A PRELIMINARY STUDY TO MODEL CARRYING ANGLE VARIATIONS DURING FLEXION-EXTENSION OF THE ELBOW

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The aim of this work was to identify an accurate method to evaluate the variability of the carrying angle during the flexion extension of the elbow and to define a mathematical description of this movement applicable in sport and rehabilitation field.
In order to develop this objective, we marked the arm and the forearm by six reflective markers of six healthy subjects performing the flexion extension movement and acquired the coordinates using six infrared cameras (VICON Motion System). Five repeated measures were performed for each subject in order to verify the reliability of the measures. Our results demonstrated that this movement can be easily modelled as a linear variation of the carrying angle in function of the flexion angle. The reliability between repeated measures was high and adopting a linear fit the accuracy was more than 94% in all cases. This is the first study to compute the flexion-extension movement by a carrying angle evaluation.

KEY WORDS: carrying angle, model, flexion-extension movement.

INTRODUCTION: With the elbow joint fully extended, the axis of the forearm laterally deviates, in the distal plane, from the axis of the humerus. This deviation is called carrying angle and presents a linear variation during the flexion-extension movement (Morrey, 1976). Morrey and Chao (1976) , in an in-vitro study, reported that this angle is greatest in valgus at full extension, diminishing during flexion, and became varus at full flexion. Few *in-vivo* investigations are present in the literature and the results are conflicting (London, 1981; Amis, 1982; Goto, 2004).
In order to give a contribute to this topic, we tried to model the variation of the carrying angle during the flexion-extension movement of the elbow *in-vivo*. This study could also investigate the biomechanical implications to the elbow determined in many sport techniques using prevalently the upper extremities and in particular the flexion-extension of the elbow.
Therefore a detailed understanding of the individual biomechanics of elbow function is essential not only for a precise upper arm biomechanical description, but also for sport and clinical issues to improve the correct description of athletic movements, to determine pathological elbow joint conditions, and evaluating elbow reconstruction.
The purpose of our study was to adopt an accurate and non invasive experimental method to estimate carrying angle an *in-vivo* set-up in order to identify the model of the flexion extension movement usable in both rehabilitative and sportive field. We performed an experimental analysis of reliability, by comparing five repeated acquisitions in six adult healthy subjects.

METHOD: We tested right arm in six adult subjects, aged from 22 to 27 years. All participants were healthy, fit, and had no symptoms or signs of relevant pathologies affecting the shoulder, elbow and wrist joints. The acquisitions were carried out using the VICON Motion System 460 optoelectronic system, with six infra-red cameras (max resolution 300.000 pixel, frequency 100 Hertz). Five reflecting passive markers (diameter 14 mm) were placed in specific repere points on the arm and forearm of the subject according to ISB recommendations (2005):

Scapula:
AH: gap between acromion and humerus
Humerus:
EM: most caudal point on medial epicondyle
EL: most caudal point on lateral epicondyle
Forearm:
US: most caudal-medial point on the ulnar styloid
RS: most caudal-medial point on the radial styloid.

Every subject performed five repeated flexion-extension movements of the elbow and the 3-D coordinates of the digitized points were used to compute the reference systems relative to the arm and forearm. The arm reference system was constructed by defining the Y-axis as the long axis of the humerus (line connecting AH and the mid point of EL and EM, pointing to AH); the X-axis was the line perpendicular to the plane formed by EL, EM and Y, pointing forward; the Z-axis was the line perpendicular to Y and X axes. The forearm reference system was defined by unified segments on the radius and ulna: the y-axis was the line connecting the midpoint of RS and US and the midpoint between EL and EM; the x-axis was the line perpendicular to the plane through US and RS and the y axis; the z-axis was the line perpendicular to y and x-axes.
The transformation matrix from the forearm reference system to the arm reference system was computed and used to obtain Cardan angles in the sequence Z-X-Y. The rotation around the floating z-axis corresponded to the flexion-extension, the carrying angle was defined as the rotation around x-axis corresponding to the abduction-adduction; and the rotation around y-axis corresponded to the prono-supination.

