-third of S2. Crighton et al. [27] reported that the distance of termination of the dural sac from the beginning of the sacrococcygeal membrane was 1.4 cm (Fig. 3).

Ultrasonography

Diagnostic imaging including plain radiography, computed tomography, and magnetic resonance imaging can provide accurate anatomic information regarding the location of the epidural space, but their use is impractical in most clinical settings where epidural analgesia is used. In contrast, the safety and feasibility of bedside ultrasonography during pregnancy or in neonates or children are well established [8–14]. The sacral canal is studied with patient in prone position and a linear-array ultrasound transducer by using the "acoustic window" [10] in both the longitudinal midline and cross-sectional planes to identify the sacral hiatus. In the transverse sonographic view, two hyperechoic reversed U-shaped structures correspond to the two bony prominences of sacral cornua, between which there are two hyperechoic band-like structures. The band-like structure on top is the sacrococcygeal ligament. The band-like structure at the bottom is the dorsal surface of the sacrum. The sacral hiatus corresponds to the hypoechoic region observed between the two hyperechoic band-like structures [8, 11]. The longitudinal view is obtained by rotating the transducer 90°. In the longitudinal sonographic view, the hyperechoic structure corresponds to the ventral end of the sacrum, and the deep hyperechoic band like structure corresponds to the posterior surface of the sacrum. The hypoechoic band-like structure between the two hyperechoic zones corresponds to the sacrococcygeal ligament.

Fig. 3 MR sagittal image of the caudal space

To avoid the most important limitation of the ultrasound-guided caudal epidural injection, i.e. inadvertent intravascular injection [28, 29], color Doppler ultrasonography can be added. The color Doppler ultrasonography shows unidirectional flow (observed as one dominant color) of the injection of the solution through the epidural space beneath the sacrococcygeal ligament, with no flows being observed in other directions (observed as multiple colors) [14].

Conflicts of Interest Statement We declare that we have no conflict of interest.

References

1. Brailsford JF (1953) The radiology of bones and joints. J & A Churchill, London
2. Romanes GJ (ed) (1981) Cunningham's textbook of anatomy, 12th edn. Oxford University Press, Oxford, UK
3. Standring S, Borley NR, Collins P, Crossman AR, Gatzoulis MA, Healy JC, Johnson D, Mahadevan V, Newell RLM, Wigley CB (eds) (2008) Gray's anatomy, ed 40. Churchill Livingstone, Spain, pp 1002–1003
4. Boone D, Parsons D, Lachmann SM, Sherwood T (1985) Spina bifida occulta: lesion or anomaly? Clin Radiol 36:159–161
5. Avrahami E, Frishman E, Fridman Z, Azor M (1994) Spina bifida occulta of S1 is not an innocent finding. Spine 19:12–15
6. Albrecht TL, Scutter SD, Henneberg M (2007) Radiographic method to assess the prevalence of sacral spina bifida occulta. Clin Anat 20:170–174
7. Botwin KP, Thomas S, Gruber RD, Torres FM, Bouchlas CC, Rittenberg JJ, Rao S (2002) Radiation exposure of the spinal interventionalist performing fluoroscopically guided lumbar transforaminal epidural steroid injections. Arch Phys Med Rehabil 83:697–701
8. Chen CP, Tang SF, Hsu TC, Tsai WC, Liu HP, Chen MJ, Date E, Lew HL (2004) Ultrasound guidance in caudal epidural needle placement. Anesthesiology 101:181–184
9. Grau T, Leipold RW, Horter J, Conradi R, Martin E, Motsch J (2001) The lumbar epidural space in pregnancy: visualization by ultrasonography. Br J Anaesth 86:798–804
10. Grau T, Leipold RW, Horter J, Conradi R, Martin EO, Motsch J (2001) Paramedian access to the epidural space: the optimum window for ultrasound imaging. J Clin Anesth 13:213–217
11. Park JH, Koo BN, Kim JY, Cho JE, Kim WO, Kil HK (2006) Determination of the optimal angle for needle insertion during caudal block in children using ultrasound imaging. Anaesthesia 61:946–949
12. Willschke H, Bosenberg A, Marhofer P, Willschke J, Schwindt J, Weintraud M, Kapral S, Kettner S (2007) Epidural catheter placement in neonates: sonoanatomy and feasibility of ultrasonographic guidance in term and preterm neonates. Reg Anesth Pain Medic 32:34–40
13. Willschke H, Marhofer P, Bosenberg A, Johnston S, Wanzel O, Sitzwohl C, Kettner S, Kapral S (2006) Epidural catheter placement in children: comparing a novel approach using ultrasound guidance and a standard loss-of-resistance technique. Br J Anaesth 97:200–207
14. Yoon JS, Sim YH, Kim SJ, Kim WS, Koh SB, Kim BJ (2005) The feasibility of color Doppler ultrasonography for caudal epidural steroid injection. Pain 118:210–214
15. Macdonald A, Chatrath P, Spector T, Ellis H (1999) Level of termination of the spinal cord and the dural sac: a magnetic resonance study. Clin Anat 12:149–152
16. Zacchi C, Macchi C, Fiore D (2000) Radiologic anatomy, vol 15. CEDAM, Padova, p 35
17. Ballinger PW, Frank ED (1999) Merrill's atlas of radiographic positons and radiologic procedures, 9th edn. Mosby, St. Louis, MO
18. Moller TB, Reif E (1997) Pocket atlas of radiographic positioning. Thieme, New York, pp 74–77
19. Bontrager KL, Lampignano JP (2001) Textbook of radiographic positioning and related anatomy, 6th edn. Mosby, St. Louis, MO
20. Lippert JA, McGraw JK (2002) Spine interventions. Sem Roentgenol 37:266–281
21. Jones SB, Shaw DW, Jacobson LE (1997) A transsacral approach through the sacral hiatus for myelography. AJR Am J Roentgenol 169:1179–1181
22. Zheng F, Farmer JC, Sandhu S, O'Leary PF (2006) A novel method for the quantitative evaluation of lumbar spinal stenosis. HSSJ 2:136–140
23. Solomon LB, Rühli FJ, Lee YC, Henneberg M (2009) Secular trend in the opening of the sacral canal: an Australian study. Spine 34:244–248
24. Grossterlinden L, Begemann PG, Lehmann W, Nuechtern J, Schumacher U, Nagel HD, Linhart W, Adam G, Rueger JM, Briem D (2009) Sacroplasty in a cadaveric trial: comparison of CT and fluoroscopic guidance with and without balloon assistance. Eur Spine J 18(8):1226–1233
25. Scapinelli R (1990) Anatomical and radiologic studies on the lumbosacral meningo-vertebral ligaments of humans. J Spinal Disord 3:6–15
26. Adewale L, Dearlove O, Wilson B, Hindle K, Robinson DN (2000) The caudal canal in children: a study using magnetic resonance imaging. Paediatr Anaesth 10:137–141
27. Crighton IM, Barry BP, Hobbs GJ (1997) A study of the anatomy of the caudal space using magnetic resonance imaging. Br J Anaesth 78:391–395
28. Edward R (2005) Ultrasound-guided caudal epidural injection. Anesthesiology 102:693
29. Huang J (2005) Disadvantages of ultrasound-guided caudal epidural needle placement. Anesthesiology 102:693

