THE SPINAL COLUMN AND ABDOMINAL PRESSURE CHANGES AND THEIR RELATIONSHIP WITH PAIN SEVERITY IN PATIENTS WITH LOW BACK PAIN

Journal website at;
http://mrtbjournal.org/index.php/njmr/issue/current/showToc

Suraj Kumar[1], MPS Negi[2], VP Sharma[3] and Rakesh Shukla[4]
[1]*PhD Scholar, Physical Therapy, Department of Physical Medicine and Rehabilitation, Chhatrapati Sahuji Maharaj Medical University, Lucknow-226018, India*
[2]*Technical Assistant, Biometry & Statistics Division, Central Drug Research Institute, Lucknow-226001, India*
[3]*Head and Professor, Department of Physical Medicine and Rehabilitation, Chhatrapati Sahuji Maharaj Medical University, Lucknow-226018, India*
[4]*Professor, Department of Neurology, Chhatrapati Sahuji Maharaj Medical University, Lucknow-226003, India*

Correspondence to:
Suraj Kumar
Email : surajdr2001@yahoo.com (Suraj Kumar)
Phone: +91-522-2611055
Fax : +91-522-2329408

SUMMARY

Background: Low back pain (LBP) is a complex condition which is mainly associated with back (multifidi) and abdominal (transverses abdominis) muscles dysfunction. Though pain is one of the indicators of LBP, the literature data regarding relationship between pain and muscle dysfunction is lacking.

Objective: The objective of this study is to investigate the differences in spinal column pressure changes (SCPC) and abdominal pressure changes (APC) in male and female patients with LBP and evaluate their relationship with pain severity.

Methods: Thirty nine patients (28 male and 11 female) with sub-acute or chronic LBP participated in the study. Spinal and abdominal muscles pressure changes were measured by pressure measuring device (PMD) while pain severity (Pain) was assessed by Visual Analogue Scale (VAS). Eight physical characteristics such as Age, Weight, Height, waist circumference (WC), hip circumference (HC), systolic blood pressure (SBP), diastolic blood pressure (DBP) and pulse rate (PR) were also taken while waist hip ratio (WHR) and body mass index (BMI) were estimated from WC and HC and Weight and Height respectively. Statistical analysis was done using independent Student's t-test, Spearman rank correlation and step wise multiple regression analysis.

Results: The mean Age, Weight, WC, HC, WHR, SBP, DBP, DUR and Pain of male and female were found to be similar ($p>0.05$). The mean level of both SCPC and APC in male and female differed significantly ($p<0.01$) and the levels of both were significantly ($p<0.05$) high in male than female and for this, significant ($p<0.05$) differences in Height, BMI and PR were found to be the responsible. Both spinal column and abdominal pressure changes showed inverse and significant ($p<0.01$) correlation with the Pain severity. The WC (waist circumference), HC (hip circumference), BMI and PR were found to be significant risk factors for LBP as they correlate positively and significantly ($p<0.01$) with the pain severity. Pain and DUR (duration of pain) were found to be significant predictors of SCPC which accounts for 73% variations of SCPC while Pain, Height and WC of APC which accounts for 61% variations of APC.

Conclusion: In LBP, spinal column and abdominal pressure changes have inverse and significant ($p<0.01$) relation with the pain severity. Though, most of the physical characteristics of male and female were similar, their spinal and abdominal pressure changes differed significantly. The findings of this study may be helpful in the management of LBP and it is recommended that clinicians should adopt both the pressure changes for diagnostics and prognostics of LBP.

KEYWORDS: Pressure changes, Pressure measuring device, Lumbar stabilization, Lumbar musculature dysfunction, Low back pain.

INTRODUCTION

Low back pain (LBP) is one of the most common problems that the humans are exposed to at some time in their lives by either anthropogenic activities or inadvertently by necessity. Low back pain is a general term which may be acute (< 6 weeks), sub acute (6-12 weeks) and chronic (> 12 weeks) and may be duration dependent and location specific (Refshauge and Maher, 2006). Several researchers have suggested different predictors (walking distance, disability, physical functions, quality of life, stress, stand-ups, stair climbing, depression, work losses, cognitive factors, sitting, and pain etc) for LBP. Among the predictor factors, pain was considered to be the most useful indicator variable (Koes, 2006). Low back pain is not necessarily a consequence of degenerative processes as many patients with recurring LBP have no evidence of degenerative changes and those with degenerative radiological changes have no back pain. Numerous hypothesis concerning the cause of non-specific LBP including reduced trunk extensor endurance (Luoto et al, 1995), psychological distress (Croft et al, 1995), hamstring flexibility (Hultmon, 1992), poor muscle control of the trunk (Hodges, 2000), poor posture (Milgrom, 1993), and low body mass (Milgrom, 1993). Low back pain is a complex condition with several factors contributing to its occurrence and is triggered by some combination of overuse, muscle strain, or injury to the muscles and ligaments that support the spine.

