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Review

Dynamic MRI in the evaluation of the spine: state of the art

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Summary. *Introduction:* Degenerative disease of the spine is a generic term encompassing a wide range of different disease processes, which leads to spinal instability; traumatic/neoplastic events can accelerate this aging process. Therefore, the dynamic nature of the spine and its mobility across multiple segments is difficult to depict with any single imaging modality. *Methods:* A review of PubMed databases for articles published about kMRI in patients with cervical and lumbar spinal desease was performed. We focused on the physiopathological changes in the transition from supine to upright position in spine instability. *Discussion:* Until a few years ago, X-ray was the only imaging modality for the spine in the upright position. Of the imaging techniques currently available, MRI provides the greatest range of information and the most accurate delineation of soft-tissue and osseous structures. Conventional MRI examinations of the spine usually are performed in supine position, in functional rest, but the lumbar spine instability is often shown only by upright standing. This can result in negative findings, even in the presence of symptoms. Regardless, the final result is distorted. To overcome this limitation, Kinetic MRI (kMRI) can image patients in a weight-bearing position and in flexed and extended positions, thus revealing abnormalities that are missed by traditional MRI studies. *Conclusion:* Despite some limitations, the upright MRI can be a complementary investigation to the traditional methods when there are negative results in conventional MRI in symptomatic patients or when surgical therapy is scheduled. (www.actabiomedica.it)

Key words: kinetic MRI, spinal instability, upright position, dynamic imaging, weight-bearing MRI, lumbar stenosis, spine degeneration, cervical spine desease, disc degeneration, low back pain

Introduction

The spine is a complex biomechanical system with a double support and protection function. It can adapt to various stresses to which it is subjected by posture or daily activities but these functions presuppose spine stability.

Degenerative disease of the spine is a generic term encompassing a wide range of different disease processes, from herniated discs to the pathology of yellow ligaments, and traumatic events can accelerate this aging process (1-5).

Examples include low back pain, sciatica, spinal deformity, spinal tumors and spinal injury, including trauma to the spinal cord. Frequently these are related with a loss of stability (instability) particularly at the lumbar level (6-10).

Spinal instability can be defined as the loss of the ability of the spine under physiologic loads to maintain its patterns of displacement; there is no initial or additional neurologic deficit, no major deformity and no incapacitating pain (11-15) and it is due to a loss of stiffness (7, 16-20) with abnormal or excessive motion at one or more levels which can result in low back pain

(LBP) and can impair neural structures. Abnormal movements include angular rotation between vertebral segments, or translational motion where parallel vertebrae move past each other (21-25).

The intervertebral discs provide the majority of the spine intrinsic stability by resisting small movements, and disc degeneration is widely associated with segmental instability. In fact, minute differences in translational motion are linked to the degree of disc degeneration (26-30).

The nucleus pulposus is normally soft and deformable. It exhibits a characteristic hydrostatic pressure along with the inner annulus fibrosus. Degeneration in the intervertebral discs typically begins during the second decade of life in men and the third decade in women (31-35). With increasing age and degeneration, the nucleus becomes dehydrated, fibrous, and stiff; thereby providing less cushioning effect. This results in increased axial loading stress on the vertebral endplates, and endplate morphology remodeling may occur around the degenerated disc. Damage to an adjacent endplate or supporting trabeculae can also lead to signal changes in the vertebral endplate (36-40).

Degeneration then appears posteriorly in the facet joints, causing altered mechanical function of the disc and ultimately spinal instability and clinical symptoms (39, 41-45).

Imaging of the spine poses particular challenges, both to the radiologist and to the clinician. The dynamic nature of the spine and its mobility across multiple segments is difficult to depict with any single imaging modality (46-50).

We can find different phases in the chronic spinal degenerative cascade: in the dysfunction phase (occasional undefined pain epiodes, with no or minimal changes in the spinal joints) frequently there are no imaging findings; in the instability phase (characterized by more frequent to chronic pain episodes) multiple signs are appreciable on radiologic examinations (X-Ray, MRI, and CT scans), such as facets degeneration and disk space narrowing: these elements lead to abnormal vertebral movement and alignment, up to anterolisthesis or retrolisthesis (end plate, peduncle, and isthmic edema; Modic changes; traction spurs; extended discal vacuum; facets gapping with joint effusion or vacuum; synovial cysts; annular tears; spondylolysthesis; and retrolysthesis are typical imaging findings of the full-blown disease). In the final phase, restabilization, structural compensatory remodeling phenomena bring reduced mobility and stiffness. Marginal osteophytes, disk collapse, radial expansion of vertebral bodies and facets and end plate, spinous and transverse sclerosis: all these remodeling processes interrupt vertebral slippage but also block physiologic movements (6, 32, 51-55).

Unlike degenerative instability, the relationship between imaging findings and clinical symptoms tends to be more direct in traumatic spinal instability (56-60).

The thoracolumbar spine is the most common site afflicted by trauma; L1 is the most common vertebra followed by T12 (61-65). The most important finding in recognizing stable versus unstable fractures is the state of the posterior ligaments; the status of posterior ligaments after an injury is of great importance for the stability of the injured spine: the condition of the posterior column in fact suggests fracture instability, which increases remarkably in cases of lesions to the posterior ligaments (6, 45, 66-70).

Spinal instability can also be the result of a neoplastic process associated with movement-related pain, symptomatic or progressive deformity, neural compromise under physiologic loads and requires a specific and different set of criteria for stability assessment (71-75).

Imaging of the spine

Until a few years ago, X-ray was the only imaging modality for the spine in the upright position. This examination is valid and useful for evaluating spinal curvatures, but it shows its limitations for disc structures or when it is necessary to obtain measurements free from problems due to overlapping of anatomical images (67, 76-80).

Of the imaging technique scurrently available, magnetic resonance imaging (MRI) provides the greatest range of information and most accurate delineation of soft-tissue and osseous structures, enabling detection of subtle abnormalities with great sensitivity (2, 40, 69, 81-85).

MRI is a noninvasive diagnostic tool that is widely used to evaluate various diseases of the lumbar spine (86).

Conventional MRI examinations of the spine usually are performed in supine position, in functional rest, but the lumbar spine instability is often shown by upright standing and hidden in the supine position (87, 88).

However, it provides only non-weightbearing, static images, whereas spinal disorders, especially cervical and lumbar stenosis, are posture-dependent. This is unaccounted for in supine radiographs, computed tomography (CT), and magnetic resonance imaging (MRI) (89).

False negatives in the supine position are often due to patient position, with knees and hips bent and spinal variation with increasing breadth of the foramen and vertebral canal. Pathological conditions underlying clinical symptoms, often prompted by standing or sitting, are therefore not seen. This can result in negative findings, even in the presence of symptoms, or an underestimation of pathological specimens. Regardless, the final result is distorted (90). To overcome this limitation, radiographic studies of spinal kinematics have shown that changes occur in the seated and erect posture in relation. Kinetic MRI (kMRI) can image patients in a weight-bearing position (either standing up or sitting) and in flexed and extended positions, thus revealing abnormalities that are missed by traditional MRIstudies (91-93).

A first attempt to evaluate the spine under the loading condition was done with the axial load technique, which is to simulate physiological loading of the spine in the orthostatic position, both with CT and MRI, by compression devices which administer an axial compression force. Although results were certainly interesting, the technique has not achieved a general consensus. Studies with axial load, even if they allow better assessment in relation to the higher signalto-noise ratio (SNR) afforded by the high-field equipment, do not allow evaluation of the influence that physiological load - represented by the weight of the head and body and by muscle activation – has on the lumbar spine, simulating a load with caudate-cranial direction (94-96).

