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# Development of innovative training solutions in the field of functional evaluation aimed at updating of the curricula of health sciences schools

TEACH



## MODULE BIOMECHANICS OF SPINE

## Didactic Unit D: INSTRUMENTED ANALISYS OF THE SPINE

## D.4 How is a normal biomechanical assessment of the lumbar spine?

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# Index

## 1. Objectives

- To recognize the normal results of a lumbar biomechanical assessment.
- To become familiar with the interpretation of the results obtained in the lumbar biomechanical assessment of a normal population.
- To become familiar with the interpretation of the results obtained in the assessment of lumbar muscle strength in a normal population.
- To apply the knowledge acquired to a clinical case.

## 2. Functional assessment of the lumbar spine

Low back pain is one of the most common causes of disability that affects most people at some point in their lives. The quality and validity of lumbar spine assessment applications depends on the measuring instruments used.[1] In current clinical settings, the lumbar spine analysis is usually performed using subjective and qualitative approaches, such as human observation and patient self-reporting. Although some severe movement disorders can be observed by human eyes, without quantitative measurements, subtle changes can go unnoticed.

Lumbar pain can be assessed with tests that show actual damage at the level of body structure, physiological functions or activities that may be altered by this symptom. Clinical standards and the main studies on lumbar pathologies focus on the assessment of mobility. Patients with low back pain (LBP) have been shown to have some limitations in spinal motion that compromise their function. The inability to rise from a sitting position or lifting a weight is recognized by the World Health Organization (WHO) as a disabling condition for low back pain. In particular, normal spine mobility is necessary for the optimal performance of these daily activities. It has been reported that the impairment of spinal mobility can result in various forms of functional disabilities, which may have serious adverse effects on life quality.[2] Therefore, the ability to reliably measure and evaluate lumbar spine motion in these activities is essential in elucidating the pathophysiologies of various musculoskeletal disorders, such as LBP.[1]

The anatomy and function of the lumbar spine is complex and requires a measuring technique that can record 3-dimensional (3D) movements and forces. Biomechanical laboratories have adopted standard movement analysis tools based on optical motion capture systems, force plates and electromyography (EMG) systems.

The quantitative analysis of functional activities using optical motion analysis systems is well established and has been used in clinical contexts in order to help to diagnose, plan the treatment, and assess the treatment outcomes.[3] Early identification of impaired daily life activities and administration of tailored interventions may prevent the loss of functional abilities and fall incidents. Easy applicable objective methods that can be used to assess or monitor the performance of sit-stand and stand-sit movements can assist in developing effective interventions and in optimizing individual application of interventions.[3,4,5]

When the goal of the analysis is the assessment of functional limitations, the reference population for a patient should comprise asymptomatic subjects with the same sex and belonging to the same age range (e.g. childhood, adult, or elderly). Another way to do functional assessment is comparing results from different measurement sessions of the same patient over time.[6,7,8,9]

In short, the kinematic approach seems to be essential for the functional assessment of the lumbar spine, since some of the most important variables that are impaired in patients with pain or other kind of lumbar pathologies are the ROM, which is fundamental for many daily life activities, and motor control, which can be kinematically measured by different specific tests and a functional task.

Impaired mobility function is one of the earliest and most characteristic symptoms of a wide variety of neuromusculoskeletal disorders. Mobility is essential to maintain independence and an essential attribute of life quality. Impaired mobility is a critical determinant of independence and a major contributor to physical disability.

You can consult details of the measuring protocols mentioned in this section in didactic unit D.2. Which thoracic and lumbar biomechanical instrumented evaluation protocols exist?

Remember the elements that determine a biomechanical assessment test:

- The **function** that is subject to assessment.
- The **instrumental technique** it is based on.
- The **assessment protocol** used.
- The **results it provides**, in what units and with what data analysis techniques they have been obtained.
- Th existence of **standardized criteria for interpretation**.

This section focuses on the analysis of the results obtained in the lumbar assessment of normal population using biomechanical analysis techniques. The students will acquire skills to interpret these results, they will be able to recognize them and establish a relationship with a normal pattern of lumbar functionality.

# 3. Assessment of the lumbar range of motion (ROM)

Generally, flexion-extension movements, lateralizations and axial rotations are performed in the spinal column. The range of motion of each joint is small and depends on the orientation of the interapophyseal joints and the elasticity of the discs. However, if we add all the degrees achieved at each functional level, great mobility is provided to the whole spine.

Most scientific studies show that there are age-related changes in the range of motion (ROM) that may affect some movements more than others. The disadvantage of these studies lies in the fact that they use a great variety of instruments and methods to determine the range of the thoracic, thoracolumbar and lumbar movements, which makes it difficult to compare the results. Despite this, all of them conclude that mobility changes with age and the range of motion reduces as the person gets older.

As an example, we use the work of Mc Gregor et al.[10], which shows that age has a significant effect on all planes of movement. According to these authors, the maximum extension is the most affected movement, significantly decreasing in each decade of life. Lateral flexion decreases after age 40 and every decade thereafter. Flexion initially decreases after age 30, but it remains the same until a subsequent decline occurs after the age of 50. However, no decreases or similar tendencies are observed in axial rotation.

The type of results obtained in the assessment of the range of motion using biomechanical techniques, as well as the standardized criteria to interpret such results, are shown below.

## Assessment using inclinometry

It is difficult to accurately measure true spine motion by physical examination. This is due to the soft tissue coverage of the spine, the curves of the spine, movement variations in different sections of the spine, and the presence of hip motion. In fact, a person may bend forward 90 degrees with the motion taking place entirely in the hips, not in the spine.

Figure 1. Electronic system of dual inclinometry located on the appropriate bone projections (T12-sacrum) to assess the maximum range of motion of the joint during the flexion movement of the lumbar spine.

To obtain more accurate measurements, an instrumental technique such as inclinometers can be used (Figure 1). The American Medical Association (AMA)[11] recommends them as an accurate method to estimate the true motion of the spine. The lumbar ROM must be measured with the patient in the standing position. This is the zero starting position.

The result obtained with this measuring device is:

- **Maximum range of motion in degrees** of the active mobility of the spine segment assessed.

Indirectly, from the previous result we can obtain or calculate:

- **Mobility loss or deficit** (ML) as a percentage of the segment assessed with respect to the reference values.