Lumbar muscles (multifidi) and abdominal muscles become weaker with chronic back pain and dysfunction may be disproportionate between these muscles. Strength, co-ordination and timing of transversus abdominis (TA) and multifidi (MF) muscles contraction may be important in stabilizing the low back, and contraction of these particular muscles may be one of the factors capable of preventing and reducing LPB in general population. The function and strength of TA and MF muscles are difficult to measure. Several researchers have used pressure biofeedback unit (PBU) in measuring deep cervical flexor muscles (Hudswell, 2005), transversus abdominis function (Storheim, 2002), lumbar stabilization (Cynn et al, 2006), abdominal muscle endurance (Mulhearn, 1999) and in the quantification of abdominal muscular dysfunction (Cairns, 2000).

The MF has distinct superficial and deep fibers that originate from the spinous process and lamina of each lumbar vertebra. The superficial fibers serve to control extension of the lumbar spine and maintain lumbar lordosis. The deep fibers stabilize the spine via compression, and they protect intervertebral shear and torsion (Moseley, 2002). The TA runs horizontally around the abdomen. It attaches to the transverse processes of each lumbar vertebra via the throcolumbar facia, and it is thought to play an integral role in stabilizing the lumbar spine and the sacroiliac joints. It can be strengthened by slowly pulling the umbilicus towards the spine without contracting the rectus abdominus (Richardsan et al, 2002). We hypothesized that spinal column pressure and abdominal pressure changes may have some relationship with pain severity (intensity) in patients having LBP.

To identify serious pathology all guidelines for management of LBP have recommended use of a diagnostic triage. Based on the history and physical examination, LBP was classified into nonspecific and specific (Refshauge and Maher, 2006). Non specific diagnosis of chronic LBP, to which lumbago can be referred are most common, with a prevalence of about 90% to 95% in the early phase of the chronic condition (Borenstein, 1996). Specific LBP are those which have known cause such as infection, trauma, neurological disorder, cancer, fracture, inflammatory disorder and cauda equine syndrome (Refshauge and Maher, 2006).

There are many existing diagnostic tools for LBP such as x-ray, MRI, computed tomography (CT) scan, nerve conduction tests and myelography, but most of them are cost effective. However, at present no reliable and valid classification system exists for diagnostic and prognostic of LBP (Koes, 2006).

In this study, for the first time to our knowledge, spinal and abdominal muscles contractions were measured in terms of pressure changes using pressure measuring device (PMD) and their levels were correlated with the pain severity. Differences in male and female, influencing variable, estimation of both the spinal and abdominal pressure changes were also evaluated.

MATERIALS AND METHODS

Subject section

The present study was conducted on 39 (28 male and 11 female) sub-acute and chronic low back pain patients ranged from 20-40 years of age diagnosed clinically by physicians at OPD of CSM Medical University, Lucknow in 2007.

Inclusion & Exclusion criteria

Subjects were excluded from the study if they suffered from any known neurological disorder or muscular degenerative condition such as muscular dystrophy or if they had undergone any lumbar spine surgery, infection, vascular problem and leg pain/or low back pain for less than 6 weeks. Thus, the subjects included in this study were either sub-acute (6-12 weeks) or chronic (> 12 weeks) and non specific (muscular inefficiency) LBP patients and hereafter LBP should be considered as sub-acute or chronic LBP patients.

Ethical approval and patients' informed consent

This study was approved by Institutional Ethics Committee of CSM Medical University, Lucknow, India. Consultants referring patients to the unit were informed about proposed study and received written and verbal explanations regarding the study. Patients' informed consent was also taken.

