THE INFLUENCE OF ABDOMINAL OBLIQUE MODELLING ON PREDICTED MUSCLE FORCES AND LUMBAR SPINE LOADS

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SUMMARY

Lumbar spine models are vital to assess physical exposure, document lumbar function, and explain injury mechanisms. It is recognized that using straight lines between origins and insertions to represent the multiple lines of action of the abdominal oblique muscles is questionable. In the present investigation, different abdominal oblique muscle models were compared using a multi-joint EMG-assisted by optimization lumbar spine model. In these models, the geometry of the oblique muscles was approximated by either linear or curvilinear lines of action. Estimated muscle forces and lumbar spine loads served to contrast the models. The differences reached 32% for muscle forces and 30% for joint loads in asymmetric lifting, but it was negligible for symmetric trunk flexion. Impact on the lumbar spine loading of abdominal oblique muscle modelling is modulated by physical demands to these muscles.

INTRODUCTION

Reliable lumbar spine musculoskeletal models are necessary tools to assess physical exposure and to investigate lumbar function and injury mechanisms. As such, they play a crucial role in prevention of occupational injuries and design of rehabilitation interventions. Simplifying assumptions with different degrees of accuracy are nevertheless often required in order to predict muscle forces and joint loads. An example involves the use of a straight line between origin and insertion to represent the lines of action of the abdominal oblique muscles. Some methods are proposed [4, 5, 7] to deal with this issue, but their experimental evaluation remains yet to be done.

The present study aims to compare linear and curvilinear abdominal oblique muscles lines of action, using measured kinematics to drive the musculoskeletal lumbar spine model and measured EMG to assist muscle force partitioning. It is hypothesized that predicted muscle forces and lumbar spine loads are effectively influenced by the anatomical modelling of abdominal oblique muscles.

METHODS

In vivo experiment. Data were collected on one healthy male (52 yr, 1.7 m, 68 kg) during (1) symmetric full trunk flexion and (2) asymmetric upright lifting at 4 different heights (5.2 kg mass lifted by the right upper hand at 90, 120, 150, and 180 cm from the floor, weight constrained to follow a vertical path at constant sagittal and lateral horizontal distances to the S1). Kinematics data were collected by a 4-sensor OptoTrak system at 30 Hz. Ground reaction forces were measured by a large custom-made force plate and surface EMG signals were recorded (1024 Hz) from 12 DelSys active electrodes positioned bilaterally on longissimus pars thoracis, iliocostalis pars thoracis, multifidus, rectus abdominis, external and internal oblique (EO, IO) muscles [1].

Inputs to the lumbar spine model. A global 3D inverse dynamic multi-link model estimated the net moments at the L5-S1 joint [6]. Then, a local 3D inverse dynamic lumbar spine model from the S1 to the T12 estimated the net moments at each lumbar joint. Before optimization, lumbar joint moments were updated accounting for passive ligamentous spine resistance and muscle forces. These passive estimates were taken from a nonlinear finite element kinematics-driven lumbar spine model [3]. A multi-joint EMG-assisted by optimization 76-muscle musculoskeletal lumbar spine model was used for the analyses including, in addition to the EMG-measured global muscles, the following multiple fascicles local muscles [1, 2]: multifidus, longissimus pars lumbaris, iliocostalis pars lumbaris, quadratus lumborum, and iliopsoas. Activity of deep local muscles was assumed on the basis of the recorded surface EMG signals. Maximum allowable stress in muscles was set to 0.6 MPa.

Modelling the line of action of abdominal oblique muscles. The initial geometry [8] of the muscles was approximated in 4 different ways. In the **Torso Curves** model, a method based on stacked ellipses [5] was implemented (**Figure 1**). In the **Torso Lines** model, straight lines between fascicle endpoints from the **Torso Curves** method were used.

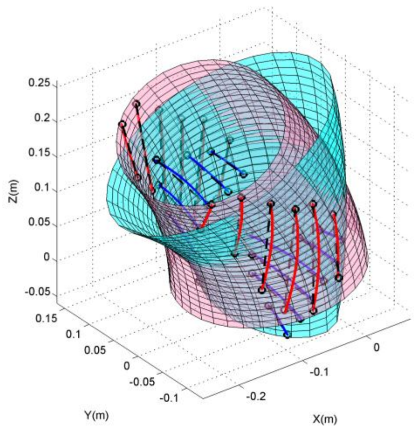

Figure 1: Abdominal EO (red for **Torso Curves** and dashed black for **Torso Lines**) and IO (blue for Torso Curves and dashed black for Torso Lines) muscles shown in the symmetric 30° trunk flexion posture. The stacked torso ellipses are subsampled from a total of 250 for illustration purpose.

