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EDITORIAL

Imaging of the spine: Where do we stand?

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Abstract

The number of patients presenting with spine-related problems has globally increased, with an enormous growing demand for the use of medical imaging to address this problem. The last three decades witnessed great leaps for diagnostic imaging modalities, including those exploited for imaging the spine. These developments improved our diagnostic capabilities in different spinal pathologies, especially with multi-detector computed tomography and magnetic resonance imaging, *via* both hardware and software improvisations. Nowadays, imaging may depict subtle spinal instability caused by various osseous and ligamentous failures, and could elucidate dynamic instabilities. Consequently, recent diagnostic modalities can discern clinically relevant spinal canal stenosis. Likewise, improvement in diagnostic imaging capabilities revolutionized our understanding of spinal degenerative diseases *via* quantitative biomarkers rather than mere subjective perspectives. Furthermore, prognostication of spinal cord injury has become feasible, and this is expected to be translated into better effective patient tailoring to management plans with better clinical outcomes. Meanwhile, our confidence in diagnosing spinal infections and assessing the different spinal instrumentation has greatly improved over the past few last decades. Overall, revolutions in diagnostic imaging over the past few decades have upgraded spinal imaging from simple subjective and qualitative indices into a more sophisticated yet precise era of objective metrics *via* deploying quantitative imaging biomarkers.

Key words: Spine; Radiography; Multi-detector computed tomography; Magnetic resonance Imaging

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Core tip: Advancements in diagnostic imaging over the last few decades have developed spinal imaging from simple subjective and qualitative indices into a more sophisticated yet precise era of objective metrics *via* deploying quantitative imaging biomarkers. These have revolutionized our understanding of the patho-physiological basis of a lot of spinal pathologies and spinal biomechanics that were not previously available. This is projected to improve patient care from both diagnostic and prognostic perspectives in the near future.

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INTRODUCTION

Over the last few decades, the number of patients presenting with spine-related problems has globally increased across all age groups with variable etiologic factors, of which degenerative diseases constitute the major bulk[1,2]. Subsequently, more imaging modalities are exploited to address these health problems, with a rise of the total health expenditure[1,2]. Furthermore, our understanding of spinal biomechanics has been evolved over the last 25 years[3]. This imposed a great demand for more qualitative indices of the different imaging modalities, which have grown enormously over that time. Meanwhile, the efficient use of these new diagnostic tools in different clinical scenarios requires judicial deployment for improved cost-effective and patient-tailored management plans[4].

Spinal imaging is complicated by the complex anatomy, different osseous, and soft tissue components and biomechanics of the spines[3]. Since the early days of radiology, the spine was assessed by plain radiography that was limited to assessment of osseous elements and its projections. By the mid-1970s, computed tomography (CT) started to reproduce clinically useful two- and three-dimensional images of the spine. A few years later, a major breakthrough of spinal imaging has been achieved thanks to the introduction of magnetic resonance imaging (MRI) that enabled non-invasive visualization of the spine anatomy. Since then, continual technological improvements in CT and MRI have continued. Consequently, progressive improvement in health care of patients with spine-related disorders has followed[5].

SPINAL INSTABILITY

With regards to spinal instability, dynamic upright radiographs have been the cornerstone for assessing spinal motion segmental instability for decades. However, they are inconvenient in trauma, and suffer from both measurement errors as well as dimensional limitations[6]. More importantly, radiographs miss the soft tissue factors associated with instabilities[6]. Besides, subtle spinal instabilities may not be recognized on conventional non-weight-bearing CT and MRI in the recumbent position where they might be self-reduced[7].By the current millennium, axial loading on both CT and MR imaging were visionary tools in the work-up of spinal instability[8,9]. However, some argued that the parameters assessed differ from those measured in the upright position and dismiss the actual variable effects of body weight, gravity and neuromuscular factors working on the spine in the erect posture that may be clinically relevant[9,10].

On the other hand, volumetric isotropic high resolution CT imaging, achieved by the introduction of multi-detector CT (MDCT) in clinical practice during the last 15years, made identification of subtle instabilities caused by osseous failure amenable, especially in trauma settings[11]. In parallel, technologic advances in MRI (hard- and soft-wares); including the availability of vertical gap open MRI systems and functional devices that can be applied on high-field units; allowed the investigation of spinal instabilities in a feasibly functional way with acceptable reproducibility[12]. Thus, MRI may nowadays depict subtle spinal instability caused by various ligamentous failures, and could elucidate dynamic instabilities caused by movements using novel dynamic MRI with the advantage of non-ionizing radiation exposure.

ADOLESCENT SPINAL DEFORMITIES

Upright serial radiography of the spine has been the gold standard for evaluating adolescent spinal deformities, with subsequent deriving of quantitative indices of angular deformities, as well as judgment of curve structure and spine flexibility for optimized management[13]. However, it is disadvantaged for repeated exposure to ionizing radiation[14,15]. Besides, the development of 3D rendering of adolescent spinal deformities and the various interplaying factors in adolescent spinal deformities, such

as spino-pelvic relationship, diurnal variations, and the effect of different groups of acting muscles, questioned the reliability of 2D radiographic imaging[16,17].