Instrumentation

Pressure measuring device

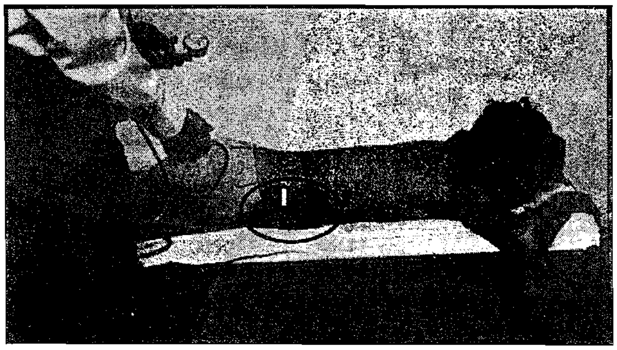
In this study pressure measuring device (PMD) similar to pressure biofeedback unit (Storheim, 2002) which consists of pressure gauge, inflatable cell sensor (ICS) and inflation bulb with valve. It is a quality product of Sareen Surgical Products, calibrated for 0 to 300 mmHg and highly reproducible. The ICS is made up of single cell unit of elastic material and covered by cotton cloth. The objective of PMD is quantification of back and abdominal muscles in terms of pressure changes. PMD operates on the principle that body movement or changes of position in any plane cause volume changes in the cells which are measured as a pressure changes. Before taking the measurements, the subjects were fully trained about how to press back muscle and contract abdominal muscle on ICS. The inflatable cell was placed centrally beneath the abdomen with the lower edge at the level of the anterior superior iliac spine (ASIS). The patient is in supine lying position with hip and knee in extended position and the ICS is inserted between the low back and exercise surface and is inflated to fill the irregularly shaped space (Fig. 1a). Same procedure is applied in the prone lying position in which ICS is inserted between the abdomen and exercise surface (Fig. 1b). Readings were taken at the start and finish of a ten second contraction and maximum of three consecutive contractions from base line of 70 mmHg (i.e. the pressure in the cell that fill the space behind the back giving the patient an awareness only of its presence) were taken. The holding capacity or fragibility of these muscles is judged by the time that the correct activation is held. There will be a slight fluctuation (± 2 mmHg) which is registered by the PMD as movement associated with breathing. All readings were subject and investigator blind. Thus, total 39 spinal column pressure changes (SCPC) and abdominal pressure changes (APC) were obtained.

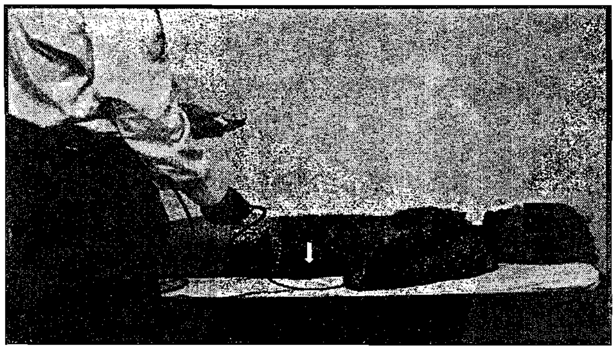
Visual analogue scale

Pain intensity (Pain) was measured by visual analogue scale (VAS), a 0-10 cm scale, where 0 represent no pain and 10 represent the worst imaginable pain.

Research design

This is a observational, prospective and only case study of patients.





a. *Fig. 1. Figures shows measurement of spinal column pressure changes in supine lying position (a) and abdominal pressure changes in prone lying position (b) by PMD.* b.

Experimental setup

Spinal column pressure changes and abdominal pressure changes of all 39 patients were correlated with their pain severity. Physical characteristics such as age, weight, height, waist circumference (WC), hip circumference (HC), waist hip ratio (WRH), body mass index (BMI), systolic blood pressure systolic (SBP), diastolic blood pressure (DBP), pulse rate (PR) and duration of pain (DUR) were also obtained to find out risk factors. The obtained data of all 39 patients were submitted for statistical analysis.

Data Analysis

Statistical analysis was done using independent Student's t-test, Spearman rank correlation and step wise multiple regression analysis. Student's t-test was used to compare significance of mean difference between two independent groups/variables while Spearman rank correlation was used to assess significant relationship between variables. Step wise multiple regression analysis was done to identify significant predictors of both the back and abdominal pressure changes, considering back and abdominal pressure changes as dependent variable and pain and physical characteristics as independent variables. STATISTICA (version 7), GraphPad Prism (version 5) and MS EXCEL were used for the analysis. A two-tailed (a=2) probability (p) value less than 0.05 ($p<0.05$) was considered statistically significant.