Imaging in Degenerative Spine Pathology

Cesare Colosimo, Simona Gaudino, and Andrea M. Alexandre

Abstract The lack of radiation, high soft tissue contrast and capacity for multiplanar and three-dimensional imaging have made magnetic resonance imaging (MRI) the imaging modality of choice for evaluating spinal cord diseases. In diagnostic imaging of the spine, MRI is clearly superior to both conventional radiography (CR) and computed tomography (CT) and it should be preferred as first diagnostic examination when degenerative spine pathologies are suspected.

The other technological equipments (CT, CR, dynamic orthostatic X-ray, myelography, discography and skeletal scintigraphy) have to be selectively chosen and adapted to the individual patient.

Both “container” and “contents” of the spine should be primly evaluated. Finally, a correlation between clinical and radiological features seems to be mandatory for selecting the correct therapeutic choice, since the reliability of the MRI as potential prognostic indicator has been demonstrated.

Keywords Degenerative spine pathology · Spine imaging · Neuroimaging of the spine

MRI, CT and Radiography: Indications and Diagnostic Protocol

Technological weapons that can be used by a (neuro)radiologist in degenerative pathologies of the spine (DSP) include three major techniques: magnetic resonance imaging (MRI), computed tomography (CT), radiography (X-ray); and some others that have a supporting role: myelography and myelo-CT, discography, skeletal scintigraphy and nuclear medicine. In fact while MRI, CT and X-ray are widely used for DSP, the others have particularly strict indications. Myelography and myelo-CT can be used in case of myelopathy, dynamic evaluation or in patients with contraindications to MRI (e.g. pacemaker). Discography is an important tool before percutaneous procedure, while the criticism to discography is related mainly to its invasive nature, reliability of the response, and lack of specificity [1, 2]. Skeletal scintigraphy provides a panoramic view of the spine, and has an important role in dynamic evaluations such as the use of marked granulocytes to discover infections. During the last two decades the diagnostic protocol used for degenerative spine pathologies has changed completely; in fact, in the early 1990s, the sequence of the exams proposed was: X-ray for a general evaluation of bone structures, CT for additional information about soft tissue, while MRI was reserved to well-selected cases. In the middle of the 1990s X-ray was keeping the role of first exam, whereas CT had started to be used electively in lumbar tract and MRI was preferred in cervical myelopathies. Nowadays the situation has changed and MRI is slowly used as first diagnostic exam, followed by CT and then by X-ray. It is difficult for a standard X-ray to maintain the role of screening because of its poor sensibility and specificity and especially because of radiation exposure. CT should be used as a completion, above all in patients suspected for bone or joint alterations. Dynamic X-ray in orthostatism is suggested in case of suspected instability (Fig. 1).

Therefore, despite important differences depending on the tract of spine that is to be examined, MRI should be chosen as first exam wherever available.

MRI and CT: Requirements and State-of-the-Art

Which MRI?

It should be a high field MRI, with dedicated phased-array coils, with efficient and fast gradient echo sequences.