Dynamic MRI use open magnet scanners that allowed upright scanning in either seated or standing body position, which allow better performance in terms of assessment of spinal instability and variations of some pathologic conditions from recumbent to upright position.

Imaging of the spine in a weight-bearing position with extension and flexion or placing the spine in the position of pain may also increase the diagnostic accuracy also for spine surgeons (69, 97).

Usually the magnetic fields are 0.25 T, 0.5 T, and 0.6 T. Images are obtained with patient both supine and upright in the flexed, extended, rotated, standing, and bending positions. Cervical and lumbar spine are most commonly studied.

Evaluation of cervical degeneration by kMRI

kMRI may better relate the patient's clinical symptoms to objective images demonstrating pathology. The disc degeneration level can be difined as(98) :

- Grade 0 (no degeneration),
- Grade I (mild degeneration),
- Grade II (moderate degeneration),
- Grade III (severe degeneration).

Modic et al. identified and classified them into three types(99):

- type 1, hypointense signal on T1- weighted sequences and hyperintense signal on T2- weighted sequences;
- type 2, hyperintense signal on T1 sequences and hyper- or isointense signal on T2 sequences;
- type 3, hypointense signal on T1 and T2 sequences.

Histological and radiological studies have demonstrated that type 1 reflects inflammatory changes in the vertebral endplates; type 2 reflects fatty marrow; and type 3 represents sclerotic changes of the endplates.

kMRI can improve the evaluation of disc degeneration, but also the detection of cervical disc bulges. A significant increase in the degree of cervical disc bulge can be found in extension views when compared to neutral views alone. Extension MRI compared with traditional neutral MRI can reveal that the incidence of missed disc bulges is high. This suggests that extension MRI views yield a higher detection rate of missed

cervical disc bulges (more than flexion views). Flexion and extension MRI views provide valuable, additional information when assessing patients for cervical disc bulges and may be especially useful in situations where symptomatic radiculopathy is present with unimpressive traditional neutral MRI studies (Fig. 1) (100).

kMRI can also be used to evaluate patients with neck pain and no prior history of surgery. Although disc height, translational motion, and angular variation is significantly affected at the level of disc herniation, there is no apparent significant changes in adjacent segments. These findings indicate that, regardless of the degree of disc degeneration or the size of disc herniation, herniated discs have no effect on range of motion in adjacent levels, suggesting that the natural progression of disc degeneration and adjacent segment disease may be separate, unrelated processes within the cervical spine (101).

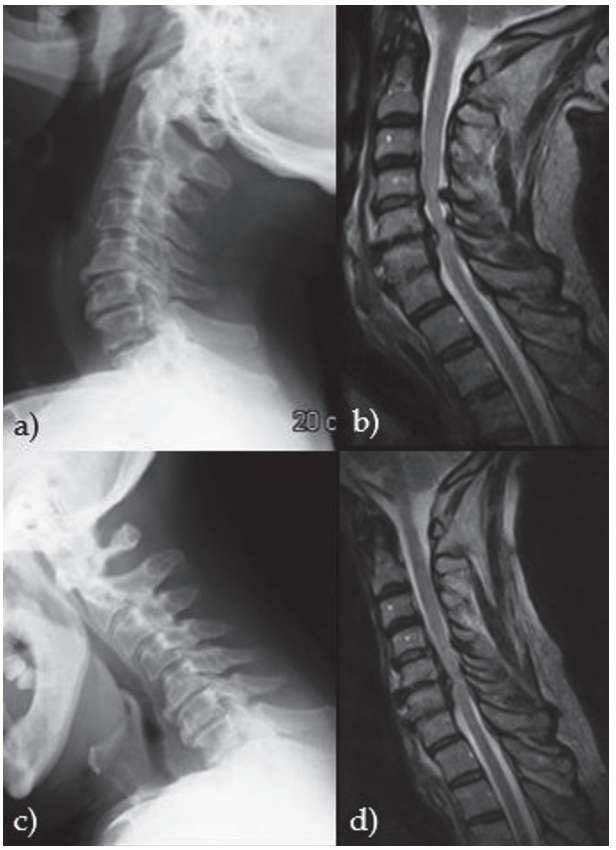

Figure 1. Cervical Spine MRI in extended (a, b) and flexed (c, d) position. The extended position better underlines both cervical disc bulges and the yellow ligament hypertrophy with its extrusion (unmatched aspect in the flexed position)

Changes in sagittal alignment of the cervical spine affect the kinematics and progress of cervical intervertebral disc degeneration (102).

In fact the degenerative process affects the mobility of the functional spinal unit, which moves from a normal disc to a more unstable phase with increased mobility and further degeneration. However, as the degeneration enters the later phases and becomes more severe, the range of motion stabilizes because ankylosis develops (103).

In general, the translation motion decreased from proximal segment to distal segment, and the disc from C2 to C6 moved posteriorly and C7 moved anteriorly (98).

Regarding the relationship between the grade of disc degeneration and motion of the segmental unit of the cervical, in severely degenerated segments (grade 5 discs), angular motion of C4-5 and C5-6 is significantly decreased (104).

Cervical segments with MCs at C4-5 and C5-6 have less motion than those without MCs, as well as segments with MCs have significantly severe disc degeneration. The segments with MCs likely tend to ankylose and lose mobility with severe degeneration (93).

With a MR analyzer software we can also measure the two-dimensional motion of the spinal on true MR images (98).

In normal cervical spines, most of the total angular mobility is attributable to C4-5 and C5-6 and that mobility is significantly reduced in these segments in patients with severe disc degeneration and in segments with severe cord compression compared with those with no cord compression (105, 106).

Cervical cord compression was defined as obliteration of the subarachnoid space in the presence of disc herniation, osteophyte formation, or hypertrophy of the ligamentum flavum (93).

Cervical cord compression at each segment can be evaluated using a 5-point grading scale (107, 108):

- 0: Normal width of the spinal canal, no signs of anterior and posterior subarachnoid space narrowing.
- 1: Partial obliteration of the anterior or posterior subarachnoid space or of both.

- 2: Complete obliteration of the anterior or posterior subarachnoid space or of both.
- 3: Anterior or posterior cord compression with the deformation of spinal cord .
- 4: Spinal cord impingement with the deformation of spinal cord from both anterior and posterior side.

Kinematic trait associated with a congenitally narrow canal may greatly contribute to pathological changes in the cervical spine. Cervical spinal canal diameter of less than 13 mm may be associated with an increased risk for development of pathological changes in cervical intervertebral discs. Subsequently, the presence of a congenitally narrow canal can expose individuals to a greater risk of developing cervical spinal stenosis (109).

Evaluation of lumbar degeneration by kMRI

An open-configuration, low-field tilting MRI system is a feasible and promising tool to study the degenerative pathology of the lumbar spine. It is important to evaluate and quantify the statistical significance of variations of some anatomical parameters of the lumbosacral spine and reveal occult disc pathologiesin the transition from recumbent to upright position in patients with acute and chronic low back pain.