RESULTS

Table 1: shows the summary of physical characteristics, spinal and abdominal pressure changes and pain intensity of all male and female patients. Mean comparison showed that the level of SCPC in all, male and female patients were significantly ($p<0.01$) high than the respective APC and the levels of both SCPC and APC were significantly ($p<0.05$) high in male than female while levels of Pain in both the male and female did not differ significantly ($p>0.05$). The mean physical characteristics of male and female were also found to be similar i.e. did not differ significantly ($p>0.05$) except Height, BMI and PR. The height of male was significantly ($p<0.01$) high than the female while BMI and PR were significantly ($p<0.05$) high in female than the male.

Table 2: shows the correlation coefficient between variables. Correlation between SCPC and APC was positive and significant ($p<0.01$) while both SCPC and APC show negative and significant ($p<0.01$) correlation with the Pain. WC, HC, BMI and PR also shows positive and significant ($p<0.01$) correlation with the Pain.

Table 3: shows stepwise regression analysis summary for SCPC and APC and also shown graphically by Fig. 2. Pain and DUR were found to be significant (ANOVA F= 48.62, $p<0.01$) predictors of SCPC which accounts 73% variations of SCPC while Pain, Height and

WC (ANOVA F= 18.15, p<0.01) of APC which accounts 61% variations of APC and by the following best fit regression equations, both SCPC and APC can be estimated as

SCPC = 29.49 - 2.70 Pain + 0.03 DUR ..... (i)

APC = 5.15 - 1.19 Pain + 0.12 Height - 0.13 WC ..... (ii)

DISCUSSION

The present study examined the relationship of spinal (back) and abdominal pressure changes with pain intensity in LBP patients and found an inverse and significant linear relationship with each other. At same pain intensity this study found that both the back and

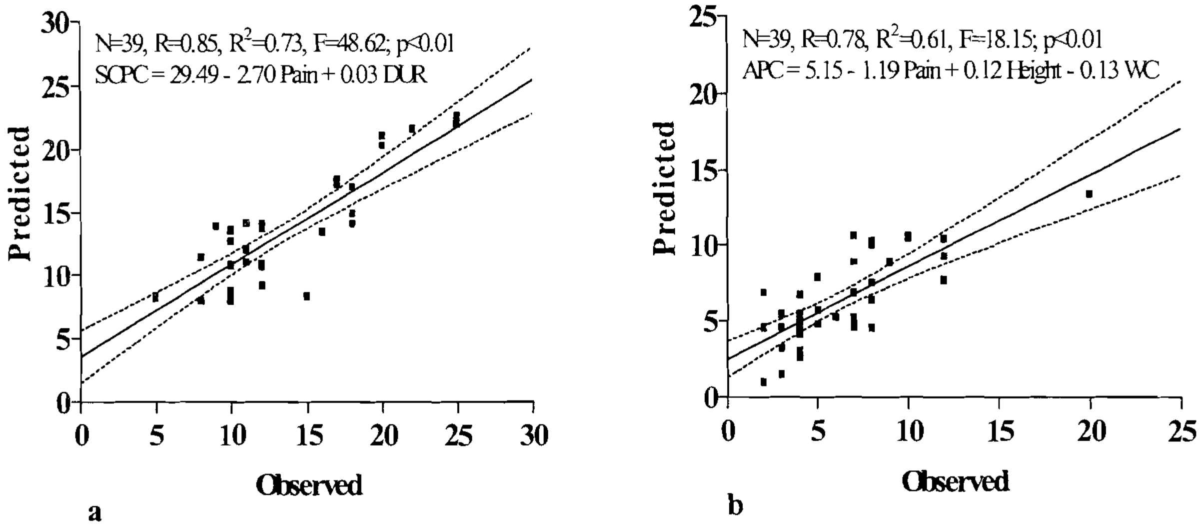


Fig.2. Best fit regression equation for spinal column (a) and abdominal (b) pressure changes with lower and upper 95% confidence limits for â (slope).

Table 1. Summary statistics (Mean ± SE) of physical characteristics, pressure changes and level of pain in patients with LBP.