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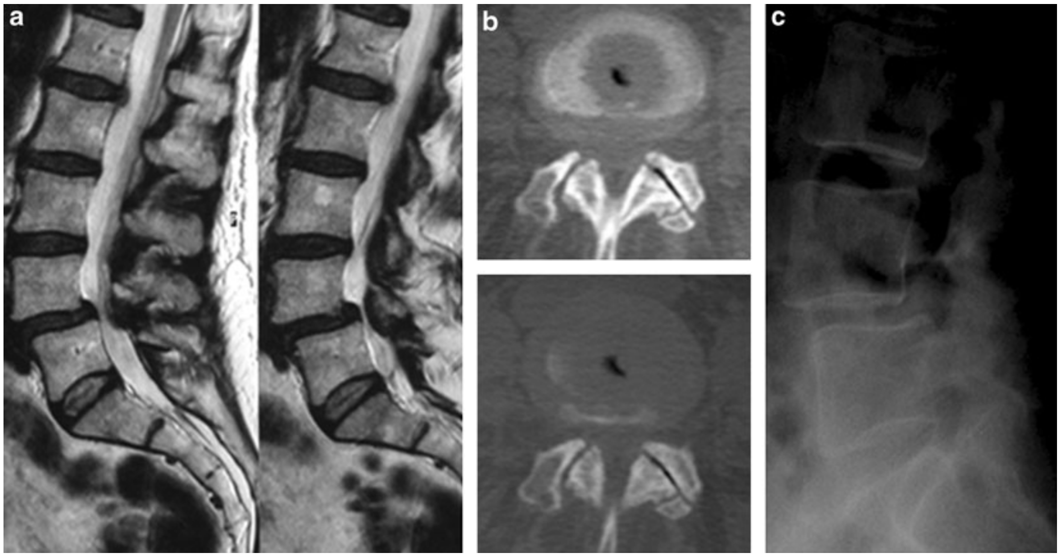

Fig. 1 Imaging of the spinal instability. Sagittal T2-weighted images demonstrate L4-L5 discopathy and L1-L2 herniated disc; the associated decreased antero-posterior canal dimension is suspected for spondylolisthesis (**a**). Axial CT demonstrating a zygapophyseal sublussation (**b**). Dynamic orthostatic X-ray confirms L4-L5 instability (**c**)

Multiplanar imaging offers several significant advantages, therefore at least sagittal and axial sections, with T1 and T2-weighted images and 3 millimetre thickness, seems to be mandatory to us (Fig. 2). In case of bone alterations other techniques that suppress adipose tissue signal can be used (e.g. SPIR/SPAIR, FAT-SAT, STIR); in fact, for these lesions the best approach to characterization and to precisely defining their extent and relationships is to combine unenhanced non-fat-suppressed T1-weighted imaging with fat-suppressed T2-weighted or STIR imaging, and post-contrast SPIR T1-weighted imaging [3] . If a lumbar spinal canal stenosis is noted, a myelo-MRI is needed to quantify the spinal cord compression. In selected patients the use of intravenous contrast agent can be very important, above all after spine surgery [4]. Finally orthostatic MRI, when necessary, is preferable to an axial loader technique since the first is more physiological (Fig. 3).

Fig. 2 Sagittal and axial high quality T2-weighted Magnetic Resonance images of the cervical spine permit an high-resolution anatomic evaluation of the cervical spine

Which CT?

First of all CT should be used only in selected patients after an MRI, and particularly to focalize the attention on bone structures, however a multislice CT scanner, at least a 16-64-slice system, is required, as well as 2D and in some case 3-Dimensional (3D) multiplanar reconstruction images. The spine must be studied with both "bone" and "soft tissue" algorithm, even if thickness acquisition can differ in relation to the pathology that is to be investigated. Injection of contrast agent should be avoided since it can be used with fewer risks and even less radiation during MRI.

Container and Contents, Finding and Report

Spine imaging must give a complete evaluation of "container" degenerative modifications, that is modifications of vertebrae, discs, facet joints and ligaments, moreover it is

