Relaxation phenomenon in lumbar trunk muscles during lateral bending

D D Raftopoulos PhD
M C Rafko
M Green *
A B Schultz PhD*

Department of Mechanical Engineering, The University of Toledo, Toledo, Ohio, USA.
* Department of Mechanical Engineering and Applied Mechanics, The University of Michigan, Ann Arbor, Michigan, USA.

Summary

This paper reports myoelectric activity measurements in the lumbar trunk muscles when subjects performed tasks involving various degrees of lateral bending. Biomechanical model analyses were made to estimate the tensions in the lumbar trunk muscles required to perform those tasks. The tensions and the activity measurements were compared to see if a muscle relaxation phenomenon occurred. A relaxation phenomenon in the erector spinae muscles was observed to occur in quiet standing in a laterally-bent position of the trunk, qualitatively similar to the flexion–relaxation phenomenon reported by Schultz et al. in 1985[13]. However, no relaxation was observed to occur in the lateral oblique abdominal muscles in laterally-bent postures of the trunk.

Relevance

When standing in a maximum laterally-bent posture, passive mechanisms for the maintenance of equilibrium are present.

Key words: Relaxation phenomenon, Lumbar muscles, Myoelectric lateral bending

Introduction

Interest in lumbar trunk muscle contraction forces needed to perform everyday tasks arises because of the association of low back pain disorders with heavy work (Andersson et al.[1] for example). Recent investigations that measured and/or predicted these forces include those of Schultz and Andersson[2] and Schultz et al[3-5]. These studies used quantitative electromyography to validate biomechanical-model-predicted lumbar trunk muscle contraction forces required to perform physical tasks.

As early as 1911, Fick[6] suggested that the erector spinae muscles need not be active when the trunk is fully flexed. This hypothesis of a 'flexion–relaxation' phenomenon was confirmed by Allen[7], Floyd and Silver[8,9], Portnoy and Morris[10] and Pauly[11]. These investigators proposed that in full trunk flexion ligamentous tissues carry the posterior tissue tensions needed to

equilibrate upper body segments. Kippers and Parker[12] quantified relations between postural configurations and myoelectric activity decreases. Schultz et al.[13] quantified the tissue tensions involved in the flexion–relaxation phenomenon and showed that substantial myoelectric activity arose when exertions were made in those flexed positions.

The present study examined whether similar phenomena might arise in lateral bending of the trunk. It addressed the following questions:

1. What internal loads must lumbar trunk structures sustain in tasks involving lateral bending?

2. What levels of myoelectric activity are found in the lumbar trunk muscles in quiet standing with various degrees of trunk lateral bending?

3. Does a relaxation phenomenon occur in lateral bending of the trunk?

4. Do trunk muscle myoelectric activities increase when external forces are applied to the trunk in laterally bent configurations?

To answer these questions, measurements of myoelectric activities in the lumbar muscles were made using subjects performing tasks involving various

degrees of lateral bending, and biomechanical model analyses were made to estimate the required tensions in the lumbar trunk tissues.

Experimental methods

Nine male volunteers aged between 21 and 25 years participated. Their heights ranged from 171 to 189 cm, with a mean of 180 cm, and weights ranged from 624 to 780 N, with a mean value of 696 N. The width and the depth of the subjects' trunks at the L_3 level ranged from 27 to 31 cm, with a mean of 28 cm, and 25 to 20 cm, with a mean of 18·2 cm, respectively. All subjects were in good health and none had a history of significant back pain or injury.

Subjects were tested in an apparatus designed so that external loads could be applied, their postures could be controlled, and the mass centres of their upper body segments could be located (Figure 1). Each subject's pelvis was strapped to a support board after he assumed comfortable foot and leg positions. Subjects performed five types of tasks.

