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ESTIMATING FINITE ROTATION AXES OF THE RADIUS FOR FOREARM ROTATION

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SUMMARY

The axis of radius rotation is widely used in forearm rotation research. Though it is generally assumed to be consistent, no studies have demonstrated this convincingly. This study used magnetic resonance imaging to evaluate the movement of the radius during forearm rotation, and estimated the axis of rotation for a series of finite rotations.

INTRODUCTION

The human forearm is a complex and functionally important part of the body whose biomechanical behaviour is not well understood. The way in which rotation of the forearm is used to produce task-specific rotation of the hand has been particularly challenging to study.

Most models of forearm rotation assume an axis of rotation passing through the head of the radius proximally and the head of the ulna distally. It should be noted that this axis describes only the movement of the radius over the ulna. It does not represent the overall rotation of the forearm achieved through both radius and ulna motion.

This axis of radius rotation is widely employed in forearm rotation research, yet there are relatively few studies that have attempted to validate its position and proposed consistency. Studies that have reported a consistent radius axis have not considered sequential finite rotations – instead, they've calculated average axes over a large range of motion [3]. Others present very little data, so their results are hard to interpret [1]. One study that did investigate sequential rotations chose to calculate each axis from neutral [2]. This creates an increasingly larger average axis, which makes it hard to investigate movement of the axis through the range of motion. Nevertheless, they show a more variable axis than has previously been shown.

The aim of this study was to evaluate the axis of radius rotation through a range of forearm rotation. It is hypothesized that, on average, the axis of rotation will correspond to the radius axis presented in literature.

METHODS

The right forearm of a 27 year old healthy male participant was scanned using a 3T Siemens Skyra magnetic resonance imaging (MRI) scanner. A specially designed jig was used to hold the forearm and constrain rotation about a fixed external axis (Figure 1A). The arm was scanned in 7 positions of forearm rotation: neutral, 25, 50 and 75 pronation and supination. The acquired images were T1-weighted, with an in plane resolution of 0.5625mm and a slice thickness of 3mm.

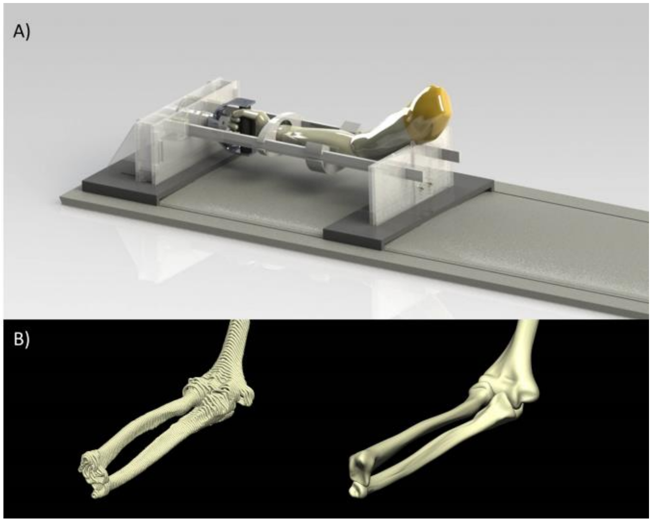

Figure 1: The MRI compatible jig used to position and constrain the forearm during scanning (A). Segmented data clouds representing the humerus, ulna and radius, and the finite element model of these bones (B).

The humerus, radius and ulna bones were manually segmented from the MR images using in-house bioengineering modeling software CMISS (www.cmiss.org) to provide three-dimensional data clouds that represent each bone in the seven positions of forearm rotation (Figure 1B). A closest-point algorithm was used to register the data clouds with each other, and determine the transformation matrices (TMs) that represent the movement of each bone from one position to the next. The inverse of the humerus and ulna TMs could then be multiplied with the radius TMs, so that the radius TMs represent only the movement of the radius with respect to a fixed humerus and ulna.

Finally, a dual-quaternion approach was used to extract three parameters from the TMs: the unit vector that represents the axis of rotation, a point through which the vector passes, and the magnitude of rotation about the vector.

Radius rotation was considered in three different ways. Firstly, the overall rotation axis was determined (P75-S75). Secondly, the axes representing the rotation from neutral to each of the other 6 positions were calculated (N-P/S25, N-P/S50, N-P/S75), similar to previous studies. Finally, sequential finite rotation axes were calculated for the radius (N-P/S25, P/S25-P/S50, P/S50-P/S75).

RESULTS AND DISCUSSION

The axis that describes the overall rotation of the radius from 75° pronation to 75° supination passed through the center of the radius proximally and the center of the ulna distally (Figure 2). This conforms to what literature suggested.