By the year 2000, EOS Imaging® had been introduced as low radiation dose equipment that produce both 2D and 3D images of the whole spine comparable to those acquired by CT and similarly reproducible measurements[18,19].

Furthermore, ultrasound has been explored for the evaluation of spinal scoliotic curves, vertebral rotation deformities and skeletal maturity, with the goal to reduce radiation exposure to a minimum with encouraging results[20,21].

On the other hand, medical imaging using real-time image guidance and computerized navigational systems has revolutionized the spinal surgical procedures for better surgical planning, minimal invasiveness, and optimized outcomes[22]. However, discussion of these advancements is beyond the scope of this editorial.

SPINAL DEGENERATIVE DISEASE

Currently, MRI is the benchmark for imaging spinal degenerative disorders, thanks to its exquisite soft tissue contrast and the superb identification of intervertebral disk zonal anatomy. In addition, it is capable of addressing degenerative marrow changes of the spine, as well as inflammatory changes induced by degenerative disc disease that are largely responsible for patient symptoms[23]. Promisingly, emerging functional MR techniques, such as T2/T2* mapping, T1ρ calculation, T2 relaxation time measurement, diffusion quantitative imaging, chemical exchange saturation transfer and MR spectroscopy, have shown the potential to quantitatively address the disk's zonal chemical composition with a greater ability to discern painful spines that warrant different clinical interventions[24-28]. A recent frontier is the study of stiffness of the intervertebral discs *via* MR elastography shear propagation[29]. Walter *et al*[29]found significant developments in intervertebral discs stiffness in the higher grades of disc degenerations, and this showed significant correlation with the classic Pfirrmann's scoring system. These advances are projected to be clinically implemented in the forthcoming years as non-invasive mechanical biomarkers of spinal degeneration. This may result in a revolution in patient-tailored management strategies by using targeted novel minimally-invasive interventions[30].

SPINAL CANAL STENOSIS

In the spectrum of degenerative spinal disease, spinal canal stenosis is an increasingly recognized reason for spinal imaging, especially in the elderly. It results from a myriad of spinal pathologic entities, of which degenerative processes prevail[31]. CT and/or myelography have been employed to elucidate morphologic changes associated with neural compromise in the central neural canal, lateral recess or at foramen levels. However, MRI surpassed these modalities thanks to the lack of ionizing radiation and invasiveness, as well as its surplus soft tissue contrast[32].

There are many considerations to be accounted for when imaging spinal canal stenosis. Firstly, the imaging diagnosis of spinal stenosis relies mainly on arguable subjective and objective imaging indices to suspect the existence of neurovascular compromise[33,34]. Among these variables, antero-posterior dimensions of the spinal canal, its cross-sectional area and spinal cord-CSF congruity were the most agreed parameters for diagnosing central stenosis[33]. Notably, the compression of the nerve root at the lateral recess was the most acceptable index of lateral recess stenosis[33]. Furthermore, nerve root impingement and foraminal zone compromise were the most consensual parameters for diagnosis of foraminal stenosis[34]. Secondly, not all imaging of spinal stenosis is clinically symptomatic[35]. A judicial clinical assessment is crucial for evaluating the relevance of the imaging findings in view of the proper clinical settings[36]. Thirdly, and to add complexity, spinal canal stenosis should be perceived as a dynamic phenomenon. A lot of spinal canal stenosis subjects report position-dependent symptoms due to postural changes in the dimensions of the spinal canal[12,37].

Taking the aforementioned points into account, further functional imaging workup became of immense importance to discern clinically-relevant canal stenosis. Nowadays, axial-loaded MR and MDCT cross-sectional studies, as well as upright and dynamic MR systems, may be deployed to elucidate the cause of radicular pain in symptomatic spinal stenosis subjects with routine imaging studies with equivocal results[8,10,12,37]. Despite this, logistics as well as economic factors and clinical consensus are limiting the widespread clinical adoption of these tools, especially in developing countries.

Another remarkable achievement for MR imaging of the spine is the wide availability of newer MR techniques. As an example, 3D volumetric T2-high resolution sequences, whether those employing the steady-state precession principle *e.g.*, CISS (constructive interference in steady state) or those based on fast-spin imaging *e.g.*, SPACE (Sampling Perfection with Application optimized Contrast Evolution), combine high resolution, clear T2 contrast and non-distorted visualization in different orthogonal planes due to their isotropic sampling[38]. These tools yield better signal-to-noise ratios of different spinal structures in a clinically-relevant shorter acquisition time. Furthermore, they accurately depicted spinal cord lesions, as well as the spinal nerve roots and those based on fast spin imaging that advantageously resist motion and susceptibility artifacts[38,39]. These advances allowed a robust rapid screening for vague cervical and low back pain causes, including spinal degenerative disease and spinal stenosis, which subsequently increases the radiology departments' potency and lessens MRI abuse in an economically compromised health system[40,41].