In the assessment with this type of test, the results obtained for the range of motion can be compared with the mobility results of a group of subjects without movement limitations whose characteristics are comparable to those of the person assessed and who were measured using the same measurement technique and protocol; they can be also compared with reference values that have been accepted and validated by the scientific community, or with other results of the same person obtained in different assessment sessions.

The results of the maximum range of lumbar motion in a person with no pathology or painful pattern in the lumbar spine are shown below. This measurement was performed using the dual inclinometer technique applying the recommendations of the American Medical Association (AMA) for measuring the lumbar spine regarding both position and number of repetitions: *When determining the range of motion, the examiner must select three consecutive measurements and calculate the average of the three. If the average is less than 50º, three measurements must fall within 5º from the mean; if the average is greater than 50º, three measurements must fall within 10% from the mean.*

| | Pos. Neutra (D12/SACRO) | Pos. Flexión (D12/SACRO) | Pos. Extensión (D12/SACRO) | Flexión | Criterio AMA | Extensión | Criterio AMA |
|---|---|---|---|---|---|---|---|
| 1ª | -20.2º / 36.1º | 70.3º / 65.4º | -40.5º / 23.5º | 61.0º | OK | 7.0º | >5º |
| 2ª | -27.6º / 23.4º | 74.8º / 68.5º | -43.4º / 27.6º | 57.0º | OK | 20.0º | OK |
| 3ª | -24.3º / 25.1º | 74.2º / 69.3º | -41.7º / 28.4º | 54.0º | OK | 20.0º | OK |
| 4ª | -21.8º / 27.4º | 79.5º / 74.8º | -41.1º / 25.6º | 53.0º | OK | 17.0º | OK |

Figure 2. Results recorded for each inclinometer (dual inclinometer technique) located in T12 and sacrum to assess the flexion-extension range of the lumbar spine. The measurement repeatability criterion is met (AMA criterion).

The results shown in Figure 2, with the second, third and fourth repetition, meet the repeatability criteria defined by the American Medical Association. Therefore, the results for the flexion and extension of the lumbar spine obtained in three consecutive records are valid because of their repeatability. The final deficiency is that of the greatest angle measured in a valid series of three consecutive measurements. The greatest angle of lumbar flexion is 57º, and that of lumbar extension is 20º. Let's take a closer look at these calculations.

In the example (Figure 2), the patient measurements for flexion at T12 level, starting from the second repetition, are 74.8º, 74.2º and 79.5º, and for flexion at sacral level 68.5º, 69.3º and 74.8º. The measurement of the inclinometer in neutral position must be subtracted from these data. For example, for the first repetition of the inclinometer placed in T12, it would be 74.8º - (-27.6º) = 102.4º of flexion for the inclinometer located in T12. The calculations for the sacrum inclinometer will be the same (degrees in maximum flexion - degrees in neutral position): 68.5º - 23.4º = 45.1º of flexion in the sacrum inclinometer. Therefore, the real lumbar flexion in that repetition is 102.4º- 45.1º, which is approximately 57º.

The same calculations apply to all the measurements, whatever the movement measured. The result of applying the same calculation procedure in the third repetition is 54º, and 53º for the fourth repetition. The average of the lumbar flexion angles is 55º, and all three measurements fall within 10% from the mean. Consequently, the validity criteria of the measurement have been met, and the maximum flexion angle of the valid series—57º of lumbar flexion—is finally used.

**Validity test of lumbosacral flexion and extension**

In the analysis of the range of motion of the lumbar spine, it should be noted that hip flexion is also involved in spinal flexion. For this reason, there is a validity test recommended by the AMA in those cases in which the sacral flexion-extension mobility measured with the inclinometer located in the sacrum is very low. Specifically, when the sacral flexion-extension range (sacrum or hip movement) is less than 65º in women and 55º in men.

The test is performed with the patient supine on a firm, level examining table. This is the straight leg raising test (passive motion).

Figure 3. Straight leg raising test (passive motion).

The result obtained with this test is the most closed leg raising angle (SLR). To interpret it in the context of an assessment of lumbar spine mobility, the angle obtained (SLR) must be compared with the sum of the sacral flexion-extension angles (determined by the inclinometer located in the sacrum). If the most closed SLR angle is more than 15º greater than the sum of the sacral flexion-extension angles, the results of the lumbosacral flexion measurement are not valid because the person has more mobility at hip level.

For example, the measurements of a 40-year-old bus driver are: 60° for flexion at T12, 20º for sacral (hip) flexion, and 10º for sacral (hip) extension. The right straight leg raising angle is the most closed one: 70º. Therefore, the patient has a total sacral (hip) movement of 20º + 10º, or 30º, compared to the straight leg raising angle of 70º. The difference between 70º and 30º is greater than 15º, so the validity test is applicable since the patient's total sacral movement (30º) is lower than 55º.

As an examiner, and based on the data you have recorded, you know that the real lumbar flexion is good (60º-20º = 40º). You can encourage the patient to repeat the test with a greater effort or invalidate any findings of movement deficiency of the lumbosacral spine in the sagittal plane given that greater mobility is possible.

The following figures show the final result of a lumbar assessment using a dual inclinometer technique in a person without mobility limitations. These results are valid because they meet the validity criteria of the AMA already mentioned.

| | Amplitud máxima | PM frente referencia AMA |
|---|---|---|
| Flexión | 63º | 0% |
| Extensión | 35º | 0% |
| Flexión Lateral Izquierda | 42º | 0% |
| Flexión Lateral Derecha | 50º | 0% |

Figure 4. Results of the maximum range of active motion of the lumbar spine and percentage of mobility loss or deficit (ML) in each test with respect to the reference values of the American Medical Association (AMA). Two inclinometers were used to obtain these results.

The following graph shows another way to display the results:

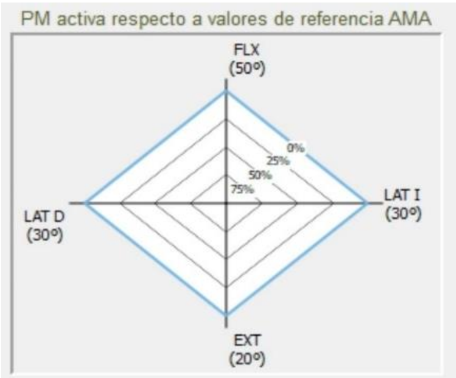


Figure 5. Comparison of the percentage of loss of active lumbar mobility with respect to the reference values of the American Medical Association (AMA) in each axis of movement assessed. The percentage of mobility loss is represented by the blue line.