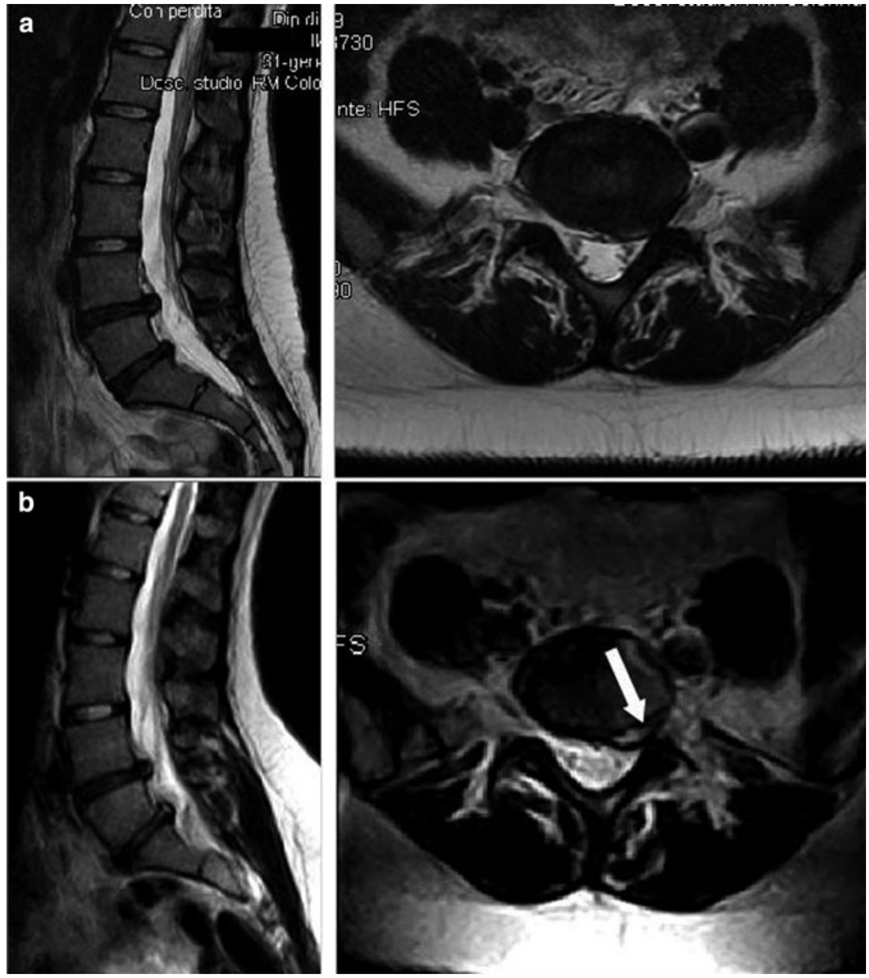

Fig. 3 Comparison between sagittal and axial MRI projections obtained in standard **(a)** and orthostatic **(b)** positions. The disc herniation, and the compression of the adjacent root is more evident during orthostatism (white arrow). (Courtesy of Prof. M. Gallucci. Dept. of Neuroradiology. University of L'Aquila)

extremely important to define and to describe accurately the effects on the "container", that is on the spinal cord, nerve roots, nerve ganglion, meninges and vascular structures. With regard to this second point it is better to separate diseases and imaging of the cervico-dorsal spine, which regard properly the spinal cord, and diseases and imaging of the lumbo-sacral spine, which involve specifically nerve roots. Finally even the smallest sign of instability must be recognised and quantified if it is present.

Cervico-Dorsal Spine

MRI sequences should be chosen in relation to the pathology that is to be studied, indeed every patient has a different situation and sequences must be adapted to the individual case, in this context we want also to underline the importance of the quality of an image in clarifying a diagnostic question (Fig. 4).

Demonstration of "soft" herniated disc and differential diagnosis between disc herniations and osteophytes requires gradient echo (GRE) axial images, and often 3D T1 and T2-weighted images, only in some cases is a CT examination preferable. In case of myelopathy, 3D GRE T2-weighted axial images are the most important sequences to visualize the extent and degree of the spinal cord compression, above all employing techniques that suppress adipose tissue signal.

Although with all equipment you can obtain images in flexion and extension, the contribution given by dynamic orthostatic X-ray still remains irreplaceable.

Disc herniations must be properly defined as: central, postero-lateral and lateral/intraforaminal. Other elements that must be always considered are: presence of osteophytes, unco-arthropathy, calcification of posterior longitudinal ligament and yellow ligament hypertrophy. Spinal canal stenosis, lateral recesses stenosis and neural foramina stenosis must be considered distinctly.

The term "spinal cord compression" (SCC) must be cautiously used; it is compulsory demonstrating or, on the other hand, excluding any radiological sign of spinal cord distress; in fact when spinal cord distress is full blown signs are clearly of vascular origin, with a major involvement of the grey matter in the context of an atrophic spinal cord (Fig. 5).

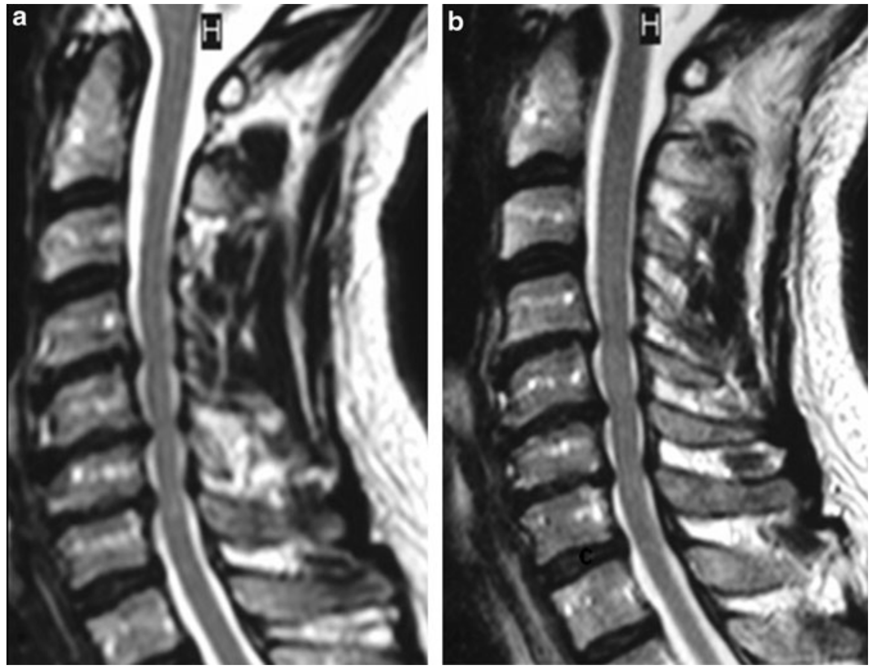

Fig. 4 The importance of the quality of MRI images. Sagittal turbo-spin echo (TSE) T2-weighted images studied in a 1,5 T equipment with a phased-array coil. The cervical spine of the same patient studied with different parameters (matrix acquisition and Turbo Factor). In (**b**) disappears the sign of spinal cord compression at C6-C7 level that could be misinterpret in (**a**)

