BIOMECHANICAL ANALYSIS OF THE PARAVERTEBRAL MUSCLE STATUS USING IMAGING METHODS

Cătălin POPA1*, Alexandru CHIVARAN1, Miheea MARIN1, Hisham Mohammad Othnan ABU TAHA1, Mihaela ZĂVĂLEANU1, Mihai-Robert RUSU1, Ligia RUSU1

1 University of Craiova, Faculty of Physical Education and Sport, Craiova, Romania
*Corresponding author: catalin.popa@edu.ucv.ro

Abstract. Introduction: In recent decades, people’s lifestyles, physical activities, working conditions and habits have dramatically changed, leading to a major increase in the incidence of low back pain (LBP) and lumbar disc herniation (LDH), which is due to the lack of early functional diagnosis. The purpose of this observational study is to analyse paravertebral muscle imbalances. Methodology: The study included 8 participants (mean age: 28 years) with no lumbar spine pathology or symptoms. The assessment was performed during two gait cycles to analyse muscle strength balance in the right/left spinal erectors - iliolumbar muscles across three phases: heel strike (phase I), left foot stance (phase II) and left foot toe-off (phase III). The VICON Motion System was used to collect data for BoB (Biomechanics of Bodies) software to quantify muscle strength in the lumbar region. Results: The data recorded for paravertebral muscles are: phase I - 24.67 N (left), 9.34 N (right), imbalance 37%; phase II - 15.67 N (left), 4.67 N (right), imbalance 29.62%; phase III - 8.81 N (left), 6.42 N (right), imbalance 72.87%. An important left/right imbalance occurs in phase III where muscle strength has close values. Significantly different left/right values and large imbalances occur in phases I and III, which indicates major asymmetry that may cause instability. Conclusion: Segmental assessment of the behaviour of paravertebral muscles, especially spinal erectors, can provide information about the possibility of developing vertebral instability due to muscle failure and is the starting point for assessing various daily activities.

Keywords: muscle imbalance, muscle strength, instability.

Introduction

In recent decades, people’s lifestyles, physical activities, working conditions and habits have dramatically changed, leading to a major increase in the incidence of low back pain (LBP) and lumbar disc herniation (LDH), which is due to the lack of early functional diagnosis. Most cases of LBP are not diagnosed in their early stages, which is why this disease becomes difficult to treat efficiently. Changes associated with LBP, namely muscle imbalances or strength disorders and spine instability, often have a negative development.

Various studies conducted from 1995 to 2010 tried to estimate and establish the prevalence of LBP in the population by gender and age group or according to different risk factors or professions. Research findings indicate a range between 14% and 42% (Schochat & Jäckel, 1998) or the occurrence of a new episode of LBP in 34% of men and 37% of women (Croft et al., 1999).

A systematic analysis by GBD 2019 Diseases and Injuries Collaborators (2020) describes the global prevalence of low back pain in 2019 as ranked fourth in the 25-49-year age group. Kaptan et al. (2020) state that “LBP is most commonly seen in individuals exposed to physical work activities such as heavy work, frequent bending down, sudden tough movements, repetitive tasks, or weight lifting” (p. 1295) Another study conducted by Cieza et
al. (2020) examined the prevalence of musculoskeletal disorders and found that LBP was the most prevalent condition that needed rehabilitation care in 134 of the 204 countries analysed.

Other studies tried to verify whether the assessment of the range of motion (ROM) was reliable using the inertial sensor system. Williams et al. (2013) investigated the reliability of a clinically-based inertial sensor system to measure ROM through angular velocities and accelerations in LBP patients. This method was able to demonstrate differences in movement irregularity scores, as well as excellent peak value similarities, with small error measurements for all kinematic parameters. The study by D’hooge et al. (2013) concluded that alterations in the trunk muscle behaviour played a pathogenic role in the recurrence of LBP despite the patient’s recovery from pain episodes. The findings of the above authors were that concurrent alterations occurred in the multifidus structure and activity in patients with unilateral recurrent LBP although they were pain free and functionally recovered.

