4 Biomechanics of Degenerative Vertebral Column and Segmental-Multisegmental Instability

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The situation which arises by the change of structural and material characteristics of the structures which form the vertebral column depending on time and loads incurred is called "degeneration". Clinical symptoms of degeneration are realized in general with increasing ages since it is established in due course. In addition, clinical symptoms may occur as a result of misuse of the vertebral column such as nicotine consumption , repetitive microtraumas or effects of factors such as genetic properties in the degenerationobserved in the young-adult age group.

Clinically, degeneration is evaluated in three separate stages as "disfunction stage", "instability stage" and "restabilization" stage [1,2]. Which stage continues how long, the transition period from one stage to another and occurrence or non-occurrence of clinical symptoms vary from case to case.

Surgical therapy alternatives are considered in case repetitive lumbagoes of chronic nature and limitation of movement of waist, segmental or multisegmental instability and neurological deficit emerge.

Biomechanics of degenerative lombar vertebral column

It shall be appropriate to evaluate the biomechanical changes between the normal and degenerative vertebral column by handling the elements of the vertebral column one by one. When, in some cases, only one element of vertebral column is degenerated, in some other cases, it shall be possible to observe the degeneration of more than one element of vertebral column.

Intervertebral Disc Tissue

Tissue of the disc is composed of nucleus and annulus tissues. Normal disc tissue is converted to a structure having osmotic pressure when it loses its mechanical properties, water content, its proteoglycan ratio increases in favor of keratan sulfate and decrease of Type Iı collagene due to the increase in hydrostatic pressure caused by its water and proteoglycan balance. Since the nucleus and annulus tissues have an anisotropic and viscoelastic structure, low loading values are used when their biomechanical properties are tested. During in vitro tests concerning the strength of disc tissue, their strength is tested by tensile loadings rather than compressive loadings. In compression tests, disc tissue behaves as an elastic object under low load values and rigid objects under high load values. A normal disc tissue acts as an elastic tissue during daily activities, but the disc tissue which has lost its elasticity by degeneration acts as a rigid body. While compressive stresses are formed in the nucleus during the behavior of a normal disc tissue against compression loading, tensile stresses are formed in the annulus fibers. In other words, the normal disc tissue carries the compression load by means of nucleus.

In the event of degeneration, the load is rather carried by the annulus and facet joints since the nucleus acts as a rigid body. Due to this reason, annular ruptures or disc hernia are formed clinically when the strength values of the annulus is exceeded. Annulus fibers are weaker morphologically especially at the external side segments. Due to this reason, disc hernia is evaluated in the clinic by the formation of compression from the right or left side of the ependymal canal.

On the other hand, clinically midline disc hernia is observed less since the annulus fibers are stronger in the midline in axial plan. Mechanical behavior of the disc and annulus tissues in flexion, extnesion and lateral bending motions resemble each other. Basically accepted; the compressive stresses are formed in the nucleus and annulus fibers at the direction of bending and tensile stresses occur at the opposite side. However, when the stresses concentrate especially at the external side's annulus fibers in axial plan during the rotational motion, the stress at the center of nucleus is at the lowest level during the same motion. Due to this reason, stresses are increased at the external side's annulus fibers during the physical activities which twist the vertebral column at the lombar zone and sometimes ruptures may occur.

Facet Joint/Facet Capsule

%90 of the axial compression loads are carried by disc and annulus when there is not any disc degeneration and the compression load through the facet joints forms about %10 of the total load. After the disc degeneration, while the ratio of the compression load through the anterior annulus and disc tissue retrieve to %20, the ratio of compression load through the posterior annulus and disc tissue and facet joints increases to %40 [2,3].

When the load through the anterior annulus and disc tissue decreases because of degeneration, it is observed in the clinical examinations and radiological examinations that traction osteophytes from the adherence locations of the end plates of the anterior longitudinal ligament show progress in increasing ages. The reason for this may be explained as that the facet joints are assigned the duty of carrying more load as the intervertebral disc spacing decreases in time and degenerated disc tissue may no more carry the load [4].

