Acta of Bioengineering and Biomechanics
Vol. 18, No. 4, 2016

Original paper
DOI: 10.5277/ABB-00555-2016-03

Assessment of postural stability in patients with lumbar spine chronic disc disease

ALEKSANDRA TRUSZCZYŃSKA[1]*, MARTYNA DOBRZYŃSKA[1],
ZBIGNIEW TRZASKOMA[1], JUSTYNA DRZAŁ-GRABIEC[2], ADAM TARNOWSKI[3]

[1] Faculty of Rehabilitation, Józef Piłsudski University of Physical Education in Warsaw.
[2] Institute of Physiotherapy, University of Rzeszów, Poland.
[3] Psychology Department, Warsaw University.

Purpose: The pain, motor and sensory deficits are common symptoms of the lumbar disc disorder, and they can significantly affect human postural control. The aim of this study was to assess postural stability in patients with severe symptoms of lumbar spine disc disease qualifying them for surgical treatment and to compare them with a control group. *Methods:* The study involved 103 subjects: 54 patients and 49 healthy subjects. Patient's mean age was 46.4 ± 11.3 years, mean body height 172.2 ± 10.3 cm, mean body mass 83.1 ± 18.9 kg, and mean body mass index (BMI) was 27.9 ± 5.2 kg m^{-2}. The mean time of their recent pain episode was 9.7 ± 8.5 months. *Results:* We found statistically significant differences between postural stability in patients with lumbar spine disc disease and the control group. The measurements taken with eyes closed, as compared with the clinical control group, revealed higher and statistically significant values of the mean amplitude of COP, mean amplitude of COP on sagittal plane, and maximal sway in sagittal plane parameters. The analysis of pressure value differences between the right and left lower limbs in both groups revealed statistical significance. In the study population the difference was significantly greater in comparison to the control group. The patients had significantly greater asymmetry of lower limb load. *Conclusions:* 1. Patients with lumbar spine discogenic pain had decreased postural control. 2. The patients had significant asymmetry in foot pressure resulting from pain radiating to a lower limb.

Key words: *degenerative disc disease, postural stability, chronic pain, lumbar intervertebral disc*

1. Introduction

A chronic disc disease leads to balance disorders in standing position and to asymmetrical load of lower extremities. This asymmetry results from pain radiating to lower extremities and leads to distorted postural stability, as well as to other motor deficits [19]. The pain and sensory deficits are common symptoms of the lumbar disc disease, and they can significantly affect human postural control [8], [20].

The aim of this study was to assess postural stability in patients with severe symptoms of lumbar spine disc disease qualifying them for surgical treatment and to compare them with a healthy clinical control group.

2. Material and methods

The study was conducted at the Professor A. Gruca Independent Public Research Hospital, Otwock, at the Department of Orthopedic Surgery between April and August 2014. The consent to conduct the study was obtainted from the Bioethic Commission of the Medical Department of the University of Rzeszów.

The study involved 103 subjects. 54 patients whose disc disease of the lumbar spine was diagnosed clinically and radiologically by X-ray and MRI. The control group consisted of 49 healthy subjects. The patients were qualified for surgical treatment by an experienced orthopaedist specializing in spinal surgery. The study population consisted of 24 women

* Corresponding author: Aleksandra Truszczyńska, Faculty of Rehabilitation, Józef Piłsudski University of Physical Education in Warsaw, ul. Marymoncka 34, 00-968 Warsaw, Poland. Tel: +48601566789, e-mail: aleksandra.rapala@wp.pl

Received: January 18th, 2016
Accepted for publication: March 8th, 2016

(44.4%) and 30 men (54.6%). Their mean age was 46.4 ± 11.3 years, mean body height 172.2 ± 10.3 cm, mean body mass 83.1 ± 18.9 kg, and their mean body mass index (BMI) was 27.9 ± 5.2 kg m^{-2}. The mean time of their recent pain episode was 9.7 ± 8.5 months. The MRI revealed nucleus pulposus protrusion in 8 patients (14.8%), nucleus pulposus extrusion in 43 patients (79.6%) and sequestration in 3 patients (5.6%). The MRI analysis revealed intervertebral disc damage on the L4-L5 level in 17 patients (31.5%), on the L5-S1 level in 21 patients (38.9%), disc damage on several levels in 13 patients (24.1%), and 3 patients (5.6%) had disc herniated at other lumbar levels. 24 patients (44.4%) suffered from decreased muscle strength and 31 patients (57.4%) suffered from sensory deficits.