The same conclusion was reached by Stambolian et al. (2016), who analysed one of the major causes of low back injury, namely the box lifting activity using “the AnyBody (AB) biomechanical models and optimization within the AB software system in conjunction with motion capture” (p. 10), obtaining appropriate estimates of joint reaction forces of the body.

Arshad et al. (2016) used Anybody and MiSpEx in an attempt to improve knowledge about spinal loads and trunk muscle forces and thus elucidate the possible mechanical causes of various spinal diseases. An inverse dynamic musculoskeletal model was used to examine “the influence of lumbar spine rhythms and intra-abdominal pressure on the compressive and shear forces in L5-L5 disc and the trunk muscle forces during upper body inclination” (Arshad et al., 2016, p. 333). The above study showed that variation in predicted loads and muscle forces increased with larger flexion. The conclusion is that the parameters of this model need to be adapted in order to accurately predict spinal loads and trunk muscle forces.

Bassani et al. (2017) tried to validate “the suitability of the AnyBody model in computing lumbar spine loads at L4-L5 level” (p. 58) by calculating the intersegmental loads during 12 specific exercise tasks. Hwang et al. (2016) used Magnetic Resonance Imaging (MRI) to perform a polynomial regression analysis as a novel approach to predict the trunk muscle geometry. The authors found that the predictability of muscle parameters was higher for erector spinae than other muscles.

Goubert et al. (2017) used a Dixon MRI scan to assess spinal muscle cross-sectional area and fat infiltration in patients with chronic and recurrent lower back pain, concluding that recurrent LBP or chronic LBP might be directly proportional to the amount of structural and functional alterations of paraspinal muscles. The authors state that muscle degeneration (such as atrophy, fat infiltration, alterations in muscle fibre type and altered muscle activity) impairs “proper biomechanics and motion of the spinal units in LBP patients” (Goubert et al., 2017, p. 1285). Wu et al. (2020) studied the biomechanical properties of the bilateral lumbar extensor myofascia (at L3/L4 level) using the MyotonPRO to test the reliability of these measurements. They found that muscle tone, stiffness and elasticity of the left and right lumbar extensor myofascia in patients with chronic LBP were very reliable among different operators. Their results showed a significantly higher average of lumbar extensor muscle tone and stiffness in patients with chronic LBP than the average found in healthy controls.
Purpose of the paper

This observational/ascertaining study aims to examine the functional aspects and assess the outcomes of the physical-kinetic therapy applied to patients with LBP. Early diagnosis of possible muscle strength disorders and imbalances that lead to lumbar spine instability, which in turn most often leads to LBP and LDH, can offer specialists a good method of assessing and monitoring therapeutic outcomes. We believe that the analysis of the biomechanical parameters of paravertebral muscles with the help of modern special devices and software programs will be able to provide a complex overview of the clinical, functional and developmental aspects, as well as rehabilitation management for patients with LBP.

Research objectives

The main objective of the study was to assess the biomechanical parameters necessary to identify a correlation between symptomatology and vertebral instability through the biomechanical analysis of muscle strength imbalances in people with acute or chronic LBP. Using the results of this analysis, a specialist can design a complete assessment protocol that will enhance the early diagnosis of LBP. Therefore, the therapist can implement a targeted and personalised prophylactic exercise programme according to the needs of each patient.

Such an approach can be one of the keys to a successful outcome of a particular therapy applied to LBP patients. In this research, we aim to assess the back muscle force generated during specific activities, because we believe that muscle imbalances and deficits are the main cause of overloading lumbosacral intervertebral discs. Therefore, we propose and promote the large-scale use of modern non-invasive imaging tools to identify the presence of lumbar muscle disorders as early as possible.

