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THE RELATIONSHIP BETWEEN SHOULDER COUNTER-ROTATION AND LUMBAR MECHANICS DURING FAST BOWLING

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The purpose of this study was to quantify lumbar kinematics and kinetics during fast bowling using a novel inverse dynamics model, and to explore the relationship between shoulder counter-rotation (SCR) (a variable that has been associated with the development of spondylolysis in fast bowlers) and lumbar range of motion and moments. Ten fast bowlers participated in the study. A large correlation was found between SCR and lumbar rotation range of motion between front foot contact and ball release ($r=0.628$, $p<0.01$) which in turn was found to have a moderate correlation with the peak lumbar flexion moment ($r=0.437$, $p<0.05$). This is a significant finding as SCR is a relatively simple measurement that can be used as a field based screening tool. Future research should investigate the link between these variables and spondylolysis development.

KEY WORDS: cricket, injury, spondylolysis, bowling technique

INTRODUCTION: Young athletes in sports that involve repetitive flexion and extension of the trunk, particularly when combined with rotation, are prone to developing stress fractures of the pars interarticularis of the lumbar spine (spondylolysis) (Brukner & Kahn, 2007; d'Hemecourt et al., 2000). In fast bowling in cricket, large shoulder counter-rotation (SCR) has been associated with increased risk of lumbar spondylolysis (Foster et al., 1989; Portus et al., 2004). SCR is the change in alignment of the shoulders, rotating away from the batsman, between back foot contact (BFC) and front foot contact (FFC) during the bowling delivery stride. A threshold of 30° is commonly used to designate a bowling action associated with increased risk of injury (Ranson et al., 2008). SCR can be measured in the field using two-dimensional methods, with a video camera positioned above the bowler (Elliot et al., 2002), and is therefore a convenient measurement for coaches as well as researchers. However, the greatest load on the spine occurs after FFC, when ground reaction forces are at their highest (Ferdinands et al., 2009) and it is therefore unclear how SCR is related to the mechanism of injury. It has been suggested that large SCR may be associated with a similarly large range of lumbar motion during the front foot stance phase, and that this may be the mechanism through which increased loading and eventual injury occurs. Previous work has reported a relationship between SCR and the rotation of the lower trunk (Ranson et al., 2008), however, the relationship between SCR and lumbar kinetics is yet to be explored.
One of the difficulties in estimation of lumbar kinetics is the availability of inertial parameters for the trunk. Traditional inertial parameter data utilise boundaries selected so as not to sever internal organs during cadaver dissection, and not according to vertebral level. A descriptive study of lumbar kinetics during fast bowling has been performed (Ferdinands et al., 2009) using these traditional segment definitions, such that the cephalic boundary of the lumbar segment is at the level of the xyphoid process, thereby incorporating part of the thoracic spine. Such inclusion may have a significant impact on the kinematic inputs used for inverse dynamics analysis.
This study aimed to quantify the three-dimensional motion of the lumbar spine relative to the pelvis during fast bowling in cricket as well lumbar kinetics estimated using a novel inverse dynamics model. This allowed exploration of the relationship between SCR and lumbar kinematics and moments.

METHODS: Ten male right-arm fast bowlers (mean age 16.8 ± 1.3 years, height 181 ± 6.9 cm, weight 69.9 ± 8.6 kg) volunteered to participate in the study. Volunteers were included if they were members of a district and/or state junior cricket squad and classified as fast or fast-medium bowlers by their coaches. They were excluded if they had any symptomatic injuries at the time of testing. Ethical approval was obtained from Human Research Ethics at the University of Western Australia (UWA) and all participants (and their guardians, where required) gave written consent after being informed of the study requirements.

Data collection was undertaken at the biomechanics laboratory at the School of Sports Science, Exercise and Health, UWA. A 12-camera VICON MX motion analysis system (VICON, Oxford, UK) operating at 250Hz and a 1.2m x 1.2m force plate (Advanced Mechanical Technology Inc., Watertown, MA) sampling at 2000Hz were used to collect kinematic and ground reaction force (GRF) data. After carrying out a self-directed warmup, subjects were required to bowl 3 overs (18 deliveries) at match pace. Trials in which the front foot did not land with the force plate boundaries were considered unsuccessful. Three successful trials per subject were selected for analysis.

Retroreflective markers were affixed to the subjects' skin according to the UWA marker set (Dempsey et al., 2007) for the lower limbs and pelvis. To define the lumbar segment, markers were placed on the spinous processes of L1, L3, L5 and approximately 5cm on either side of the spine at the level of L2 and L4 (LUL, RUL, LLL, RLL). The L5 marker was used to represent the origin of the lumbar segment coordinate system. The y axis was defined using a vector from the L5 to L1 markers, the x axis was calculated from the cross product of the y axis, and a defining line between the LLL and RLL markers. Finally, the z axis was calculated as the cross product of the y and x axes. The lumbar angle was defined as the orientation of the lumbar segment relative to the pelvis. Flexion, left lateral flexion and left rotation were defined as positive.

A fourth-order low-pass Butterworth filter was run at a cut-off of 15Hz for the trajectories and 50Hz for the GRF data, following a residual analysis to determine the appropriate cut-off frequencies.

A mathematical model that utilised inverse dynamics and scaled inertial parameters (de Leva, 1996) was extended to calculate lumbar segment kinetics. The segment inertial parameters for the pelvis and lumbar spine were obtained from Pearsall et al which divided the trunk in a similar way to the marker set described above (Pearsall et al., 1996).

Statistical analysis was carried out using SPSS 19.0 (SPSS Inc., Chicago, IL.) and significance set at $p < 0.05$. Pearson's correlation coefficients were used to investigate the relationship between SCR and each of the kinematic and kinetic variables of interest, i.e. lumbar range of motion (ROM) for flexion-extension, lateral flexion and rotation between BFC and FFC and between FFC and ball release, and peak lumbar moments during the front foot stance phase.

