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Editors

Advances in Minimally Invasive Surgery and Therapy for Spine and Nerves

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Edited by
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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.

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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].

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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,

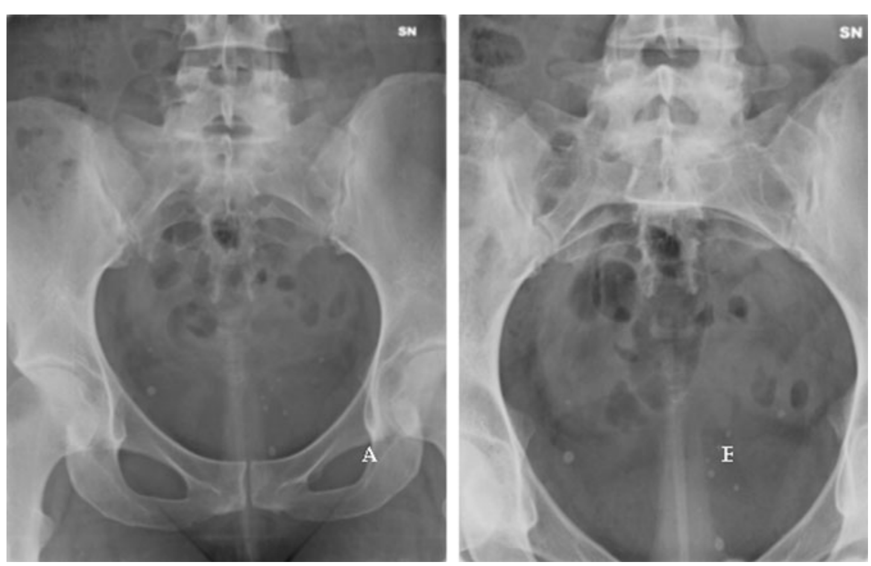

Fig. 1 Antero posterior radiograph of the sacrum showing the sacral hiatus

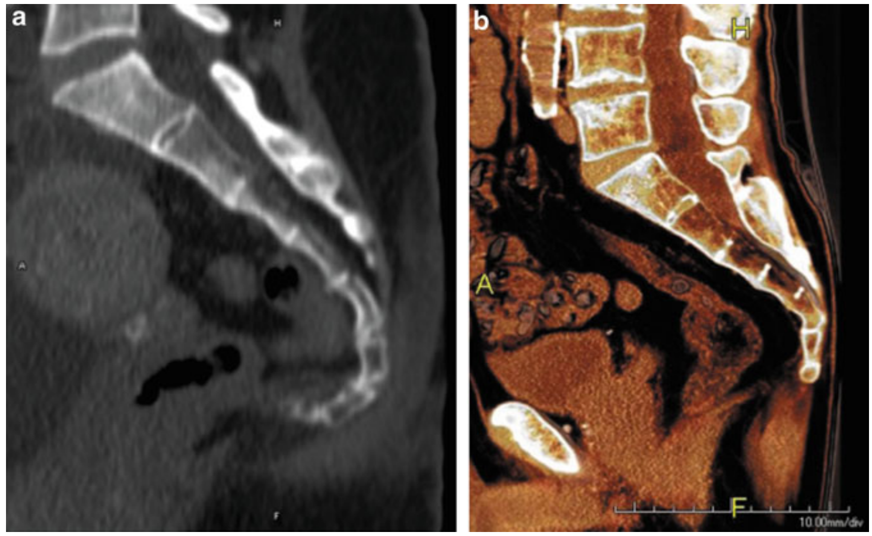

Fig. 2 CT sagittal image (**a**) and volume rendering reconstruction (**b**), showing the caudal space, the sacrococcygeal membrane appears hypodense (*asterisk*)

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.

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Imaging in Degenerative Spine Pathology

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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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