The control group consisted of 25 women (51%) and 24 men (49%) aged 46.2 years ± 13.2, body height 168.7 cm ± 9.7, body mass 72.7 kg ± 15.4, and body mass index (BMI) of 24.6 ± 4.0 kg m^{-2}. There were no statistically significant differences concerning age and body height between the subjects of the two groups.

The criteria for subject inclusion in the study population were the following: disc disease of the lumbar spine confirmed with the MRI, qualification for surgical treatement by an orthopaedist specializing in spinal surgery, pain lasting longer than 3 months, as well as consent to participate in the study. Orthopedic examination consisted of the following steps: history taking, objective examination: range of motion of lumbar spine testing, neurologic examination: muscular and sensory deficits testing, SLR test. Examination was suplemended by rediological examination (X-ray anterior-posterior and lateral view in standing postion, and MRI).

The criteria for subject exclusion were the following: spinal disoders other than disc disease, i.e., spinal canal stenosis, spondylolisthesis, prior surgical treatment to the spine, vestibular disorders, visual disorders, other disorders of the locomotor system, recent injuries, inability to stand upright, no consent to participate in the study.

The examination consisted in performing measurements of postural stability on a two-plate stabilometric platform (CQstab). The CQstab platform makes it possible to carry out the analysis of the measured parameters for each leg separately. COP shift is recorded in the *x*-axis (medio-lateral) and *y*-axis (anterio-posterior) in the form of a statokinesiogram as well as a stabilogram where kinematic values are presented as a function of time. Examined persosns stepped onto the platform and maintained natural standing position with the upper limbs hanging along the body. The measurement time was 30 seconds with eyes open followed by 30 seconds measurement with eyes closed. The tests were conducted in accordance with the applicable standards. Before each measurement, calibration of the equipment was performed according to the manufacturer's instructions. The tests were conducted in the morning. All patients rested for a few minutes in a sitting position before the measurements. The following parameters were assessed for the left and the right leg and for both feet together: the COP sway path (SP), the sway path along the *y*-axis (SPAP), the sway path along the *x*-axis (SPML), the mean amplitude of COP (MA), the mean amplitude of COP in the anterio-posterior direction (MAAP), the mean amplitude of COP in the medio-lateral direction (MAML), the maximum distance between two furthest points in the anterio-posterior direction (MaxAP) and medio-lateral direction (MaxML), the field of COP during the test (SA), the quotient of the sway path determined by the COP projection during the test to the field marked by this path (SPSA), the mean frequency of COP (MF) [6].

We considered the following variables in the analysis of pressure value differences between the right and left lower limbs: MNDP – the arithmetic mean of difference in pressure, MDDP – the median of difference in pressure, MinDB – the minimum of difference in pressure, MaxDB – the maximum of difference in pressure of feet $DB(t) = (ML(t) - MP(t))/(ML(t) + MP(t))*100\%$ where $ML(t)$ denotes the mass measured on the left platform at the t moment, $MP(t)$ denotes the mass measured on the right platform at the t moment, and t denotes time.

Statistical analysis

We used the Student's *t*-test to calculate the significance of differences between the analyzed variables. We set statistical significance at $p < 0.05$. We confirmed the lack of normal distribution with a Kolmogorov–Smirnov test, and therefore we used the nonparametric methods to conduct the statistical analysis. The significance of differences between groups was assessed by the Mann-Whitney U test. We applied two-tailed statistical significance. To calculate the differences of pressure between the two lower limbs we used the independent two sample *t*-test and Levene's test of equality of variance.

