Lumbar Segmental Instability and Deformity

Lomber Segmental İnstabilite ve Deformite

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ABSTRACT

Lumbar spine instability develops as a result of a gradual degenerative process. Segmental instability causes chronic low back pain and decreases the quality of life of the patient. The deformity that develops secondary to lumbar instability is seen as coronal and sagittal imbalance. The diagnosis is made with the radiological and clinical findings. Surgery and stabilization is necessary for those patients when conservative treatment modalities fail.

KEYWORDS: Deformity, Segmental instability, Instrumentation

ÖZ

Dejenerasyon başlayan omurgada zaman içerisinde stabilite bozulmakta ve instabilite gelişmektedir. Omurga segmentindeki değişikliklere bağlı olarak ortaya çıkan segmental instabilite kronik bel ağrısına yol açarak hastanın yaşam kalitesini bozmaktadır. İnstabilite sonrasında ortaya çıkan deformite hem sagital hem koronal planda balans bozukluğu ile karşımıza çıkmaktadır. İnstabilite ve deformite tanısı için radyolojik incelemeler ve klinik bulgular önemlidir. Konservatif tedaviden fayda görmeyen hastalara stabilizasyon uygulanmaktadır.

ANAHTAR SÖZCÜKLER: Deformite, Segmental instabilite, Enstrümantasyon

LUMBAR SEGMENTAL INSTABILITY

Lumbar segmental instability is a disorder occupying an important place in the patient group with chronic back pain. We encounter this entity less than we expect in our spine surgery practice because of the fact that it cannot be described in detail and viewed adequately. The reason may be due to the absence of any gold standard in the diagnosis and treatment methods of this disease.

Anatomic and biomechanical characteristics of the normal segment

To sufficiently understand the issue, anatomic, physiological and biomechanical characteristics of the structure that stabilize the spine and the lumbar spine segment must be known.

A Functional Spinal Unit (FSU) is the smallest physiological motion unit reflecting biomechanical characteristics in the entire spine. FSU (motion segment) consists of two adjacent vertebra, intervertebral disc and ligaments. This segment supports physiological and excessive loads overlapping on top of it, and also enables flexion, extension, lateral bending and neutral rotation in the sagittal, coronal and axial planes. Motion of the spine in every direction has a certain limit and level and they are defined as Range of Motion (ROM). Motion within physiological limits and conservation of ROM (range of motion) are very important for a stable spine. The motion that occurs within the spine with active movement of the muscles is limited by facets, disc, frontal and posterior ligament structures and stability is preserved by preventing excessive motion (1).

Compression at the front of the disc and an opening in facet joints develop during flexion motion at the sagittal plane. Any excessive motion that may occur is prevented especially by the posterior ligaments (interspinous and supraspinous), facet joint and capsule, intervertebral disc and paraspinal muscles (2, 3). Excessive motion during extension is prevented by anterior longitudinal ligament, the frontal side of the annulus fibrosis, facet joint and the rectus abdominus muscle (4, 5). Similarly, rotational motion above physiological limits is restricted by disc and facet joints.

Systems stabilizing the spine

Three subsystems that keep the spine stable against excessive loads are defined by Panjabi (6, 7).

1. Active subsystem: muscles, tendons
2. Passive subsystem (osteoligamentous): vertebra, facet, disc
3. Neural subsystem

As a result of the harmonious working of these 3 subsystems, sufficient stability may be obtained during posture change and static or dynamic overloads (Figure 1).

Active system: Muscle and tendon structures surrounding the vertebral colon are very important for stabilization and stability cannot be achieved even during lower loads in case of absence or weakness. The active subsystem enables stabilization voluntarily or as a reflex when a load is applied on to spine (8). Sufficient support cannot be provided for the passive system and the required stability to protect the physiological motion during sudden overload can not develop in case of muscle dysfunction. Various studies regarding the problems occurring in spine stabilization in anatomic or functional disorders and insufficiencies of the active system are present in the literature (1, 7, 9, 10).