Dynamic MRI allows to evaluate the following parameters (76):

1. **Lumbosacral angle**: It is defined as the anterior open-angle intercepted by two tangent lines of the anterior walls of L5 and S1. The lumbosacral angle decreases in relation to verticality of the spine, which is necessary to support the increase in weight. The normal range for this angle is 120-180°. An increased angle corresponds to vertical tilting of the sacrum, which biomechanically produces an increased load on the anterior column and accelerates the degenerative processes of the L5-S1 disc. On the contrary, a decreased lumbosacral angle is associated with sacrum horizontalization, which consequently creates an amplified load on the posterior elements (facet joints) (Fig. 2).
2. **Lordosis angle**: It is defined as the superior open angle intercepted between the two perpendicular lines to the tangent of the superior endplate of L1 and the inferior endplate of L5. This angle has a normal value of about 50°. The increase in lordosis angle reflects compensation by muscle contracture (Fig. 2).
3. **Disc height**: This is measured at the point of maximum distance between the inferior and superior endplates of two adjacent vertebrae. In standing position intervertebral disc thickness is reduced from supine to standing position. In particular, the reduction of disc height affects the posterior portion, whereas anteriorly there is a slight increase, with major changes at L2-L3 and L3-L4.
4. **Interspinous distance between two adjacent vertebrae.**
5. **Maximum anteroposterior diameter of the dural sac**.

The lumbar segments act as load-bearing, provision of movement, and protection of neural elements, in which endplate is the point of transfer of force between the vertebrae and the disc. Signal changes in the endplate described by Modic et al have been shown

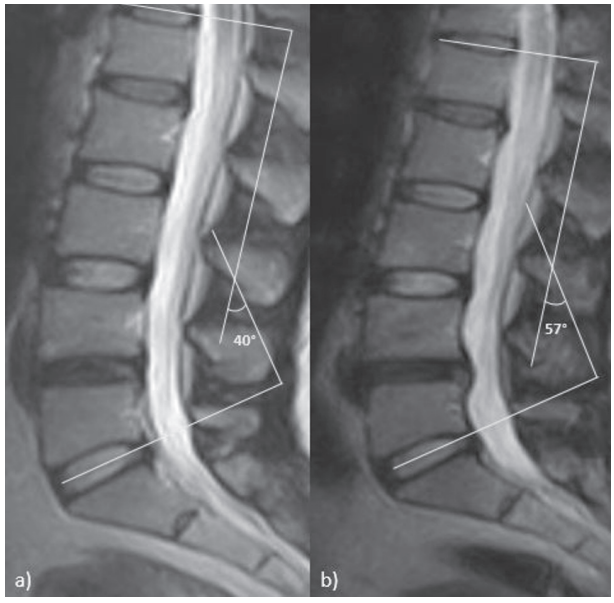

Figure 2. Fast spin echo (FSE) T2-weighted magnetic resonance images (MRI) in the sagittal plane. a) Supine position: lumbosacral angle 124°, lordosis angle 40°; b) Upright position: lumbosacral angle 115°, lordosis angle 57°

constitute the crucial element in the degenerative process around the disc in relation to LBP and clinical findings (38). Disc degeneration and Modic changes would probably reinforce each other because endplate disruption could lead to degenerative changes in the nucleus by various biological means and nucleus dehydration would lead to greater stress concentrations acting on the endplate (110) and disc degeneration with Modic changes is frequently associated with instability and LBP (111).

Therefore, it has been postulated that intervertebral disc and vertebral endplate degenerative changes would result in increased or abnormal spinal segmental motion (112).

The vertebral endplate has an important role in maintaining the integrity and function of the intervertebral disc and endplate remodeling may occur around the disc in response to altered load distributions (37, 113).

Endplate remodeling may occur as an adaptation to restrain abnormal movement of the lumbar segment. Using KMRI, analized sagittal endplate shape at each level of the lumbar spine. It was categorized as concave, flat, or irregular: concave if the lateral endplate image demonstrated a smooth concave curvature; flat if the endplate seemed to be a straight line with no apparent curvature; irregular if the endplate seemed convex, jagged, or rough due to calcification.

Translational motion in the lumbar spine is greatest in the proximal lumbar levels whereas angular motion is similar in the mid-lumbar levels but decreased at L1-L2 and L5-S1 (114) and it is higher at levels with irregular endplates and progressively decreased at those with flat and then concaves endplates. Angular motions follow the opposite trend (115).

It is possible also to define 3 stages of degeneration with accompanying changes in stability and motion. The first stage is characterized by temporary dysfunction with early signs of disc degeneration and fi brillation of the articular cartilage. The second stage involves unstable, abnormal movement of the spinal units. The third, most advanced stage, accompanies secondary responses in adjacent osseous and soft-tissue structures that restabilize the spine (116).

Lumbar degeneration is also closely associated with abnormal segmental motion. Abnormal segmental motion noted on kinetic MR images is closely associated with disc degeneration, facet joint osteoarthritis, and the pathological characteristics of the interspinous ligaments, ligamentum flavum and paraspinal muscles. By measuring abnormal segmental motion and grading radiographic parameters simultaneously, kMRI of patients with mechanical back pain may provide valuable information about the stability of the functional spine unit (117). Also joint degeneration and ligamentum flavum status are an important factor in spine degeneration with increasing age (118, 119).

Facet tropism has been investigated as a predisposing factor for degenerative changes in the lumbar spine (Fig 3).

Facet tropism is defined as asymmetry between the orientation angles of the right and left vertebral facet joints. It has been investigated as a predisposing factor for degenerative changes in the lumbar spine. Do et al. defined mild facet tropism as a bilateral angle positive difference between the mean (6°) and +1 SD (11°), based on the L4-L5 distribution, and severe facet tropism as a difference greater than +1 SD. Although mean facet asymmetry increases from L3-L4 to L5-S1, the distribution of facet asymmetry at those levels is not significantly different, so it is possible to use a single definition for all three levels. Age is also associated with increased severity of facet tropism (120).

kMRI can be used to assess the relationship between degree of facet tropism and amount of dynamic disc bulge in the lumbar spine in patients with low back pain. Severe facet tropism is associated with increased disc bulge at L4-L5 in older patients (121).

Facet joint degeneration is followed by disc degeneration with increasing age and that segmental mobility is influenced by disc degeneration, facet joint osteoarthritis and ligament pathology. Therefore, the current status of the intervertebral discs, facet joints and ligamentum flavum should be taken into consideration when evaluating stability within the lumbar spine. Lumbar segmental instability has been recognized as a cause of low back pain and a highly controversial concept (118).

Segmental instability is defined kinematically as the abnormal increased motion of each vertebra com-

pared to the normal range of motion of normal spines (122). The many causes of instability include fractures, dislocations, tumors, infections, scoliosis, spondylolisthesis, and degenerative changes. Instability can result in pain and put the neural structures at risk (123).

Facet joint degeneration is followed by disc degeneration with increasing age and that segmental mobility is influenced by disc degeneration, facet joint osteoarthritis, ligament pathology and conjugation phoramen variations (Fig.4).

Therefore, the current status of the intervertebral discs, facet joints and ligamentum flavum should be taken into consideration when evaluating stability within the lumbar spine (118).

Using kMRI, excessive translational motion significantly increased in patients with grade IV discs, but decreased when the disc degeneration advanced to grade V. Angular motion was similar regardless of disc grade, excet in grade V degeneration in which angular motion decreased significantly (124).