3. Results

The analysis of the collected data revealed statistically significant differences between the analyzed parameters of postural stability in patients with disc

Table 1. Values of analyzed variables in measurements with eyes open

Variable	Study population			Clinical control group			Mann–Whitney U test	Z	Statistical significance
	Mean	SD	Median	Mean	SD	Median			
SP [mm]	145.44	45.92	140.50	140.10	26.59	136.00	1282	–.271	.787
SPAP [mm]	105.94	33.53	101.00	104.90	25.22	101.00	1309.5	–.089	.929
SPML [mm]	76.70	27.20	69.00	70.98	12.04	70.00	1302	–.139	.890
MA [mm]	2.69	1.33	2.30	1.99	.89	1.90	892	–2.850	**.004**
MAAP [mm]	2.31	1.22	2.05	1.76	.90	1.60	927	–2.617	.009
MAML [mm]	.91	.81	.70	.65	.37	.60	1028.5	–1.955	.051
MaxAP [mm]	8.03	3.83	7.30	5.95	2.53	5.60	884.5	–2.896	**.004**
MaxML [mm]	4.62	5.90	2.75	2.23	1.07	1.90	881.5	–2.918	**.004**
SA [mm^2]	133.41	153.6	101.00	80.29	39.91	63.00	944	–2.503	**.012**
SPSA [–]	1.60	.81	1.42	2.06	.75	1.89	842	–3.176	**.001**
MF [Hz]	.34	.14	.31	.43	.16	.42	861	–3.052	**.002**

Table 2. Values of analyzed variables in measurements with eyes closed

Variable	Study population			Clinical control group			Mann–Whitney U test	Z	Statistical significance
	Mean	SD	Median	Mean	SD	Median			
SP [mm]	203.02	93.00	179.00	187.57	99.49	164.00	1233.5	–.591	.554
SPAP [mm]	168.20	86.51	146.00	154.69	93.48	131.00	1217	–.700	.484
SPML [mm]	80.81	31.32	73.00	76.63	29.88	73.00	1304	–.126	.900
MA [mm]	2.77	1.53	2.35	2.12	1.06	1.80	932	–2.584	**.010**
MAAP [mm]	2.45	1.32	2.05	1.91	.99	1.60	934.5	–2.56	**.010**
MAML [mm]	.86	.86	.60	.63	.42	.60	1139.5	–1.224	.221
MaxAP [mm]	10.12	6.17	9.10	7.15	3.54	6.40	888	–2.873	**.004**
MaxML [mm]	3.21	2.62	2.35	2.54	2.54	2.00	1104	–1.447	.148
SA [mm^2]	162.09	184.5	104.00	111.35	149.72	79	1038	–1.882	.060
SPSA [–]	1.83	.80	1.68	2.22	.87	2.11	962	–2.384	**.017**
MF [Hz]	.43	.15	.42	.51	.19	.48	952.5	–2.447	**.014**

Table 3. Values of analyzed variables characterising differences in pressure between the lower limbs in measurements with eyes open

Variable	Study population		Control group		Levene's test of equality of variance		Independent sample *t* test	
	Mean	SD	Mean	SD	F	Significance	T	Df
MNDB [–]	14.02	15.62	5.16	4.01	30.29	<0.001	3.85	101
MDDB [–]	14.11	15.53	5.29	4.04	30.16	<0.001	3.86	101
MinDB [–]	15.02	15.57	5.71	4.40	32.26	<0.001	4.04	101
MaxDB [–]	14.89	16.67	5.41	3.63	28.07	<0.001	3.90	101

Table 4. Values of analyzed variables characterising differences in pressure between the lower limbs in measurements with eyes closed

Variable	Study population		Control group		Levene's test of equality of variance		Independent sample *t* test	
	Mean	SD	Mean	SD	F	Significance	T	Df
MNDB [–]	14.89	15.68	5.24	4.38	29.18	**<0.001**	4.16	101
MDDB [–]	15.13	15.61	5.14	4.37	28.96	**<0.001**	4.32	101
MinDB [–]	15.96	15.38	6.14	5.03	28.87	**<0.001**	4.26	101
MaxDB [–]	14.33	15.90	5.55	4.25	27.01	**<0.001**	3.74	101

disease of the lumbar region of the spine and the clinical control group. Tables 1 and 2 present these results.

In the analysis of the measurements taken with eyes open, we observed higher values of the following parameters: SP, SPAP, SPML, though the results were not statistically significant. The MAML parameter showed a strong trend towards statistical significance ($p = 0.51$). The mean frequency of COP was smaller in the clinical control group. The measurements in the study population taken with eyes closed, as compared with the clinical control group, revealed higher and statistically significant values of the MA, MAAP, MaxAP parameters.