Parameters	Total (n=39)			Female (n=11)			Male (n=28)		
	Min	Max	Mean ± SE	Min	Max	Mean ± SE	Min	Max	Mean ± SE
Age (yrs)	20	40	35.77 ± 0.83	29	40	36.73 ± 1.23	20	40	35.39 ± 1.06^{ns}
Weight (kg)	50	99	69.65 ± 1.82	50	85	64.28 ± 3.14	51	99	71.76 ± 2.11^{ns}
Height (cm)	146	188	164.54 ± 1.61	146	158	152.77 ± 1.09	155	188	169.16 ± 1.45**
WC (cm)	58	109	89.34 ± 1.66	58	109	90.52 ± 4.11	69	104	88.87 ± 1.70^{ns}
HC (cm)	42	62	50.88 ± 0.83	42	61	50.80 ± 1.58	44	62	50.92 ± 1.00^{ns}
WHR	1	2	1.76 ± 0.03	1	2	1.79 ± 0.08	1	2	1.75 ± 0.03^{ns}
BMI (kg m^{-2})	19	34	25.73 ± 0.57	22	34	27.52 ± 1.25	19	30	25.03 ± 0.59*
SBP (mmHg)	110	150	128.46 ± 1.49	110	150	128.64 ± 3.51	110	145	128.39 ± 1.61^{ns}
DBP (mmHg)	80	100	85.46 ± 1.06	80	100	87.73 ± 2.64	80	100	84.57 ± 1.05^{ns}
PR (min)	70	106	80.23 ± 1.18	76	106	85.55 ± 2.93	70	90	78.14 ± 0.94**
DUR (month)	2	84	22.59 ± 3.33	3	60	21.27 ± 5.40	2	84	23.11 ± 4.18^{ns}
SCPC (mmHg)	5	25	13.10 ± 0.79	5	18	10.64 ± 0.95	5	25	14.07 ± 0.98*
APC (mmHg)	2	20	6.38 ± 0.58	2	8	4.09 ± 0.53	2	20	7.29 ± 0.71*
Pain (score)	3	8	6.36 ± 0.24	6	8	6.91 ± 0.25	3	8	6.14 ± 0.31^{ns}

ns – not significant (p>0.05), * - significant (p<0.05), ** - significant (p<0.01)

Keys

WC – Waist circumference, HC – Hip circumference, WHR – Waist hip ratio, BMI – Body mass index, SBP – Systolic blood pressure, DBP – Diastolic blood pressure, PR – Pulse rate, DUR – Duration of pain, SCPC – Spinal column pressure changes, APC – Abdominal pressure changes

Table 2. Inter correlation among parameters (n=39) by Spearman rank correlation analysis.

Parameters	Age	Weight	Height	WC	HC	WHR	BMI	SBP	DBP	PR	DUR	SCPC	APC	Pain
Age	1.00													
Weight	-0.02	1.00												
Height	-0.17	0.50**	1.00											
WC	0.29	0.67**	0.05	1.00										
HC	-0.14	0.63**	0.21	0.56**	1.00									
WHR	0.42**	0.04	-0.19	0.41**	-0.48**	1.00								
BMI	0.17	0.68**	-0.23	0.73**	0.51**	0.20	1.00							
SBP	0.09	0.33*	0.16	0.32*	0.47**	-0.25	0.16	1.00						
DBP	0.52**	0.01	-0.15	0.19	0.19	-0.01	0.18	0.53**	1.00					
PR	0.13	0.04	-0.11	0.35*	0.20	0.10	0.10	0.22	0.01	1.00				
DUR	-0.09	-0.09	-0.01	-0.20	-0.09	-0.10	-0.09	-0.25	-0.05	-0.15	1.00			
SCPC	-0.13	-0.25	0.08	-0.36*	-0.42**	0.15	-0.37*	-0.31	-0.11	-0.47**	0.37*	1.00		
APC	-0.29	-0.24	0.30	-0.63**	-0.38*	-0.25	-0.52**	-0.11	-0.11	-0.45**	0.28	0.47**	1.00	
Pain	0.13	0.29	-0.04	0.43**	0.56**	-0.18	0.42**	0.26	0.18	0.41**	-0.31	-0.71**	-0.62**	1.00

* - significant ($p<0.05$), ** - significant ($p<0.01$)

Keys

WC – Waist circumference, HC – Hip circumference, WHR – Waist hip ratio, BMI – Body mass index, SBP – Systolic blood pressure, DBP – Diastolic blood pressure, PR – Pulse rate, DUR – Duration of pain, SCPC – Spinal column pressure changes, APC – Abdominal pressure changes

Table 3. Best fit regression summary for spinal column and abdominal pressure changes in patients with LBP.