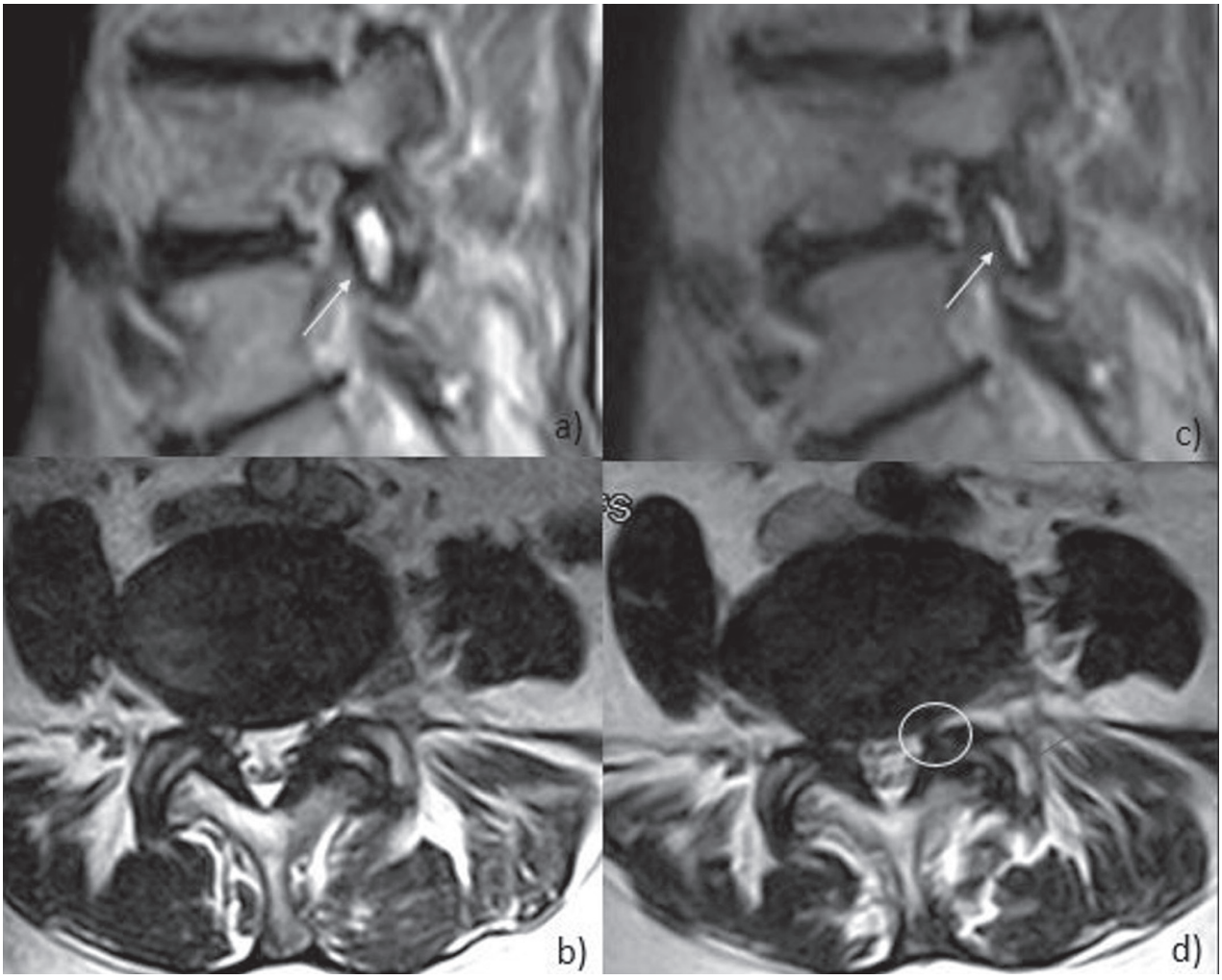

Figure 3. Fast spin echo (FSE) T2-weighted MRI images in the sagittal and axial planes in supine position (a, b) and in weightbearing position (c, d). The upright images show a reduction of conjugate phoramen and an anterior sliding of the right joint capsule with reduction of the neural foramen. The degree of disc and facet joint degeneration has a positive association with excessive translational motion while the degree of facet joint degeneration has a negative association with excessive angular motion

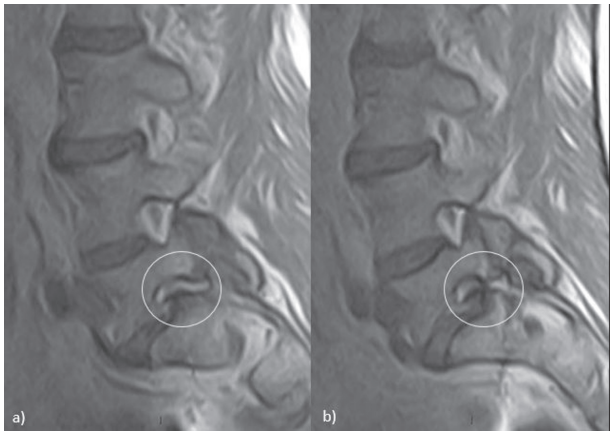

Figure 4. Conjugation foramen width in the transition from supine (a) to upright position (b)

Limits

Dynamic MRI is a promising technique because it can more thoroughly investigates each patient and facilitates better understanding of the true nature of the spine pathology (115).

Despite this, it also entails some limitations, first of all represented by the low-field magnet resulting in a low signal-to-noise ratio with a reduced image quality compared with the common high-field magnet (76).

Another important limit is the long scanning time compared with conventional supine MRI because of the additional acquisitions in upright standing, which induces pain problems exacerbated by upright position and motion artefacts; symptomatic patients, in fact, may find difficult to maintain the immobility position necessary for the whole duration of the imaging acquisition in the upright position. Consequently, difficulties can occur in reproducing the positioning between the sequences (76).

These limits could be partially balanced by the use of 3-D scan protocol with a precise postprocessing reconstruction using the MPR algorithm with an effective thickness of 1 mm, parallel to the vertebral end plate in the coronal and sagittal planes (125).

Finally, some investigators also reported an occasional difficulty encountered in evaluating the most lateral areas of the spine, such as exit foramen and lateral recesses, due to section thickness and degree of patient rotation and lateral flexion. These devices also have the advantage of eliminating a patient's feeling of claustrophobia, which sometimes limits diagnostic evaluation of the spine (76, 96).

Conclusions

Clinical disorders of the human spine actually have a high prevalence in society and they are frequently related with a loss of spine stability, particularly at the lumbar level, for traumatic, neoplastic, and degenerative factors. These are causes of spinal pain and disability with a high social and economic impact.

Therefore, imaging of the spine poses particular challenges for radiologists because the dynamic nature of the spine is difficult to depict with any single imaging modality.

Supine MRI remains the technique of choice for detecting degenerative spine disease associated with acute and chronic pain. However, conventional MRI performed in the supine position sometimes is unable to answer the clinical question because the patient position can hide the presence of spine instability signs and bring to false negative results. In these cases and when it is necessary to assess more accurately the degree of spinal instability, particularly if surgical therapy is scheduled, the upright MRI can be a complementary investigation to the traditional methods.

Upright or postural MRI is conceptually the modality of choice for dynamic imaging of the spine. It combines the superior contrast resolution of MRI with the advantages of imaging the spine in a truly functional position and may more specifically and sensitively relate the patient's clinical symptoms to objective imaging evidences. The literature has widely demonstrated its potential usefulness in cases of occult stenosis, dynamic disc herniations, and spinal instability and it also can assist in the planning of complex surgical procedures.

Therefore, despite the limits associated with the higher impact on time and costs and with a lower tolerabilty by the suffering patients, kMRI can become a promising technique in the diagnostic path of spine desease with a high diagnostic accuracy and a full evaluation of all involved factors.