In order to **interpret these results**, it is recommended that the students follow some standardised interpretation criteria by answering some questions:

- What was the maximum range recorded for each movement?
- Is the mobility recorded for each axis within normality?
- What values were taken as a reference for normality?
- What is the most limited movement or the movement that shows the greatest loss of mobility? And the least limited movement?
- Is the loss of mobility significant?
- Were important asymmetries found in the laterality of the movements?

By applying these criteria, you can interpret the results of the example proposed. The interpretation would be as follows:

> As shown in Figure 4, a maximum value of 63º was obtained for lumbar flexion and 35º for extension. For left and right lateral flexion, 42º and 50º, respectively.
>
> In general, these values are considered normal in lumbar spine mobility since they are greater than the reference values used in this assessment (50º for flexion, 20º for extension, and 30º for lateralizations), as shown in the graph of Figure 5.
>
> No significant asymmetries were recorded since the only difference is 8º in the lateral flexion.

In summary, in this case, the final interpretation of the data recorded with inclinometers concludes that the patient's lumbar mobility is very good. It is generally higher than the mobility values considered as a reference, and there are no significant asymmetries. Therefore, it is considered as normal mobility, there being no lumbar mobility deficiency in the movements analysed.

Using these values, or other values that you use as a reference, the mobility deficit or loss (ML) must be calculated from the relationship of the reference mobility degrees with respect to those measured. The calculation of the percentage of mobility loss (% ML) is based on the following formula:

$$\%ML = (1 - (\text{Value measured}/\text{reference value})) \times 100$$

# 4. Kinematic assessment of the lumbar spine

Although photogrammetry is an instrumental technique that is widely used in biomechanical assessment, there are other smaller and portable devices that can also perform a movement analysis. Inertial devices should be particularly highlighted, which use motion sensors placed at specific points on the subject with minimal interference.

To measure the mobility of the lumbar spine in one plane, the person is instrumented and asked to perform the movement to be assessed, usually lumbar flexion-extension. The patient is normally asked to perform different movement cycles, as seen in the cervical assessment test of the previous unit. In a similar way to the cervical spine, this type of analysis makes it possible to assess:

- Maximum angle of mobility in each plane.
- Angular speed and/or acceleration of the lumbar spine.
- Repeatability of the movement analysed.

The maximum range reached is measured by recording several repetitions of the same movement, for example, lumbar flexion-extension. If there are mobility limitations, the maximum value recorded can be compared with those obtained using the same measuring device and protocol, or with reference values established, such as those of the AMA.

On the other hand, since the same movement is repeated over time under the same measuring conditions, significant variations are not expected to be found in a normal pattern, especially if the time between an assessment series and another is short. The standard deviation and the coefficient of variation of the measurements are two parameters that help to analyse the repeatability of the movement performed in this type of assessment.

The type of graph obtained with this analysis represents the cycles of movement over time, or the representation of the maximum range of the movement with respect to its angular velocity. This last graph also shows the regularity of the movement and the smoothness of its performance.

In order to **interpret the results** of the kinematic assessment of the lumbar spine movement, it is recommended that the students add the following criteria to those discussed in the previous section:

- What was the speed of the movement performed in each axis? Was it a slow movement? Was it a quick movement?
- Was the movement performed repeatable?
- Was the movement performed smooth?

As with the results of the kinematic assessment of the cervical spine in didactic unit D.3, the results for the lumbar area can be interpreted the same way.

# 5. Kinematic and kinetic assessment in daily activities and low back pain

Low back pain limits or alters mobility, due to either an organic or psychic cause. People affected by this symptom usually complain about not being able to carry out frequent and common activities of daily life, such as sitting and getting up from a chair at home, at work or leisure places, bending over, or handling and moving weights during both domestic and work tasks. These tasks cause an increase in the moments of force at the joints of the lower limb and the lumbar spine, as well as in muscle activity, which may require a significant effort or overload from the person who performs them. They involve functional activity by the lumbar spine in coordination with other structures (mainly the lower limbs), in addition to generating significant activity in the abdominal muscles, spinal erectors, and hip flexor/extensors.

In people with low back pain, activities such as bending the trunk or lifting weights are associated with significant increases in the intradiscal pressure, and consequently pain. In 1976, Nachemson[12] conducted a study on intradiscal pressures at $L_3$-$L_4$ level during different activities. He determined that the values in the sitting position are greater than standing and that they increase if the person is holding a weight in the hand. The data represented in Figure 6 are based on this study and the values are given in relation to a reference value established in the standing position (100%).

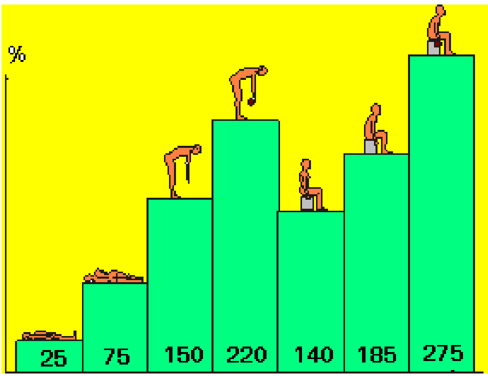


Figure 6. Graphic comparison of intradiscal pressures in L3-L4 during different activities (Nachemson[12], 1976)

The kinematic and kinetic analysis of the aforementioned movements allows us to define them more accurately through the analysis of the range of motion (ROM), angular acceleration and speed at which the movement is performed, as well as other parameters such as the reaction force and repeatability of the movement. An alteration in the parameters that define the movement is associated with a functional alteration of the person to perform the analysed tasks.

A 3D photogrammetry device can be used to assess the aforementioned kinematic parameters. This technique is still considered the gold standard in the kinematic analysis of human movement. It is described as a harmless and non-invasive technique, with a high potential for the functional assessment of motor impairments in general.

On the other hand, the use of dynamometric platforms to assess the forces that produce movement allows us to analyse the reaction force of the lower limbs against the floor during different activities in which the trunk or paravertebral muscles are engaged, such as when rising from the sitting position on a chair or lifting a weight. This type of record provides information on the support, movement stability, and possible abnormalities in the force exerted by the lower limb in case of pain, for example, unilateral sciatica. This pathology usually shows an asymmetry in the distribution of force between both legs.