The analysis of pressure value differences between the right and left lower limbs in both groups revealed statistical significance. In the study population the difference was significantly greater in comparison to the clinical control group. The patients has significantly greater asymmetry of lower limb load. Tables 3 and 4 present these results.

4. Discussion

Chronic low back pain causes a significant economic and social burden [10]. It may result in disability, which constitutes even greater burden in terms of cost of treatment and care [7]. Intervertebral disc diseases are a common cause of low back pain [14], [26]. Nucleus pulposus extrusion may cause compression of nerve roots, leading to pain radiating to lower limb, muscle and sensory deficits [9], [26]. Lumbar spine diseases may result in dysfunctions of neuro-muscular facilitation and distorted postural control, as presented in numerous studies [12], [14]–[17], [22] and may lead to life-dangerous falls [5].

Postural control depends on age, body height and mass, as well as any medical conditions [11], [23], [25]. To limit the impact of anthropometric factors on the analyses we conducted, we found a clinical control group with similar features in terms of age, sex and body height to the study population. The body mass and the BMI of the study population were higher than in the clinical control group. Overweight and obesity are some of the risk factors of the disc disease; they also influence the effectiveness of treatment [9].

Numerous authors have discussed postural stability in patients with disc disease, for instance, Sipko et al. [19]–[21], Bouche et al. [1], Leinonen et al. [16]. We studied postural stability in patients with disc disease of the lumbar spine and we found that these patients had worse static balance than the clinical control group. The study population patients had higher values of total sway path length, the sway path along the *y*-axis and along the *x*-axis. These variables took higher values in the study population than in the clinical control group in both measurements (both with eyes open and with eyes closed), but the differences were not statistically significant. A greater path length shows that the COP (centre of foot pressure) has to take a longer path to maintain a stable posture [18]. We also found higher values of MA and MAAP parameters in the study population. Higher values of mean amplitude suggest decreased postural control. Brumagne et al. [3] found more frequent sways of COP in the anterior direction in patients with low back pain. The authors believe that an increased forward bend of the torso results from postural instability and may play a key role in recurrence of painful syndromes. Such posture may also result from fear of falling down.

In our study, we found statistically significant differences in the maximal amplitude of COP. In the study population, in measurements with eyes open we noted significantly higher parameters in the antero-posterior (MaxAP) and medio-lateral (MaxML) planes, while with eyes closed only the parameters in the antero-posterior plane (MaxAP) were higher. An increase in the maximal amplitude points to decreased ability to maintain an upright posture. Bouche et al. [1] assessed postural control in patients in long term after discectomy – the mean time was 63 months after surgery. Their measurements with eyes open did not reveal a statistically significant difference in the COP path length between the study population patients without pain and healthy control group. The patients with pain had statistically significantly longer COP path than the clinical control group. Without visual control the COP path length significantly increased in both groups of patients, when compared to the clinical control group. Bouche et al. suggested that in the long term, post-surgery patients develop visual compensatory mechanisms, yet these mechanisms are not efficient enough in patients with pain.

In our study, an analysis of the field of COP (SA) revealed significant differences between the patients and the clinical control group, in measurements with eyes open. In the measurements with eyes closed the SA parameter showed a trend for statistical significance. A significantly larger field of COP suggests decreased postural control. Braga et al. [2] had similar results. They compared the field of COP and the COP velocity in healthy controls and in patients with low back pain lasting at least 6 months. Their measurements were taken with visual control. The mean field of COP values for patients with pain and for healthy subjects were then calculated. The reason for a larger field of COP may be the limited ability to use hip joint strategies to maintain balance. In addition, patients with back pain tend to reveal strategies of the ankle joint to maintain balance.