Predictors	Coefficient	Standard error	t stat	P-value	Confidence interval Lower 95%	Upper 95%
Spinal column pressure changes (SCPC)						
Constant	29.49	2.11	13.97	0.00	25.21	33.77
Pain	-2.70	0.30	9.04	0.00	-3.30	-2.09
DUR	0.03	0.02	1.58	0.12	-0.01	0.08
Abdominal pressures changes (APC)						
Constant	5.15	6.88	0.75	0.46	-8.82	19.12
Pain	-1.19	0.28	4.29	0.00	-1.75	-0.62
Height	0.12	0.04	3.22	0.00	0.05	0.20
WC	-0.13	0.04	3.30	0.00	-0.21	-0.05

$p>0.05$ – not significant, $p<0.01$ – significant

Keys

DUR – Duration, WC – Waist circumference

abdominal pressure changes significantly differed between male and female patient. The levels were higher in male patients than the female patients. For this the reason could be significant differences in Height, BMI and PR. Heon-Seock et al, (2006) also found sex dependent differences which affect the lumbopelvic stability between men and women, but they did not measure the differences. In their study they suggest that in women a higher percentage of maximum voluntary isometric contraction in gluteus medius, external oblique, and rectus abdominis is needed to maintain lumbopelvic stability during hip abduction in side lying position. Less skeletal muscle mass, thickness of lateral abdominal muscle, and physiologic cross-sectional area of abdominal region in women were also reported (Janssen, 2000; Marras, 2001; Springer et al, 2006).

Among investigated physical characteristics WC, HC, BMI and PR were significant risk factors for LBP and were more associated with female patients compared with the male. Several authors also found that working hours (Andrusaitis, 2006), BMI (Evans, 2005), hard work, disc degeneration (Lebou-Yde, 2004), age, gender, being married/divorcee, smoking, previous LBP history, extra professional activity, migraine, heavy weight lifting (Bejia et al, 2005) were risk factors for LBP. Exercises are suggested for protecting factor against LBP (Bejia et al, 2005).

Prospective randomized studies have shown that dysfunction of the transversus abdominis and multifidi muscles is important in the management for LBP (George, 2007) which affected the most and pain is one of the most outcomes of dysfunction (Koes, 2006). The pressure biofeedback unit (PBU) is a device designed to teach and measure transversus abdominis muscle function, but intra-tester reproducibility of this is low and is affected by respiration (Storheim, 2002). Multi channel electromyography (EMG) was also used to investigate activity of the supporting muscles of the trunk, but it is a invasive procedure, requires fine wire electrodes, injected into the muscles and generally not recommended in clinical practices. In contrast, the PMD may be a better alternative for diagnostics as it is highly reproducible, easy to use and cost effective. However, further trials are needed before PMD can be recommended in daily clinical practices.

CONCLUSION

This study revealed that spinal (multifidi) and abdominal (transversus abdominis) pressure changes have an inverse and significant relation with pain intensity in patients with LBP and the association of multifidi was more than transversus abdominis while the mean level of transversus abdominis was high than the multifidi. The contractions of both the muscles in males were significantly high than the females and for this differences in height, BMI and pulse rate were found to be responsible. Thus the spinal and abdominal muscle pressure changes and pressure measuring device both may play an important role in assessing LBP.

