ASSESSING THE ACCURACY OF INVERSE KINEMATICS IN OPENSIM TO ESTIMATE ELBOW FLEXION-EXTENSION DURING CRICKET BOWLING: MAINTAINING THE RIGID LINKED ASSUMPTION

Denny Wells, Jacqueline Alderson, Kane Middleton and Cyril Donnelly

The School of Sport Science, Exercise and Health, the University of Western Australia

The aim of this study was to determine how maintaining the rigid-linked assumption and employing inverse kinematics within OpenSim (OpenSim-IK) influences a model's estimates of elbow flexion-extension (FE) during cricket bowling. To test this 1) estimates of elbow FE angles were calculated by OpenSim-IK and traditional models using markers attached to a mechanical linkage arm (both static and low velocity range of movement). 2) The same models were used to estimate elbow FE during cricket bowling. Under both static and low velocity dynamic conditions both models produced highly correlated elbow FE estimates (r^2= 0.96 to 1.00). When comparing total elbow extension range between models, significant differences were not observed (p=0.87 to 0.96) indicating that both models produce similar recommendations for bowler legality.

KEY WORDS: upper body, kinematics, cricket, legality.

INTRODUCTION: In order for scientists to study human movement, subject-specific kinematic models are created to estimate the motion of the underlying skeletal system. There is a substantial amount of research examining the repeatability, reliability and validity of lower limb kinematic models (Della Croce, Cappozzo, Kerrigan, & Lucchetti, 1997; Reinschmidt, van den Bogert, Nigg, Lundberg, & Murphy, 1997; Leardini, Cappozzo, Catani, Toksvig-Larsen, Petitto & Sforza, 1999; Besier, Sturnieks, Alderson & Lloyd, 2003). However, limited research is available assessing methods to estimate upper limb kinematics (Schmidt, Disselhorst-Klug, Silny & Rau, 1999; Rau, Disselhorst-Klug, & Schmidt, 2000). One widely used method to estimate upper limb motion during cricket bowling is the UWA upper body model (UWA-TK) (Elliott, Alderson & Denver, 2007). As with all biomechanical models, there is an assumption that all segments are rigidly linked and rigidly connected. However, it is unlikely that this assumption is maintained during high velocity sporting tasks like cricket bowling, where it is known soft tissue artefact has the potential to distort kinematic estimates (Leardini, Croce, & Cappozzo, 2005). The aim of this study was to use a rigid-linked skeletal model and inverse kinematics (IK) in OpenSim (OpenSim-IK) to determine how maintaining the rigid-linked assumption influences a model's estimates of elbow flexion-extension (FE) during cricket bowling. A second aim was to determine if the rigid-linked assumption affects the assessment of bowler legality (i.e. allowable elbow extension range) as defined by the International Cricket Council (ICC).

METHODS: There were two phases in this investigation: 1) direct estimates of elbow FE angles by both the OpenSim-IK and UWA-TK models using markers attached to a mechanical linkage arm and 2) estimates of dynamic elbow FE motion during cricket bowling using both the OpenSim-IK and UWA-TK models.

The OpenSim rigid-linked skeletal model consisted of three segments (ulna, radius and humerus) and three degrees of freedom (elbow flexion/extension, elbow abduction/adduction, radio-ulnar pronation/supination). The UWA-TK model employs a traditional kinematic approach to calculate joint angles about these degrees of freedom. The OpenSim-IK skeletal model, which maintains the rigid linked assumption, uses IK to estimate joint angles (Delp, Anderson, Arnold, Loan, Habib & John, 2007).

In the first phase of this study a mechanical linkage arm was used to compare elbow FE estimates between the UWA-TK and OpenSim-IK models in both static postures and low velocity dynamic range of motion conditions. The elbow flexion angles tested (-8°, 0°, 5°, 10°, 20°, 40°) were representative of static elbow angle joint combinations commonly found in elite cricket bowlers (Elliott et al., 2007). Each elbow FE angle was tested across three elbow abduction conditions (0°, 10° and 20°) (Table 1). The dynamic trials involved manually moving the mechanical linkage through an FE range of motion typical of bowlers (-8° to 90°). A Pearson's correlation was used to compare elbow FE estimates between the OpenSim-IK and UWA-TK models.