Carriage of the load by the facet joints and pedicule shall be able to cause changes later on in the bone marrow as seen in the end plate [5].

There exists synovium between the joint surfaces of the facet joint as the other diarthrodial joints. Especially the upper facet joint starts to carry more load because of degeneration of the disc tissue and decrease in the height of disc in the coming period. Clinically, synovial cysts may be created in the form of facet arthrosis or sometimes the overflow of synovium lining the facet through the joint spacing.

In general, while the formation of synovial cysts is associated with the degeneration of facet joint and facet instability, it is accepted that it may not have a direct relation with the disc degeneration. %2,3 of the synovial cysts develop towards the ependymal canal by degeneration, %7i3 develop towards out of the ependymal canal [6].

End Plate

In the fatigue tests of functional spinal unit(FSU) performed by constant compression loading, the first damage is formed at the end plate prior to the disc tissue. Therefore, Schmorl nodes may be formed with/without symptoms [%38-75] at the end plate clinically secondery to the repetitive microtraumas and degeneration in time clinically [7]. Some signal variations may be formed in the bone marrow of the vertebral object neighboring the end plate as the result of degeneration which may be imaged by magnetic resonance (MR). Such MR findings defined as "modic changes" may be observed in three types (Table 1).

Table 1: Dgenerative changes (Modic changes) identified in the bone marrow neighboring the end plate by magnetic resonance (MR) imaging.

Type	T1 MR Image	T2 MR Image
Type I	Hypointense	Hyperintense
Type II	Isointense/Hyperintense	Hyperintense
Type III	Hypointense	Hypointense

Type I changes arise from cracks at the end plate and fibrosis vascularized tissue development in the neighboring bone marrow, **Type II changes** from cracks at the end plate and accumulation of fat deposits (fat degeneration) in the neighboring bone marrow, and **Type III changes** from closing of intervertebral disc spacing and development of sclerosis at the end plate and the neighboring bone marrow. The importance of the mentioned degenerative changes in clinical evaluation shall be addressed under the heading "Diagnostic Criteria of Lombar Instability".

Ligaments

The ligaments providing lombar vertebral column stabilization are composed of "anterior longitudinal ligaments", "posterior longitudinal ligaments", "ligamantum flavum, supraspinous" and "intertransversal ligaments". Loosening, loss of elastic properties, calcification and hypertrophy of these ligaments may be developed after the disc and facet joint degeneration of the vertebral column. In cases where the lombar vertebral column segment has become instable, ligamantum flavum hypertrophy may develop to contribute to stabilization as observed in the facet joints and ependymal canal comression may emerge clinically. In a similar way, in the event of excessive increase of lombar lordosis, spinous projections come closer to each other due to excessive segmental extension and cause the loosening and degenration of the ligaments.

Lombar Segmental Stability/Instability

Range of motion (ROM) for the vertebral column is composed of "neutral zone" and "elastic zone" [8] (Figure 1).

The neutral zone constitutes the first part of the ROM and the resulting loads on the spine, and a small movement in this area (the area of the spine is flexible) results in minimal resistance.

This resistance is caused by the ligaments and is known as "ligament resistance". Thus, in the upper limit of the neutral zone ligaments are the backbone of the resistance movement. This region covers a small area in the neutral region, referred to by some authors as the "ligament laxity zone" ("ligamentous laxity", "lax zone", "LZ") [9].

Spine stabilisation disruption (trauma, degeneration etc) occurs in cases of instability which begin from an increase in the neutral region.

Therefore, increase in the neutral zone is more important than an increase in the ROM.

The elastic region is the second part of the ROM. In this region, the spine is moving against the resistance and the resistance against the movement created by the joints. Spine stabilisation of the passive, active and neural control systems are thus provided.

