Validation of a Universal Algorithm for Upper Extremity Kinematic Analysis

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Introduction

Most methods currently used for determining upper extremity kinematics using marker-based data collection use the order-dependent technique of Euler angles [1]. While this method works well in the kinematic analysis of the lower extremities in gait, where motions are largely constrained to motion in one or two planes, problems are found in applying such techniques to joints with higher ranges of motion, such as the shoulder. Previous authors have pointed out possible solutions to the problems, such as gimbal lock, that may occur with select motions [1,2]. However, making such changes to data analysis programs are not efficient and would require a priori knowledge of the nature of the motion being analyzed. Further, given the high number of degrees-of-freedom in the upper extremity, select tasks used clinically to evaluate a patient's impairment may be performed along a variety of paths, making changing the program to accommodate the motions entirely impractical. We suggest using the helical axis method described by Woltring [3]. Through the proper selection of marker placement and segment coordinate selection, any motion can be analyzed and broken down into clinically significant joint rotations

Clinical Significance

In order to accurately assess patients' upper extremity functional capabilities and responses to therapeutic intervention, objective measurement techniques are essential. The purpose of this paper is to report the accuracy and repeatability of this upper extremity analysis algorithm.

Methodology

A mechanical jig with rigid segments representing the hand, lower arm, upper arm, trunk, and head was fabricated with revolute axes joining the segments at the wrist, elbow, and shoulder, accordingly.

Motion Analysis: Motion data was collected using a 10 camera RealTime Motion Analysis system (Motion Analysis Corporation, Santa Rosa, CA). Thirteen one-inch diameter retroreflective markers are used to construct local coordinates on each segment (Table 1). A static trial was collected with the model in a neutral position, from which all subsequent joint angles were referenced. Kinematic trials involved moving the jig through ranges of motion for shoulder abduction, adduction, flexion, and extension. Joint angles for the kinematic trials were solved for using helical-axis decomposition [3] in MATLAB (Mathworks, Natick, MA). Accuracy and repeatability was assessed through comparing the output of the algorithm with angles measured by an electrogoniometer (Penny and Giles Biometrics Ltd., UK).

Table 1. Locations and representations for the thirteen markers used to define the segments of the upper extremity for this kinematic analysis.

Segment:	Markers:	Motion Referenced To:
Head	Forehead	Trunk
	Left Temple	
	Right Temple	
Trunk	Sternal Notch	Lab
	Xiphoid Process	
	Spinous Process of C7	
Upper Arm	Acromion Process	Trunk
	Lateral Epicondyle of Elbow	
	Medial Epicondyle of Elbow	
Lower Arm	Radial Styloid Process	Upper Arm
	Ulnar Styloid Process	
Hand	Lateral Aspect of 2^{nd} MCP Joint	Lower Arm
	Medial Aspect of 5^{th} MCP Joint	

Results

In general, the algorithm was accurate to within 2.5% FS (Table 2). Between trials, this method was shown to be repeatable within 99%.

Table 2. Results of upper extremity kinematic trials from goniometer and helical axis decomposition. Errors are reported in %Full Scale.

Motion	Error
Abduction	2.22%
Adduction	0.16%
Flexion	1.11%
Extension	0.22%

Discussion

A tool to accurately and repeatably measure upper extremity motion would be a valuable tool for orthopedic clinicians and researchers. This algorithm, as applied to the specified upper extremity motion analysis, has been shown to be both accurate and repeatable. Additionally, the use of helical-axis decomposition avoids the issue of gimbal lock and the propagation of errors in other, sequence-dependant analysis methods. This in turn frees examiners from any constraints to the types of motion they incorporate into their analyses.

References

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2) An KN, and Chao EYC. Kinematic analysis of human movement. Ann Biomed Eng 1984;12:585-97.
3) Woltring HJ, Huiskes R, deLange A. Finite centroid and helical axis estimation from noisy landmark measurements in the study of human joint kinematics. J Biomech 1985;18:379-89.

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