Some of the results that can be found in this type of assessment include:

- Activity performance time
- Reaction force during support
- Asymmetry in the support of both lower limbs while performing the activity
- Angular speed and/or acceleration of the trunk during the activity
- Repeatability of the movement performed

Some of the results obtained in a biomechanical analysis, within what would be considered a normal movement pattern, as well as how to interpret them, is shown below. The objective is for the students to recognise and interpret the results, which will help them to identify differences with respect to the results for a movement altered by low back pain.

**Activity performance time**

It refers to how long (in seconds) it takes the person to perform the activity assessed.

The graphs in Figure 7 show the kinetic and kinematic representation of the sit-to-stand movement in a healthy subject. The vertical reaction force (blue line: Fz) and the flexion angle of both the trunk (green) and the lower limb at knee level (red) are represented. The yellow shaded area indicates the beginning and end of the activity of standing up from the chair, which is especially important when assessing the functionality of the lumbar spine because it is subjected to a greater load.

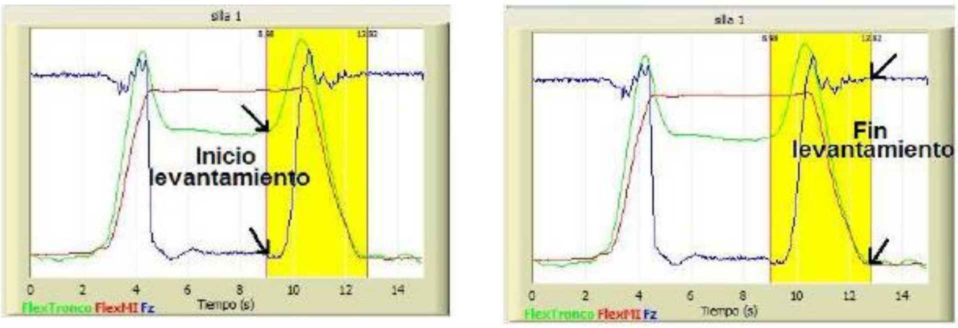


Figure 7. Graphic representation of the activity of sitting/rising from a chair. The part of the movement when the person is standing up from the chair is highlighted in yellow.

At the initiation of the lift (yellow stripe), the person is sitting, with a trunk and knee flexion of approximately 90º. To stand up, the person starts to increase trunk flexion (green line), and begins to generate the momentum, which is represented by the maximum vertical force reached (blue line), to raise the person's centre of gravity and reach the upright position. In addition, in order to achieve the lift, the subject must extend both lower limbs with the help of a powerful contraction of both quadriceps.

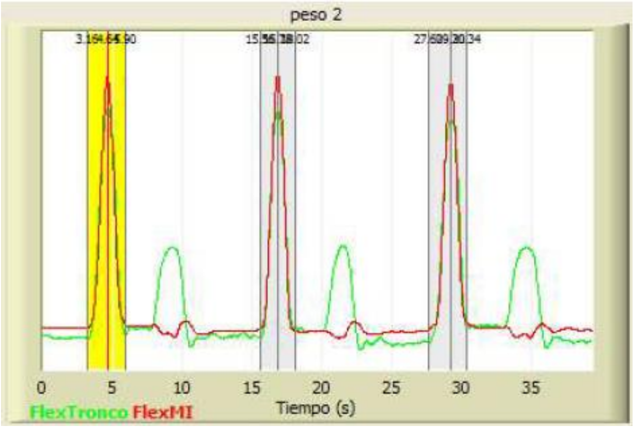


Figure 8. Graphic representation of the activity of lifting a weight. The same movement is performed but each time lifting a different weight. The portion of the movement assessed is highlighted in yellow.

The graph in Figure 8 shows a kinematic representation of the movement performed during the assessment of weight lifting in a healthy patient. In this case, the subject must pick up a weight from the floor (boxes weighing 0 kg, 5 kg, and 10 kg) with both hands, lift it to the waist and finally place it on a table placed on one side. There is an important trunk flexion (green line), a secondary lower limb flexion (red line) followed by a subsequent total extension (lifting the box) and finally a slight trunk flexion when the subject bends to leave the box on the table.

The time it takes the person to perform the movement is essential in any study about the mobility of people with a spinal disorder or damage. As early as 1986, Marras and Wongsam[13] considered the speed of the movement a quantitative measure in people with back disorders, which could help to monitor the progress of a disease or treatment. Subjects without any pathology of the spine or lower limbs usually perform a quick movement of rising from the chair or lifting a weight, that is, high speed and low total performance time.

Older people need more time to get up from the chair, which seems to be due to their need for greater stability. However, there are no conclusive studies in this regard, and some authors do not find any differences in the healthy population by age.[14]

**Support reaction force and asymmetry of forces**

These parameters refer to the value of the vertical component of the reaction force recorded by each dynamometric platform during the entire activity performed, and to the difference in the force or support in both lower limbs. The unit of measurement is N, and if the force is normalised to the weight, it is dimensionless.

The graph below represents the vertical reaction force during the activity of getting up from a chair in a healthy person. It shows how this force is very small at the beginning (approximately 20% of body weight), since the subject is supporting practically all his weight on the chair and not on the force platform. At the initiation of the lift, the patient begins an acceleration phase that helps generate enough momentum to get up from the chair. That is why a rapid rising in the reaction force occurs (slope of the vertical curve) and ends with a maximum peak force. The greater the momentum generated in the movement is, the higher this peak will be. Finally, this force partially decreases until it remains stable once full standing is reached with a value similar to that of the subject's body weight (100%).

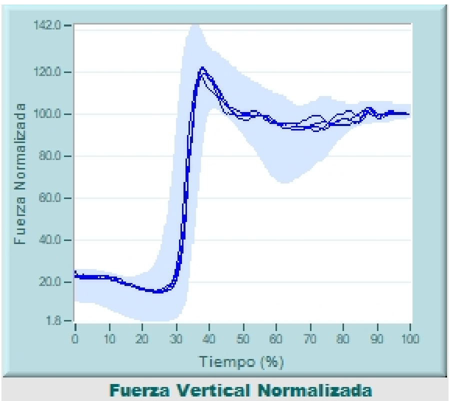


Figure 9. Vertical reaction force (normalised to body weight) during the sit-to-stand movement. The graph shows 4 repetitions of this activity (dark blue lines). The blue band represents the normal force pattern considered in the measuring equipment used (NedLumbar/IBV).

Therefore, the vertical reaction force is related to the momentum generated to get up from the chair (the faster the movement is, the greater the vertical reaction force). Generally speaking, healthy subjects, or those without low back pain, perform a fast and energetic movement, consequently, the values of the maximum vertical force are high.