Task type 1. The subject, with his arms unsupported and at his side, bent his trunk first to the right and then to the left, in 10° increments to the maximum lateral bend he could achieve.
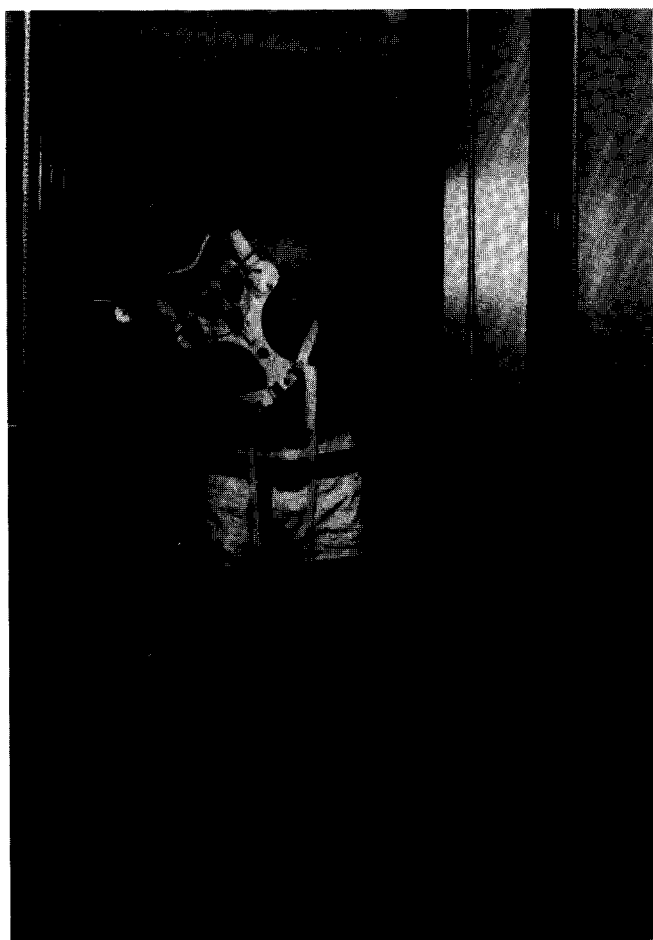
Figure 1: General view of the apparatus designed for lateral bending. The subject pulls as hard as he can on an anchored load cell.

Task type 2. The subject straightened from his maximum lateral bending posture, first from the right and then from the left, returning in increments of 10° to his upright position.
Task type 3 and 4. The subject held a 5 kg mass in his hand on the side to which the bending was performed, and then repeated task type 1 and 2.
Task type 5. The subject bent, first right and then left, to his maximum bending posture and then straightened slightly (5° at most). In this posture he pulled upright as hard as he could on an anchored load cell.

A minimum of 1 minute's rest was given to the subject between each task, and no fatigue was reported by the subject during any of the tasks.

During the performance of all tasks, configurations and myoelectric measurements were made. The configuration measurements were made by locating a set of targets placed on the subject's right and left elbows, forehead, sternum and umbilicus.

A horizontal scale and plumb bob line were used to estimate, within 1 centimetre, the location of these targets in each configuration. Care was taken to ensure that no anterior/posterior flexion of the trunk occurred during lateral bending.

Myoelectric activity was measured by surface electrodes at eight sites. The axis of the bipolar electrodes was aligned parallel to the direction of the muscle fibres. All electrodes were placed at the L_3 level. Approximate bilateral symmetry was assumed, so five of the electrodes were placed on the right side muscles and three placed over the left side muscles. Those three enabled the symmetry assumption to be checked. On the right side an electrode was placed on the back 3 cm lateral to the midline of the spine at the L_3 level. Another electrode was placed 6 cm lateral to the midline at the L_3 level. Anteriorly, an electrode was placed over the right rectus abdominus muscle at the level of the umbilicus and 3 cm lateral to the midline. Another pair was placed over the right medial oblique abdominal muscles, 3 cm medially and superior to the anterior spine of the iliac crest, and another over the most lateral fibres of the right lateral oblique abdominal muscles.

On the left side an electrode was placed on the back, 6 cm lateral to the midline at the L_3 level. Anteriorly, an electrode was placed over the left medial oblique abdominal muscles, 3 cm medial and superior to the anterior superior iliac spine, and another over the leftmost fibres of the lateral oblique abdominal muscles. A ground electrode was placed on the subject's right wrist.

The electrodes were filled with a conducting gel and attached to the subject's skin. The electrode signals were fed to pre-amplifiers, amplified again in main amplifiers, full wave rectified, integrated with a time constant of 0·2 s and recorded on a chart recorder (Grass Instrument Co., Model 7P3 equipment) together with the load cell output. A visual examination was made on the myoelectric signals and any artifacts due to unwanted movements or coughs were eliminated. Root mean square

(RMS) values over the recording period were estimated for each subject and each electrode. Finally, the mean and standard deviation of the RMS values were calculated over the nine subjects for each of the 22 tasks.