Passive system: This system consists of intervertebral disc, corpus vertebra, facet joints and ligament structures. The passive subsystem prevents the development of instabilities by limiting the excessive motion that can appear during overload. When various problems such as stretch or relaxation of ligaments, nucleus pulposus degeneration and loss of flexibility, annular ruptures and weakening of annulus fibrosis and outer portion of the disc, or deterioration of anatomic structure of facet joint develop the passive subsystem may not perform its stabilizer function.

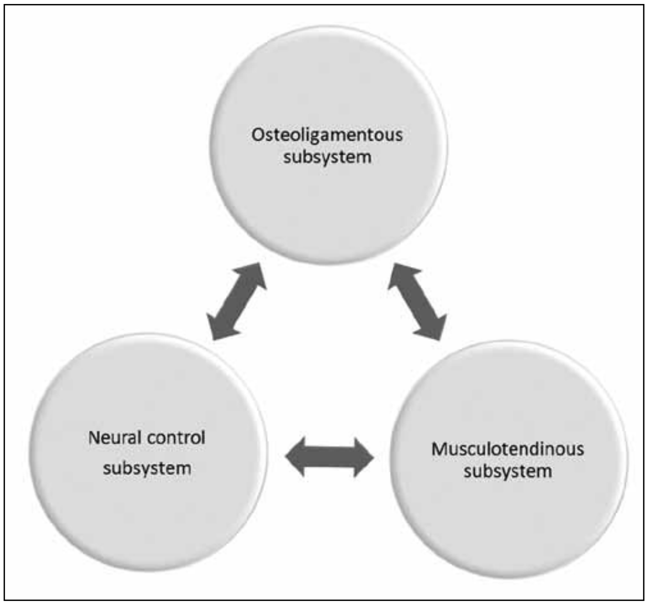

Figure 1: The active subsystem (muscles and tendons), *passive subsystem*, (intervertebral disc, facet joints, corpus vertebra and ligaments) and *neural subsystem* work together and prevent the risk of spinal instability.

Neural control system: This is a subsystem that determines the current situation through a stimulus it receives from muscle, tendon and that which are the active and passive systems and provides spinal colon stabilization by means of the active system (spinal muscles).

More load than the body weight falls on the spine in normal stand up position and also when load is carried or sudden movements are made. These 3 sub-systems should work in cooperation to carry this load and to prevent any injury to the spine. Contraction of the muscles, performance of necessary physiological movements, prevention of excessive motions with ligaments and muscles and performance of all these in harmony and under the control of the neural subsystem are of vital importance for a stable spine.

Physiological motion of the lumbar spine

Movement of the spine occurs within specific limits in each of 3 planes and with different level and rates on every segment (6, 7). All intervertebral motion performed within physiological limits from the neutral position in the normal spine is defined as the "Range of Motion". This physiological motion range is divided into 2 parts by Panjabi (Figure 2).

1) Neutral Zone: It is the region where motion starts in the spine and encounters minimum resistance. Motion in this region encounters resistance from ligaments and the resistance is at the lowest level.
2) Elastic Zone: It is the motion region that starts in final point of motion in neutral region and continues till the physiological end point. In contrast with neutral region

