Research Article

International Journal of Orthopaedics Research

The Effect of Abdominal and Spinal Muscles Fatigue in Spinal Postures

Mohammed Elmajee[1], Mahmoud Al Hinai[2], Ahmed Aljawadi[3*], Lugman Elgayar[4], Shoaib Khan[5], Jamie A Court[6], Frances Arnall[7], Anand Pillai[8] and Irfan Siddique[9]

[1]ST4 Spine department, Royal Orthopaedic Hospital NHS Foundation Trust, Birmingham, UK, B31 2AP

[2]MSc student, Trauma and orthopaedic, University Of Salford, Salford, Manchester

[3]Trauma and Orthopaedics, Wythenshawe Hospital, Manchester, UK, M23 9LT

[4]Speciality registrar, Trauma and Orthopaedics, Wales Deanery, UK

[5]ST3 Trauma and Orthopaedics, Arrowe Park Hospital, CH49 5PE

[6]ST4 Department of trauma and orthopaedics surgery, University, Hospital of South Manchester, Wythenshawe, Manchester, M23 9LT

[7]Trauma & Orthopaedics Academic Module lead, School of Health Sciences Allerton Building C711, University of Salford, Fredrick Road Campus M6 6PU

[8]Consultant Trauma and Orthopaedics, Department of trauma and orthopaedics surgery, University Hospital of South Manchester, Wythenshawe, Manchester, M23 9LT

[9]Department of Spinal Surgery, Salford Royal NHS Trust, Stott Lane, Salford, M6 8HD

***Corresponding author**
Ahmed Aljawadi, Department of Trauma and Orthopaedics, Wythenshawe Hospital, Manchester, UK, M23 9LT

Submitted: 23 Jan 2020; **Accepted**: 01 Feb 2020; **Published**: 17 Feb 2020

Abstract
Background: *A Pre/Post-Test Cohort investigating the effect of spinal and abdominal muscles fatigue on spinal curvatures.*

Method and Results: *The effect of spinal and abdominal muscle fatigue on pelvic tilt, trunk inclination and the lordotic angle, and on the rotation of the T6, L2 and L4 vertebras was investigated in 10 healthy individuals. Abdominal and spinal muscles fatigue had a significant effect (p <0.05) on pelvic tilt, trunk inclination and lordotic angle.*

Conclusion: *Application of simple and quick fatigue tests resulted in changes in all static parameters (pelvic tilt, trunk inclination and lordotic angle) as measured by the DIERS system.*

Keywords: Abdominal muscles, Formetric 4D Dynamic Model, Fatigue, Spinal muscles, Spinal postures

Introduction
Spinal and abdominal muscles are key components in maintaining spinal movements and postures, both in static and dynamic positions [1]. Fatigue of spinal and abdominal muscles is correlated with low back pain (LBP) disorders [1]. The relationship between changes in the lumbar lordosis angle and musculoskeletal conditions such as LBP, facet pain and radiculopathy has been observed [2]. An increase in lumbar lordosis has been suggested to increase the load on the lumbar spine area [3].

To the author's best knowledge, no studies have investigated the effect of abdominal and spinal muscles fatigue on pelvic tilt, trunk inclination and lordotic angle in a static spinal posture and on the rotation of vertebras in a dynamic spinal posture applying the DIERS system. The DIERS system is a new formetric 4D dynamic model that has been developed to analyse the spine in static and dynamic postures. It has the ability to capture images of the patient's spine at a rate of 50 frames per second through simple movement (e.g. walking on a treadmill) for a period of 5 seconds. Consequently, about 250 static images are composed and rapidly transformed into a 3D demonstration of the patient's spine. The images are combined and formatted into a real-time 3D illustration of the shape and motion of the individual segments of the spine throughout the gait cycle.

Method

A (pre/post-test) cohort study was conducted in 10 healthy individuals to investigate the effect of spinal and abdominal muscles fatigue on pelvic tilt (DL-DR), trunk inclination (VP-DM) and the lordotic angle (ITL-ILS max) in a static spinal posture. Three different levels of vertebrae were randomly chosen (T6, L2 and L4) to assess the effect of spinal and abdominal muscle fatigue on the rotations of these vertebrae. Prior to the study, ethical approval was obtained. The inclusion criteria for participation in this study were male individuals, aged between 18 to 45 years old, able to walk for 2 – 3 minutes on a treadmill, able to understand both written and spoken English language, able to attend the University of Salford testing laboratory and had no history of any musculoskeletal diseases. Spinal muscles fatigue was induced using the Sorenson test and abdominal muscles fatigue was made using the double leg lowering (DLL) test [4]. The new technology, the DIERS formetric 4D dynamic system, was used as an outcome measure (Figure 1).