At the same time, if two force platforms are used, the force exerted by each lower limb while standing up can be assessed. The normal pattern of strength shows symmetrical support, since performing any activity, whether it is getting up from a chair or lifting a weight, involves a similar stabilisation and body weight support in both lower limbs.

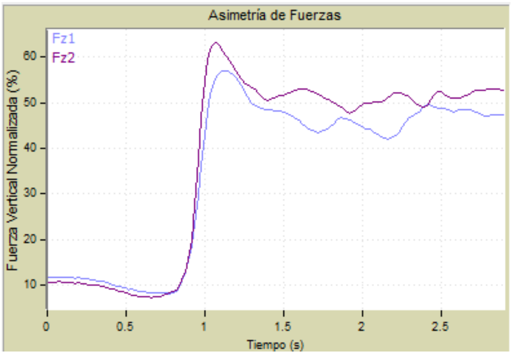


Figure 10. Normalised vertical force representing the vertical reaction force performed by each lower limb when supporting the body weight on them as the person rises from the chair.

In Figure 10, Fz1 represents the reaction force of the right lower limb, and Fz2 that of the left side. In this case, the distribution of forces during the support while performing the movement is practically similar, which would be within a normal movement pattern.

**Angular speed and acceleration**

These parameters refer to the angular speed and acceleration of the trunk during the movement performed. The units of measurement are º/s and º/s$^2$ respectively.

The following figures show graphs representing the angular velocity versus the angular acceleration of the trunk in the two activities analysed.

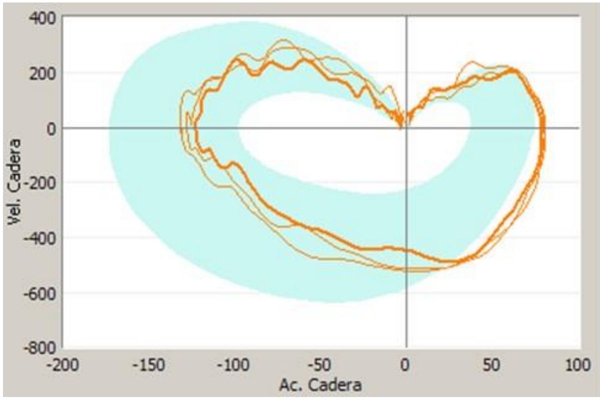


Figure 11. Graphic representation of the angular velocity with respect to the angular acceleration of the trunk when performing the activity of getting up from a chair. The blue band represents the normal force pattern considered in the measuring equipment used (NedLumbar/IBV).

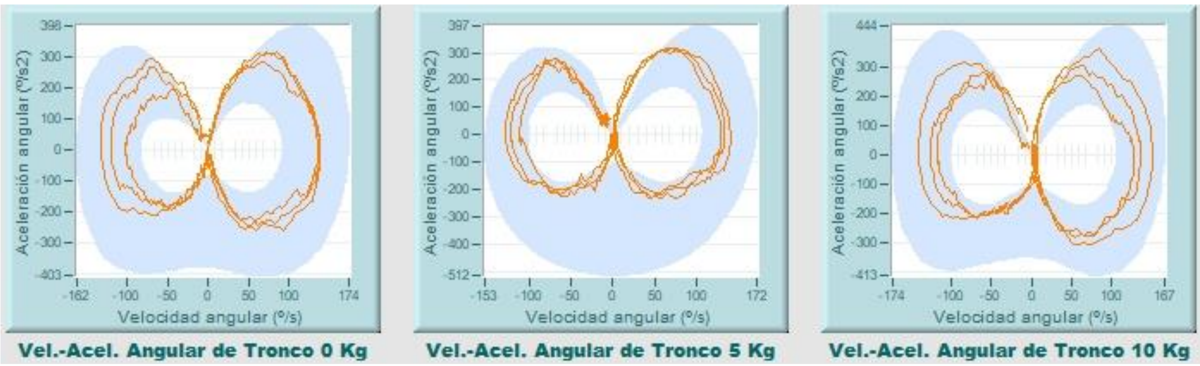


Figure 12. Graphical representation of the angular velocity-acceleration of the trunk when performing the activity of lifting a weight (0 kg, 5 kg, and 10 kg on the left, centre and right, respectively). The blue band represents the normal force pattern considered in the measuring equipment used (NedLumbar/IBV).

According to the graphic representation, and taking as a reference the blue band that represents the reference movement pattern, the spinal movement performed by the person in the activity assessed was fast or at an adequate speed, since both acceleration and speed are within the band that this measuring system considers as normal. In addition, another interpretation from this result is that no significant decrease in the speed and/or acceleration of the trunk is observed when the load lifted is increased, which also corresponds to a normal pattern of movement.

**Repeatability**

Based on all the graphs shown in this subsection, the activity recorded through several measuring repetitions (both Figure 11 and 12 show three repetitions of the activity of getting up from a chair, and three repetitions of the activity of lifting each weight) generally shows high repeatability, since the movement pattern performed by the person being assessed is practically the same. Repeatability indicates the similarity among the different repetitions of the same movement or activity. In the field of biomechanical assessment, the coefficient of variation of the measurements is often used to calculate repeatability. The expected result in a normal movement pattern involves high repeatability.

Many other parameters can be obtained with this type of tests. You can increase your knowledge by reading the following systematic review by Papi et al.[4] on the use of kinetic and kinematic measures as a clinical assessment of the lumbar spine:

> Papi, E., Bull, A. M., & McGregor, A. H. (2018). Is there evidence to use kinematic/kinetic measures clinically in low back pain patients? A systematic review. *Clinical Biomechanics*, *55*, 53-64.

# 6. Force assessment of the lumbar spine

The assessment of the lumbar spine strength using an instrumental technique focuses on muscular strength (isokinetics) and on muscle activity (sEMG).

## Assessment of muscle strength. Isokinetics.

Maximum muscle capacity is defined as the greatest force that a muscle can exert on the skeletal system under certain load conditions. This is the most used parameter in clinical practice since muscular capacity varies according to the angle of the joint on which it acts, or in other words, its lever arm. The relationship between the force couple generated and the joint angle is influenced by a large number of variables, which should be considered in the final results of an assessment, such as age, gender, subject's motivation, pain, muscle and joint physiology, as well as by the conditions of the exercise performed (eccentric, concentric, isometric, isokinetic). In addition, any injured component of the muscle/tendon unit (deformation, tear, tendinitis, pain) can limit the muscle ability to produce force.