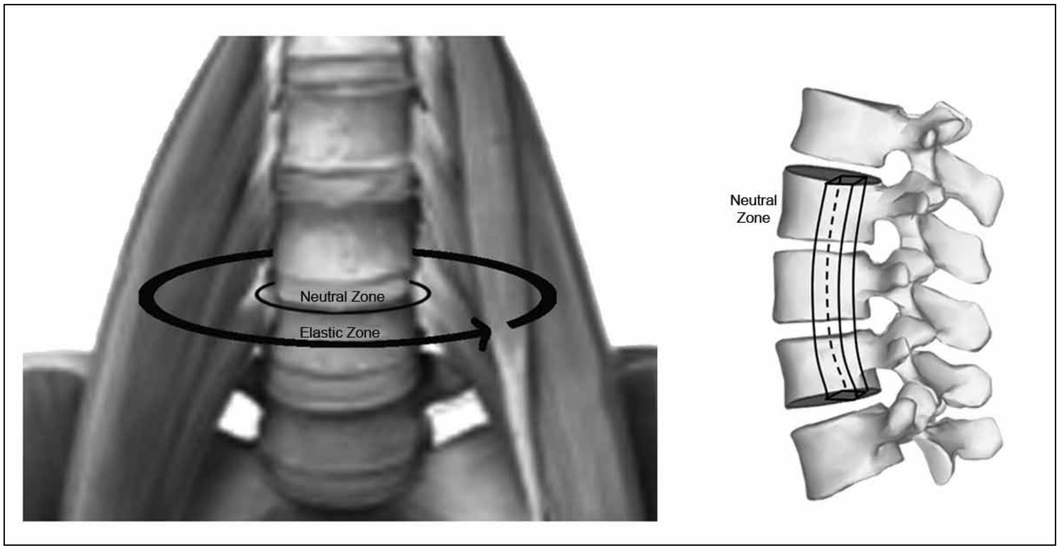

Figure 2: A schematic view of the *Neutral Zone* in which the movement begins with little resistance, and the *Elastic Zone* where the rest of the movement occurs against high resistance. Total movement in these 2 regions together forms the Range of Motion.

the motion in this region is performed against a high resistance.

The sum of the motions performed by these two regions is defined as total physiological ROM. When a small amount of load is applied on the spine, the first motion starts in the more flexible neutral zone with minimal resistance. When the load increases, the limit in the neutral zone is exceeded and the motion against the resistance continues in the elastic zone (11).

Panjabi stated that active, passive and neural control systems defined by him provide stability by controlling ROM through neutral zone and elastic zone. The active subsystem consisting of muscles and tendons provides control in the neutral zone, the starting point of the motion and where the resistance is minimal. However, the passive subsystem that consists of bones and ligaments controls the less flexible elastic zone where the resistance is higher.

Panjabi described an analogy named "a ball in a bowl" for the purpose of visualization of the neutral zone and load-displacement curve (7). A ball moves easily in the bottom of the bowl (neutral zone). However, more power is needed for further movements in the steeper sides of the bowl. In a deeper bowl like a wine glass, the neutral zone is decreased and this represents a stabilized pain-free spine. However, in a shallow bowl like a soup plate, neutral zone is enlarged, the ball moves more and this represents an unstable painful spine (Figure 3).

DEFINITION and CLASSIFICATION of SEGMENTAL INSTABILITY

Panjabi defined segmental instability as "*extension of the neutral region that cannot be held at physiological limits when a problem occurs in sub-systems that provide the stability in the spine*". Extension in neutral region causes an increase in motion flexibility (ROM), occurrence of movements above normal limits in the segment and instability.

Frymoyer et al. defined instability as "*pain and deformity development following normally tolerable load after a decrease in the stiffness of the spine and development of a more elastic one*" (12).

Segmental instability is defined by AAOS (American Academy of Orthopedic Surgeons) as "*development of motion above normal when there is any load on the spine*".

The neutral region is the area where motion develops with more elastic and minimal resistance. Motion meets more resistance in elastic region. When there is an enlargement in the neutral region, the spine becomes ready for more and easier motion after the load. Cholewicki and McGill report that neutral region is the most sensitive region to instability in lumbar spine and point out that when there is muscle weakness there is especially a possibility of instability even at small load (13). As a result of various in vitro studies it is reported that the detection of enlargement only in the neutral zone is a more important finding than an increase in total Range of Motion (ROM) for diagnosis of segmental instability (7, 11, 14).

As a result of in vitro and in vivo studies, segmental instability can be defined as "expansion of the motion in the segment that does not remain in the limits due to problems developed in the stabilizing subsystems of the spine". When anatomic or physiological pathologies related to the vertebral corpus, intervertebral disc, facet joints, ligaments or muscles occur, the subsystems cannot perform their normal stabilization tasks and instability develops in neutral zone following the enlargement of this region. The motion limiting capacity decreases following the changes in structures that keep the spine stable and the lumbar segment can move outside normal physiological limits.