Passive System

Passive elements that constitute the system are vertebral body, facet joints, joint capsule, ligaments and muscle tendons. In particular, the passive system provides elastic stability of the ROM. The stabilisation role of these structures has been demonstrated in vitro studies [10].

Stabilisation of the spine flexion movement; posterior ligaments, facet joints and capsules is provided by the disc structures. Stabilisation of the extension movement, primarily the front part of the anterior longitudinal ligament, including the anterior part of fibrosusun annulus and the facet joints, and stabilisation of the axial rotation movement by the disc tissue and the facet joints is provided. Lateral bending movements are stabilised by intertransvers ligaments.

Passive system, positional changes in the spine passing the neural control system and try to keep it stable in neutral zone.

Active System

Composed of muscle and tendon structures in the spine, the active system and the nervous system are primarily responsible for the stabilisation of the neutral zone. Stripped of muscle

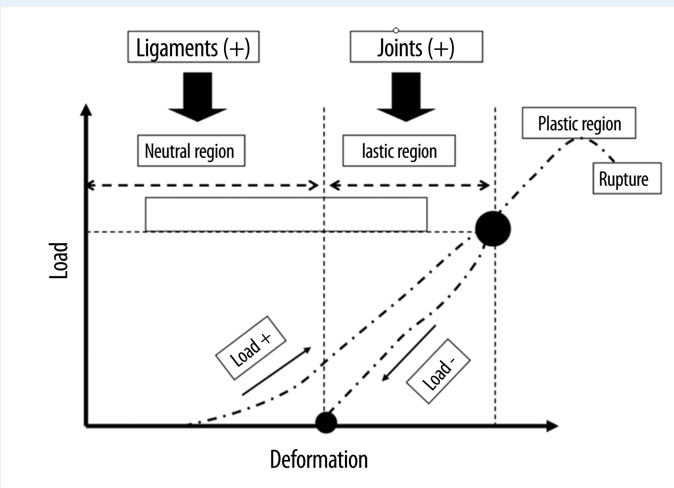

Figure 1: The range of motion of the spine (range of motion / ROM); are neutral, elastic and plastic region borders.

tissue in vitro models, the change in the stabilisation have been shown in vitro studies [11,12].

In the spine there are two muscle groups: one segment ("unisegmental") and the multi-segment ("multisegmental"). More deep-seated muscles of a single segment (intertransvers muscle, such as muscle interspinal) affect the position and movement of the spine and communicate with the neural system.

These muscles are in proximity to the axis of rotation of the instant and high-density muscle spindles comprising the above-mentioned characteristics of single-segment muscles as evidenced [13].

Even more multi-segment superficial muscles (abdominal muscles, spinal muscle of the erector, etc.) provide large movements of the spine. Although some of the spine muscles do not touch it directly, others affect a number of movements of the spine.

For example, the erector spinals muscle of extension movement and the superficial abdominal oblique muscle provide the rotation movement. Other multi-segment muscles provide direct contact with the movements of the spine. For example, the multifidus muscle has spinous protrusions to transverse projection of a lower rank, iliac bone and sacrum extending for movements of flexion and rotation stabilisation of the form [14].

The quadratus lumborum muscle provides for stabilisation of the lateral bending of the spine [15].

Neural System

Neural system, passive and active systems to receive information and with the control of muscles provide stabilisation of the spine.

Lumbar Segmental / Multisegmenter Instability Diagnosis

Although not always easy to diagnose, segmental instability can be diagnosed using clinical history and radiographic images. Radiological with the sagittal plane dynamic (hyperflexion / hyperextension) radiographs were used to evaluate segmental instability in 1944 [16].

Later studies by some researchers used the standard X-rays and [17,18] dynamic radiographs of people without back pain to diagnose signs of instability. It was noted that a stand-alone assessment using dynamic radiographs could give false-positive results [19].