References

1. Gallucci M, Limbucci N, Paonessa A, Splendiani A. Degenerative disease of the spine. Neuroimaging Clin N Am 2007; 17(1): 87-103.
2. Splendiani A, Bruno F, Patriarca L, Barile A, Di Cesare E, Masciocchi C, et al. Thoracic spine trauma: advanced imaging modality. Radiol Med 2016; 121(10): 780-92.
3. Floridi C, Radaelli A, Abi-Jaoudeh N, Grass M, De Lin M, Chiaradia M, et al. C-arm cone-beam computed tomography in interventional oncology: Technical aspects and clinical applications. Radiol Med 2014; 119(7): 521-32.
4. Carotti M, Salaffi F, Di Carlo M, Giovagnoni A. Relationship between magnetic resonance imaging findings, radiological grading, psychological distress and pain in patients with symptomatic knee osteoarthritis. Radiol Med 2017.
5. Valeri G, Ferrara C, Ercolani P, De Nigris E, Giovagnoni A. Tendon involvement in rheumatoid arthritis of the wrist: MRI findings. Skeletal Radiol 2001; 30(3): 138-43.
6. Izzo R, Guarnieri G, Guglielmi G, Muto M. Biomechanics of the spine. Part II: Spinal instability. Eur J Radiol 2013; 82(1): 127-38.
7. De Filippo M, Corsi A, Evaristi L, Bertoldi C, Sverzellati N, Averna R, et al. Critical issues in radiology requests and reports. Radiol Med 2011; 116(1): 152-62.
8. de Filippo M, Azzali E, Pesce A, Saba L, Mostardi M, Borgia D, et al. CT arthrography for evaluation of autologous chondrocyte and chondral-inductor scaffold implantation in the osteochondral lesions of the talus. Acta Biomedica 2016; 87(3): 51-6.
9. Cataldi V, Laporta T, Sverzellati N, De Filippo M, Zompatori M. Detection of incidental vertebral fractures on routine lateral chest radiographs. Radiol Med 2008; 113(7): 968-77.
10. Azzali E, Milanese G, Martella I, Ruggirello M, Seletti V, Ganazzoli C, et al. Imaging of osteonecrosis of the femoral head. Acta Biomed 2016; 87 Suppl 3: 6-12.
11. White AA, 3rd, Panjabi MM. The basic kinematics of the human spine. A review of past and current knowledge. Spine (Phila Pa 1976) 1978; 3(1): 12-20.
12. Bernuzzi G, Petraglia F, Pedrini MF, De Filippo M, Pogliacomi F, Verdano MA, et al. Use of platelet-rich plasma in the care of sports injuries: our experience with ultrasound-guided injection. Blood Transfus 2014; 12 Suppl 1: s229-34.
13. De Filippo M, Rovani C, Sudberry JJ, Rossi F, Pogliacomi F, Zompatori M. Magnetic resonance imaging comparison of intra-articular cavernous synovial hemangioma and cystic synovial hyperplasia of the knee. Acta Radiol 2006; 47(6): 581-4.
14. De Filippo M, Pogliacomi F, Bertellini A, Araoz PA, Averna R, Sverzellati N, et al. MDCT arthrography of the wrist: diagnostic accuracy and indications. Eur J Radiol 2010; 74(1): 221-5.
15. De Filippo M, Bertellini A, Sverzellati N, Pogliacomi F, Costantino C, Vitale M, et al. Multidetector computed tomography arthrography of the shoulder: diagnostic accuracy and indications. Acta Radiol 2008; 49(5): 540-9.
16. Izzo R, Popolizio T, D'Aprile P, Muto M. Spinal pain. Eur J Radiol 2015; 84(5): 746-56.
17. Miele V, Andreoli C, Grassi R. The management of emergency radiology: Key facts. Eur J Radiol 2006; 59(3): 311-4.
18. De Cecco CN, Buffa V, Fedeli S, Vallone A, Ruopoli R, Luzietti M, et al. Preliminary experience with abdominal dual-energy CT (DECT): True versus virtual nonenhanced images of the liver. Radiol Med 2010; 115(8): 1258-66.
19. Pinto F, Miele V, Scaglione M, Pinto A. The use of contrast-enhanced ultrasound in blunt abdominal trauma: Advantages and limitations. Acta Radiol 2014; 55(7): 776-84.
20. Miele V, Piccolo CL, Sessa B, Trinci M, Galluzzo M. Comparison between MRI and CEUS in the follow-up of patients with blunt abdominal trauma managed conservatively. Radiol Med 2016; 121(1): 27-37.
21. Sato H, Kikuchi S. The natural history of radiographic instability of the lumbar spine. Spine (Phila Pa 1976) 1993; 18(14): 2075-9.
22. Miele V, Piccolo CL, Galluzzo M, Ianniello S, Sessa B, Trinci M. Contrast-enhanced ultrasound (CEUS) in blunt abdominal trauma. Br J Radiol 2016; 89 (1061).
23. Miele V, Piccolo CL, Trinci M, Galluzzo M, Ianniello S, Brunese L. Diagnostic imaging of blunt abdominal trauma in pediatric patients. Radiol Med 2016;121(5): 409-30.
24. Grassi R, Lombardi G, Reginelli A, Capasso F, Romano F, Floriani I, et al. Coccygeal movement: assessment with dynamic MRI. Eur J Radiol 2007; 61(3): 473-9.
25. Muto M, Perrotta V, Guarnieri G, Lavanga A, Vassallo P, Reginelli R, et al. Vertebroplasty and kyphoplasty: Friends or foes? Radiol Med 2008; 113(8): 1171-84.
26. Karadimas EJ, Siddiqui M, Smith FW, Wardlaw D. Positional MRI changes in supine versus sitting postures in patients with degenerative lumbar spine. J Spinal Disord Tech 2006; 19(7): 495-500.
27. Briganti F, Delehaye L, Leone G, Sicignano C, Buono G, Marseglia M, et al. Flow diverter device for the treatment of small middle cerebral artery aneurysms. J NeuroIntervent Surg 8 2016; (3); 287-294.
28. Caranci F, Tedeschi E, Leone G, Reginelli A, Gatta G, Pinto A, et al. Errors in neuroradiology. Radiol Med 2015; 120(9): 795-801.
29. Reginelli A, Pinto A, Russo A, Fontanella G, Rossi C, Del Prete A, et al. Sharp penetrating wounds: spectrum of imaging findings and legal aspects in the emergency setting. Radiol Med 2015; 120(9): 856-65.
30. Pinto A, Reginelli A, Pinto F, Sica G, Scaglione M, Berger FH, et al. Radiological and practical aspects of body packing. Br J Radiol 2014; 87(1036).
31. Zigler J, Strausser D. The aging spine. In: Surgeons RAAoO, editor. Orthopaedic knowledge update: spine 22002. p. 122-33.
32. Cappabianca S, Colella G, Pezzullo MG, Russo A, Iaselli F, Brunese L, et al. Lipomatous lesions of the head and neck