Frymoyer defined instability under two groups; primary and secondary. The situation that develops following degenerative disc disorder and spondylosis is defined as primary instability, and the one that develops following surgery is called as secondary stability (12, 15). Lumbar segmental instability is divided into 2 groups by Benzel; acute and chronic (16). Acute instability is divided into 2 sub-groups: overt and limited. Acute instability is a situation that is encountered in patients with damage in their spine anatomy and that develops generally after trauma, tumor, infection or surgery.

Glacial instability, a subtype of chronic instability is a pathology that progresses and develops rather slowly over time (16). The development of the degeneration or deformity is very slow; progressive kyphotic, scoliotic or translational deformities can develop like an iceberg movement in months and years.

Dysfunctional segmental motion is another chronic instability discussed and defined by Benzel. This situation is defined as "mechanical instability" in some literatures. As in glacial instability, it does not result in significant deformity and there is no important disability in the entire spine segment. It is a chronic instability situation characterized by the occurrence of excessive motion in the segment following the development of excessive motion after a degenerative course in intervertebral disc and bone structure. Although it can be called chronic lumbar instability, lumbar segmental instability, mechanical instability, dysfunctional segmental motion, degenerative lumbar instability and primary instability, the basis is biomechanically, anatomically and physiopathologically the same.

Degenerative progression and chronic lumbar segmental instability

As it is well known, the lumbar spine carries a rather high load. During axial load on the healthy spine, 80% of the load is carried by the disc and 20% by facet joints. Ligaments provide the stability of the segment and prevent excessive movements. A degenerative course in the lumbar region first starts in the disc tissue. Proteoglycan, water and collagen levels decrease progressively and the disc becomes a more fibrotic and less elastic structure. Weakening and tearing in annulus causes advanced problems in the load carrying capacity of the disc tissue. Degeneration course accelerates with decrease in disc height and absence of rehydration when the load is removed. Similarly, endplate structures are affected and disc diffusion is decreased due to generated sclerosis. Nutrition of disc tissue is disturbed during this course and some catabolic product such as lactic acid cannot be discarded and tey accumulate in the disc (1, 17).

When a decrease in the disc height occurs, the load on facet joints increases, and degeneration and deformation start in facet joints. Spinal stenosis, foraminal narrowing, ligamentum flavum hypertrophy, loosening in ligaments and compression to neural structures related to hypertrophic facet or herniated disc occurs. (18-20). As a result, the spinal segment loses its stable structure and instability develops during both physiological and excessive loading (21).

Instability that develops during disc degeneration is investigated by Kirkaldy-Willis in 3 clinical and biomechanical phases: dysfunction, instability and stabilization (22). The first phase, defined as the temporary dysfunction phase, is described with degeneration in disc, ligaments and facet joints. In the second phase, instability develops following the decrease in disc height, loosening of ligaments and facet degeneration (Figure 4). In the third phase restabilization starts and ROM decreases extensively following hypertrophic facet joints, collapsed intervertebral disc and osteophytes (20, 23, 24). Many subsequent cadaver studies and clinical researches presented supporting this defined degenerative process (23-29).

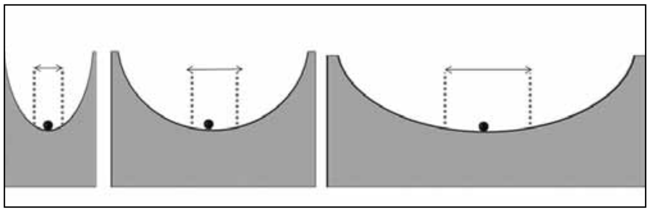

Figure 3: The ball moves easily against minimal resistance in the bottom of the bowl (Neutral Zone), and moves against high resistance and needs more power at the lateral part of the bowl (Elastic Zone). The movement of the ball is limited when the bottom of the bowl is narrow, representing a small Neutral Zone (stable spine). When the base of the bowl is large, this represents an enlarged Neutral Zone (unstable spine). Adapted from the description by Panjabi MM (7).

CLINICAL FINDINGS and DIAGNOSTIC METHODS

In patients with lumbar segmental instability, the correlation of clinical and radiological findings is very important for both correct diagnosis and treatment planning. Leone et al. emphasise the importance of complaints like long term-duration of recurrent back pain, worsening with time and increased pain with mechanical stress while decreasing with rest (1).