For the diagnosis of lumbar segmental instability in the sagittal plan dynamic graphs, 3 mm wide, or the width of the vertebral body drift as much as 9%, and in the sagittal plane 9 degrees of rotation of the lumbar motion segment is considered as a sign of instability [18,19]. Similarly, the diagnosis of lumbar segmental instability; sagittal plane displacement in the width of 4-4.5 mm or vertebral body reaches 10 to 15% indicate researchers [20].

Today, sagittal plane dynamic radiographs have become standard practice in the diagnosis of segmental instability. From L1-L5 sagittal plane dynamic flexion / extension x-rays based on the normal rotation of the lumbar segment ("rotation") and normal displacement ("translation") values, the width of the front and rear proportioning spine in the sagittal plane by Posner and colleagues, forward displacement of 8%, ddisplacement of the back 9% and 9% the angular displacement is considered normal (Figure

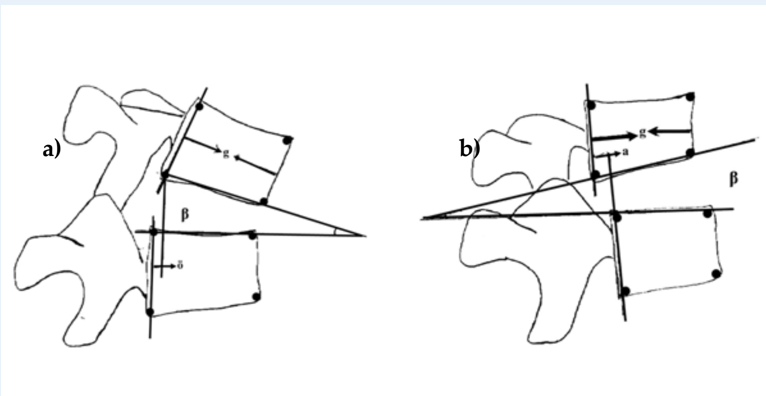

Figure 2: a) Rotation (angle) and translation (mm or %) measurement of segmental stability during flexion. **b)** Rotation (angle) and translation (mm or %) measurement of segmental stability during extension. (G: width, d: Featured drift, a: back translation, ß: Rotation angle)

2a and 2b). Some have been reported by researchers at the lumbar functional spinal unit, dynamic rotation and displacement values are shown in Table 2.

Table 2: Normal rotation (degrees) and translation (%) values.of the functional spinal unit at sagittal plane dynamic radiographs

Researcher	Level	Rotation	Translation
Hayes et al[19]	L1-L5 L5-S1	2-3 3	7-13 14
White et al[20]	L1-L4 L4-L5	3 3	15 20
Kanayama et al[21]	L5-S1 L1-L5	3 4	25 10

Radiologically proven, however, it is not routinely used in other radiological radiography, axial compression and extension to evaluate the sagittal plane displacements [22].

This type of x-ray has been tried on patients diagnosed with spondylolisthesis or instability retrolisthesis. However, a study on this issue in recent years has shown patients clinically suspected of instability dynamic flexion / extension radiographs of 26%, and axial push / pull radiographs of 2% the rate of diagnosed by segmental instability.

In 96% of patients with a diagnosis of lumbar instability dynamic flexion / extension radiographs demonstrated, however, that in 8% of patients with axial compression / tensile instability shown by X-rays. Thus in this technique was reported to be useless [23].

Instability in the diagnosis of computerised tomography (CT) more clearly than direct x-ray images osteophytes, facet joint disorders, and in the disc space can be seen vacuum. Functional CT examinations suggested the diagnosis of instability.

In this diagnostic method, the patient's pelvis is held fixed, CT images are taken by rotating the body to the right and to the left, the extreme increase in the facet joint opening can be considered as a sign of instability [24].

Unlike X-rays and CT exams in the diagnosis of instability, better results can be obtained with MR images of the disc degeneration [25], bone marrow endplate changes (Modic changes) [26], annular tears, synovial cyst, facet osteoarthritis and soft-tissue changes such as ligamantum flavum hypertrophy.