In our study, the patients with intervertebral disc disease had a lower mean frequency of COP sways than the clinical control group. Lafond et al. [15] reported similar findings. They noted a significantly lower COP frequency in the A-P and M-L directions in patients with low back pain. Three measurements were taken for each patient: the first took 60 seconds, the second one 30 minutes, the third one 60 seconds. The obtained results did not differ for the prolonged, or 30 minute, standing. The last measurement revealed decreased COP frequency in the anteroposterior direction when compared to the first measurement. These results may point to increased tension and muscle stiffness in patients with back pain. Moreover, it has been proved [15] that long-term standing results in a decrease of COP path, as well as in postural changes in the sagittal and coronal planes in patients with chronic low back pain. These may be caused by decreased mobility of the spine as well as by changes to the muscle activation, a strategy that limits mobility of the spine even further [13]. The decreased number of postural changes in patients with chronic low back pain may be related to the decreased amount of proprioceptive information from the lumbar spine, or to the altered sensory-motor integration [15]. Sipko et al. [19], in their study on patients with intervertebral disc extrusion, found a significant increase in the frequency of COP in post-surgery patients. This may be due to the increased central nerve system activation in postural control, as well as an increased frequency of corrective movement that ensure postural stability.

Janssens et al. [12] found an increase in activity of the diaphragm in exercise that consisted in maintaining stable posture. Their results suggest that tiredness of the diaphragm may increase postural instability. Respiratory muscles training in patients with back pain may have an impact on postural control improvement. Kolar et al. [13] observed decreased diaphragm movement in motor activities by patients with chronic back pain, as compared with healthy controls. Simultaneously, they found a steeper angle of diaphragm inclination in its medioposterior part, which may make the painful syndromes of chronic spinal condition more acute, through increased sheer forces in the region of the spine. An increased activation of the back muscles may result from incorrect posture [17]. These would support earlier studies which had found that patients with low back pain stiffen their spine by extensive muscle tension in order to maintain correct posture. Altered movement patterns may constitute one of the reasons for low back pain to recur.

The results of measurements with eyes closed are related to the quality of information integration from proprioceptive receptors, or the proprioreceptors of the vestibular system. In our study, closing eyes resulted in an increase of the analyzed parameter values. Two of the parameters proved to be exceptions from this rule, as they took higher values in tests with eyes open – these were the MAML and MaxML. This can be explained by the fact that in situations of short term lack of visual control the subject may have concentrated more on the task they had to do. Still, this explanation has limitations, as the remaining parameters did not show similar results. It was interesting that in the analysis of the results obtained from test with eyes closed we found a smaller number of statistically significant differences between the study population and the clinical control group. This may suggest a smaller dependence of postural stability from visual control. Lack of visual information results in subjects relying more on proprioception [21]. Mann et al. [17] studied the impact of visual control on balance in patients with non-specific back pain. A group of patients had higher COP movement amplitudes in the anteroposterior direction both with eyes open and with eyes closed. The results of our study were similar. Postural control in patients with low back pain is characterized by increased visual dependence. Lack of visual control resulted in statistically significant differences between the study population and the clinical control group. During the test with eyes closed the sensory-motor information received through relevant receptors may be insufficient to correct the posture.

Surgical treatment of the damaged intervertebral disc may result in improved biomechanical conditions in the lumbar region of the spine. As a result, the pain is less acute and postural stability deficits decrease. In measurements with eyes open, both prior to and after the surgery, we observed that the study population had similar postural stability to the clinical control group. This may mean that the patients had learned how to efficiently rely on visual information. In measurements with eyes closed prior to the surgery, all analyzed parameter values in the sagittal and coronary planes were higher. After the surgery, the analyzed values were not significantly higher in patients with intervertebral disc diseases in comparison to the healthy controls. This may result from improved proprioception achieved through central nervous system stimulation to increase activity in stabilizing body posture. The above-mentioned results suggest a considerable visual dependence in patients with disc diseases [1], [19].

Sipko et al. [20] studied patients with intervertebral disc disease in the lumbar region of the spine prior to the surgery and shortly after the surgery (the third day). They observed torso transposition in 75% of patients. The transposition may result in asymmetry of foot pressure. On the non-painful side the foot pressure was greater. In early post-surgery period the pain was less acute and the postural control was better – in the coronal plane the torso was transposed in 50% of patients. Asymmetrical changes to the foot pressure did not diminish. In patients with normal torso position the foot pressure was similar for both feet. The surgery led to an improvement of these results [20]. Our study revealed a high statistical significance in all parameters characterizing foot pressure. The asymmetry in foot pressure may result from radiating pain and from proprioception disorder [6], [10].