RESULTS: The range of motion of the forearm on the arm was from about 20° to 150 ° of flexion. The range is in agreement with the values reported in literature for physiological conditions in healthy subjects.
In all subjects, the carrying angle changed during flexion extension movement from valgus in full extension to varus in full flexion. The observed values in function of the flexion angle showed a linear trend. Adopting a linear fit the error was less than 6% in all cases (from 1% to 6%) These results are presented in the Table 1 and Fig 1.

Tab 1. Carrying angle values reported as Mean ± typical error on 5 repeated measures.

Subject	***Carrying angle in full extension***	***Carrying angle in full flexion***	***Trend***	***R^2 of linear fit***
#1	13.43 ± 0.06(°)	-6.34 ± 0.2(°)	***linear***	*0.99*
#2	20.36 ± 0.10(°)	-10.5 ± 0.4(°)	***linear***	*0.99*
#3	16.29 ± 0.12(°)	-2.5 ± 0.2(°)	***linear***	*0.98*
#4	17.29 ± 0.06(°)	-3.4 ± 0.2(°)	***linear***	*0.96*
#5	17.49 ± 0.4(°)	-0.29 ± 0.3(°)	***linear***	*0.99*
#6	15.24 ± 0.5(°)	-3.57 ± 0.3(°)	***linear***	*0.94*

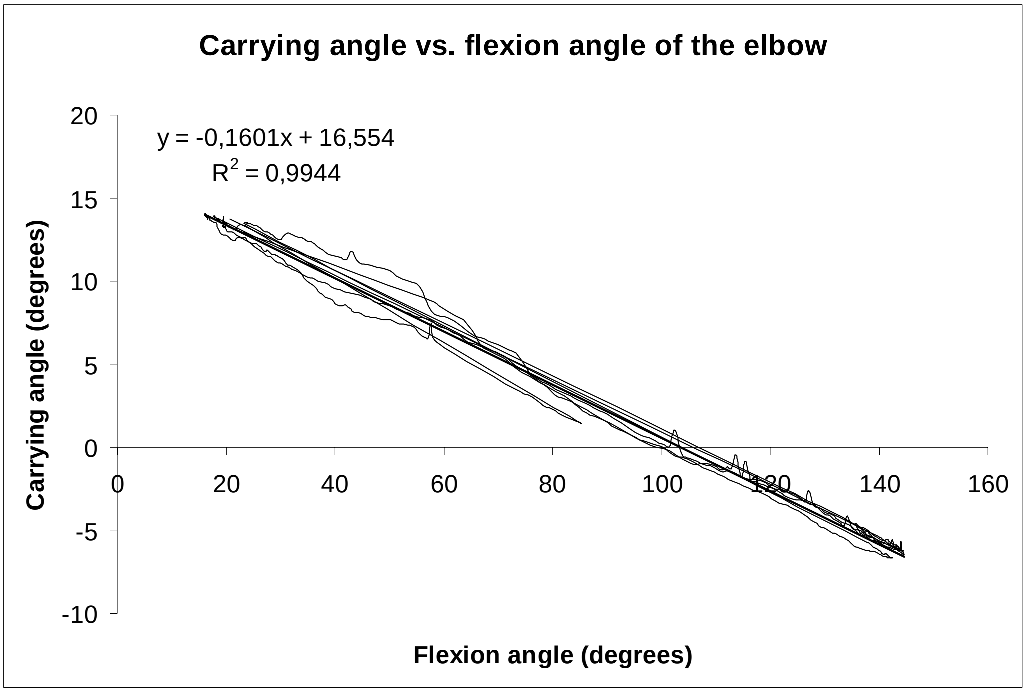

Fig 1. Trend of the carrying angle values during the flexion extension movement on 5 repeated measures on subject #1.

DISCUSSION AND CONCLUSION: The most important findings were that the trend of the carrying angle is similar in all trials and shows a linear variation in all considered subjects.
The accuracy obtained in this estimation is very high and presents a similar trend as identified by Morrey and Chao (1976).
The current preliminary study was carried out in order to estimate the possibility to develop the model of the upper extremity using a kinematic angle called carrying angle. This angle resulted subject to individual variations probably due to the fact that each subject presented a proper anatomical morphology. More subjects are needed to be tested in order to validate this trend. Concluding, our model relative to the flexion-extension movement of the upper extremity, using the carrying angle evaluation, could permit the monitoring of the correct biomechanics technique during the increasing of the physical activity. In particular this method permits to define the variation of this angle respect to the flexion.

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