In the second phase of this study, elbow FE of three fast bowlers were measured during cricket bowling using the OpenSim-IK and UWA-TK models. The bowlers were tested as per the ICC illegal bowling action testing protocols: Elbow extension range was calculated between two discrete events (maximum flexion to maximum extension, occurring between upper arm horizontal and ball release), and compared between the two models using a one-way ANOVA (α=0.05). The orientation of the shoulder joint centres (SJC) and lengths of the humerus were also compared between the OpenSim-IK and UWA-TK models from one randomly selected bowling trial.

RESULTS: When using the mechanical linkage arm, only one trial (40° flexed/20° abducted) of the 18 static postural combinations returned a between model difference greater than 1°. For the three elbow abduction conditions (0°, 10° and 20°), the maximum difference in elbow FE estimates between the OpenSim-IK and UWA-TK were 0.09°, 0.4° and 1.5° respectively (Table 1). The low velocity dynamic range of motion comparisons between the UWA-TK and OpenSim-IK models returned correlations of 1.00 for each elbow abduction condition (Figure 1).

Table 1: Differences in elbow FE angle between the UWA-TK and OpenSim-IK models across three elbow abduction conditions using the mechanical linkage. All values are in degrees. Negative elbow FE angles represent hyperextension.

UWA-TK Elbow Angle (°)	0° Elbow Abduction		10° Elbow Abduction		20° Elbow Abduction	
	OpenSim	Difference	OpenSim	Difference	OpenSim	Difference
-8°	-8.06	0.06	-7.64	-0.36	-7.05	-0.95
0°	-0.06	0.06	0.23	-0.23	0.55	-0.55
5°	4.93	0.07	5.23	-0.23	5.69	-0.69
10°	9.94	0.06	10.16	-0.16	10.44	-0.44
20°	19.95	0.05	20.01	-0.01	20.156	-0.16
40°	39.91	0.09	39.60	0.40	38.67	1.33
Total RMS		*0.063*		*0.266*		*0.727*

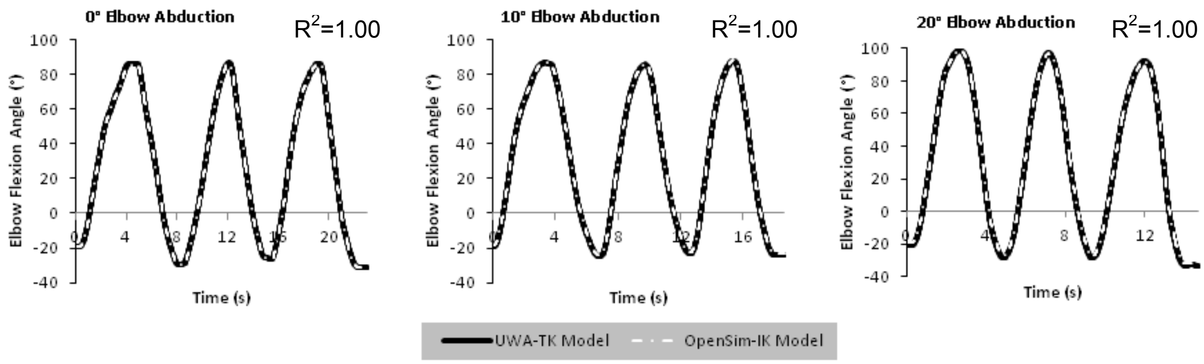

Figure 1: Comparison of dynamic, low velocity ROM elbow FE estimates calculated using the UWA-TK model and OpenSim-IK models across all three elbow abduction conditions.

When elbow FE estimates were compared during cricket bowling trials, the UWA-TK and OpenSim-IK models were not correlated (r^2 as low as 0.19). However, when extension range (as per ICC guidelines) was compared between the UWA-TK and OpenSim-IK models no significant differences were observed (p=0.87 to 0.96) and were less than 1° (Table 2).