Prediction of trunk muscle forces

The contraction forces in the lumbar trunk muscles needed to perform each task along with the compression and shear load acting on the spine at the L_3 level were calculated for each subject and for each individual task using the 22 muscle biomechanical model described by Schultz et al.[5] This analysis began by computing first the net forces and moments needed to equilibrate the trunk at the L_3 transverse section in the laterally-bent positions. The calculation of these net reaction components were made based upon the applied loads and the locations of the mass centres of the body segments. The weights of the head, each arm and the trunk above L_3 were taken to be 5, 4·5 and 36·1% of the subject's body weight, respectively. Then the contraction forces in the 22 model muscles along with the spine compression and shear loads were calculated by optimization techniques (Bean et al.[14]). The objectives of this optimization were to minimize first muscle contraction intensity and then spine compression force. This technique maintains activity in antagonistic muscles at a minimum.

Essentially, this model computed a set of forces that would maintain equilibrium, with no distinction made between forces passively developed by the ligamentous tissues and forces actively developed by the muscles. It was assumed that the L_3 spine motion segment developed no significant moment resistance, but resisted compression, and lateral and antero-posterior shears. Furthermore, the effects of any abdominal cavity pressurization developed were neglected. The L_3 cross-sectional geometry of the muscles modelled was estimated from anatomical drawings to be in proportion to the trunk depth and width at the L_3 level for each subject. Further details of this technique can be found in the earlier report of Schultz et al.[3]

The mean predicted muscle contraction tissue-tension forces were correlated with corresponding mean measured amplitudes of the myoelectric signals by a linear least squares regression analysis.

Results

The means of the largest observed myoelectric signals in the left and right lateral oblique abdominal muscles with a 0·0 kg applied load were 21·7 and 23·6 μV, respectively; and for a 5·0 kg applied load, 26·3 and 24·8 μV, respectively. Similarly, for the left and right erector spinae muscles 6 cm from the midline, the largest signals with 0·0 kg load applied were 23·5 and 27·3 μV respectively, and for a 5·0 kg load applied, 30·2 and 26·3 μV, respectively (Tables 1 & 2).

The means of the corresponding largest predicted tissue tensions were 57·3, 59·3, 77·1, 68·1, 241·0, 249·6, 324·3 and 294·4 N. The largest mean predicted compression on the L_3 intervertebral disc was 1731 N. The mean maximum lateral bending moment that the trunk structures resisted in these tasks was 56.1 Nm.