The value of the study

The value of the study is the homogeneous group of patients with disc disease of the lumbar region of the spine that qualified for surgical treatment. The results show that postural stability in patients with intervertebral disc disease is worse than in healthy controls. It is an important premise to advise working on balance improvement, as well as postural and proprioceptive reeducation in patients with disc extrusion.

Limitations of the study

We conducted one measurement with eyes open and one measurement with eyes closed. We did not repeat the measurements due to considerable disability of our patients. Another limitation concerns difference in BMI of examined groups. Both groups did not differ in sex distribution, age and body height. However, control group had normal BMI, and clinical group was overweight. It is known that higher weight is favorable for better stability, so most probably the difference would be even higher than found in our study. Overweight causes degenerative changes in lower extremity joints, and is also a risk factor for low back pain. We ruled out persons with joints degenerative problems and that is why control group (mean result) has normal weight. It was not our aim to artificially look for overweight healthy group.

5. Conclusions

1. Patients with intervertebral disc disease in the lumbar spine have decreased postural control.
2. The patients had significant asymmetry in foot pressure resulting from pain radiating to a lower limb.

References

[1] BOUCHE K., STEVENS V., CAEMAERT J., DANNEELS L., *Comparison of postural control in unilateral stance between healthy controls and lumbar discectomy patients with and without pain*, Eur. Spine J., 2006, 15, 423–432.

[2] BRAGA A.B., RODRIGUES A.C., DE LIMA G.V., DE MELO L.R., DE CARVALHO A.R., BERTOLINI G.R., *Comparison of static postural balance between healthy subjects and those with low back pain*, Acta Ortop. Bras., 2012, 20(4), 210–212.

[3] BRUMAGNE S., JANSSENS L., JANSSENS E., GODDYN L., *Altered postural control in anticipation of postural instability in persons with recurrent low back pain*, Gait Posture, 2008, 28(4), 652–657.

[4] DARIO A.B., FERREIRA M.L., REFSHAUGE K.M., LIMA T.S., ORDOÑANA J.R., FERREIRA P.H., *The relationship between obesity, low back pain and lumbar disc degeneration when genetics and the environment are considered: a systematic review of twin studies*, Spine J., 2015, 15(5), 1106–1117.

[5] DRZAŁ-GRABIEC J., RACHWAŁ M., PODGÓRSKA-BEDNARZ J., RYKAŁA J., SNELA S., TRUSZCZYŃSKA A., TRZASKOMA Z., The *effect* of *spinal curvature* on the *photogrammetric assessment* on *static balance* in *elderly women*, BMC Musculoskelet Disord., 2014, 29, 15, 186. DOI: 10.1186/1471-2474-15-186.

[6] DRZAL-GRABIEC J., RACHWAŁ M., TRZASKOMA Z., RYKAŁA J., PODGÓRSKA-BEDNARZ J., CICHOCKA I., TRUSZCZYŃSKA A., RĄPAŁA K., *The foot deformity versus postural control in females aged over 65 years*, Acta Bioeng. Biomech., 2014, 16(4), 75–82.

[7] ETEMADI Y., ARAB A.M., SALAVATI M., *Balance recovery reactions in recurrent non-specific low back pain patients*, Iran Rehabil. J., 2014, 12(19), 38–42.

[8] FROST R.L., BIJMAN M., STRZAŁKOWSKI N.D.J., BENT L.R., BROWN S.H.M., *Deficits in foot skin sensation are related to alterations in balance control in chronic low back patients experiencing clinical signs of lumbar nerve root impingement*, Gait Posture, 2015, 41(4), 923–928.

[9] HEUCH I., HEUCH I., HAGEN K., ZWART J.A., *Body Mass Index as a Risk Factor for Developing Chronic Low Back Pain: A Follow-up in the Nord-Trøndelag Health Study*, Spine (Phila Pa 1976). 2013, 15, 38(2), 133–139.

[10] HOY D., BROOKS P., BLYTH F., BUCHBINDER R., *The epidemiology of low back pain*, Best Pract. Res. Clin. Rheumatol., 2010, 24(6), 769–781.

