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## HOW ACCURATE IS THE ESTIMATION OF ELBOW KINEMATICS USING ISB RECOMMENDED JOINT COORDINATE SYSTEMS?

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**Summary/conclusions**
The International Society of Biomechanics (ISB) proposes the use of standardized Joint Coordinate Systems (JCS) for the description of elbow kinematics. The use of JCS imposes simplification over the position and orientation of the elbow flexion-extension and prono-supination axes. The aim of this work was to access the effects of these assumptions by comparing the kinematics estimated by ISB suggested JCSs with respect to a known motion imposed to the hinge joints of the two reference models presented in [1]. Results showed that during a pure flexion-extension movement of 140° of range, JCSs estimate a fictitious prono-supination ranging from 12° to 16°. These results suggest a careful interpretation of in-vivo kinematic data, in particular those related to complex activities of the daily living.

**Introduction**
The ISB has recently realised recommendations for the description of elbow kinematics [2], based on JCS. These require the definition of a bone-embedded reference frame for each bone forming the joint, that is humerus and forearm. Elbow axes of rotations are assumed, therefore, as the medio-lateral axis of the humerus frame (flexion-extension) and as the caudo-cranial axis of the forearm (prono-supination). Since these are conventionally defined based on anatomical landmarks, they are only approximations of the real joint rotation axes. The aim of this work was to quantify the errors in the estimation of elbow kinematics when using ISB recommended JCSs, compared to a known motion imposed to the hinge joints of two elbow reference models s2R and s4R, derived from cadavers data [1].

**Statement of clinical significance**
The assessment of the accuracy of JCSs estimated kinematics is essential for a correct interpretation of in-vivo motion analysis results in clinics.

**Methods**
The ISB suggests the use of two alternative bone-embedded frames for the humerus, that is H1 and H2, and the system of reference F for the forearm [2]. It is important here to notice that, while H1 medio-lateral axis is only based on humerus anatomical landmarks (ALs), that of H2 is defined as normal to the long axis of humerus and forearm when the elbow is flexed 90° and completely supinated (reference pose). This means that for H2 definition the coordinates of US and RS in the reference pose must be known. From these systems of reference, the JCSs matrices ${}^{H1}R_F$ and ${}^{H2}R_F$ are defined. The decomposition of these matrices with the Euler sequence Z-X'-Y'' provides the estimation of the elbow flexion-extension (FE), carrying angle (CA) and prono-supination (PS) patterns. In order to assess the errors coming from JCS application, a pure, single elbow flexion-extension movement of 140° of range was applied to the models s2R and s4R, while keeping a full pronation, starting from the anatomical posture. Before computing ${}^{H1}R_F$ and ${}^{H2}R_F$ values during the motion (this was made possible since the models embed all the necessary ALs), H2 was defined by obtaining US and RS coordinates in H2 reference pose: a maximum supination of 175° was assumed for the cadavers [3]. In addition to the kinematics from ${}^{H1}R_F$ and ${}^{H2}R_F$, we also computed the relative orientation of the models Denavit-Hartenberg (D-H) systems of reference ${}^{G}T_{L1}$ and ${}^{G}T_{L3}$, obtaining ${}^{L1}T_{L3}$ over

time. Thanks to D-H definitions, the decomposition of ${}^{L1}T_{L3}$ with the Euler sequence Z-X'-Z'' returns the gold standard estimation of elbow kinematics, with the Z and Z'' patterns identical to those applied to the models hinge joints $\theta_{L2}$ and $\theta_{L3}$ and X' measuring the CA. The FE, PS and CA ranges of motion estimated by ${}^{H1}R_F$ and ${}^{H2}R_F$ were compared to those reported by ${}^{L1}T_{L3}$: the differences were considered the measure of the JCSs kinematic error.

**Results**

Table 1 reports the s2R and s4R ranges of motion for FE, CA and PS from ${}^{H1}R_F$ and ${}^{H2}R_F$ ${}^{L1}T_{L3}$, while figure 1 reports CA and PS motion patterns. CA patterns were reported negated to be consistent with data in the literature [4].