Figure 4: At the second stage of disc degeneration, instability develops and the third stage ends with fusion and restabilization.

Biely et al. reported that back pain increased with sudden motion that worsened gradually and presented as several recurrent attacks was the most commonly encountered symptoms in segmental instability (10). Moreover, the pain becomes a chronic situation in a long period and difficulty in sitting without support, temporary recovery with corset, sudden and immense pain following some movements define as important symptoms and signs. Findings such as muscle spasm, posture impairment, and difficulty to obtain neutral position are observed during examination of the patients. They also stated the importance of recurrent and long term lumbar pain attacks and an increase with mechanical stress and decrease with rest in pain.

Kotilainen underlined 3 criteria for the diagnosis of lumbar instability: sudden and intense pain when lowering the leg during flat leg stretching test and when turning to neutral position during kneeling down and feeling of space in the waist together with basophobia during movement while standing (30).

Radiological investigations

X-Ray: Radiological findings required for the diagnosis of spinal instability are first defined by Knutson (31). Some features detected with neutral radiographs can accepted as indirect findings with regards to instability. Narrowing in disc space, vertebra endplate sclerosis, osteophyte development, bone spur structures and vacuum phenomenon are findings observed in radiography, but they are not important on their own.

Functional radiographs are obtained in the sagittal plane in the neutral state and by applying flexion, extension or additionally axial traction and compression. Pitkonen et al stated that the application of traction and compression did not have any additional benefits for the diagnosis with the results obtained from 306 patients with clinical instability (32).

The question of debate is to whether to perform flexion and extension graphies, which are the most commonly performed examinations because they are cheap and can be performed everywhere, while the patient is standing or in the lateral decubitus position. During imaging in the standing position, movement in the vertebra can be limited by both intense pain and also muscle spasm and instability may not be detected (22, 33). The real motion of the spine may also not be reflected on film because the load on the spine is eliminated during the image taken while lying down (33-36).

Functional images present 4 direct findings in patients with lumbar segmental instability (Figure 5).

1) Forward translation
2) Backward translation
3) Angular instability
4) Rotating axial translation, double contour (abnormal axial rotation)

Specificity and accuracy of the findings obtained through neutral or functional graphs are matter of debate. Problems such as patient position, equipment quality, angle changes during graphs, and the fact that pain and muscle spasm limit the real instability motion should not be forgotten. Detection of 1-4 mm or 3-15% of vertebra length sagittal translation mistakes during measurements are reported in the literature (8, 25, 37-39). Hayes reported above 3 mm translation in 42% of asymptomatic patients without lumbar pain (14, 40). Breen et al. reported that the measurements performed using "quantitative fluoroscopy" technique are more compatible with the clinical picture and the error rate is lower because there could be incorrect evaluations related to various factors (41). Although various translations and angle ratios are reported, the presence of 3 mm or above translations in neutral graph and detection of 3 mm or above translation and 10^0 angulation in dynamic graphs are radiologically regarded as instability criteria (14, 32, 42, 43).

Computerized Tomography (CT): Shows indirect instability findings such as disc degeneration, endplate sclerosis, vacuum phenomenon and facet joint degeneration more accurately than radiographs. Scans through facet joints are displayed during the motion performed with the patient in the lumbar region and used as functional CT in showing abnormal motion or tearing in facet joints.

Magnetic Resonance Imaging (MRI): Disc degeneration, fusion in facet joint, annular tearing and Modic changes can be displayed using MRI (1,8,44,45). Dynamic MRI helps to monitorize excessive motion in lumbar segment (46, 47). Findings regarding the instability may be obtained with MRI taken in the sitting, prone and standing positions with flexion-extension and loading.

Treatment methods in lumbar segmental instability

Although several methods are used in the treatment of lumbar segmental instability, no consensus has been reached yet regarding the treatment or the diagnosis. Recurrent and increasingly worsening pain is the most important complaint in great majority of the patients, and medical or surgical treatment methods that enable patients to perform their daily normal life activities should be used.