Thus, the assessment of some biomechanical parameters using modern devices such as the complex VICON system and the Nexus and BoB software programs offers important details necessary for the early diagnosis of LBP, respectively the prognosis of this disease progression towards LDH. Thus, with the help of modern imaging methods, we can simulate the muscular behaviour of the specific muscle groups that we aim to analyse, finding out information about muscle imbalances that occur in functional movements.

Methodology

The research was performed in the Laboratory of Innovative Techniques and Processes in Bioengineering - Research Infrastructure in Applied Sciences INCESA - University of Craiova (UCV). The study was approved by the Research Ethics Committee of the UCV and all the participants agreed with the information contained in the Informed Consent Form.

Data were collected between January and May 2020 by the team researchers of the above-mentioned laboratory. The inclusion criteria were represented by young adult patients with an episode of pain in the lumbar region, in the absence of any neurological signs. The exclusion criteria were recent back trauma, fracture, malignancy or prior spine surgery. The interview with each patient was conducted by a person from the lab team and mainly established the pain characteristic and the inclusion and exclusion criteria. Each participant also received
brief information regarding the stages and the way of conducting the assessment, as well as what was expected of them during the assessment.

The study was conducted on 8 female patients aged 28 years on average, with no lumbar spine pathology and no obvious symptoms indicating a serious lumbar disorder.

The patient assessment protocol was performed during two gait cycles, analysing muscle strength balance (as an expression of stress) to in the right/left spinal erectors - iliolumbar muscles across three phases: heel strike (phase I), left foot stance (phase II) and left foot toe-off (phase III).

The VICON Motion System was used to collect data for BoB software to quantify muscle strength in the lumbar region.

*Patient assessment performed with VICON and BOB*

The Biomechanics of Bodies (BoB, 2021) software simulates muscle behaviour based on data collected experimentally with the complex VICON (2021) image analysis system. VICON will record the kinematic parameters (trajectory, speed and acceleration) of some points marked on the human body (joint areas), archiving these values in files specific to video analysis (*.c3d). The BoB software imports *.c3d files that are created by the VICON system and contain the actual motion trajectories recorded by the analysed patients. These trajectories are assigned to a pre-existing skeleton in the BoB software so that the actual recorded motion is transferred to the skeleton. The skeleton is dimensionally parameterised and is loaded with approximately 600 muscles. The motion of the skeleton generates changes in muscle length and thus changes in muscle force, simulating the behaviour of these 600 muscles in the real motion recorded by a human patient. Variations in force of these muscles as well as muscle imbalances (left/right muscle force imbalances or superficial/deep planes) are provided in the form of colour maps (as a qualitative aspect) but also in the graphical form (as a quantitative aspect) of BoB software.

The analysis of simulation results gives information about significant muscle imbalance that could involve excessive use of the lumbar spine (an overload of the lumbar intervertebral discs). This aspect is important in our practice for finding the best solutions to improve the functional status of muscle groups identified with imbalances and disorders. We assessed spinal kinematics during gait with the VICON device and analysed the paravertebral muscle behaviour using BoB. The behaviour of paravertebral muscles, more precisely the components represented by the lumbar spinae-erector spinae group lt1, was monitored in terms of developed force and imbalance during gait.

**Results**

The results obtained are shown in the images below corresponding to the studied phases of the gait cycle (Figure 1 a, b, c).
Tables 1, 2 and 3 show the muscle force results obtained using the BoB software for each patient during the gait phases described below.