REFERENCES

- Andrusaitis S.F., Oliveira R.P., Eloy P.R. Study of the prevalence and risk factors for low back pain in truck drivers in the state of Sao Paulo, Brazil. *Clinical Sciences* 2006; **61:** 503-10.
- Bejia I., Younes M., Jamila H. B., Khalfallah T., Salem K.B., Touzi M., Akrout M., Bergaoui N. Prevalence and factors associated to low back pain among hospital staff. 2005; **72:** 254-259.
- Borenstein DG. Chronic low back pain. *Rheum Dis Clin North AM* 1996; **22:** 590-7.
- Cairns MC, Harrison K, Wright C. Pressure Biofeedback: A useful tool in the quantification of abdominal muscular dysfunction? *Physiotherapy* 2000; **86(3):** 127-138.
- Croft P.R., Papageorhiou A.C., Ferry S. et al. (1995).Psychologic distress and low back pain. Evidence from a prospective study in the general population. Spine, 20, 1731-7.
- Cynn HS, Oh JS, Kwon OY, Yi CH. Effects of Lumbar Stabilization Using a Pressuyre Biofeedback Unit on Muscle Activity and Lateral Pelvic Tilt During Hip Abduction in Sidelying. *Arch Phys Med Rehabil* 2006; **87:** 1454-1458.
- Evans K., Refshauge K.M., Adams R., Aliprandi L. Predoctors of low back pain in young Elite golfers: A preliminary study. *Physical Therapy in Sport.* 2005; **6:**12-130.
- George S. G, John A. B., Jeffrey M. S. The lumbar spine and low back pain in golf: a literature review of swing biomechanics and injury prevention. *The Spine Journal*, 2007: 1-11.
- Heon-Seock C., Jae-Seop O., Oh-yun K., Chung-Hwi Y. Effect of lumbar stabilization Using a Pressure Biofeedback Unit on Muscle Activity and Lateral Pelvic Tilt During Hip Abduction in Sidelying. 2006; **87:**1454-1458.
- Hodges PW. (2000).The role of motor system in spinal pain: implication for rehabilitation of the athlete following lower back pain. J Sci Med Sport, 3, 43-53.
- Hudswell S, Mengersen MV, Lucas N. The cranio-cervical flexion test using pressure biofeedback: A useful measure of cervical dysfunction in the clinical setting? *International Journal of Osteopathic Medicine* 2005; **8:** 98-105.
- Hultmon G., Saraste H., Ohlssen H. (1992). Anthropometry, spinal canal width, and flexibility of the spine and hamstring muscle in 45-55 year old men with and without low back pain. J Spinal Disorder, 5, 245-253.
- Janssen I, Heymsfield SB, Wang Z, Ross R. Skeletal mass and distribution in 468 men and women aged 18-88 yr. *J Appl Physiol* 2000; **89:** 81-8.
- Koes B.W., Van Tulder M.W., Thomas S. Diagnosis and treatment of low back pain – Clinical review. *BMJ* 2006; **332:**1430-4.
- Lebou-Yde C., Back pain-individual and genetic factors. *Journal of Electromyography and Kinesiology*. 2004; **14:**129-133.
- Luoto S., Heliovaara M., Hurri H. et al. (1995). Static back endurance and the risk of low back pain. *Clinical Biomech*, 10, 323-4.
- Marras WS, Jorgensen MJ, Granata KP, Wiand B. Female and male trunk geometry: size and prediction of the spine loading trunk muscles derived from MRI. *Clin Biomech* (Bristol, Avon) 2001; **16:** 38-46.
- Milgrom C, Latimer J, Refshauge K. (1993) Prescription of activity for low back pain among recruits: a prospective study of risk factors and treatment regimens. J Spinal Disorder, 6, 187-93.
- Moseley GL, Hodges PW, Gandevia SC. Deep and superficial fobers of the lumbar multifidus muscle are differentially active during voluntary arm movements. *Spine* 2002; **27(2):** E29-36.
- Mulhearn S, George K. Abdominal Muscle Endurance and its Association with Posture and Low Back Pain. *Physiotherapy* 1999; **85(5):** 210-216.
- Refshauge KM, Maher CG. Low back pain investigations and prognosis: a review. *Br J Sports Med* 2006; **40:** 494-498.
- Richardsan CA, Snijders CJ, Hides JA, Damen L, Pas MS, Storm J. The relations between the transverses abdominis muscles, sacroiliac joint mechanics, and low back pain. *Spine* 2002; **27(4):**399-405.
- Springer BA, Mielcarek BJ, Nesfield TK, Teyhen DS. Relationship among lateral abdominal muscles, gender, body mass index, and hand dominance. *J Orthop Sports Phys Ther* 2006; 36: 289-79.
- Storheim K, BO K, Pederstad O, Jahnsen R. Intra-tester reproducibility of pressure biofeedback in measurement of transverses abdominis function. *Physiotherapy Research International* 2002; **7(4):** 239-249.