INTRODUCTION

Precision pinch plays an important role in hand function and is essential for many everyday tasks. It requires accurate coordination as the thumb opposes the index finger. Thumb opposition is a complex motion that results from coordination of several joints moving in multiple planes. Methods exist to describe thumb opposition independently of the fingers despite the fact that the primary role of opposition is to coordinate with other fingers. Thumb-finger coordination is the critical part to achieving an accurate pinch. Several studies focused on the location of digit tips or joint angle variability but a good method to describe the relative orientation of the thumb and index finger distal phalanges is still lacking. The knowledge of the relative orientation is crucial to fully describe the coordination between the two digits and might be helpful to quantify kinematic impairment caused by hand disorders. However, finger kinematic studies face the challenge of tracking small segments which exaggerates misalignment errors and skin movement artifacts. Therefore, the purpose of this study was to present a method that utilizes a Digit Alignment Device (DAD) to virtually track the nail coordinate system to describe the relative orientation of the thumb and index finger distal phalanges during pinch.

METHODS

Experimental Devices. Marker clusters consisting of 3 reflecting markers (4 mm in diameter) attached via a thin rod to an acrylic nail plate (Figure 1) were used to track the 3D motion of the thumb and index finger distal phalanges. The marker clusters easily attached to the finger nail with double sided tape. During the static trial the DAD was used to establish the relationship between the virtual nail coordinate system and the cluster. The device consisted of a rectangular block (11 cm × 5 cm × 3.5 cm) with 8 markers used to define the orientation of the distal phalanges’ anatomy. Markers 1, 3 and 2, 4 were aligned with the longitudinal axis of the device. The thumb and index finger were placed onto the lateral side and top of the device, respectively, aligning the fingers with a longitudinal line on the center of the device. Using this device allowed the markers to be spread out on a flat surface avoiding out of plane misalignment (Figure 1).

Coordinate System Definitions. The origin of the virtual nail coordinate system was located on the center of the nail surface. The x axis was oriented from the midpoint of markers 3 and 4 to the midpoint of markers 1 and 2 and defined the longitudinal axis of the finger. The z axis was defined as the vector perpendicular to the x axis and was oriented to the right. The y axis was orthogonal to the x and z axes as determined by the right hand rule (Figure 2). An arbitrary technical coordinate system was defined from each marker cluster as its orientation does not have any importance. The coordinate system of the marker cluster was then transformed into the virtual coordinate system of the nail (Figure 2).
Experimental Procedure. To illustrate the proposed method, we analyzed the precision pinch of one subject. During the dynamic trial, the virtual nail coordinate systems were tracked with the marker clusters. The subject performed 50 cycles at a pace of 1 Hz with the eyes closed. A marker-based motion analysis system (Vicon, Oxford, UK) was used to capture digit motion data. The pinch cycle began with the thumb and index finger at maximum aperture and ended at pulp contact.

Data Analysis. Biomechanical analysis software (Visual 3D, C-Motion Germantown, MD) was used to carry out the kinematic analysis and orientation of the thumb relative to the index finger was described using Euler angle notation yaw (rotation around y), pitch (rotation around z’), and roll (rotation around x’’). Mean ± standard deviation of amplitude of rotations during movement and orientation at timing of pulp contact was calculated.

RESULTS

Throughout the closing phase of the pinch cycle, the thumb rotates around the index finger y axis (yaw) 99.6° ± 6.9°. It rotates 62.0° ± 6.6° and 104.7° ± 5.9° around the z’ (pitch) and x’’ (roll) axes respectively (Figure 3). At pulp contact, the thumb distal phalange was orientated with a yaw of 33.2° ± 3.1°, a pitch of 32.4° ± 2.6°, and a roll of -149.2° ± 2.2° relative to the index finger distal phalange.

DISCUSSION

Previous studies investigated thumb opposition as an independent motion, tracking only the thumb tip rotation, joint angle ranges of motion and coordination among the joints14. This study proposes a new method to investigate the thumb and index finger relative orientation during precision pinch. Specifically we developed a Digit Alignment Device (DAD) that overcomes the limitation associated with the small scale of the digits and avoids skin movement artifact and marker misalignment errors. Furthermore, we propose to describe the orientation of the digits’ distal segment the way it is usually done with attached segments. The sequence used here (yaw, pitch and roll), allowed us to avoid any particularities generally encountered with inappropriate choice of rotation order. This method takes advantage of the nail, which is a unique feature of the digits and accurately represents the underlying skeleton2, to track the virtual nail coordinate system. The ease of use and limited number of markers needed make this method useful for tracking the small segments of the hand.

REFERENCES