Neuroimaging of Spinal Instability

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KEYWORDS

• Back pain • Spinal instability • Dynamic radiography • CT • Dynamic MRI • Open MRI scanner

KEY POINTS

- Degenerative, traumatic, and neoplastic instabilities are based on different pathophysiologic mechanisms, so each pattern requires a peculiar integrated clinical-radiologic approach.
- Dynamic radiographs with upright true lateral neutral-flexion-extension projections are still the most widely used imaging approach to diagnose instability in the daily practice.
- In traumatic instability, computerized tomography (CT) is the preferred image modality because it is able to detect quickly even the tiniest unstable fractures with reduced patient manipulation.
- Conventional MRI acquired in supine rest position often correlates poorly with clinical findings because of the loaded positional dependence of patient symptoms.
- Novel dynamic MRI approaches simulate closely the pathologic conditions that elicit symptoms in patients with instability, providing strict linkage between clinical status and imaging.

INTRODUCTION

The human spine is a complex biomechanical system composed of multiple articular structures controlled by muscles. It has 2 principal crucial functions: support and protection. The spine supports the head and trunk and protects the spinal cord, nerve roots, and vertebral arteries during every movement. Furthermore, it transfers power forces between upper and lower limbs.

These functions presuppose spine stability; however, even though several articles have been published about this concept, a consensus definition of stability is still lacking.

Clinical problems of the human spine continue to be prevalent in society. Examples include low back pain, sciatica, spinal deformity in both adults and children, spinal tumors, and spinal injury, including trauma to the spinal cord.[1] Frequently these are related with a loss of stability (instability) particularly at the lumbar level. Traumatic, neoplastic, and degenerative instability are important causes of spinal pain and disability.[2]

Conventional radiology with dynamic projections has long been considered the technical reference to assess the degree of instability,[3] and different methods have been developed to assess the presence of listhesis; however, radiography has proved inadequate to assess stability in case of spinal fractures.[4] Furthermore, because patients with instability frequently present concomitant disk and radicular pathologies, conventional radiography is limited by its diagnostic use in the assessment of these structures. CT, instead, yields high-resolution reconstructions in every spatial plane to detect even the tiniest fractures, revealing potentially unstable lesions.

MRI is the only imaging modality that directly assesses ligaments integrity, which is crucial for spine stability. In the past 2 decades, novel loaded

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MRI systems have been developed to evaluate instability in a more realistic pathologic condition, adding relevant information to conventional supine MRI.[5–7]

This article reviews the basic pathologic concepts of spinal instability and describes the role of the different imaging techniques in the assessment of this clinical issue.

PATHOLOGIC PRINCIPLES OF INSTABILITY

Spinal stability depends on the interaction of 2 strictly related elements, column and muscles, under the control of the central nervous system.[8] The loss of stability leads to instability, because for stability, a univocal definition has not been agreed on, even if it remains critical in the surgical decision-making process. White and Panjabi[9] defined instability as "the loss of the ability of the spine under physiologic loads to maintain its patterns of displacement so there is no initial or additional neurologic deficit, no major deformity, and no incapacitating pain."[9] Pope and colleagues[10] intended instability as a loss of stiffness leading to abnormal and increased movement in the motion segments. Spinal movements are 3-D with coupled movements, so spine instability always causes dysfunctional motions in more than 1 direction.

There are different patterns of instability based on the pathophysiologic mechanisms that sustain the process: degenerative, traumatic, and neoplastic.

Degenerative Instability

Spinal degenerative instability is a common cause of pain and disability. This pathologic process starts with the lesion of a component of the column, leading to an inappropriate response of the muscles and consequently an erroneous positional feedback of the column. In this way, a vicious circle causes a chronic dysfunction and pain through 3 steps, the degenerative cascade: dysfunction, instability, and restabilization.

Dysfunction phase

The dysfunction phase is characterized by an occasional undefined low back pain, with no or minimal changes in the spinal joints; frequently in this situation no imaging findings are appreciable.

Instability phase

In the instability phase, back pain becomes more and more frequent to chronic. 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. At the beginning of the instability phase, the process is usually limited to a single joint but then, it involves the adjacent joints, resulting in a multifocal pathology. 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.[2] Sometimes on standard supine scans, signs of instability are available but vertebral alignment is preserved; however, this alignment is a misleading condition due to the absence of load bearing. In these cases, a dynamic radiograph or an upright MRI is suitable to diagnose occult instability.[11]

Restabilization phase

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.

Traumatic Instability

Unlike degenerative instability, the relationship between imaging findings and clinical symptoms tends to be more direct in traumatic spinal instability. Every time a trauma damages a column element, it produces a certain degree of instability; all spinal components contribute to stability. Different studies have analyzed the effects of trauma on the spine and different models have been developed. Denis[12] proposed a model formed by 3 vertical columns: an anterior column, including the anterior halves of the bodies and disks with the adjacent anterior longitudinal ligament; a middle column, including the posterior half of the bodies and disks with posterior longitudinal ligament; and a posterior column, consisting of neural arches and the posterior ligamentous complex, including the supraspinous, interspinous, and flava ligaments and facet joint capsules. Denis assessed that instability was due to the simultaneous failure of at least 2 columns, creating situations of instability.[12] Today Denis's model remains among the most accepted references.

Although a considerable amount of energy is required to produce the first injury in a vertebra, just a small additional trauma is sufficient to convert a lesion from stable to unstable and to switch from conservative treatment to surgical stabilization.[2]