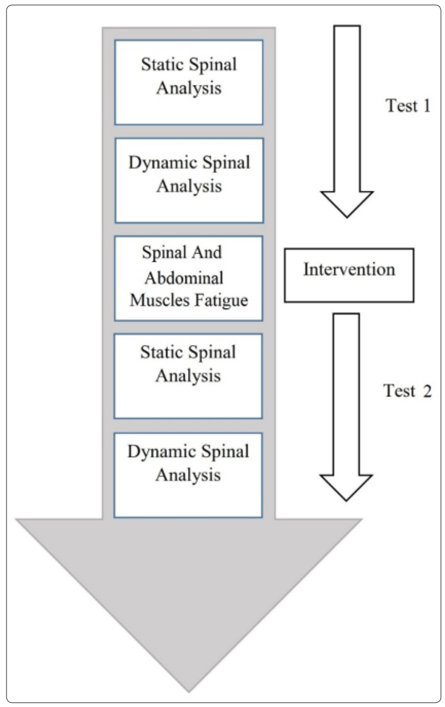

Figure 1: The Study Protocol

Results

All statistical analyses were performed using SPSS® (version 23.0, IBM, USA) software, by applying descriptive statistics [mean and standard deviation (SD)] to represent the whole data set. The statistical significance of the results achieved was set at a value of $p < 0.05$.

In the static spinal analysis, abdominal and spinal muscles fatigue had a significant effect ($p < 0.05$) on pelvic tilt (DL-DR), trunk inclination (VP-DM) and lordotic angle (ITL-ILS max) for the majority of the participants (Table I). The effect of fatigue differed between subjects, with increases and decreases observed in all parameters.

In dynamic spinal analysis, abdominal and spinal muscle fatigue had less significant effect in peak to peak ($p = 0.634$) and on the mean values of T6 ($p = 0.055$), L2 ($p = 0.256$, $p = 0.676$, respectively) and L4 ($p = 0.75$, $p = 0.70$, respectively) vertebra rotations of all participants involved in the study. Table II demonstrates one of the three assessed vertebrae, T6.

Table 1: Description of the static spinal analysis of all participants

Participants	Parameters	Pre muscle fatigue		Post muscle fatigue		P value
		Mean	SD	Mean	SD	
1	Pelvic Tilt DL-DR °	-5.050	0.219	-2.540	0.966	0.000
	Trunk Inclination VP-DM °	-1.000	0.085	-0.075	0.176	0.002
	Lordotic Angle ITL-ILS (max)	38.75	0.437	36.7667	0.459	0.000
2	Pelvic Tilt DL-DR °	-7.820	0.459	-7.560	1.025	0.754
	Trunk Inclination VP-DM °	1.250	0.206	0.733	0.201	0.002
	Lordotic Angle ITL-ILS (max)	41.583	0.863	40.09	1.900	0.031
3	Pelvic Tilt DL-DR °	-1.50	0.00	1.950	1.690	0.000
	Trunk Inclination VP-DM °	8.470	0.080	6.290	0.144	0.002
	Lordotic Angle ITL-ILS (max)	2.300	0.112	31.61	2.352	0.002
4	Pelvic Tilt DL-DR °	2.300	0.112	31.61	2.352	0.002
	Trunk Inclination VP-DM °	1.200	0.239	0.325	0.333	0.002
	Lordotic Angle ITL-ILS (max)	40.841	0.689	41.15	0.4699	0.058
5	Pelvic Tilt DL-DR °	-2.580	0.728	-2.240	0.124	0.129
	Trunk Inclination VP-DM °	1.910	0.406	-0.614	0.227	0.002
	Lordotic Angle ITL-ILS (max)	33.725	0.422	37.40	0.447	0.000
6	Pelvic Tilt DL-DR °	-3.84	0.355	-2.24	0.260	0.000
	Trunk Inclination VP-DM °	-0.266	0.137	3.208	0.09	0.002
	Lordotic Angle ITL-ILS (max)	37.58	0.401	31.408	0.828	0.000
7	Pelvic Tilt DL-DR °	-3.320	1.854	-3.510	2.016	0.665
	Trunk Inclination VP-DM °	4.575	4.060	3.175	3.175	0.345
	Lordotic Angle ITL-ILS (max)	29.50	2.462	31.00	1.289	0.051
8	Pelvic Tilt DL-DR °	-0.270	0.045	-1.590	0.962	0.007
	Trunk Inclination VP-DM °	3.009	0.165	7.025	0.252	0.002
	Lordotic Angle ITL-ILS (max)	27.733	0.238	32.17	0.739	0.002
9	Pelvic Tilt DL-DR °	-0.500	0.987	-1.201	0.989	0.099
	Trunk Inclination VP-DM °	0.833	0.049	4.300	0.229	0.002
	Lordotic Angle ITL-ILS (max)	29.833	0.192	26.333	0.439	0.000
10	Pelvic Tilt DL-DR °	0.750	1.090	0.408	1.440	0.487
	Trunk Inclination VP-DM °	6.808	0.099	7.871	0.105	0.002
	Lordotic Angle ITL-ILS (max)	37.316	0.476	34.991	1.856	0.009