**Discussion**

While ${}^{H1}R_F$ and ${}^{H2}R_F$ estimation of FE differs slightly from the imposed motion (less then 5°), the greatest difference appear for CA and PS. Considering CA, s2R and s4R show different patterns which are consistent with the literature for the range of variation [4] and representative of known inter-subject variability [3]. From a robotics viewpoint, however, the only correct value of CA is that of ${}^{L1}T_{L3}$, since the CA is an intrinsic, geometric parameter of the robots, that cannot change in time. Considering PS, ${}^{H1}R_F$ and ${}^{H2}R_F$ reported a range of 12.16° and 15.56°, respectively, instead of the constant value obtained from ${}^{L1}T_{L3}$. These differences cannot be drawn back to a difference in definition (as for CA), but are due to the approximated definition of elbow axes. The reported errors are of great magnitude and suggest a careful interpretation of in-vivo kinematic data, in particular those related to complex activities of the daily living. Simulations with different levels of PS are currently underway.

| | s2R | | | s4R | | |
|---|---|---|---|---|---|---|
| | ${}^{L1}T_{L3}$ | ${}^{H1}R_F$ | ${}^{H2}R_F$ | ${}^{L1}T_{L3}$ | ${}^{H1}R_F$ | ${}^{H2}R_F$ |
| FLEX | 140,00 | 135,28 | 135,26 | 140,00 | 135,47 | 135,04 |
| CA | 0,00 | 16,01 | 17,39 | 0,00 | 9,26 | 11,62 |
| PS | 0,00 | 15,72 | 12,16 | 0,00 | 11,43 | 15,56 |

**Table 1.** Ranges of motion in degrees

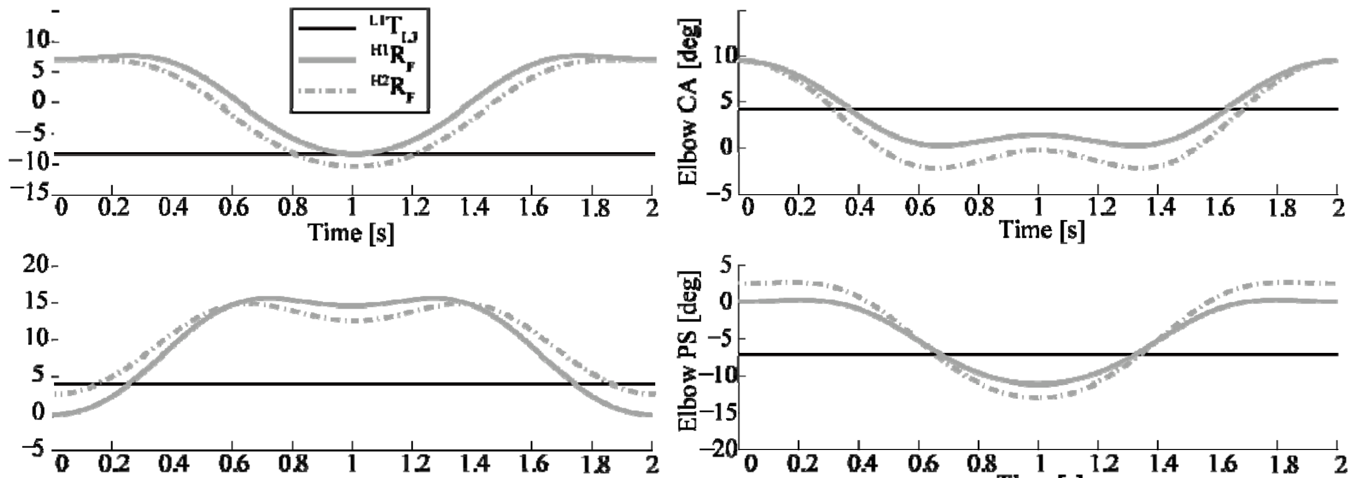


**Figure 1.** CA and PS patterns for s2R (left) and s4R (right)


**References**

[1] Cutti, A. G. et al., (2006), JEGM06 proceedings, *submitted*

[2] Wu, G. et al., (2005), J. Biomech., 38, 981-992

[3] Kapandji, I. A. (1982), Churchill Livingstone

[4] Goto, A. et al., (2004), J. Shoulder. Elbow. Surg., 13, 441-447