In the **Linear** model, straight line vectors between upper and lower attachment points were used. Finally, in the **Spline Curves** model, some fascicle paths (EO 1-4 and

IO 1-3) were calibrated in the reference posture to follow virtual points attached to the rectus abdominis and then interpolating cubic splines predicted the missing points during the tasks (**Figure 2**).

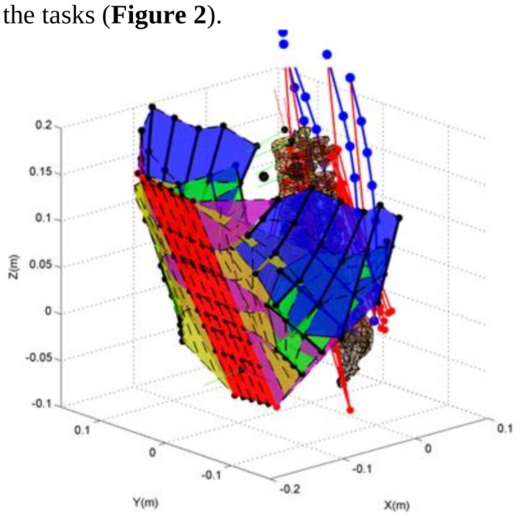

Figure 2: Abdominal EO (blue patches with black lines) and IO (green patches with black lines) muscles modelled with the **Spline Curves** in the same posture as in Figure 1. Parts of the lumbar spine musculoskeletal model are also shown: back global muscles in blue and local muscles in red.

Oblique abdominal muscle forces as well as lumbar spine loads (compression and shear forces) predicted by the musculoskeletal model served to compare the oblique muscle models. For the symmetric task, detailed analyses were made for neutral posture, flexion angles of 30 and 60°, and full flexion. For the asymmetric lifting, 90, 120, 150 and 180 cm heights were analysed.

RESULTS AND DISCUSSION

In the asymmetric lifting, large differences in muscle forces (Table 1; 8-32%) and lumbar spine loads (Table 2; 10-30%) were computed. In the symmetric flexion task, the maximum difference in lumbar spine loads did not exceed 6% (~200 N in full flexion). In both tasks, the EO muscles were much more activated (~6:1 ratio) than the IO muscles.

As expected, the impact on the estimations of the modelling approach used to represent the lines of action of abdominal oblique muscles was found crucial only when they were recruited at higher activity levels. Otherwise, their contribution to joint loading as well as to elicit the participation of other antagonistic or synergist muscles became negligible, thus justifying the use of conventional models with straight line of action.

CONCLUSIONS

The approach to model the line of action of abdominal oblique muscles warrants careful consideration, especially when there are high physical demands to these muscles.

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Table 1: Abdominal oblique muscle forces (N) across the models in asymmetric lift at 150 cm.

	Muscle	Linear	Spline Curves	Torso Curves	Torso Lines
Left	EO-1	25	0	0	0
	EO-2	0	0	0	0
	EO-3	0	0	0	0
	EO-4	48	76	123	80
	EO-5	44	0	0	0
	EO-6	96	74	109	143
Right	EO-1	0	0	0	0
	EO-2	0	0	0	0
	EO-3	0	0	9	0
	EO-4	1	6	39	1
	EO-5	37	42	11	45
	EO-6	160	128	171	171
	Sum EO	411	326	462	440
Left	IO-1	0	0	0	0
	IO-2	0	0	0	0
	IO-3	0	0	0	0
	IO-4	9	9	9	9
	IO-5	0	0	0	0
	IO-6	71	65	58	41
Right	IO-1	0	0	0	0
	IO-2	0	0	0	0
	IO-3	0	0	0	0
	IO-4	0	0	0	0
	IO-5	0	0	0	0
	IO-6	0	0	0	0
	Sum IO	80	74	67	50
	Sum	491	400	529	490

Table 2: Compression force (N) along the lumbar spine across the models in asymmetric lift at 150 cm.

Joint	Linear	Spline Curves	Torso Curves	Torso Lines
T12-L1	846	771	921	873
L1-L2	970	855	1055	977
L2-L3	1095	952	1185	1086
L3-L4	1209	1052	1310	1196
L4-L5	1337	1149	1458	1319
L5-S1	1382	1167	1517	1361
Avg	1140	991	1241	1135
SD	210	160	232	192