region: Imaging findings in comparison with histological type. Radiol Med 2008; 113(5): 758-70.
33. Nurzynska D, Di Meglio F, Castaldo C, Latino F, Romano V, Miraglia R, et al. Flatfoot in children: anatomy of decision making. Ital J Anat Embryol 2012; 117(2): 98-106.
34. Pinto A, Brunese L, Pinto F, Acampora C, Romano L. E-learning and education in radiology. Eur J Radiol 2011; 78(3): 368-71.
35. Zappia M, Cuomo G, Martino MT, Reginelli A, Brunese L. The effect of foot position on Power Doppler Ultrasound grading of Achilles enthesitis. Rheumatol Int 2016; 36(6): 871-4.
36. Antoniou J, Steffen T, Nelson F, Winterbottom N, Hollander AP, Poole RA, et al. The human lumbar intervertebral disc: evidence for changes in the biosynthesis and denaturation of the extracellular matrix with growth, maturation, ageing, and degeneration. J Clin Invest 1996; 98(4): 996-1003.
37. Grant JP, Oxland TR, Dvorak MF, Fisher CG. The effects of bone density and disc degeneration on the structural property distributions in the lower lumbar vertebral endplates. J Orthop Res 2002; 20(5): 1115-20.
38. Modic MT, Steinberg PM, Ross JS, Masaryk TJ, Carter JR. Degenerative disk disease: assessment of changes in vertebral body marrow with MR imaging. Radiology 1988; 166(1 Pt 1): 193-9.
39. Russo A, Reginelli A, Zappia M, Rossi C, Fabozzi G, Cerrato M, et al. Ankle fracture: radiographic approach according to the Lauge-Hansen classification. Musculoskelet Surg 2013; 97 Suppl 2: S155-60.
40. Barile A, La Marra A, Arrigoni F, Mariani S, Zugaro L, Splendiani A, et al. Anaesthetics, steroids and platelet-rich plasma (PRP) in ultrasound-guided musculoskeletal procedures. Br J Radiol 2016; 89(1065).
41. Avinash G, Ioannis N, Leonard I. Biomechanics of the spine. In: Spivak J, Connolly P, editors. Orthopaedic knowledge update: spine 32006. p. 25-32.
42. Perrotta FM, Astorri D, Zappia M, Reginelli A, Brunese L, Lubrano E. An ultrasonographic study of enthesis in early psoriatic arthritis patients naive to traditional and biologic DMARDs treatment. Rheumatol Int 2016; 36(11): 1579-83.
43. Zappia M, Di Pietto F, Aliprandi A, Pozza S, De Petro P, Muda A, et al. Multi-modal imaging of adhesive capsulitis of the shoulder. Insights Imaging 2016; 7(3): 365-71.
44. Zappia M, Carfora M, Romano AM, Reginelli A, Brunese L, Rotondo A, et al. Sonography of chondral print on humeral head. Skelet Radiol 2016; 45(1): 35-40.
45. Di Pietto F, Chianca V, de Ritis R, Cesarano E, Reginelli A, Barile A, et al. Postoperative imaging in arthroscopic hip surgery. Musculoskeletal Surg 2017; 101: 43-9.
46. Wilke HJ, Neef P, Caimi M, Hoogland T, Claes LE. New in vivo measurements of pressures in the intervertebral disc in daily life. Spine (Phila Pa 1976) 1999; 24(8): 755-62.
47. Cappabianca S, Colella G, Russo A, Pezzullo M, Reginelli A, Iaselli F, et al. Maxillofacial fibrous dysplasia: personal experience with gadoliniumenhanced magnetic resonance imaging. Radiol Med 2008; 113(8): 1198-210.
48. Cappabianca S, Scuotto A, Iaselli F, Pignatelli di Spinazzola N, Urraro F, Sarti G, et al. Computed tomography and magnetic resonance angiography in the evaluation of aberrant origin of the external carotid artery branches. Surg Radiol Anat 2012; 34(5): 393-9.
49. Iudici M, Cuomo G, Vettori S, Bocchino M, Sanduzzi Zamparelli A, Cappabianca S, et al. Low-dose pulse cyclophosphamide in interstitial lung disease associated with systemic sclerosis (SSc-ILD): efficacy of maintenance immunosuppression in responders and non-responders. Semin Arthritis Rheum 2015; 44(4): 437-44.
50. Valentini G, Marcoccia A, Cuomo G, Vettori S, Iudici M, Bondanini F, et al. Early systemic sclerosis: analysis of the disease course in patients with marker autoantibody and/or capillaroscopic positivity. Arthritis Care Res (Hoboken) 2014; 66(10): 1520-7.
51. Valentini G, Marcoccia A, Cuomo G, Vettori S, Iudici M, Bondanini F, et al. Early systemic sclerosis: marker autoantibodies and videocapillaroscopy patterns are each associated with distinct clinical, functional and cellular activation markers. Arthritis Res Ther 2013; 15(3): R63.
52. Cappabianca S, Iaselli F, Negro A, Basile A, Reginelli A, Grassi R, et al. Magnetic resonance imaging in the evaluation of anatomical risk factors for pediatric obstructive sleep apnoea-hypopnoea: a pilot study. Int J Pediatr Otorhinolaryngol 2013; 77(1): 69-75.
53. Caranci F, Napoli M, Cirillo M, Briganti G, Brunese L, Briganti F. Basilar artery hypoplasia. Neuroradiol J 2012; 25(6): 739-43.
54. Muccio CF, Di Blasi A, Esposito G, Brunese L, D'Arco F, Caranci F. Perfusion and spectroscopy magnetic resonance imaging in a case of lymphocytic vasculitis mimicking brain tumor. Pol J Radiol 2013; 78(3): 66-9.
55. Briganti F, Delehaye L, Leone G, Sicignano C, Buono G, Marseglia M, et al. Flow diverter device for the treatment of small middle cerebral artery aneurysms. J Neurointervent Surg 2016; 8(3): 287-94.
56. Barile A, Limbucci N, Splendiani A, Gallucci M, Masciocchi C. Spinal injury in sport. Eur J Radiol 2007; 62(1): 68-78.
57. Pinto A, Pinto F, Faggian A, Rubino G, Caranci F, Macarini L, ert al. Sources of error in emergency ultrasonography. Critical Ultrasound Journal 2013; 5 (suppl 1): 1-5.
58. Caranci F, Briganti F, La Porta M, Antinolfi G, Cesarano E, Fonio P, et al. Magnetic resonance imaging in brachial plexus injury. Musculoskeletal Surg 2013;97(suppl 2): S181-S90.
59. Briganti F, Tedeschi E, Leone G, Marseglia M, Cicala D, Giamundo M, et al. Endovascular treatment of vertebrovertebral arteriovenous fistula. A report of three cases and literature review. Neuroradiol J 2013; 26(3): 339-46.
60. Izzo R, Guarnieri G, Guglielmi G, Muto M. Biomechanics of the spine. Part I: Spinal stability. Eur J Radiol 2013; 82(1): 118-26.