Table 2: Peak to Peak (P-P) and Mean Values of T6 Vertebral Rotation (Pre- & Post- Fatigue) of all subjects

	Pre-Fatigue		Post-Fatigue	
	P-P	Mean	P-P	Mean
Subject 1	7.2	4.2	-2.1	-3.77
Subject 2	4.9	7.5	-0.87	-1.26
Subject 3	5.8	6	-10.77	-10.17
Subject 4	9.8	9.5	-1.24	-2.67
Subject 5	3.8	2.9	1.82	1.42
Subject 6	4	5.9	3.6	-2.19
Subject 7	6.8	5.2	-0.11	-2.15
Subject 8	6	4.9	1.86	-1.14
Subject 9	4.5	8.3	-2.27	-3.87
Subject 10	4.6	6.3	-8.57	-7.02

Discussion

To the best knowledge of the authors, no previous studies have examined the effects of abdominal and spinal muscles fatigue (utilising Sorenson and DLL tests) on static parameters including pelvic tilt (DL-DR), trunk inclination (VP-DM), lordotic angle (ITL-ILS max) and dynamic parameters including T6, L2 and L4 vertebral rotations.

Suboptimal and excessive use of abdominal and spinal muscles forces can lead to certain changes in the biomechanics of the spine, which may limit spinal stability and increase spinal load [5]. However, previously published studies have applied empirical assessment to assess fatigue in spinal and abdominal muscles utilising tools such as electromyography (EMG) [6-7]. In our study, the assessment of fatigue was performed by measuring changes in six different spinal parameters (three in static and three in dynamic positions). An assessment of these parameters can inform health-care professionals about real time structural changes in the spine during fatigue. This could assist our understanding of conditions such as Low Back Pain (LBP) and in different implications for ergonomic industry.

Static Parameters

In this study, 50% of the participants showed an increase in the mean degree of pelvic tilt (DL-DR). Conversely, they also showed a decrease in the mean degree of pelvic tilt (DL-DR) which was observed in the other 50% participants. With regards to trunk inclination, six of the participants showed an increase in the mean degree of trunk inclination (VP-DM), with a decrease observed in the other four participants. Regarding lordotic angle, the results of this study revealed that five of the participants experienced an increase in mean lordotic angle (ITL-LLs max), whereas the other five participants had a decrease in the mean lordotic angle (ITL-LLs max). The results of the static parameters suggest that spinal and abdominal muscle fatigue have an effect on the above-mentioned parameters. From the data we can summarise the individuals experience less muscle control and the ability to adapt the spine to the induced fatigue, as evidenced by the observed changes in pelvic tilt. We hypothesis the effects could be worse in unhealthy or elderly populations and patients with other de-conditioning lumbosacral disorders such as disco genic problems or LBP.

One of possible explanations for the results demonstrated above is the neuromuscular control factors and co-activation of antagonistic muscular group, which has an important role to maintain mechanical stiffness and spinal stability [5, 8]. Previous studies have identified that lumbar extensor muscle fatigue alters the onset and cessation of myoelectric silence during the performance of flexion-extension tasks [9]. Moreover reported that lumbar extensor muscle fatigue increased body sway during standing as a consequence of declined muscle proprioceptive acuity, impaired postural control and reduced trunk stability [10]. Furthermore, a subsequent study by revealed an increase in trunk muscle co-contraction after lumbar muscle fatigue to compensate for the reduced stability and to increase trunk stiffness [11].