Relaxation phenomena

Relaxation phenomena would be characterized by the diminishing of the myoelectric signal levels despite increases in soft tissue tensions predicted to be required to equilibrate the trunk in laterally-bent positions. In this study, the oblique abdominal muscles showed no noticeable relaxation.
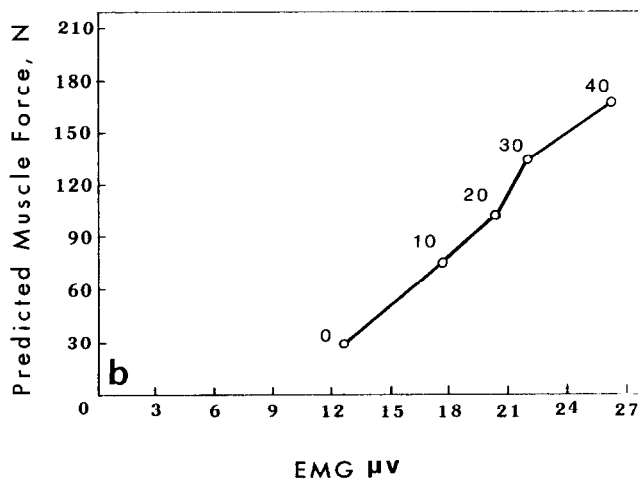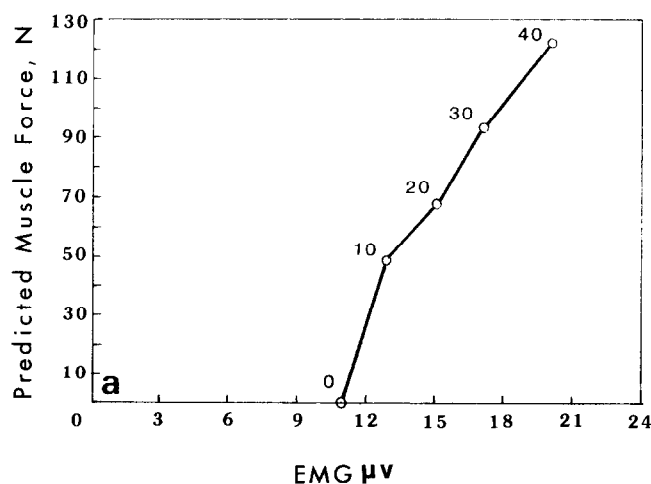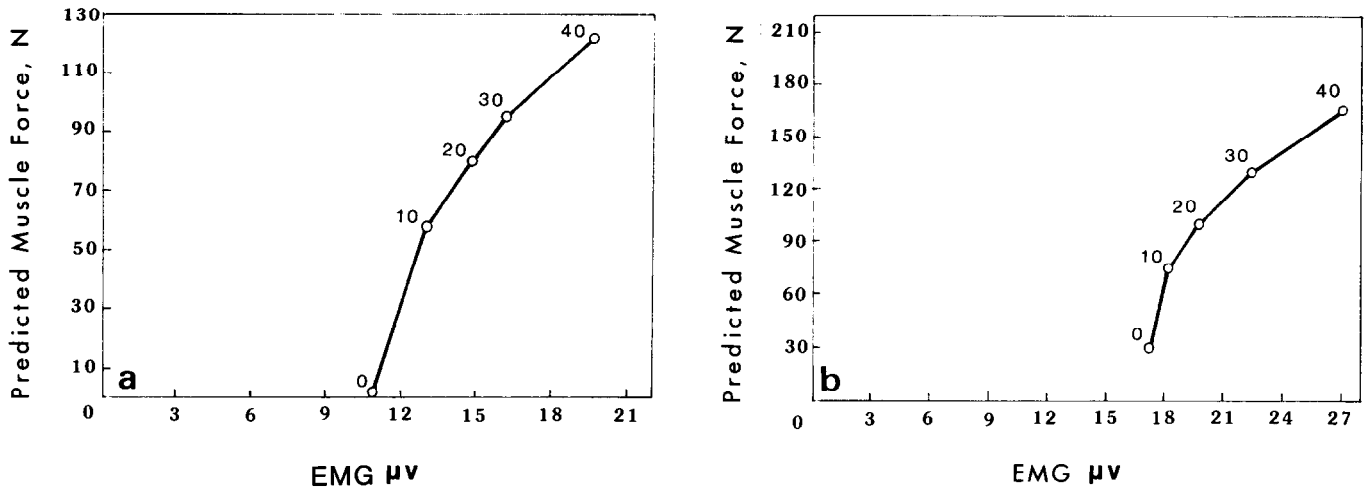

Figure 2: Mean measured L_3 level myoelectric activity versus mean predicted tissue tension in the left lateral oblique muscles during quiet standing with 0·0 load at different angles (degrees) of right-lateral bending from upright position to maximum bending, **a**; results for the right muscles, **b**, during left-lateral bending with 5·0 kg load were similar.

Table 1. Mean myoelectric signal amplitudes (μV)