There are systems to measure the strength of the paravertebral muscles. Isokinetic systems, which keep the angular velocity of the movement constant throughout the whole range of motion selected, are one of the most widely used. In order to perform the isokinetic assessment of the spine, the subject moves the trunk at a speed that is controlled and preselected by the examiner. The resistance that the measuring equipment puts up to the movement is automatically adapted to the force applied, so that the muscle maintains its maximum performance throughout the entire range of movement.

A series of graphs and tables are drawn up on the basis of the force recorded using isokinetic methods. For each muscle group tested and for each speed at which the muscle works, there is a normal curve that represents the torque of such muscle throughout the movement. This graph makes it possible to obtain the curve of the torque in correspondence with the articular arc in each case, which allows us to perform an exact analysis of the development of muscular force at each point of the arc of movement. Figure 13 shows an example of a normal graph of isokinetic contraction.

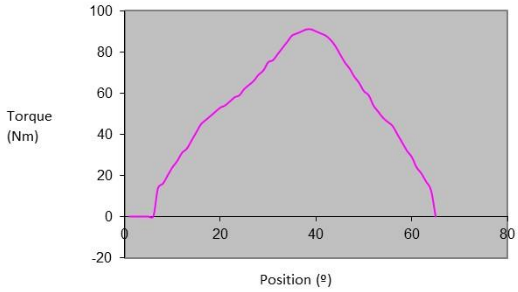


Figure 13. Normal curve of the concentric isokinetic moment of torsion. The vertical axis reflects the amount of force generated by the muscle. The horizontal axis is the range of movement in which the assessment is performed.

Generally speaking, with individual variations for each muscle, this type of graph is expected to show a parabolic form in which three essential phases can be considered:

1. Ascending or acceleration phase (time rate to torque development). The curve rapidly ascends, becomes slightly convex upwards, and tends to perpendicularity on the abscissa axis as the time it takes from the start of the contraction to the peak torque decreases. Coyle et al.[15] associate this with the explosive force of the muscle due to the action of fibres II (fast contracting fibres). If, during the initial phase of acceleration, the curve is concave and the peak torque occurs in the middle or in the final third of the curve, it is a hypofunction or muscular hypotrophy.
2. Peak torque. Segment of the curve in which it reaches the maximum at its inflection point. It corresponds to the peak torque of the muscle that is being tested.
3. Force decay phase (force decay rate). The line of the curve is usually convex and reaches the end of the movement, at which point it contacts the base line.

In the normal isokinetic pattern, it should be noted that the peak torque of a muscle decreases as the working speed increases (Figure 14).

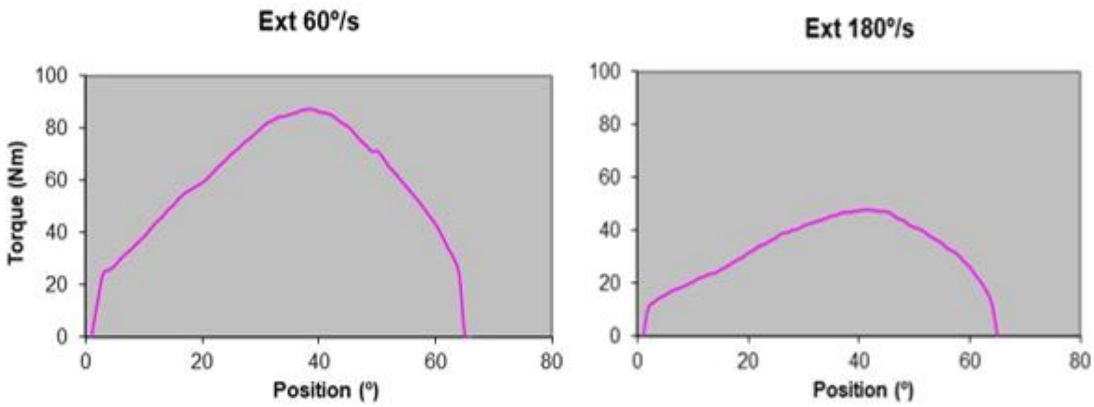


Figure 14. Isokinetic record of the extensor muscle group at a slow speed (left) and a fast speed (right).

With regard to the results obtained in an isokinetic assessment, the main information provided by trunk isokinetics in the context of a clinical evaluation include:

1. **Peak torque**. It expresses, as an absolute value, the maximum torque produced by the muscle group assessed. Peak torque is the product of the force applied around an axis of rotation by the perpendicular distance between the point of force application and the centre of rotation. The unit of measurement is Nm. This value is influenced by gender, age, sports habits, as well as by factors related to the type of muscular work, e.g., concentric or eccentric work, and the speed at which the exercise is performed. Remember that higher peak torque values are obtained at slow speeds than at fast speeds (Figure 14).
2. **Average torque**. It assesses the average torque developed throughout the entire range of motion. It is an interesting parameter because it informs about the muscle work performed throughout the entire range, not only about its action at a specific point, as is the case with peak torque. It is expressed in Nm and the conditions under which the assessment was carried out must be specified (type of contraction and speed).
3. **Analysis of the curve morphology**. Each muscle group develops a normal graph with small differences depending on the type of contraction and its speed. Morphology is

generally better studied at slower speeds. Review the points previously made about the graph.

4. **Agonist-antagonist relationship**. It expresses the quantitative relationship between the torque of the agonist group and that of the antagonist group. This is the ratio expressed as a percentage. It usually represents the correct agonist-antagonist balance and makes it possible to visualize muscle imbalances.

Finally, the isokinetic study of the spine poses a particular problem: the lack of a symmetrical joint with which to compare the results. A deficit can be defined by comparing with normative data. This alternative almost always requires having your own database, since the values are conditioned both by the study protocol applied and the type or commercial brand of the isokinetic used for measuring.

The isokinetic force of the flexors and extensors changes according to the position of the person being assessed. It is worth noting again the importance of a standardised protocol to compare the data. In addition, the lack of a contralateral limb to compare the results or a common measurement procedure makes it difficult to obtain reference values that help to interpret the results. Therefore, monitoring the progress is the best way to assess and follow up these patients.