SPINAL TRAUMA

Spinal trauma and its devastating sequels are considered a major cause for emergency room admissions and rehabilitation program admissions worldwide, respectively[42,43]. Over the last decade, MDCT has been considered the benchmark for clearance of spinal trauma patients as a result of robust data acquisition and provided spatial resolution[44]. Though further MR imaging may not be warranted, the utility of MRI in assessing the severity of soft tissue injuries may affect clinical outcomes and should not be underestimated, especially in spinal cord injury (SCI) patients[45]. Over the years, conventional MR sequences like TSE and STIR depicted the presence and extent of subtle vertebral fractures and spinal cord edema. Nevertheless, it remains limited due to its inability to address degenerative and regenerative processes at the microstructural level of the spinal cord. Currently, a novel array of MR techniques such as susceptibility weighted (SW), diffusion weighted (DW) and diffusion tensor imaging (DTI) are revolutionizing SCI imaging, with improved clinical decision making and clinical outcome. For instance, SW is able to assess spinal cord petechial hemorrhages an important neural recovery prognostication index[46]. Furthermore, DW and DTI are becoming more handy clinical tools that show promise in addressing the spinal cord micro-architecture[47]. They can non-invasively provide quantitative probing of directional diffusivities of cord tracts, as well as assess SCI, its recovery, and remyelination[48]. Another potential for MR imaging is functional MRI, which is based on neural activation-induced changes resulting from oxygen and water molecules shifts between the intra- and extra-vascular spaces[49]. Clinical trials showed its ability to reveal spinal cord injuries and monitor results of rehabilitation[50].

SPINAL INFECTION

Spinal infection continues to be a challenge to both clinician and radiologists alike. Though infectious spondylitis and spondylodiskitis are uncommon, they remain as increasingly recognized health problems worldwide. This may be due to growing life expectancy across most communities, prevalence of chronic diseases, outbreaks of immune-suppression, and increased spinal instrumentation procedures[51].

MR imaging exhibited the highest sensitivity and specificity of all imaging modalities to diagnose spinal infections because of its superb soft tissue contrast, lack of ionizing radiation and different image weights that depict early pathologic changes in marrow, disc and soft tissues[52]. Dynamic contrast-enhanced magnetic resonance proved to be useful supplements in differentiating spinal infection when conventional MR sequences are equivocal[53]. The use of DW may be an excellent alternative where contrast use is not advocated[54]. Recently,[18]F-FDG-PET has offered a promising comparable sensitivity and specificity to MR in the diagnosis of spinal infection and its anatomic extents when MRI use is unlikely, as in the case of spinal instrumentations[55].

On the other hand, CT can diagnose spinal infection by documenting bony changes in established spinal infections and depicting soft tissue calcifications in TB spondylitis. Interestingly, CT perfusion parameters showed the potential to non-invasively differentiate neoplastic and inflammatory paraspinal masses, a fairly common arduous diagnostic task[56]. Furthermore, it has carved its niche as a widely acceptable handy tool for guiding MSK biopsies and drainage procedures for spinal infections[57].

SPINAL INSTRUMENTATION

Over the last few decades, there was an escalating trend in the number of spinal instrumentation deployed to manage different spinal pathological entities[2,58]. Subsequently, there has been robust growth in the requested imaging procedures that assess outcomes and instrument-related complications. Radiography used to be the convenient imaging tool employed for this purpose. In contrast, the use of CT and MR was hampered by beam-hardening and magnetic susceptibility artifacts; respectively[58]. Over the last two decades, synchronous advances in MDCT and MR technologies, coupled with similar developments in spinal hardware materials have revolutionized imaging of those patients.

The reduction of metallic artifacts in MDCT has been achieved via the use of anti-scatter grids and collimation, along with improved post-processing reconstruction algorithms, especially when dual energy (DE) CT is exploited[59]. Likewise, new MR techniques such as view angle tilting, slice encoding for metal artifact correction, and multi-acquisition variable-resonance image combination, used solely or in hybrid, have been clinically exploited to overcome susceptibility artifacts produced by implanted spinal hardware[60]. These improvements have been translated into enhanced diagnostic imaging quality, thus enabling better chances for fruitful clinical outcomes.

CONCLUSION

In conclusion, significant improvements in diagnostic imaging over the last few decades have upgraded spinal imaging from simple subjective and qualitative indices into a more sophisticated yet precise era of objective metrics via deploying quantitative imaging biomarkers. These have revolutionized our understanding of the patho-physiological basis of many spinal pathologies and spinal biomechanics that were not available previously. Consequently, these developments are projected to improve patient care from both diagnostic and prognostic perspectives in the near future.

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