	0	10	20	30	40	50
	0·0 kg load					
	Erector spinae					
Right bend:						
From upright to maximum bend	14·99 (0·58)	15·68 (0·58)	16·17 (0·60)	17·07 (0·60)	17·51 (0·54)	
From max. bend to upright position	21·09 (0·69)	22·60 (0·78)	23·47 (0·87)	18·60 (0·55)	13·66 (0·39)	
Left bend:						
From upright to maximum bend	12·00 (0·82)	15·08 (0·73)	15·33 (0·61)	18·21 (0·73)	20·22 (1·15)	21·69 (1·21)
From max. bend to upright position	22·62 (1·16)	27·28 (1·78)	26·65 (1·48)	25·28 (1·37)	19·18 (1·19)	10·58 (0·20)
	Lateral oblique					
Right bend:						
From upright to maximum bend	10·96 (0·09)	12·80 (0·18)	14·97 (0·38)	17·16 (0·46)	20·84 (0·87)	
From max. bend to upright position	21·71 (0·51)	20·03 (0·53)	17·09 (0·34)	13·32 (0·26)	10·70 (0·07)	
Left bend:						
From upright to maximum bend	11·37 (0·44)	13·25 (0·46)	16·77 (0·51)	18·38 (0·62)	21·23 (1·14)	21·64 (1·18)
From max. bend to upright position	23·50 (0·44)	23·59 (1·04)	21·30 (0·82)	18·44 (0·64)	14·15 (0·34)	11·15 (0·10)
	5·0 kg load					
	Erector spinae					
Right bend:						
From upright to maximum bend	18·44 (0·75)	20·75 (1·00)	21·85 (1·06)	22·79 (0·82)	28·61 (1·16)	
From max. bend to upright position	26·89 (1·39)	30·09 (1·82)	30·20 (1·83)	29·21 (1·78)	23·93 (1·58)	
Left bend:						
From upright to maximum bend	16·14 (0·81)	17·68 (0·83)	19·01 (0·77)	22·75 (1·27)	25·16 (1·53)	
From max. bend to upright position	25·61 (1·51)	26·29 (1·77)	25·18 (1·50)	27·21 (1·50)	16·96 (0·65)	
	Lateral oblique					
Right bend:						
From upright to maximum bend	12·17 (0·16)	17·71 (0·54)	20·53 (0·67)	22·10 (0·76)	26·29 (1·01)	
From max. bend to upright position	24·80 (1·01)	22·09 (0·72)	20·31 (0·63)	17·45 (0·55)	13·03 (0·24)	
Left bend:						
From upright to maximum bend	14·70 (0·39)	17·20 (0·39)	20·24 (0·55)	22·89 (0·93)	22·84 (1·00)	
From max. bend to upright position	24·85 (1·14)	23·68 (1·15)	21·20 (0·94)	18·02 (0·73)	14·31 (0·41)	

Table 2. Mean predicted forces (22 muscle model) (*N*)

	0	10	20	30	40	50
	0·0 kg load					
	Erector spinae					
Right bend:						
From upright to maximum bend	1·9 (0·2)	71·7 (3·2)	137·1 (3·7)	189·8 (3·7)	241·0 (3·0)	
From max. bend to upright position	213·0 (3·1)	158·3 (3·6)	108·3 (5·2)	39·9 (2·8)	6·3 (0·6)	
Left bend:						
From upright to maximum bend	0·0 (0·0)	74·4 (3·4)	116·2 (3·0)	179·8 (2·8)	218·3 (3·4)	245·3 (5·2)
From max. bend to upright position	249·6 (5·4)	205·6 (6·6)	130·2 (4·4)	104·3 (4·8)	34·7 (2·4)	1·3 (0·4)
	Lateral oblique					
Right bend:						
From upright to maximum bend	0·5 (0·1)	17·0 (0·8)	32·6 (0·9)	45·2 (0·9)	57·3 (0·7)	
From max. bend to upright position	50·7 (0·7)	37·6 (0·9)	258·8 (1·2)	9·5 (0·7)	1·5 (0·1)	
Left bend:						
From upright to maximum bend	0·0 (0·0)	17·7 (0·8)	27·6 (0·7)	42·7 (0·7)	51·9 (0·8)	58·3 (1·2)
From max. bend to upright position	59·3 (1·3)	48·9 (1·6)	31·0 (1·0)	24·3 (1·0)	8·3 (0·7)	0·3 (0·1)
	5·0 kg load					
	Erector spinae					
Right bend:						
From upright to maximum bend	62·8 (1·5)	149·1 (2·1)	201·8 (2·8)	258·4 (3·6)	324·3 (4·6)	
From max. bend to upright position	273·1 (3·8)	232·0 (3·7)	179·6 (4·3)	129·5 (7·0)	45·7 (3·0)	
Left bend:						
From upright to maximum bend	54·5 (1·8)	116·6 (2·3)	194·1 (6·1)	246·8 (4·7)	294·4 (3·6)	
From max. bend to upright position	281·8 (3·1)	227·2 (8·2)	176·2 (6·5)	99·0 (4·0)	47·2 (1·1)	
	Lateral oblique					
Right bend:						
From upright to maximum bend	14·9 (0·4)	22·5 (0·5)	48·0 (0·7)	61·5 (4·8)	77·1 (1·1)	
From max. bend to upright position	64·9 (0·9)	55·2 (0·9)	42·7 (1·0)	30·8 (1·7)	10·9 (0·7)	
Left bend:						
From upright to maximum bend	13·0 (0·4)	27·7 (0·5)	44·2 (1·4)	57·5 (1·1)	68·1 (0·7)	
From max. bend to upright position	67·0 (0·7)	54·0 (1·9)	41·9 (1·5)	23·6 (0·9)	11·1 (0·3)	