61. Azam MQ, Sadat-Ali M. The Concept of Evolution of Thoracolumbar Fracture Classifications Helps in Surgical Decisions. Asian Spine J 2015; 9(6): 984-94.
62. Masala S, Nano G, Marcia S, Muto M, Fucci FPM, Simonetti G. Osteoporotic vertebral compression fractures augmentation by injectable partly resorbable ceramic bone substitute (Cerament™|SPINE SUPPORT): A prospective nonrandomized study. Neuroradiology 2012; 54(6): 589-96.
63. Guarnieri G, Vassallo P, Pezzullo MG, Laghi F, Zeccolini F, Ambrosanio G, et al. A comparison of minimally invasive techniques in percutaneous treatment of lumbar herniated discs a review. Neuroradiol J 2009; 22(1): 108-21.
64. Lanzillo R, Prinster A, Scarano V, Liuzzi R, Coppola G, Florio C, et al. Neuropsychological assessment, quantitative MRI and ApoE gene polymorphisms in a series of MS patients treated with IFN beta-1b. J Neurol Sci 2006; 245(1-2): 141-5.
65. Splendiani A, Perri M, Marsecano C, Vellucci V, Michelini G, Barile A, et al. Effects of serial macrocyclic-based contrast materials gadoterate meglumine and gadobutrol administrations on gadolinium-related dentate nuclei signal increases in unenhanced T1-weighted brain: a retrospective study in 158 multiple sclerosis (MS) patients. Radiol Med 2017.
66. Barile A, Arrigoni F, Bruno F, Guglielmi G, Zappia M, Reginelli A, et al. Computed Tomography and MR Imaging in Rheumatoid Arthritis. Radiol Clin North Am. 2017.
67. Bruno F, Smaldone F, Varrassi M, Arrigoni F, Barile A, Di Cesare E, et al. MRI findings in lumbar spine following O2-O3 chemiodiscolysis: A long-term follow-up. Interv Neuroradiol 2017; 23(4): 444-50.
68. Reginelli A, Zappia M, Barile A, Brunese L. Strategies of imaging after orthopedic surgery. Musculoskeletal Surg 2017; 101.
69. Splendiani A, D'Orazio F, Patriarca L, Arrigoni F, Caranci F, Fonio P, et al. Imaging of post-operative spine in intervertebral disc pathology. Musculoskeletal Surg 2017; 101: 75-84.
70. Patriarca L, Letteriello M, Di Cesare E, Barile A, Gallucci M, Splendiani A. Does evaluator experience have an impact on the diagnosis of lumbar spine instability in dynamic MRI? Interobserver agreement study. Neuroradiol J 2015; 28(3): 341-6.
71. Fisher CG, DiPaola CP, Ryken TC, Bilsky MH, Shaffrey CI, Berven SH, et al. A novel classification system for spinal instability in neoplastic disease: an evidence-based approach and expert consensus from the Spine Oncology Study Group. Spine (Phila Pa 1976) 2010; 35(22): E1221-9.
72. Masciocchi C, Conchiglia A, Conti L, Barile A. Imaging of insufficiency fractures. Geriatric Imaging: Springer-Verlag Berlin Heidelberg; 2013. p. 83-91.
73. Barile A, Conti L, Lanni G, Calvisi V, Masciocchi C. Evaluation of medial meniscus tears and meniscal stability: Weight-bearing MRI vs arthroscopy. Eur J Radiol 2013; 82(4): 633-9.
74. Masciocchi C, Conti L, D'Orazio F, Conchiglia A, Lanni G, Barile A. Errors in musculoskeletal MRI. Errors in Radiology: Springer-Verlag Milan; 2012. p. 209-17.
75. Gallucci M, Limbucci N, Zugaro L, Barile A, Stavroulis E, Ricci A, et al. Sciatica: Treatment with intradiscal and intraforaminal injections of steroid and oxygen-ozone versus steroid only. Radiology 2007; 242(3): 907-13.
76. Tarantino U, Fanucci E, Iundusi R, Celi M, Altobelli S, Gasbarra E, et al. Lumbar spine MRI in upright position for diagnosing acute and chronic low back pain: statistical analysis of morphological changes. J Orthop Traumatol 2013; 14(1): 15-22.
77. Ripani M, Continenza MA, Cacchio A, Barile A, Parisi A, De Paulis F. The ischiatic region: normal and MRI anatomy. J Sports Med Phys Fitness 2006; 46(3): 468-75.
78. Splendiani A, Puglielli E, De Amicis R, Barile A, Masciocchi C, Gallucci M. Spontaneous resolution of lumbar disk herniation: predictive signs for prognostic evaluation. Neuroradiology 2004; 46(11): 916-22.
79. Di Zazzo E, Porcile C, Bartollino S, Moncharmont B. Critical Function of PRDM2 in the Neoplastic Growth of Testicular Germ Cell Tumors. Biology (Basel) 2016; 5(4).
80. Arrigoni F, Barile A, Zugaro L, Splendiani A, Di Cesare E, Caranci F, et al. Intra-articular benign bone lesions treated with Magnetic Resonance-guided Focused Ultrasound (MRgFUS): imaging follow-up and clinical results. Med Oncol 2017; 34(4).
81. Mariani S, La Marra A, Arrigoni F, Necozione S, Splendiani A, Di Cesare E, et al. Dynamic measurement of patello-femoral joint alignment using weight-bearing magnetic resonance imaging (WB-MRI). Eur J Radiol 2015; 84(12): 2571-8.
82. Barile A, Arrigoni F, Zugaro L, Zappia M, Cazzato RL, Garnon J, et al. Minimally invasive treatments of painful bone lesions: state of the art. Med Oncol 2017; 34(4).
83. Giordano AV, Arrigoni F, Bruno F, Carducci S, Varrassi M, Zugaro L, et al. Interventional Radiology Management of a Ruptured Lumbar Artery Pseudoaneurysm after Cryoablation and Vertebroplasty of a Lumbar Metastasis. Cardiovasc Intervent Radiol 2017; 40(5): 776-9.
84. Reginelli A, Capasso R, Ciccone V, Croce MR, Di Grezia G, Carbone M, et al. Usefulness of triphasic CT aortic angiography in acute and surveillance: Our experience in the assessment of acute aortic dissection and endoleak. Int J Surg 2016; 33: S76-S84.
85. Masciocchi C, Arrigoni F, Marra AL, Mariani S, Zugaro L, Barile A. Treatment of focal benign lesions of the bone: MRgFUS and RFA. Br J Radiol 2016; 89(1066).
86. Perri M, Grattacaso G, di Tunno V, Marsecano C, Gennarelli A, Michelini G, et al. T2 shine-through phenomena in diffusion-weighted MR imaging of lumbar discs after oxygen-ozone discolysis: a randomized, double-blind trial with steroid and O2-O3 discolysis versus steroid only. Radiol Med 2015; 120(10): 941-50.
87. Splendiani A, Perri M, Grattacaso G, Di Tunno V, Marsecano C, Panebianco L, et al. Magnetic resonance imaging (MRI) of the lumbar spine with dedicated G-scan machine