Table 1. Average values of muscle force during the gait phase: Left heel strike

| Patient | Average force of the erector spinae Lt1 L [N] | Average force of the erector spinae Lt1 R [N] | Right/Left imbalance [%] |
|---------|---------------------------------------------|---------------------------------------------|--------------------------|
| P1      | 39.525                                      | 16.439                                      | 58.4                     |
| P2      | 5.814                                       | 0.000                                       | 100.0                    |
| P3      | 0.000                                       | 0.000                                       | 41.7                     |
| P4      | 55.643                                      | 36.389                                      | 34.6                     |
| P5      | 16.057                                      | 1.167                                       | 92.7                     |
| P6      | 65.145                                      | 86.625                                      | -33.0                    |
| P7      | 33.620                                      | 10.415                                      | 69.0                     |
| P8      | 22.074                                      | 0.992                                       | 95.5                     |

Table 2. Average values of muscle force during the gait phase: Left foot stance

| Patient | Average force of the erector spinae Lt1 L [N] | Average force of the erector spinae Lt1 R [N] | Right/Left imbalance [%] |
|---------|---------------------------------------------|---------------------------------------------|--------------------------|
| P1      | 4.280                                       | 0.000                                       | 100.0                    |
| P2      | 10.185                                      | 0.000                                       | 100.0                    |
| P3      | 0.000                                       | 0.000                                       | 29.5                     |
| P4      | 66.090                                      | 8.799                                       | 86.7                     |
| P5      | 13.325                                      | 23.907                                      | -79.4                    |
| P6      | 0.000                                       | 0.000                                       | 62.0                     |
| P7      | 15.251                                      | 0.000                                       | 100.0                    |
| P8      | 1.256                                       | 0.000                                       | 100.0                    |
Table 3. *Average values of muscle force during the gait phase: Left foot toe-off*

| Patient | Average force of the erector spinae \( \text{lt1 L [N]} \) | Average force of the erector spinae \( \text{lt1 R [N]} \) | Right/Left imbalance [\%] |
|---------|--------------------------------|--------------------------------|--------------------------|
| P1      | 0.000                          | 0.000                          | 7.9                      |
| P2      | 0.000                          | 0.000                          | 76.7                     |
| P3      | 0.000                          | 0.000                          | -34.4                    |
| P4      | 27.240                         | 39.196                         | -43.9                    |
| P5      | 10.743                         | 5.721                          | 46.7                     |
| P6      | 0.000                          | 0.000                          | -75.1                    |
| P7      | 0.000                          | 0.000                          | 46.6                     |
| P8      | 7.008                          | 16.763                         | -139.2                   |

Table 4 shows the average values of muscle force developed by the two analysed muscle groups according to the information provided by the BoB software.

Table 4. *Summary table for the average values of muscle force*

| Gait phase        | Average force of the erector spinae \( \text{lt1 L [N]} \) | Average force of the erector spinae \( \text{lt1 R [N]} \) | Right/Left imbalance [\%] |
|-------------------|------------------------------------------------------------|-------------------------------------------------------------|--------------------------|
| Left heel strike  | 29.735                                                     | 19.003                                                      | 36.1                     |
| Left foot stance  | 13.798                                                     | 4.088                                                       | 70.4                     |
| Left foot toe-off | 5.624                                                      | 7.710                                                       | -37.1                    |

Muscle force values during the gait cycle are shown as variation charts in Figures 2-9 for each of the assessed patients.

Figure 2. Muscle force variation for left/right erector spinae lt 1 groups during gait – Patient 1
Figure 3. Muscle force variation for left/right erector spinae lt 1 groups during gait – Patient 2

Figure 4. Muscle force variation for left/right erector spinae lt 1 groups during gait – Patient 3
Figure 5. Muscle force variation for left/right erector spinae lt 1 groups during gait – Patient 4

Figure 6. Muscle force variation for left/right erector spinae lt 1 groups during gait – Patient 5
Figure 7. Muscle force variation for left/right erector spinae lt 1 groups during gait – Patient 6

Figure 8. Muscle force variation for left/right erector spinae lt 1 groups during gait – Patient 7
Figure 9. Muscle force variation for left/right erector spinae lt 1 groups during gait – Patient 8

There are large variations of these values in the three phases of gait, in the sense of minimal stress in the toe-off phase during which it is observed that the right/left force developed is approximately the same, meaning that this is the phase where therapeutic action is recommended through a postural rehabilitation programme, correction and proprioceptive training. In the heel strike phase, there is a load on the left side of paravertebral muscles that exceeds by 10 N the values recorded on the opposite side. This means that, in this phase, the left-right imbalance is 56% on average, which explains the possible development of an overload in the spine. There is no balancing in the stance phase but the left-right difference is accentuated, the percentage being a difference of 237%, which clearly indicates the lack of body weight transfer to limit the differentiated stress.