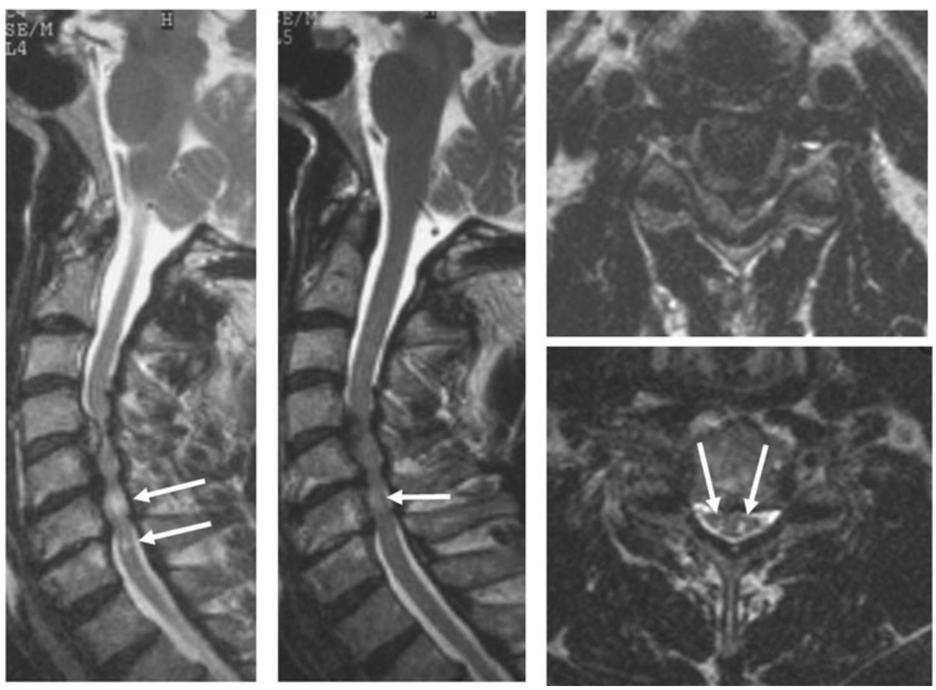

Fig. 5 Sagittal and axial T2-weighted MRI, showing a chronic cervical spondylotic myelopathy, with a symmetrical suffering of the central grey matter at multiple levels

Lumbo-Sacral Spine

When a non specific low back pain is present, MRI should be performed as the first examination [5]. Sagittal image scanning must include both neural foramina, and the choice between T1 or T2-weighted axial images should be based on what kind of equipment the (neuro)radiologist can rely on. The value of T2 relaxation times, especially, has been proved to characterize the structure of lumbar intervertebral discs [6].

Whenever bone changes are present it is mandatory to apply adipose tissue suppression techniques, or complete

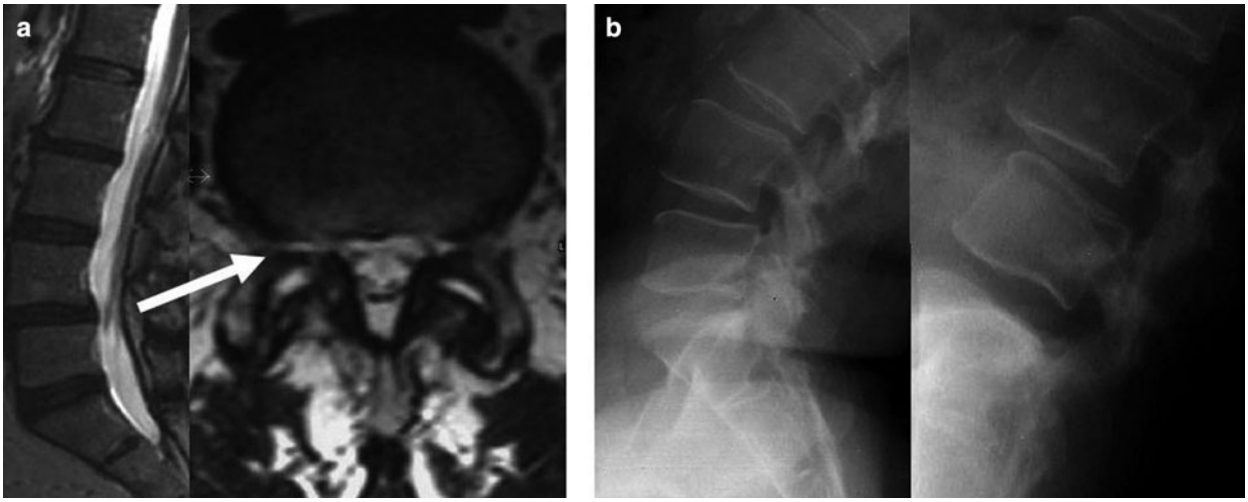

Fig. 6 Minimal signs of spondylolisthesis (white arrow) can be appreciated in sagittal and axial T2-weighted MRI (**a**). Dynamic orthostatic X-ray confirms aretrolisthesis of L5 (**b**)

the study with a CT. The use of contrast agent should be reserved to well-selected patients, even if it can be very useful to highlight bone, intra-articular and muscular findings. Even though minimal signs of spondylolisthesis are noted in a standard supine MRI, as for example exaggerated fluid in facet joints [7], bone instability must be suspected and a dynamic orthostatic X-ray or an orthostatic MRI, if it is available, must be suggested to the patient (Fig. 6).