in the upright position: a retrospective study and our experience in 10 years with 4305 patients. Radiol Med 2016; 121(1): 38-44.
88. Kanno H, Ozawa H, Koizumi Y, Morozumi N, Aizawa T, Ishii Y, et al. Changes in lumbar spondylolisthesis on axial-loaded MRI: do they reproduce the positional changes in the degree of olisthesis observed on X-ray images in the standing position? Spine J 2015; 15(6): 1255-62.
89. Yu W, Williams S. Spinal imaging: radiographs, computed tomography, and magnetic resonance imaging. In: Spivak J, Connolly P, editors. Orthopaedic knowledge update: spine 3: Rosemont: American Academy of Orthopaedic Surgeons 2006. p. 57-67.
90. Claus A, Hides J, Moseley GL, Hodges P. Sitting versus standing: does the intradiscal pressure cause disc degeneration or low back pain? J Electromyogr Kinesiol 2008; 18(4): 550-8.
91. Ruangchainikom M, Daubs MD, Suzuki A, Hayashi T, Weintraub G, Lee CJ, et al. Effect of cervical kyphotic deformity type on the motion characteristics and dynamic spinal cord compression. Spine (Phila Pa 1976) 2014; 39(12): 932-8.
92. Lord EL, Alobaidan R, Takahashi S, Cohen JR, Wang CJ, Wang BJ, et al. Kinetic magnetic resonance imaging of the cervical spine: a review of the literature. Global Spine J 2014; 4(2): 121-8.
93. Hayashi T, Daubs MD, Suzuki A, Phan K, Shiba K, Wang JC. Effect of Modic changes on spinal canal stenosis and segmental motion in cervical spine. Eur Spine J 2014; 23(8): 1737-42.
94. Vitzthum HE, Konig A, Seifert V. Dynamic examination of the lumbar spine by using vertical, open magnetic resonance imaging. J Neurosurg 2000; 93(1 Suppl): 58-64.
95. Manenti G, Liccardo G, Sergiacomi G, Ferrante L, D'Andrea G, Konda D, et al. Axial loading MRI of the lumbar spine. In Vivo 2003; 17(5): 413-20.
96. Weishaupt D, Schmid MR, Zanetti M, Boos N, Romanowski B, Kissling RO, et al. Positional MR imaging of the lumbar spine: does it demonstrate nerve root compromise not visible at conventional MR imaging? Radiology 2000; 215(1): 247-53.
97. Splendiani A, Perri M, Conchiglia A, Fasano F, Di Egidio G, Masciocchi C, et al. MR assessment of lumbar disk herniation treated with oxygen-ozone diskolysis: The role of DWI and related ADC versus intervertebral disk volumetric analysis for detecting treatment response. Neuroradiol J 2013; 26(3): 347-56.
98. Xiong C, Suzuki A, Daubs MD, Scott T, Phan K, Wang J. The evaluation of cervical spine mobility without significant spondylosis by kMRI. Eur Spine J 2015; 24(12): 2799-806.
99. Modic MT, Masaryk TJ, Ross JS, Carter JR. Imaging of degenerative disk disease. Radiology 1988; 168(1): 177-86.
100. Lao L, Daubs MD, Scott TP, Phan KH, Wang JC. Missed cervical disc bulges diagnosed with kinematic magnetic resonance imaging. Eur Spine J 2014; 23(8): 1725-9.
101. Daffner SD, Xin J, Taghavi CE, Hymanson HJ, Mudiyam C, Hongyu W, et al. Cervical Segmental Motion at Levels Adjacent to Disc Herniation as Determined With Kinetic Magnetic Resonance Imaging. Spine 2009; 34(22): 2389-94.
102. Miyazaki M, Hymanson HJ, Morishita Y, He W, Zhang H, Wu G, et al. Kinematic analysis of the relationship between sagittal alignment and disc degeneration in the cervical spine. Spine (Phila Pa 1976) 2008; 33(23): E870-6.
103. Dvir Z, Gal-Eshel N, Shamir B, Prushansky T, Pevzner E, Peretz C. Cervical motion in patients with chronic disorders of the cervical spine: a reproducibility study. Spine (Phila Pa 1976) 2006; 31(13): E394-9.
104. Miyazaki M, Hong SW, Yoon SH, Zou J, Tow B, Alanay A, et al. Kinematic analysis of the relationship between the grade of disc degeneration and motion unit of the cervical spine. Spine (Phila Pa 1976) 2008; 33(2): 187-93.
105. Morishita Y, Hida S, Miyazaki M, Hong SW, Zou J, Wei F, et al. The effects of the degenerative changes in the functional spinal unit on the kinematics of the cervical spine. Spine (Phila Pa 1976) 2008; 33(6): E178-82.
106. Morishita Y, Hymanson H, Miyazaki M, Zhang HH, He W, Wu G, et al. Kinematic evaluation of the spine: a kinetic magnetic resonance imaging study. J Orthop Surg (Hong Kong) 2008; 16(3): 348-50.
107. Muhle C, Metzner J, Weinert D, Falliner A, Brinkmann G, Mehdorn MH, et al. Classification system based on kinematic MR imaging in cervical spondylitic myelopathy. AJNR Am J Neuroradiol 1998; 19(9): 1763-71.
108. Suzuki A, Daubs MD, Inoue H, Hayashi T, Aghdasi B, Montgomery SR, et al. Prevalence and motion characteristics of degenerative cervical spondylolisthesis in the symptomatic adult. Spine (Phila Pa 1976) 2013; 38(17): E1115-20.
109. Morishita Y, Naito M, Hymanson H, Miyazaki M, Wu G, Wang JC. The relationship between the cervical spinal canal diameter and the pathological changes in the cervical spine. Eur Spine J 2009; 18(6): 877-83.
110. Adams MA, McMillan DW, Green TP, Dolan P. Sustained loading generates stress concentrations in lumbar intervertebral discs. Spine (Phila Pa 1976) 1996; 21(4): 434-8.
111. Kjaer P, Korsholm L, Bendix T, Sorensen JS, Leboeuf-Yde C. Modic changes and their associations with clinical findings. European Spine Journal 2006; 15(9): 1312-9.
112. Fujiwara A, Lim TH, An HS, Tanaka N, Jeon CH, Andersson GB, et al. The effect of disc degeneration and facet joint osteoarthritis on the segmental flexibility of the lumbar spine. Spine (Phila Pa 1976) 2000; 25(23): 3036-44.
113. Grant JP, Oxland TR, Dvorak MF. Mapping the structural properties of the lumbosacral vertebral endplates. Spine (Phila Pa 1976) 2001; 26(8): 889-96.
114. Tan Y, Aghdasi BG, Montgomery SR, Inoue H, Lu C, Wang JC. Kinetic magnetic resonance imaging analysis of lumbar segmental mobility in patients without significant spondylosis. European Spine Journal 2012; 21(12): 2673-9.

115. Yawei L, Lord E, Yermie C, Monchai R, Bing W, Guohua L, et al. Effects of Sagittal Endplate Shape on Lumbar Segmental Mobility as Evaluated by Kinetic Magnetic Resonance Imaging. Spine 392014. p. 1035-41.
116. Kirkaldy-Willis WH, Farfan HF. Instability of the lumbar spine. Clin Orthop Relat Res 1982(165): 110-23.
117. Jang SY, Kong MH, Hymanson HJ, Jin TK, Song KY, Wang JC. Radiographic parameters of segmental instability in lumbar spine using kinetic MRI. Journal of Korean Neurosurgical Society 2009; 45(1): 24-31.
118. Kong MH, Hymanson HJ, Song KY, Chin DK, Cho YE, Yoon DH, et al. Kinetic magnetic resonance imaging analysis of abnormal segmental motion of the functional spine unit. J Neurosurg Spine 2009; 10(4): 357-65.
119. Kong MH, Morishita Y, He W, Miyazaki M, Zhang H, Wu G, et al. Lumbar segmental mobility according to the grade of the disc, the facet joint, the muscle, and the ligament pathology by using kinetic magnetic resonance imaging. Spine (Phila Pa 1976) 2009; 34(23): 2537-44.
120. Kalichman L, Suri P, Guermazi A, Li L, Hunter DJ. Facet orientation and tropism: associations with facet joint osteoarthritis and degeneratives. Spine (Phila Pa 1976) 2009; 34(16): E579-85.
121. Do DH, Taghavi CE, Fong W, Kong MH, Morishita Y, Wang JC. The relationship between degree of facet tropism and amount of dynamic disc bulge in lumbar spine of patients symptomatic for low back pain. European Spine Journal 2011; 20(1): 71-8.
122. Axelsson P, Karlsson BS. Intervertebral mobility in the progressive degenerative process. A radiostereometric analysis. Eur Spine J 2004; 13(6): 567-72.
123. Perri M, Grattacaso G, Di Tunno V, Marsecano C, Di Cesare E, Splendiani A, et al. MRI DWI/ADC signal predicts shrinkage of lumbar disc herniation after O2-O3 discolysis. Neuroradiol J 2015; 28(2): 198-204.
124. Lao LF, Zhong GB, Li QY, Liu ZD. Kinetic magnetic resonance imaging analysis of spinal degeneration: a systematic review. Orthop Surg 2014; 6(4): 294-9.
125. Splendiani A, Ferrari F, Barile A, Masciocchi C, Gallucci M. Occult neural foraminal stenosis caused by association between disc degeneration and facet joint osteoarthritis: demonstration with dedicated upright MRI system. Radiol Med 2014; 119(3): 164-74.

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