Investigated the effect of fatigue tasks (3 min intense stair climbing) on spinal postures and trunk muscular activation patterns. After the fatigue protocol, the researchers concluded that participants had greater spinal flexion (16.3° maximum prior to fatigue as compared to 20.1° post fatigue) and reduced abdominal muscle co-activation post fatigue tasks (mean ranging from 16.6% maximum voluntary contraction (MVC) to 30.6% MVC prior to fatigue as compared to 14.6% MVC to 25.2% MVC post fatigue). It would be interesting to investigate the neuromuscular components that maintain the stability of the spine. For example, how do the primary muscular stabilisers and the other secondary adaptive factors integrate? [12].

In this study, fatigued-spinal and abdominal muscles failed to maintain the neuromuscular control and the spinal stability; this was evident by the changes in the static spinal parameters. However, to ascertain which factor is responsible for these changes, that is, fatigued muscles or the failure of proprioceptive mechanisms or other adaptive mechanisms, such activation of another muscular group, future larger scale studies incorporating tools to assess fatigue and proprioception could be considered.

Dynamic parameters

An advantage of the DIERS system is the ability to analyse the spine in dynamic postures. Assessment of vertebral rotation is of clinical importance, particularly in diseases such as Adolescent Idiopathic Scoliosis (AIS) [13-14]. These assessments provide more insight into the changes in vertebral column, aids in the assessment of the significance of an intervention and assist surgeons in pre-surgical planning [13].

Although the importance of assessing vertebral rotation in structural deformities, such as scoliosis, has already been investigated and emphasised with different radiological modalities, however, to the authors' best knowledge, the effect of abdominal and spinal muscles fatigue on vertebral rotation (T6, L2 and L4) in a dynamic spinal posture has not been previously investigated. This assessment will provide an insight into the effect of the integrity of these muscles and the fatigue induced by the applied fatigue tests (Sorensen and DLL tests) on musculoskeletal disorders, such as LBP. 3 vertebral levels T6, L2 and L4 were randomly selected for measurements in this study to coincide with current research in this area. We assessed the effect of spinal and abdominal muscle fatigue on the rotations of these vertebrae.

The statistical data showed that abdominal and spinal muscles fatigue had less significant difference in P-P values of T6, L2 & L4 vertebral rotations (P value= 0.634, 0.75 & 0.256 respectively) or the mean values (p = 0.055, 0.70 & 0.676) of T6, L2 & L5 vertebral rotations pre- and post-abdominal and spinal muscles fatigue (Table 2).

Although the researchers had some difficulties in determination of max P and min P values in the graphical representation of P-P values during 5 sec gait cycle of T6 vertebral rotation. However, in comparison with T6 graphical representation, the data was easier to evaluate when L2 rotation was assessed. Eight of the participants had clear graphical representation of P-P values of L2 vertebral rotation. Furthermore, when the results of fatigue on T6 and L2 vertebral rotation are compared together, P-P value of L2 rotation was more statistically significant than T6 rotation (P value of L2 = 0.256, P value of T6 = 0.634 respectively). This may be explained by the difference in muscle recruitment in the Sorensen test as this test has a task-dependency effect on lumbo-pelvic muscle fatigue. Whereby hip extensor muscles tend to fatigue simultaneously with the para-spinal muscles. Lifting the upper body mass during the Sorensen test is mostly dependant of lower lumbar and pelvic muscles in addition to hip extensors, with less contribution of the muscles in the thoracic area and subsequently, less noticeable effects of fatigue in this area [15].

The outcomes of current study should be interpreted in light of few limitations. Firstly, the low number of participants. However, all of the included participants have shown changes in the parameters measured, particularly static parameters. This could be considered as a pilot study which will pave the way for future studies in this field. Secondly, the possibility of a gender bias. Future studies which incorporate both genders are required to improve the generalization of the results of such type of studies. Thirdly, this study included healthy participants only. Assessment of changes in the parameters measured in un-healthy population is warranted which will assist researchers to understand and treat some lumbo-sacral disorders such a LBP. Finally, a technical issue was encountered during dynamic spinal analysis as there were difficulties to control the time of 5 second digital motion image capture by DIERS system and the stride length of similar limb between pre and post abdominal muscles fatigue. This could have affected dynamic data obtained and potentially the validity of the study. Future improvement of the DIERS system to overcome such difficulties with re-evaluation of the effect of fatigue on spinal postures is required.