[11] HUE O., SIMONEAU M., MARCOTTE J., BERRIGAN F., DORÉ J., MARCEAU P., MARCEAU S., TREMBLAY A., TEASDALE N., *Body weight is a strong predictor of postural stability*, Gait Posture, 2007, 26(1), 32–38.

[12] JANSSENS L., BRUMAGNE S., POLSPOEL K., TROOSTERS T., MCCONELL A., *The Effect of Inspiratory Muscles Fatigue on Postural Control in People With and Without Recurrent Low Back Pain*, Spine, 2010, 35(10), 1088–1094.

[13] KOLAR P., SULC J., KYNCL M., SANDA J., CAKRT O., ANDEL R., KUMAGAI K., KOBESOVA A., *Postural function of the diaphragm in persons with and without chronic low back pain*, J. Orthop. Sports Phys. Ther., 2012, 42(4), 352–362.

[14] KUMAR M., GARG G., SINGH L.R., SINGH T., TYAGI L.K., *Epidemiology, pathophysiology and symptomatic treatment of sciatica: a review*, Int. J. Pharm. Biol. Sci. Arch., 2011, 2(4), 1050–1061.

[15] LAFOND D., CHAMPAGNE A., DESCARREAUX M., DUBOIS J.D., PRADO M., DUARTE M., *Postural control during prolonged standing in persons with chronic low back pain*, Gait Posture, 2009, 29(3), 421–427.

[16] LEINONEN V., KANKAANPÄÄ M., LUUKKONEN M., KANSANEN M., HÄNNINEN O., AIRAKSINEN O., TAIMELA S., *Lumbar paraspinal muscle function, perception of lumbar position, and postural control in disc herniation-related back pain*, Spine, 2003, 28(8), 842–848.

[17] MANN L., KLEINPAUL J.F., PEREIRA MORO A.R., MOTA C.B., CARPES F.P., *Effect of low back pain on postural stability in younger women: influence of visual deprivation*, J. Body Mov. Ther., 2010, 14(4), 361–366.

[18] PALMIERI R.M., INGERSOLL C.D., STONE M.B., KRAUSE B.A., *Center-of-pressure parameters used in the assessment of postural control*, J. Sport Rehabil., 2002, 11, 51–66.

[19] SIPKO T., CHANTSOULIS M., KUCZYŃSKI M., *Postural control in patients with lumbar disc herniation in the early postoperative period*, Eur. Spine J., 2010, 19, 409–14.

[20] SIPKO T., CHANTSOULIS-SUPIŃSKA M., ŻMUDA M., ZWOLIŃSKI J., *Postural balance in the early post-operative period in patients with intervertebral disk disease following surgery*, Ortop. Traumatol. Rehabil., 2008, 10(3), 226–247.

[21] SIPKO T., KUCZYŃSKI M., *The effect of chronic pain intensity on the stability limits in patients with low back pain*, J. Manipulative Physiol. Ther., 2013, 36(9), 612–618.

[22] SOHN M.K., LEE S.S., SONG H.T., *Effects of acute low back pain on postural control*, Ann. Rehabil. Med., 2013, 37(1), 17–25.

[23] TRUSZCZYŃSKA A., DRZAŁ-GRABIEC J., RĄPAŁA K., GMITRZYKOWSKA E., *Stabilność posturalna chorych ze zmianami zwyrodnieniowymi stawu biodrowego. Doniesienie wstępne*, Ortop. Traumatol. Rehab., 2013, 15(6), 567–573.

[24] TRUSZCZYŃSKA A., DRZAŁ-GRABIEC J., TRZASKOMA Z., RĄPAŁA K., TARNOWSKI A., GÓRNIAK K., *A comparative analysis of static balance between patients with lumbar spinal canal stenosis and asymptomatic participants*, J. Manipulative Physiol. Ther., 2014, 37(9), 696–701.

[25] TRUSZCZYŃSKA A., RĄPAŁA K., GMITRZYKOWSKA E., TRZASKOMA Z., DRZAŁ-GRABIEC J., *Postural stability disorders in patients with osteoarthritis of the hip*, Acta Bioeng. Biomech., 2014, 1, 45–50.

[26] VALAT J.P., GENEVAY S., MARTY M., ROZENBERG S., KOES B., *Sciatica*, Best Pract. Res. Clin. Rheumatol., 2010, 24, 241–252.