Based on the published data regarding the assessment of isokinetic trunk strength, men tend to produce a greater moment of force in the flexor and extensor trunk muscles in relation to body weight than women (trunk strength is usually expressed as a percentage with respect to the total body weight). As previously mentioned, the position in which the measurement is performed influences the force values obtained. Thus, the force value of the flexors is greater in the standing position than in the sitting position. Besides, the values of the extensors are greater than those of the flexors, although it seems that this difference decreases as the speed increases. In any case, it is recommended that the trunk assessment be made at slow speeds since the substantial mass of the trunk makes it difficult to accelerate at higher speeds.[16]

Another parameter that is analysed during the isokinetic assessment is the relationship between agonists and antagonists. In this case, it would be the relation between flexors and extensors, but we face the same problem: some studies work with the flexor/extensor relationship, whereas other work with the extensor/flexor relationship.

Finally, it should be noted that rotations and lateral bending are hardly studied. Trunk rotation occurs in the transverse plane of the body and is principally produced by the internal and external oblique abdominal muscles. The internal oblique causes rotation to the same side, whereas the external oblique causes it to the opposite side. Consequently, the contraction of the right internal oblique and the left external oblique occurs to the right, and that of the left internal oblique and the right external oblique to the left. Although both contralateral and ipsilateral obliques contract during rotation, electromyographic analyses show that the activity of the contralateral obliques is greater than that of the ipsilateral obliques.[16]

In addition, lateral flexion of the trunk occurs in the frontal plane. There is little published information on the normal isokinetic values for this movement, but it seems that the difference between left and right lateral flexion is minimal.

## Assessment of muscle activity. Surface electromyography.

The activity of the trunk muscles can be indirectly estimated by means of electromyography. This is the reason why surface EMG is a technique frequently used to assess the lumbar area, specifically to analyse muscle behaviour during movements such as trunk flexion-extension.

When the flexion of the trunk is electromyographically analysed in an upright position, a sudden myoelectric silence or relaxation of the spinal erector muscles is observed at a point close to the maximum flexion. This spinal behaviour has been described in healthy people and is known as the flexion-relaxation phenomenon.

The normal activation pattern is represented in the following graph, where the lumbar flexion pattern can be identified in yellow and the hip flexion pattern in red.

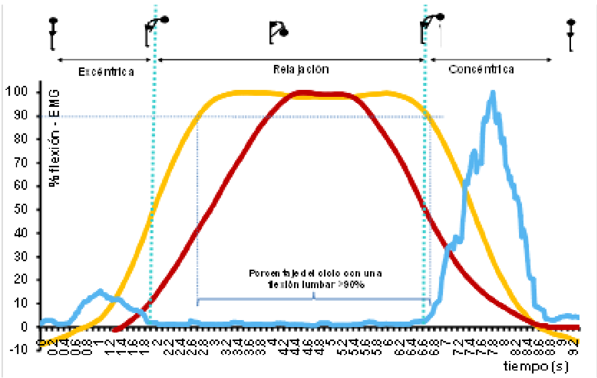


Figure 15. Lumbar flexion and hip flexion during trunk flexion-extension.

In the graph, the ordinate axis represents the percentage of flexion with respect to the maximum value. This pattern of lumbar flexion and hip flexion, which is known as lumbopelvic rhythm, is accompanied by a specific pattern of activation of the spinal erector, which corresponds to the blue line in the graph. The spinal erector is first activated eccentrically at the beginning of the flexion to control the flexion movement. At a certain point, when the lumbar spine is still far from full flexion, it deactivates and a phase of what is called myoelectric silence begins. This is the flexion-relaxation phenomenon. Shortly after the spine begins to perform the extension movement, the spinal erector is reactivated, this time more intensely, in a concentric activation peak. This physiological pattern may be altered in subjects with low back pain.

This neuromuscular response is probably triggered by the mechanical load that occurs in the ligaments and discs of the lumbar spine, highly innervated by receptors that monitor proprioceptive and nociceptive stimuli.[17] Floyd and Silver[18] suggested for the first time that the posterior lumbar passive structures (spinal ligaments and intervertebral discs) provided the necessary torque during maximum trunk flexion in the absence of muscular activity in the spinal erector muscle.

There is evidence in the literature that supports the reliability of lumbar EMG measurements during and between sessions of both static and dynamic movements/posture, including flexion and what is called "re-extension", that is, reaching the upright position from the flexed position.[19] There is controversy regarding the "ideal" results to represent the lumbar flexion-relaxation phenomenon quantitatively. The leading candidates seem to be EMG raw signal in μV (root mean square or RMS) at maximum flexion, or the flexion-relaxation ratio (FRR).[20,21,22]

In normal and healthy people, EMG activity during the flexion of the lumbar paraspinal muscles increases initially and then decreases as the ligaments start to support the trunk as the flexion angle increases. At maximum voluntary flexion (MVF), sEMG activity is often at or below the level of sEMG activity in the standing position. The pattern of sEMG activity associated with flexion and extension in a normal healthy person is illustrated in the figure below. However, in people with low back pain, this paravertebral relaxation in MVF tends to be absent or decreased. The example of a record classified as a normal pattern because of the presence of myoelectric silence is also shown below.

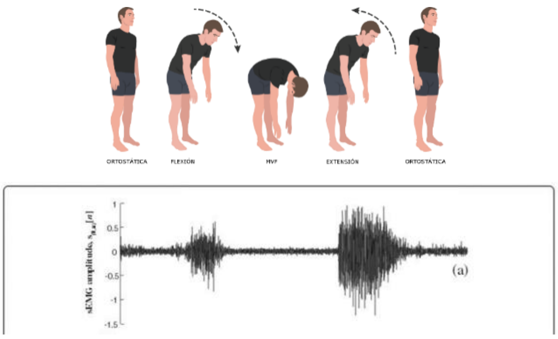


Figure 16. Muscle activity during a flexion-extension test of the lumbar spine.

## 7. Key ideas

- Most scientific studies show that there are age-related changes in the range of motion (ROM) and that such changes may affect some movements more than others. The disadvantage of these studies is that a great variety of instruments and methods are used to determine the range of movement in the thoracic, thoracolumbar and lumbar regions, which makes it difficult to compare the results. Despite this, they all conclude that mobility changes with age, and the range of motion reduces as the person gets older.

- In order to measure the range of motion of the spine more accurately, the American Medical Association (AMA)[11] recommends the use of inclinometers as an accurate method to estimate true spine motion.