Exercise programs and conservative treatment methods such as patient training programs in order to provide the required information to protect spine health are used in the early period and in those with less severe complaints (14, 48). Avoiding movements that cause excessive load on spine, and teaching basic points such as the posture and life style are important for the stability as the most essential patient training methods.

Stability of the spine is aimed by strengthening abdomen muscles, lumbar extensor muscles such as erector spinae, and segmental muscles such multifidus with physical therapy (10, 14, 49). Surgical treatment is performed when patients with chronic segmental instability do not benefit from conservative treatment. Since the purpose is to prevent excessive motion, fusion methods are the most frequently used ones. Many studies have shown that fusion surgery, used very commonly until quite recently, did not provide the expected successful clinical results (21, 48, 50, 51).

When a mobile segment becomes motionless with fusion surgery, important changes occur in the biomechanics of the spine and new problems arise with degenerations in the upper and lower parts of the segment that was subject to the surgery. Rham and Hall (52), and Lehmann et al. (53) reported that adjacent segment disorder developed in patients within 5 years after fusion surgery respectively with high rates such as 30% and 45%.

Another problem that can be encountered after fusion is the development of pseudoarthrosis. Pseudoarthrosis that can appear months or years after surgical intervention is an important complication that can disrupt daily life activities in patients with severe pain.

It is known that physiopathological changes following intervertebral disc degeneration cause instability by impairing the structure of functional segmental unit. When motion is prevented by applying fusion to a segment with excessive motion secondary to degeneration course, the same physiopathological process continues on lower and upper segments in a more rapid way and the patient requires a second surgical intervention due to severe pain after adjacent segment disorder. We should remember that biomechanical characteristics of other segments are not healthy as well. Thus, after fusion surgery for one unstable segment, there is a high risk of pseudoarthrosis or adjacent segment disease in other segments in this degenerated spine. Revision surgery is required because the clinical picture is as bad, at times even worse than pre-surgery in those patients.

Physiological methods have been used mainly instead of fusion for spine biomechanics in recent years. Posterior dynamic stabilization systems are the most commonly used methods that yield the most successful results. The purpose of the performed instrumentation is to stabilize the spine, to prevent excessive motion and to allow the motion in the functional segment to a certain extent. Thus while stabilization is achieved, risks such as adjacent segment disorder and pseudoarthrosis are eliminated (21, 48, 54, 55).

It is reported in many literature studies that clinical results of patients to whom dynamic stabilization are applied, are much better than those to whom fusion surgery were applied and ratio of the complications encountered are much less (56-60).

It is known that recovery in disc tissue and annular tears, and development of rehydration in the disc may be detected after posterior dynamic stabilization in patients with segmental instability (Figure 6). Recovery of the impaired is an important finding shows that the posterior dynamic stabilization preserves normal physiology and biomechanics of the spine. The fact that some patients where the neutral region has expanded and instability has developed after degeneration have experienced cessation of this course and even recovery is an encouraging indicator for using dynamic systems in the treatment of lumbar segmental instability.