Lumbar discs alterations represent only a small part of degenerative spine pathology, in fact the same attention should be given to modifications of other spine structures such as ligaments, zygapophyseal joints and vertebral body (Fig. 7). These structures are involved by a mechanism cycle of degeneration that is instigated by small changes in the mechanical integrity of the intervertebral disc [8]. In any case, compression effects on spinal canal, lateral recesses, neural foramina and their contents (thecal sac, nerve roots and ganglion) must be underlined if they are present. Even dural venous plexus modifications must be searched for. If a central spinal canal stenosis is diagnosed, the extent of the stenosis can be confirmed by the presence of varicose and thicker nerve roots above the site of compression.

Disc Degeneration and Lumbar Disc Herniation

Changes in discs are related to aging; in fact desiccation, fibrosis and cleft formation in the nucleus, fissuring and mucinous degeneration of the anulus, defects and sclerosis of endplates, and/or osteophytes at the vertebral apophyses are frequently seen in the asymptomatic patient during radiological examinations. Clinical features must be considered to determine whether degenerative changes on imaging are pathologic and what may or may not have contributed to their development [9], even if the distinction between aging changes and pathologic changes remains unclear [10]. The role of imaging is to provide accurate morphologic information and influence therapeutic decision making [11]. Disc degenerations should be classified with standard criteria using the Thompson Grading Scale, where, following a set of parameters, an X-ray radiographic inspection of the disc is conducted and the gross morphology is used to determine the extent of degeneration [12]. The term herniated disc means a focal lesion, and confusion with a bulging disc must be avoided. Unfortunately common classifications of herniated disc disease are not widely accepted; the absence of universal nomenclature standardization with respect to the definition of a disc herniation and its different categories, especially regarding type and location, is still a major problem that will only be overcome when major national or international scientific societies join efforts to support a particular scheme [13, 14]. Radiologists are asked anyway, to specify the localization (median, paramedian, posterolateral, lateral or foraminal and “far-lateral”), the fragment migration direction (cranial or caudal) and the continuity with the original disc. Any signal intensity or signal density can be associated with a herniated disc, even fluid or gas signal ones; these signal alterations can rapidly modify or even disappear.

Lumbar Instability

In the last decade diagnostic imaging has become an “obsessive” research of instability, while before it was almost ignored. Radiological instability signs have to be

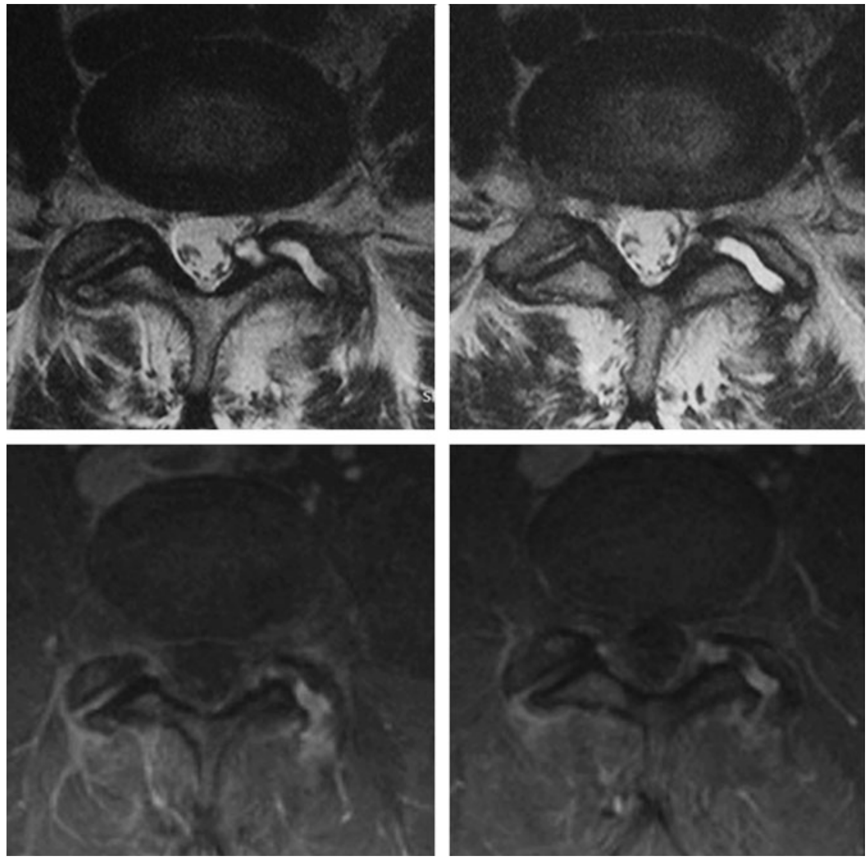

Fig. 7 T2 and T1-weighted axial images pointing out remarkable zygapophyseal joints and muscular degenerations

correlated with the patient's symptoms. Axial loader systems are not physiological and risk to "create" an instability, therefore orthostatic MRI and particularly dynamic orthostatic X-ray should be preferred. In this context multislice CT maintain a preferential role thanks to its resolution, as a complementary examination to MRI, in visualizing zygapophyseal joints, spondylolysis and pre-spondylolysis. Measurement technique of Dupuis et al. maintains a central role to quantify the entity of the instability [15].

Conclusions

Nowadays and in a recent future MRI should be preferred as first diagnostic examination when degenerative spine pathologies are suspected [1]. The other technological equipments (CT, X-Ray, dynamic orthostatic X-ray, myelography, discography and skeletal scintigraphy) have to be selectively chosen and adapted to the single patient. Radiologists should analyze both "container" and "contents" of the spine. Finally a correlation between clinical and radiological features seems to be mandatory for selecting the correct therapeutic choice, since the reliability of the MRI as potential prognostic indicator has been demonstrated [16].