A rating of intervertrebal disc degeneration can be done with lumbar magnetic resonance (MR) imaging disc (Table 3). In this evaluation, a fast spin-echo (FSE) technique was used giving a high rate of reliability of raters. Accordingly, degree of disc degeneration was shown to be five strands [25]. With lumbar MRI the adjacent endplate changes according to the degree of degeneration can be shown. "Modic changes" [26] is called grading, Type I changes "unstable", Type II and Type III variations are considered "stable". Also Type I changes, which are more stable for an average of 14 months to 3 years fading into Type II have also been reported. Similarly, the Type II variation, converts into Type I change,

Table 3: Magnetic resonance (MR) imaging with the grading of degeneration of the intervertebral disc tissue.

Grade	Disc structure	Nucleus/Annulus separation	T2 MR Signal	Disc height
I	Homogeneous, bright white	Clear	Hyperintense, isointense with CSF	Normal
II	Not homogeneous ± horizontal bands	Clear	Hyperintense, isointense with CSF	Normal
III	Not homogeneous, grey	Unclear	Medium	Normal, slightly decreased
IV	Not homogeneous, gray to black	Lost	Medium or hypointense	Normal, slightly decreased
V	Not homogeneous, black	Lost	Hypointense	Collapsed

in such cases evolved instability or osteomyelitis should be considered [27].

In other studies published, lower back pain, sciatica, lumbar disc herniation show significant relationships between the Modic changes [28,29].

Functional MR imaging of the lumbar (hyperflexion / hyperextension) in the evaluation of 309 patients, evaluated more than 3 mm drift instability from the third and fourth lumbar vertebrae (L3-L4)10%0, from the L4-L5 16.5% from the L5-S1 7.3% frequency instability was determined. The third and fourth lumbar (L3-L4) spine distance ligamantum flavum hypertrophy and the formation of degenerated disc, the fourth and fifth lumbar (L4-L5) spine distance, facet joint osteoarthritis and formation of ligamantum flavum hypertrophy was observed in patients with instability.

Also, for the distance L4-L5, 1 degenerated disc (grade 4) and facet degeneration (grade 3)2 facet degeneration (grade 2 or 3) and ligamantum flavum hypertrophy, 3 degenerated disc (grade 4) and ligamantum flavum hypertrophy, such as togetherness a statistically significant indicator of segmental instability has been reported [30].

Obvious (“overt”) standard radiological methods and diagnostic criteria for the diagnosis of instability can easily be demonstrated using a group of patients with chronic low back pain at the border of instability or hidden instability. Diagnosis of these cases remains a challenge to standard radiological diagnostic methods. For this purpose, chronic low back pain patients were considered to be due to segmental instability or multisegmental secret, the standard radiological diagnostic methods, X-rays, with provocative discography and MRI evaluation is recommended.

As a result of these evaluations, fusion or arthroplasty treatment options were reported to be a healthier way of deciding which treatment would be more appropriate [31]. Patients clinically diagnosed with instability to be treated with bracing, diagnoses of the patients and applied this method to prove the opinion of the corset is one of the diagnostic criteria. However, disadvantages are the lack of standard corsets and the restriction of all movements with the corset reduces the reliability of diagnostic criteria. In patients with chronic low back pain due to chronic segmental instability, pedicle screws are useful in patients who are currently treated with external stabilisation, fusion surgery to the clinically tested [32].

Lumbar segmental instability, which can be considered a valuable tool in clinical diagnosis criteria is marked as follows: frequent intervals to be patient with low back pain, sideways deformity due to pain development, physical therapy to benefit for a short period of time,

relief of painful periods with a corset, and a history of trauma, and contraceptive pill use [33].

Clinical diagnosis, during physical examination spinous projections sequence identified incompatibility during the manual controls and while a physical movements with a combined movements (when the flexion, axial rotation unintentionally be together, etc.) can be considered as a sign of instability. Unfortunately, not being a standard clinical examination findings, unrecognized absolute diagnosis of lumbar instability of these findings, however, raise doubts in this direction are also accepted.

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