Analysing the variation charts, it can be seen that patients 1, 4, 5 and 8 have quasi-similar behaviour of the left and right paravertebral muscles and there are tensions in restoring and maintaining posture through intrinsic spinal mechanisms, the balance of the spine. In the other patients, there are large variations throughout a gait cycle, which cause corrective intervention during walking in terms of postural control of the trunk.

Discussion

In the absence of applying early diagnostic methods that lead to the early initiation of prophylactic physical-kinetic therapies, the development of the disease is negative in most cases (from a simple low back pain to chronic LBP and LDH, which requires unwanted surgery, sometimes even emergency services. Given all these aspects, we consider it important when approaching/managing this pathology (whether it is about acute/chronic LBP or an early phase of LDH) to look for new elements that will help us establish an early diagnosis, investigations and thus make a prognosis of the LBP progression. The information
provided by the biomechanical analysis allows the development of goals for a prophylactic programme aimed at correcting the identified muscle imbalances characteristic of each analysed patient, because it was observed during medical practice that a large percentage of patients were suffering from certain degrees of LDH without presenting specific symptoms or clinically noticeable physical deficits. Our documentation so far shows that there are no many complex studies to establish an objective assessment and a prognostic protocol for the detection of muscle factors subject to imbalance, which can facilitate the onset of LDH.

Routine investigations to help the therapist objectively build a kinetic programme in order to correct the muscle disorders that occur are not usually available to see how muscles react to LBP. The results presented by us are a starting point in approaching the status of the spine prior to the development of LBP. This approach is in line with what Raabe and Chaudhari (2018) highlight in relation to the improper function of the core muscles, which can lead to abnormal spinal loading, muscle strain or injury to spinal structures, all of them being associated with an increased risk of low back pain. These authors who used the VICON, OpenSim software and Bertec 4060-10 force plates found the deep core muscles (multifidus, quadratus lumborum, psoas and deep fascicles of the erector spinae) to be weakened individually and together; their conclusion is that the superficial muscles of the trunk work as the main compensators for most conditions of muscle weakness. A similar study using the VICON system and BoB software has been recently conducted by Marin et al. (2021) to analyse the muscle behaviour of the lumbar region during the ingress and egress movements in driving position on a medium-class car.

Conclusion

Physical therapeutic decision-making regarding non-drug therapy based on exercise is a complex process that requires a lot of objective data to make sure that the chosen treatment is targeted to the real needs of the patient.

New assessment techniques are needed for early diagnosis of the main factors leading to the onset of LBP. These techniques should be predictive of postural and muscular disorders that are present in patients with LBP/LDH.

We believe that muscle strength imbalances are the main cause that generates spinal instability.

The starting point in individualising physical-kinetic therapy for young people with LBP could be the diagnosis based on the analysis of biomechanical parameters (such as muscle strength imbalances) using modern and non-invasive imaging devices.

The essential idea is to be precise in the assessment of biomechanical parameters, namely the diagnosis of the muscular behaviour responsible for the stability of the lumbar spine.

We propose further similar research by means of modern imaging tools such as VICON and BoB, which are aimed to detect through periodic assessments the influence of risk factors leading to LBP. Such factors analysed as variations in muscle strength, namely muscle imbalances, can provide valuable information able to predict the development the LBP/LDH; early detection of these elements could decrease the percentage of patients with LBP.
Authors’ Contribution

All authors have equally contributed to the design and writing of this article.

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