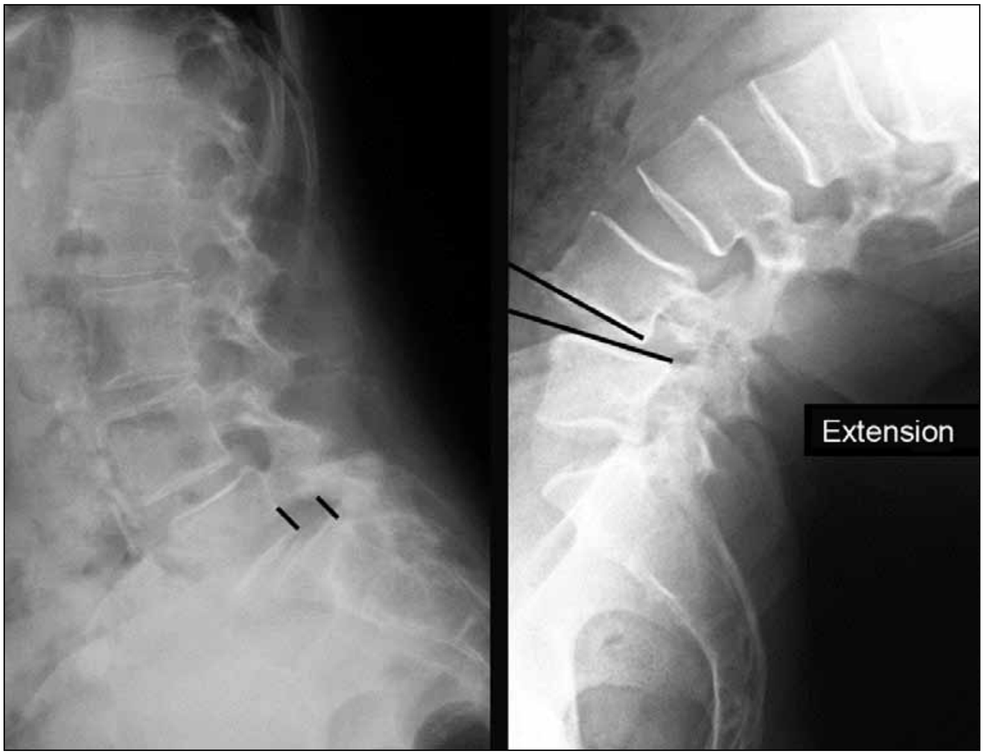

Figure 5: Measurements of functional X-ray studies disclose anterior or posterior translation and angulation of vertebra.

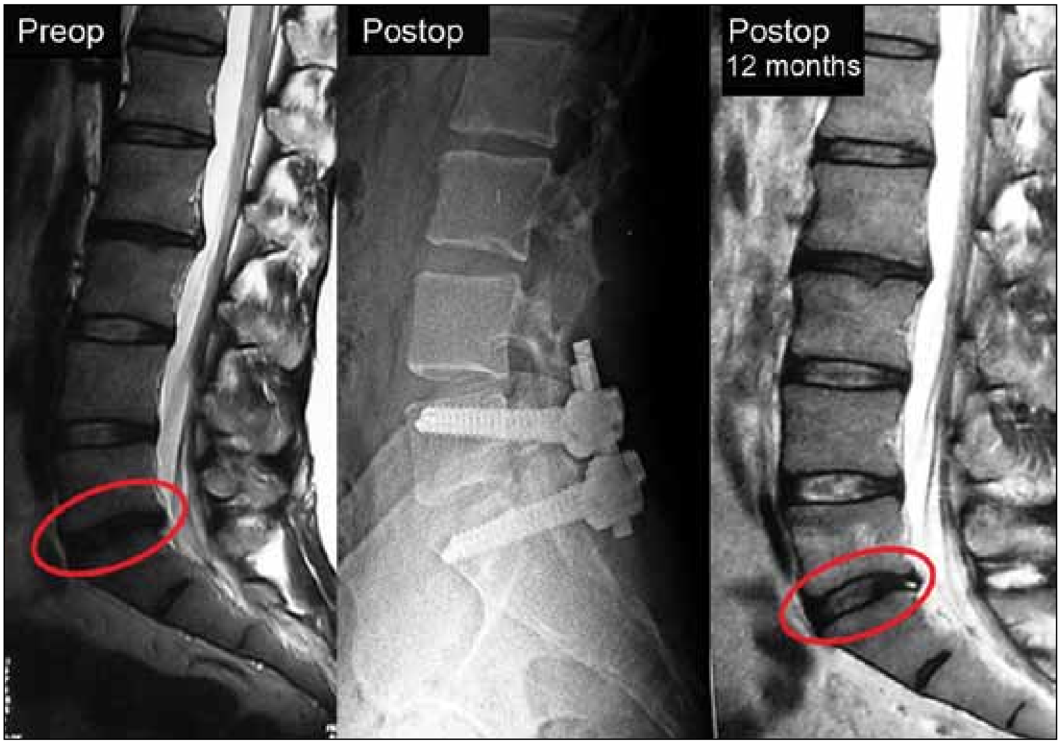

Figure 6: MRI scans show the rehydration and healing of the disc tissue after dynamic posterior instrumentation in a patient with segmental instability.

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