Figure 3: Mean measured L_3 level myoelectric activity versus mean predicted tissue tension in the left medial oblique muscles during quiet standing with, **a**, 0·0 and, **b**, 5·0 kg load at different angles of right-lateral bending from upright position to maximum bending. Results for the right muscle during left-lateral bending were similar.
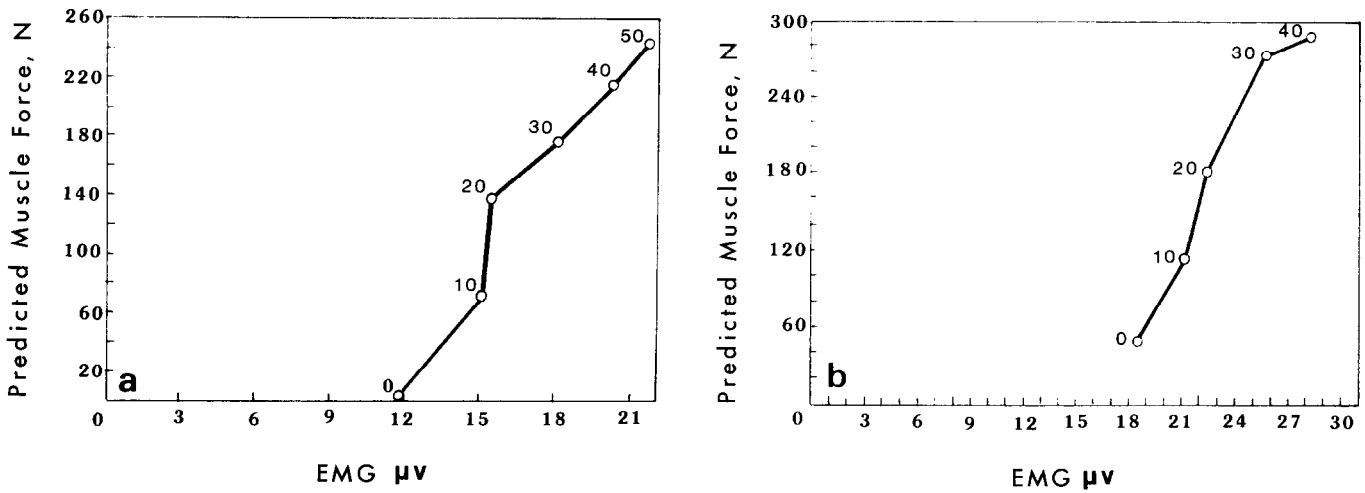
Figure 4: Mean measured L_3 level myoelectric activity versus mean predicted tissue tension in the left erector muscles, located 6 cm lateral of the spine, during quiet standing with, **a**, 0·0 and, **b**, 5·0 kg load at different angles of