Table 2
Comparison of elbow FE from 3 bowling trials for each of the three cricket fast bowlers (A, B and C). Elbow FE waveforms calculated using the UWA-TK and OpenSim-IK models for each fast bowler were compared using a Pearson correlation (R^2). Elbow extension ranges calculated between the UWA-TK and OpenSim-IK models were compared using a one-way ANOVA (α=0.05). Mean differences in extension range were also presented.

Bowler	Elbow FE Correlations (r^2)	Elbow Extension Range (ICC Guidelines)			
		UWA-TK	*OpenSim-IK*	*Difference*	*p*
A	0.98	5.99°	6.24°	0.25°	0.87
B	0.24	1.58°	1.51°	0.07°	0.96
C	0.99	2.78°	2.68°	0.10°	0.93

From a randomly selected bowling trial it was observed estimates of SJC position in the global coordinate system between the UWA-TK and OpenSim-IK models varied by up to 7 cm. During the bowling trial, humerus length calculated by the UWA-TK model fluctuated by up to 2.63 cm (8.13%) in length relative to the rigid-linked OpenSim-IK model.

Table 3
Difference in the SJC position between the UWA-TK and OpenSim-IK models from a single randomly selected trial.

Event	SJC Separation Distance	UWA-TK model Humerus Length	*Difference to OpenSim Humerus Length
Pre-UAH	0.86	33.64	1.30 (4.02%)
UAH	2.18	34.17	1.83 (5.66%)
Mid	3.10	34.97	2.63 (8.13%)
BR	7.03	34.25	1.91 (5.91%)

*Notes: Humerus length from subject scaling was 32.34 cm. This was maintained across all events during then OpenSim-IK modelling process. Humerus length as calculated by the UWA-TK model and the relative difference to the OpenSim-IK were also reported. Pre-upper arm horizontal (Pre-UAH) refers to the point just prior to upper arm horizontal when the arm is in a similar position to that in the calibration trial (arm at roughly 45° to the ground), 'Mid' refers to the middle time point between UAH and BR during each trial. All values are reported in cm unless otherwise stated.

DISCUSSION: During both the static and low velocity range of motion conditions, estimates of elbow FE between the UWA-TK and OpenSim-IK models were perfectly correlated. When the UWA-TK and OpenSim-IK models were compared in dynamic bowling conditions, significant differences in elbow FE estimates were observed. Participants A and C demonstrated similar elbow FE estimates (R^2=0.98 and 0.99 respectively) while estimates of FE for participant B were not similar (R^2=0.19 to 0.33) (Table 2). This in part can be explained by the differences in SJC and humerus length estimates observed between the model's during the bowling trials. SJC position differed by up to 7 cm and humeral length differences were up to 2.63 cm (8.13%). These results show that when the rigid-linked assumption is not maintained during the UWA-TK modelling approach and influences model's estimates of elbow FE. Another possible explanation for these differences and a limitation for both modelling approaches is that scapular motion was not modelled and may have also influenced both models estimates of SJC position and/or humeral length. As only three participants were analysed in this investigation, it is apparent future research is required, incorporating larger sample sizes and more complex models to investigate whether IK and OpenSim is a more reliable modelling approach to estimated elbow FE during cricket bowling.

Elbow extension ranges calculated by each model when implementing ICC guidelines were not significantly different (p=0.87 to 0.96) and less than 1° (Table 2). These results show that both the UWA-TK and OpenSim-IK modelling approaches produced the same recommendation (i.e. legal or illegal) for all three bowlers tested using the ICC guidelines, despite the fact that between model elbow FE waveforms were not correlated across all three bowlers.

CONCLUSION: Testing using the mechanical linkage arm indicated that there is little to no difference in elbow FE estimates between the UWA-TK and OpenSim-IK models during static and low velocity range of motion tasks.

When real bowlers were tested using the ICC illegal bowling action testing protocol, differences in elbow FE estimates were observed between models. These differences were likely due to the UWA-TK model not maintaining the rigid-linked assumption during high velocity bowling trials. However, elbow FE range calculated by each model were very similar for all participants suggesting that under the ICC illegal bowling action testing protocol, both models would likely produce the same recommendation concerning bowler legality.

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