RESULTS: Mean values for all variables of interest are presented in Table 1. SCR for each bowler ranged from 14° to 60°, with a mean of 36.6 ± 14.4°. Peak vertical ground reaction forces were normalised to body weight (BW) and the mean recorded was 5.6 ± 0.9 BW.

Table 1
Mean and standard deviation (SD) for SCR and lumbo-pelvic kinematics and kinetics

		Mean	SD
Shoulder counter-rotation (°)		36.6	14.4
Lumbar ROM (°), BF to FF	**Flexion-extension**	12.0	3.5
	Lateral flexion	13.4	5.3
	Rotation	8.0	3.2
Lumbar ROM (°), FF to ball release	**Flexion-extension**	22.5	3.4
	Lateral flexion	12.8	2.9
	Rotation	5.1	2.6
Peak lumbar moment ($Nm.kg^{-1}$)	**Flexion**	20.0	8.0
	Lateral flexion (left)	25.7	4.6
	Rotation (right)	20.7	5.4

Correlations between SCR and lumbar range of motion and moments are shown in Table 2. There were statistically significant large correlations between SCR and lumbar rotation ROM from BFC to FFC, and from FFC to ball release; and a moderate correlation between SCR and lateral flexion ROM from BFC to FFC. There was a weak correlation with a p-value of .054 between SCR and the flexion moment.
Correlations between lumbar kinematics and moments are shown in Table 3. There were statistically significant moderate correlations between the peak flexion moment and lateral flexion and rotation ROM from FFC to ball release. There was a weak correlation with a p-value of .050 between the lumbar rotation moment and lateral flexion ROM from FFC to ball release.

Table 2
Pearson's correlations (r) and p-values between SCR and lumbo-pelvic kinematics and kinetics

		r	p
Lumbar ROM (°), BF to FF	**Flexion-extension**	.192	.308
	Lateral flexion	.452	.012*
	Rotation	.648	.000*
Lumbar ROM (°), FF to ball release	**Flexion-extension**	-.190	.316
	Lateral flexion	.090	.636
	Rotation	.628	.000*
Peak joint moment ($Nm.kg^{-1}$)	**Flexion**	.355	.054
	Lateral flexion (left)	-.239	.204
	Rotation (right)	.093	.624

** Statistically significant, p<0.05*

Table 3
Pearson's correlations (r) and p-values between lumbo-pelvic kinematics and joint moments

		Flexion		Lateral flexion		Rotation	
		r	p	r	p	r	p
Lumbar ROM (°), BF to FF	**Flexion-extension**	.195	.302	.133	.483	.035	.856
	Lateral flexion	.144	.447	-.286	.125	.156	.410
	Rotation	.048	.803	-.331	.074	-.325	.080
Lumbar ROM (°), FF to ball release	**Flexion-extension**	.251	.181	-.190	.316	-.025	.898
	Lateral flexion	.451	.012*	.315	.089	.361	.050
	Rotation	.437	.016*	-.088	.643	.087	.646

** Statistically significant, p<0.05*

DISCUSSION: This was the first study to investigate lumbar kinematics and moments during fast bowling using a three-dimensional model that defines the lumbar segment according to its anatomical structure, with the cephalic and caudal boundaries at the L1 and L5 spinous processes, respectively.
Using a similar model to that used in the current study, Seay and colleagues reported a peak extension moment of 2.7 $Nm.kg^{-1}$ during running (Seay et al., 2008). The moments recorded during fast bowling are considerably higher, presumably due to larger ground reaction forces (5.6 ± 0.9 BW in the current study, vs. 1-3 BW in running (Nilsson & Thorstensson, 1989)) and higher segment accelerations encountered during bowling. These large moments demonstrate the significant load placed on the spine during fast bowling, and may contribute to the high incidence of low back injuries in this population.
Lumbar rotation and lateral flexion ROM were significantly correlated with SCR during the phase in which SCR is measured (BFC to FFC). While this is not the phase in which peak ground reaction forces or lumbar loads occur, it suggests that SCR may be an indicator of lumbo-pelvic motion in these two planes between BFC and FFC. SCR was also significantly correlated with lumbar rotation ROM between FFC and ball release. Previous studies, which classified subjects into two groups according to SCR and shoulder alignment at BFC, have

failed to find significant differences between the groups, but have reported medium effect sizes, suggesting that bowlers with larger SCR use a greater amount of lumbar flexion-extension (Burnett et al., 1998) and lower trunk lateral flexion (Ranson et al., 2008) range of motion throughout the delivery stride. Differences in the biomechanical model and statistical techniques used may account for the differences between previous findings and the current study.
Large lumbar rotation ROM between FFC and ball release was associated with higher peak flexion moments and greater SCR. There was also a trend for SCR to be correlated with the peak flexion moment. Spondylolysis occurs in athletes that perform repetitive flexion-extension of the trunk in combination with rotation (Brukner & Kahn, 2007; d'Hemecourt et al., 2000). Future research should therefore investigate whether the combination of large lumbar rotation ROM and high flexion moments during fast bowling are associated with the development of spondylolysis.

CONCLUSION: Large SCR has been linked with spondylolysis development in fast bowlers although the direct mechanism has been unclear. The results of this investigation suggest that SCR may be representative of the magnitude of lumbo-pelvic rotation ROM, which in turn is associated with increased lumbar flexion moments. This finding is significant as SCR is relatively simple field based screening tool, whereas the determination of lumbar mechanics requires more sophisticated laboratory based analyses. Future research is required to quantify the link between these variables and the development of spondylolysis.

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