right-lateral bending from upright position to maximum bending. Results for the right muscle during left-lateral bending were similar.
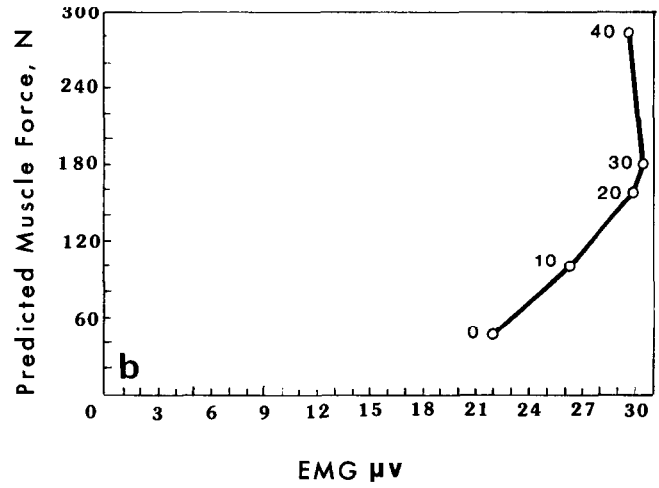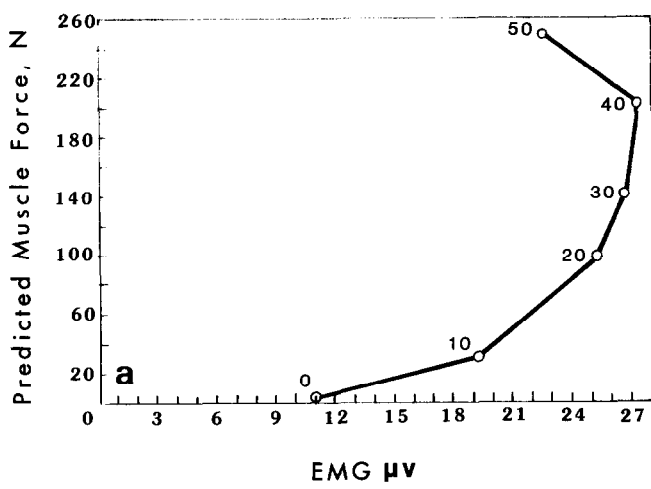
Figure 5: Mean measured L_3 level myoelectric activity versus mean predicted tissue tension in the right erector muscles, located 6 cm lateral of the spine, during quiet standing with, **a**, 0·0 and, **b**, 5·0 kg load at different angles of left-lateral bending from maximum bending to upright position. Results for the left muscle during right-lateral bending were similar.
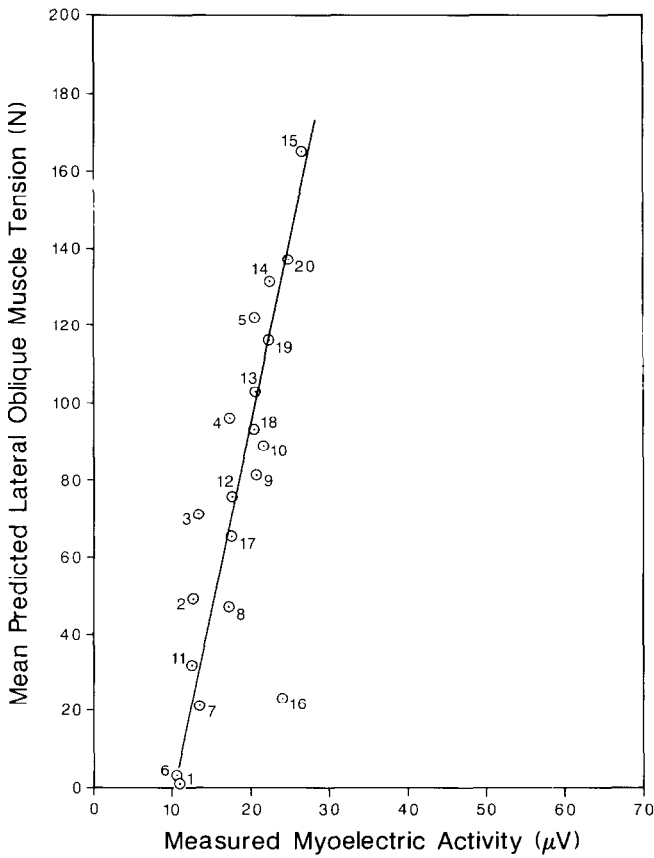