Conflicts of Interest Statement We declare that we have no conflict of interest.

References

1. Ahmed M, Modic MT (2007) Neck and low back pain: neuroimaging. Neurol Clin 25:439–471
2. Carrage EJ, Lincoln T, Parmar VS et al (2006) A gold standard evaluation of the "discogenic pain" diagnosis as determined by provocative discography. Spine 31:2115–2123
3. Colosimo C, Cianfoni A, Di Lella GM, Gaudino S (2006) Contrast-enhanced MR imaging of the spine: when, why and how? How to optimize contrast protocols in MR imaging of the spine. Neuroradiology 48:18–33
4. Ross JS, Zepp R, Modic MT (1996) The postoperative lumbar spine: enhanced MR evaluation of the intervertebral disk. Am J Neuroradiol 17:323–331
5. Bellaiche L, Petrover D (2008) Imaging in chronic low back pain: which one and when? Rev Prat 58:273–278
6. Perry J, Haughton V, Anderson PA, Wu Y, Fine J, Mistretta C (2006) The value of T2 relaxation times to characterize lumbar intervertebral disks: preliminary results. Am J Neuroradiol 27:337–342

7. Schinnerer KA, Katz LD, Grauer JN (2008) MR findings of exaggerated fluid in facet joints predicts instability. J Spinal Disord Tech 21:468–472
8. Thompson RE, Pearcy MJ, Barker TM (2004) The mechanical effects of intervertebral disc lesions. Clin Biomech 19:448–455
9. Siddiqui AH, Rafique MZ, Ahmad MN, Usman MU (2005) Role of magnetic resonance imaging in lumbar spondylosis. J Coll Physicians Surg Pak 15:396–399
10. Brant-Zawadzki MN, Jensen MC, Obuchowski N et al (1995) Interobserver and intraobserver variability in the interpretation of lumbar disc abnormalities. A comparison of two nomenclatures. Spine 20:1257–1263
11. Modic MT, Ross JS (2007) Lumbar degenerative disk disease. Radiology 245:43–61
12. Thompson JP, Pearce, RH, Schechter M T, Adams M E, Tsang IK, Bishop PB (1990) Preliminary evalutation of a scheme for grading the gross morphology of the human intervertebral disc. Spine 15:411–415
13. Fardon DF, Milette PC (2001) Nomenclature and classification of lumbar disc pathology. Raccomandations of the combined task forces of the North American Spine Society, American Society of Spine Radiology, and American Society of Neuroradiology. Spine 26:93–113
14. Millette PC (2000) Classification, diagnostic imaging, and imaging characterization of a lumbar herniated disk. Radiol Clin North Am 38:1267–1292
15. Dupuis PR, Yong-Hing K, Cassidy JD, Kirkaldy-Willis WH (1985) Radiologic diagnosis of degenerative lumbar spinal instability. Spine 10:262–276
16. Carrino JA, Lurie JD, Tosteson AN, Tosteson TD, Carragee EJ, Kaiser J, Grove MR, Blood E, Pearson LH, Weinstein JN, Herzog R (2009) Lumbar spine: reliability of MR imaging findings. Radiology 250:161–170

Operative Management of Lumbar Disc Herniation
The Evolution of Knowledge and Surgical Techniques in the Last Century

F. Postacchini and R. Postacchini

Abstract Removal of a herniated disc with the use of the operative microscope was first performed by Yasargil (Adv Neurosurg. 4:81–2, 1977) in 1977. However, it began to be used more and more only in the late 1980s (McCulloch JA (1989) Principles of microsurgery for lumbar disc disease. Raven Press, New York). In the 1990s, many spinal surgeons abandoned conventional discectomy with naked-eye to pass to the routine practice of microdiscectomy. The merits of this technique are that it allows every type of disc herniation to be excised through a short approach to skin, fascia and muscles as well as a limited laminoarthrectomy. For these reasons, it has been, and still is, considered the "gold standard" of surgical treatment for lumbar disc herniation, and the method used by the vast majority of spinal surgeons. In the 1990s, the advent of MRI and the progressive increase in definition of this modality of imaging, as well as histopathologic and immunochemical studies of disc tissue and the analysis of the results of conservative treatments have considerably contributed to the knowledge of the natural evolution of a herniated disc. It was shown that disc herniation may decrease in size or disappear in a few weeks or months. Since the second half of the 1990s there has been a revival of percutaneous procedures. Some of these are similar to the percutaneous automated nucleotomy; other methods are represented by intradiscal injection of a mixture of "oxygen-ozone" (Alexandre A, Buric J, Paradiso R. et al. (2001) Intradiscal injection of oxygen ozone for the treatment of lumbar disc herniations: result at 5 years. 12th World Congress of Neurosurgery; 284–7), or laserdiscectomy performed under CT scan (Menchetti PPM. (2006) Laser Med Sci. 4:25–7). The really emerging procedure is that using an endoscope inserted into the disc through the intervertebral foramen to visualize the herniation and remove it manually using thin pituitary rongeurs, a radiofrequency probe or both (Chiu JC. (2004) Surg Technol Int. 13:276–86).