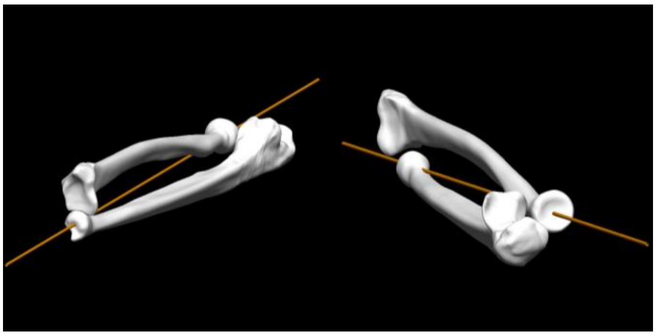

Figure 2: The overall axis of radius rotation, representing its motion from P75 to S75.

Similarly, when rotation axes were calculated over larger ranges of motion, the axes corresponded very closely to the typical axis of radius rotation (Figures 3). The axes were more consistent than those shown in a previous study [2], particularly in pronation.

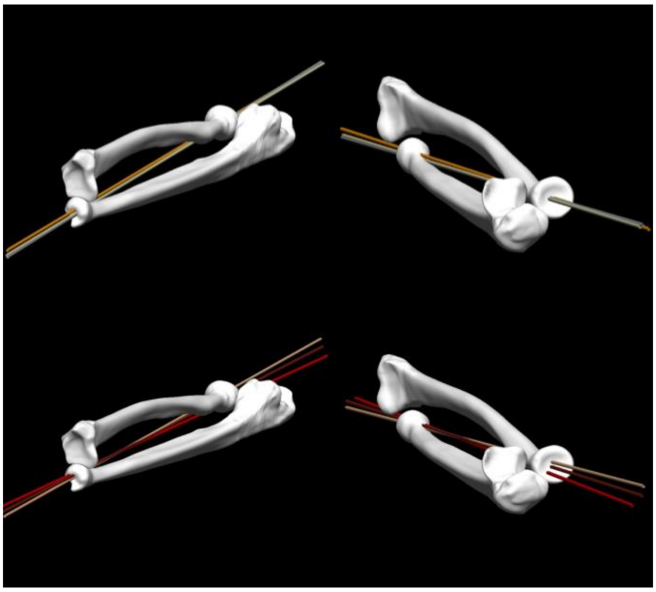

Figure 3: Axes of rotation calculated from neutral position. The top image presents the three pronation axes, and the bottom presents the supination axes.

When the rotations were divided into their finite intervals, the axes were considerably more variable (Figure 4). While the rotations between 25° supination and 50° pronation occurred about an almost identical axis, the rotations from 50° to 75° pronation, and from 25° to 75° supination were less consistent.

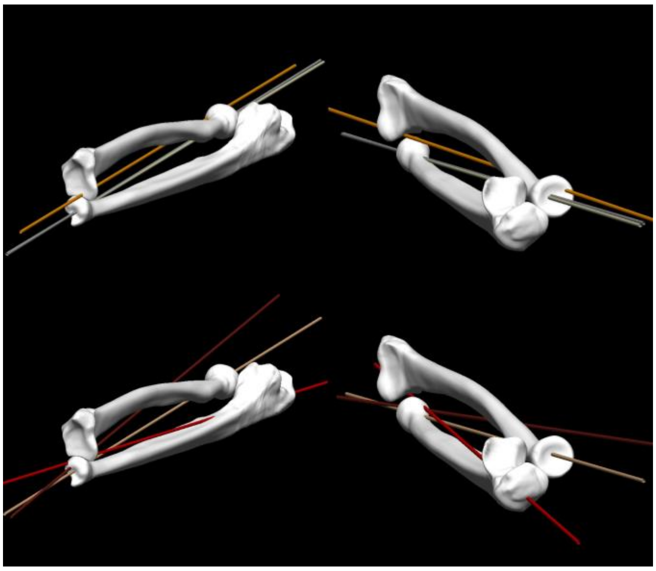

Figure 4: Axes of rotation calculated from for each finite rotation. The top image presents the three pronation axes, and the bottom presents the supination axes.

The forearm rotation positions are given with respect to total forearm rotation. It was observed that 25° of forearm rotation did not necessarily correspond to of 25° radius rotation. In fact, particularly in supination, a substantial portion of rotation was produced by ulna flexion and adduction. Errors that may have been introduced in registering the data clouds will affect axis calculations more when the magnitude of rotation is small.

It may also be that in the mid-range of motion the radius performs almost pure rotation about the ulna. As the radius moves towards its end ranges of motion, more substantial translation or sliding may occur at the distal radioulnar joint, confounding the axis calculations.

CONCLUSIONS

The results of this study confirm the radius axis of rotation presented in literature as the general axis about which the radius rotates. However, there is evidence that when radius motion is viewed over smaller finite rotations, the position of the axis may vary. This is especially evident towards the ends of the range of motion. Further study is needed to determine whether this reflects a limitation in the methodology used until now, or a real variability in the position of the axis.

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