Figure 6

Figure 7

Figure 6: Predicted contraction forces *versus* measured myoelectric activities in left-lateral oblique muscles. Each point shows nine subject mean values of forces and of electrical activities for one task, for a total of 20 tasks.
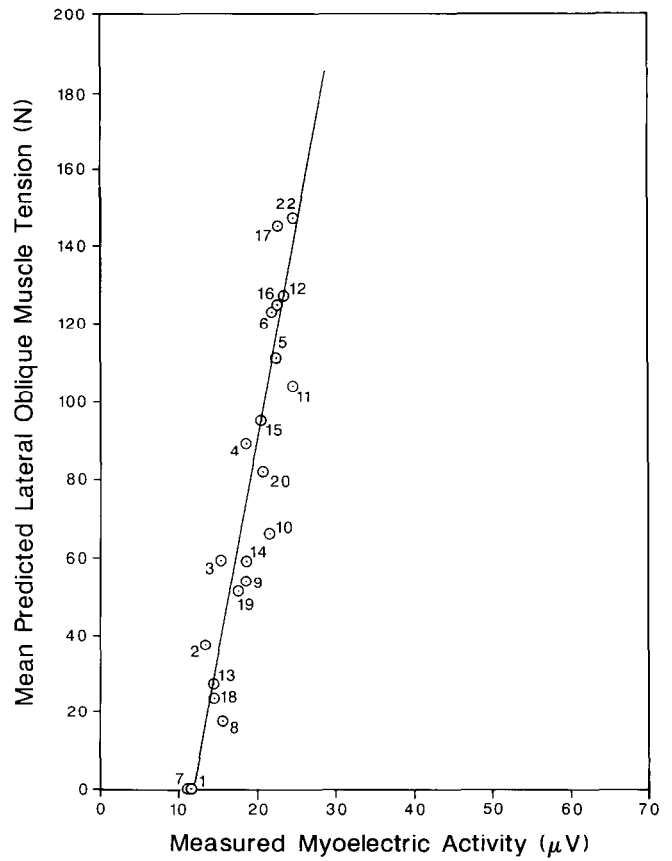
Figure 7: Predicted contraction forces *versus* measured myoelectric activities in right-lateral oblique muscles. Each point shows nine subject mean values of forces and of electrical activities for one task, for a total of 20 tasks.

The mean measured myoelectric activity in the oblique abdominal muscles was plotted against the mean predicted tissue tension for those tasks involving quiet standing in laterally bent positions, both when the subject was not (Figures 2a,b) and when he was (Figures 3a,b) holding a 5 kg mass in his hand on the side to which bending had occurred. It can be observed from these two figures that no lateral-bending relaxation was detectable in the left oblique abdominal muscles. Similar results were obtained for the right side oblique muscles.

Relaxation did occur in the erector spinae muscles. When similar plots were constructed for the erector spinae muscles these muscles did not demonstrate relaxation during lateral bending from upright to maximum bending positions (Figures 4a,b). However, these muscles exhibited relaxation during straightening from maximum bending to upright positions (Figures 5a,b).

Linearity of the myoelectric signal predicted tension relations

Plots of nine-subject-mean predicted contraction forces versus measured myoelectric activities in the left and right lateral oblique muscles for the tasks performed showed (Figures 6 and 7) the same high degree of linear correlation exhibited in the studies of trunk biomechanics cited earlier. The coefficients of linear correlation for these relations were between 0·72 and 0·87 on both the left and right sides. This suggests that the muscle contraction force predictions were reasonably valid when relaxation phenomena were not present.

Discussion

It appears that when standing in a maximum laterally bent position, passive mechanisms for the maintenance of equilibrium are present, although their effects are not strong ones. These effects are no longer seen once 30–40° of lateral bending are reached upon the return from the maximum position. Furthermore, these mechanisms are present only in the erector spinae muscles, the same muscles that exhibit flexion–relaxation[5].

Conclusions

1. The lumbar trunk structures resisted up to 1731 N in compression and up to 56·1 Nm in lateral bending moment in the lateral bending tasks studied.
2. The levels of surface myoelectric activity found in lumbar trunk muscles in quiet standing with various degrees of trunk lateral bending were as high as 27·3 μV for a 0·0 kg load and 30·2 μV for a 5·0 kg load applied.
3. In the oblique abdominal muscles, no muscle relaxa-

tion was observed to occur in quiet standing in laterally-bent positions of the trunk. In the erector spinae muscles, however, a relaxation phenomenon qualitatively similar to the flexion–relaxation phenomenon was observed.
4. Trunk muscle myoelectric activities increased when external forces were applied to the trunk in bent configurations.

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