- Low back pain limits or alters mobility, due either to an organic or psychic cause. The most frequent complaint of people affected by this symptom is not being able to carry out frequent and common activities of daily life, such as sitting and getting up from a chair at home, at work or in the place of leisure, bending over, or handling and moving weights in both domestic and work tasks.

- The kinematic and kinetic analysis of the aforementioned movements allows us to define them more accurately through the analysis of the range of motion (ROM), the angular acceleration and speed with which the movement is performed, as well as other parameters such as the reaction force and the repeatability of the movement. An alteration in the parameters that define the movement is associated with a functional alteration of the person to perform the analysed tasks.

- There are systems to measure the strength of the paravertebral muscles. Isokinetic systems, which keep the angular velocity of the movement constant throughout the whole range of motion selected, are one of the most widely used.

- The activity of the trunk muscles can be indirectly estimated by means of electromyography. This is the reason why surface EMG is a technique frequently used to assess the lumbar area, specifically to analyse muscle behaviour during movements such as trunk flexion-extension.

## 8. References

[1] Jacobs, J. V., Yaguchi, C., Kaida, C., Irei, M., Naka, M., Henry, S. M., & Fujiwara, K. (2011). Effects of experimentally induced low back pain on the sit-to-stand movement and electroencephalographic contingent negative variation. *Experimental brain research*, *215*(2), 123.

[2] Alqhtani, R. S., Jones, M. D., Theobald, P. S., & Williams, J. M. (2015). Correlation of lumbar-hip kinematics between trunk flexion and other functional tasks. *Journal of manipulative and physiological therapeutics*, *38*(6), 442-447.

[3] Pourahmadi, M. R., Ebrahimi Takamjani, I., Jaberzadeh, S., Sarrafzadeh, J., Sanjari, M. A., Bagheri, R., & Taghipour, M. (2019). Kinematics of the spine during sit-to-stand movement using motion analysis systems: a systematic review of literature. *Journal of sport rehabilitation*, *28*(1), 77-93.

[4] Papi, E., Bull, A. M., & McGregor, A. H. (2018). Is there evidence to use kinematic/kinetic measures clinically in low back pain patients? A systematic review. *Clinical Biomechanics*, *55*, 53-64.

[5] Stienen, M. N., Ho, A. L., Staartjes, V. E., Maldaner, N., Veeravagu, A., Desai, A., ... & Park, J. (2019). Objective measures of functional impairment for degenerative diseases of the lumbar spine: a systematic review of the literature. *The Spine Journal*.

[6] Peydro, M. F., López, J., Cortés, A., Vivas, M. J., Garrido, J. D., & Tortosa, L. (2011). Análisis cinético y cinemático del gesto «levantarse de una silla» en pacientes con lumbalgias. *Rehabilitación*, *45*(2), 99-105.

[7] Zijlstra, A., Mancini, M., Lindemann, U., Chiari, L., & Zijlstra, W. (2012). Sit-stand and stand-sit transitions in older adults and patients with Parkinson's disease: event detection based on motion sensors versus force plates. *Journal of neuroengineering and rehabilitation*, *9*(1), 75.

[8] Svendsen, J. H., Svarrer, H., Laessoe, U., Vollenbroek-Hutten, M., & Madeleine, P. (2013). Standardized activities of daily living in presence of sub-acute low-back pain: a pilot study. *Journal of electromyography and kinesiology*, *23*(1), 159-165.

[9] Sánchez-Zuriaga, D., López-Pascual, J., Garrido-Jaén, D., de Moya, M. F. P., & Prat-Pastor, J. (2011). Reliability and validity of a new objective tool for low back pain functional assessment. *Spine*, *36*(16), 1279-1288.

[10] McGregor, A. H., McCarthy, I. D., & Hughes, S. P. (1995). Motion characteristics of the lumbar spine in the normal population. *Spine*, *20*(22), 2421-2428.

[11] Gerhardt,J. Cocchiarella, L and Lea,R: The Practical Guide to Range of Motion Assessment, AMA, Chicago , 2002

[12] Nachemson, A. L. (1976). The lumbar spine an orthopaedic challenge. *spine*, *1*(1), 59-71.

[13] Marras, W. S., & Wongsam, P. E. (1986). Flexibility and velocity of the normal and impaired lumbar spine. *Archives of Physical Medicine and Rehabilitation*, *67*(4), 213-217.

[14] Alexander, N. B., Schultz, A. B., & Warwick, D. N. (1991). Rising from a chair: effects of age and functional ability on performance biomechanics. *Journal of gerontology*, *46*(3), M91-M98.

[15] Coyle, E. F., Feiring, D. C., Rotkis, T. C., Cote 3rd, R. W., Roby, F. B., Lee, W., & Wilmore, J. H. (1981). Specificity of power improvements through slow and fast isokinetic training. *Journal of applied physiology*, *51*(6), 1437-1442.

[16] Smith, S. S., Mayer, T. G., Gatchel, R. J., & Becker, T. J. (1985). Quantification of lumbar function. Part 1: Isometric and multispeed isokinetic trunk strength measures in sagittal and axial planes in normal subjects. *Spine*, *10*(8), 757-764.

[17] Holm, S., Indahl, A., & Solomonow, M. (2002). Sensorimotor control of the spine. *Journal of electromyography and Kinesiology*, *12*(3), 219-234.

[18] Floyd, W. F., & Silver, P. H. S. (1955). The function of the erectores spinae muscles in certain movements and postures in man. *The Journal of physiology*, *129*(1), 184-203.

[19] Mayer et al. The Quantified Lumbar Flexion-Relaxation Phenomenon Is a Useful Measurement of Improvement in a Functional Restoration Program. Spine, Volume 34, Number 22, pp 2458–2465.

[20] Sihvonen, T., Partanen, J., Hänninen, O., & Soimakallio, S. (1991). Electric behavior of low back muscles during lumbar pelvic rhythm in low back pain patients and healthy controls. *Archives of physical medicine and rehabilitation*, *72*(13), 1080-1087.

[21] Neblett, R., Brede, E., Mayer, T. G., & Gatchel, R. J. (2013). What is the best surface EMG measure of lumbar flexion-relaxation for distinguishing chronic low back pain patients from pain-free controls?. *The Clinical journal of pain*, *29*(4), 334.

[22] Geisser, M. E., Ranavaya, M., Haig, A. J., Roth, R. S., Zucker, R., Ambroz, C., & Caruso, M. (2005). A meta-analytic review of surface electromyography among persons with low back pain and normal, healthy controls. *The journal of pain*, *6*(11), 711-726.