Microdiscectomy is still the standard method of treatment due to its simplicity, low rate of complications and high percentage of satisfactory results, which exceed 90% in the largest series. Endoscopic transforaminal discectomy appears to be a reliable method, able to give similar results to microdiscectomy, provided the surgeon is expert enough in the technique, which implies a long learning curve in order to perform the operation effectively, with no complications. All the non-endoscopic percutaneous procedures now available can be used, but the patient must be clearly informed that while the procedure is simple and rapid, at least for the disc L4–L5 and those above (except for laserdiscectomy under CT, that can be easily performed also at L5–S1), their success rate ranges from 60 to 70% and that, in many cases, pain may decrease slowly and may take even several weeks to disappear.

Keywords Microdiscectomy · Percutaneous techniques

A Short Historical Review

After the enormous scientific contribution provided by "*De Ischiade Nervosa. Commentarius*" of Cotugno [1] (1764), in which the author first ascribed sciatica to the involvement of the sciatic nerve, almost one century passed before herniation of the intervertebral disc was identified by Luschka [2], who, however, did not relate the pathologic findings to the clinical features of the disease.

The first discectomy was performed by Krause in 1908 at the Berlin Augusta Hospital on advice of the neuropathologist Oppenheim [3]. The patient obtained an immediate, complete relief of pain. The tissue responsible for the symptoms, however, was mistaken for an enchondroma.

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In 1911 Goldthwait and Osgood [4] reported on the case of a patient with paresis of the lower limbs, operated by Cushing, who found a disc protrusion which was interpreted as the cause of impingement of the nervous structures and thus responsible of the patient's sciatica and cauda equina syndrome. In the 1920s, Schmorl [5] started to study 10,000 human spines and described the protrusion of disc tissue in the vertebral body as well as disc herniation in the spinal canal; however he did not attribute any clinical significance to the latter findings.

In 1930 Alajouanine and Petit-Dutaillis [6] presented a case of sciatica associated with an intraspinal lesion at the Surgical Academy of Paris and suggested that what had previously been identified as a tumour actually was herniation of the nucleus pulposus. The first patient whose preoperative diagnosis was "ruptured intervertebral disc" was operated in 1932 by the neurosurgeon Mixter and the orthopaedic surgeon Barr [7]. Two years later, the authors correlated disc prolapse with the neurologic disorders associated with this condition and stressed the therapeutic role of the surgical treatment. In the following years, Filippi [8] analysed the changes occurring in the disc after removal of the nucleus pulposus, while De Sèze [9] stated that the nerve root is affected within the spinal canal before it enters the intervertebral foramen.

In 1938, Love and Walsh [10] reported on the clinical results of surgery in 100 patients with disc herniation and for the first time, a on recurrent herniation; in 1940, their cases reached 300. In 1948 Lane and Moore [11] reported on the removal of lumbar disc herniation through a transperitoneal approach.

The Explosion of Surgical Treatment

In the 1960s and 1970s, removal of a herniated disc became one of the most frequent operative procedures performed by orthopaedic surgeons and neurosurgeons. The preoperative diagnosis was made by myelography and electrodiagnostic studies, but most often it was based only on the clinical history and physical examination. It was common practice to operate any patients with radicular pain of even very recent onset. A few surgeons made the diagnosis by asking the patient to bend forward and scheduled an operative treatment simply on the finding of sciatic pain elicited by trunk flexion.

Since the level involved was often unclear, it was common practice to explore the last two lumbar discs in order not to miss a herniated disc. Many mild disc protrusions were thus operated on and when no herniation was found an etiologic role in the genesis of radicular symptoms and nerve root irritation or compression was attributed to epidural varices.

In most cases radical discectomy was performed. It consisted in the complete removal of the nucleus pulposus as well as the cartilaginous end plates by curettes used to grasp the cartilage as extensively as possible to avoid regrowth of the nucleus. Usually the result was a severe decrease in the height of the intervertebral space.

The Advent of Percutaneous Techniques

In the early 1960s Smith [12] published an experimental study showing that the intradiscal injection of chymopapain in rabbit dissolved the nucleus pulposus. In 1963 he successively treated the first patient with the enzyme. However, only in the late 1970s and 1980s this method of treatment, called chemonucleolysis, became more and more popular and hundreds of thousands of patients with a herniated disc received intradiscal chymopapain. And hundreds of studies were carried out, which found the therapeutic efficacy of the procedure to reach 70–80% [13]. This method was widely used in USA and Europe, but often also by inexperienced doctors. This was probably the main reason for the dramatic increase in complications, particularly the most severe ones, of the procedure, namely anaphylactic shock and cord lesions. This led, in the 1990s, to the progressive decrease in the use of chymopapain, which was then withdrawn from the market in many countries.

Parallel to the decrease in popularity of chemonucleolysis, a new percutaneous technique, first performed by Hijikata and Yamagishi [14] in 1975, began to be used in few centres, i.e. the manual removal of nucleus pulposus by a percutaneous posterolateral approach to the disc using small sized pituitary rongeurs. This technique, however, did not gain popularity, at that time, because another, technically simpler method – the percutaneous automated nucleotomy with the Onik instrumentation – was introduced in the market [15]. The latter technique rapidly reached the same popularity as chemonucleolysis because of its safety and the high percentage of satisfactory results initially reported. Subsequently, however, many studies demonstrated that the percentage of success of this procedure did not exceed, on average, 65%, a figure not significantly higher than that obtained with conservative management. In addition, this method, as the previous ones, was essentially indicated for contained herniation, that is a fairly small proportion of herniated discs. During the 1990s, this method was thus almost completely abandoned, even if the concept on which it was founded was considered valid by many researchers. The concept was that it might be sufficient to decrease the intradiscal pressure by making a hole in the