Conclusion

The application of simple and quick fatigue tests resulted in changes in all the static parameters (pelvic tilt (DL-DR), trunk inclination (VP-DM) and the lordotic angle (ITLILS max)) as measured by the DIERS system, reaching statistical significance ($p < 0.05$) in nearly all participants. There was not a specific pattern for the observed changes within the same parameter or between the three different static parameters. In contrast to the changes noted in static parameters, fatigue did not induce the same effect noticed on dynamic parameters (T6, L2 and L4 vertebral rotation). To the authors' best knowledge, this is the first study which applied the parameters mentioned above to investigate the effects of spinal and abdominal muscles fatigue utilising Sorenson and DLL tests. Taking into consideration the statistically significant results obtained in statics parameters from this study it provides the basis for future studies

Acknowledgement

The authors declare that no part of this study has been taken from existing published or unpublished materials without due acknowledgement and that all secondary materials used herein has been fully referenced.

References

1. Hawes MC, O Brien JP (2006) the transformation of spinal curvature into spinal deformity: pathological processes and implications for treatment. Scoliosis 1: 3.
2. Na Y, Kang S, Bae H, Kang M, Park J, (1996) The analysis of spinal curvature in low back pain patients. J Korean Acad Rehab Med 20: 669-674.
3. Hwang S, Park S, Kim Y (2009) Measurement Comparison about Lumbar Lordosis: Radiography and 3D Motion Capture. World Congress on Medical Physics and Biomedical Engineering, Germany Springer 25: 1669-1671.
4. Demoulin C, Vanderthommen M, Duysens C, Crielaard J M (2006) Spinal muscle evaluation using the Sorensen test: a critical appraisal of the literature. Joint Bone Spine 73: 43-50.
5. Gardner Morse MG, Stokes IA (1998) the effects of abdominal muscle coactivation on lumbar spine stability. Spine 23: 86-91.
6. Bandpei MAM, Rahmani N, Majdoleslam B, Abdollahi I, Ali SS, et al. (2014) Reliability of surface electromyography in the assessment of paraspinal muscle fatigue: an updated systematic review. Journal of manipulative and physiological therapeutics 37: 510-521.
7. Arnall FA, Koumantakis GA, Oldham JA, Cooper RG (2002) Between-days reliability of electromyographic measures of paraspinal muscle fatigue at 40, 50 and 60% levels of maximal voluntary contractile force. Clinical Rehabilitation 16: 761-771.
8. Granata KP, Orishimo KF (2001) Response of trunk muscle coactivation to changes in spinal stability. Journal of biomechanics 34: 1117-1123.
9. Hu B, Ning X (2015) the changes of trunk motion rhythm and spinal loading during trunk flexion and extension motions caused by lumbar muscle fatigue. Annals of biomedical engineering 43: 2112-2119.
10. Davidson BS, Madigan ML, Nussbaum MA (2004) Effects of lumbar extensor fatigue and fatigue rate on postural sway. European journal of applied physiology 93: 183-189.
11. Granata KP, Slota GP, Wilson SE (2004) Influence of fatigue in neuromuscular control of spinal stability. Human factors 46: 81-91.
12. Gregory DE, Narula S, Howarth SJ, Russell C, Callaghan JP (2008) the effect of fatigue on trunk muscle activation patterns and spine postures during simulated firefighting tasks. Ergonomics 51: 1032-1041.
13. Lam GC, Hill DL, Le LH, Raso JV, Lou EH (2008) vertebral rotation measurement: a summary and comparison of common radiographic and CT methods. Scoliosis 3: 16.
14. Lafage V, Leborgne P, Mitulescu A, Dubousset J, Lavaste F, et al. (2002) Comparison of mechanical behaviour of normal and scoliotic vertebral segment: a preliminary numerical approach. Studies in health technology and informatics 88: 340-344.
15. Champagne A, Descarreaux M, Lafond D (2008) back and hip extensor muscles fatigue in healthy subjects: task-dependency effect of two variants of the Sorensen test. European Spine Journal 17: 1721-1726.