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Reliability and validity in measurement of true humeral retroversion by a three-dimensional cylinder fitting method

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Hypothesis and background: Humeral retroversion is defined as the orientation of the humeral head relative to the distal humerus. Because none of the previous methods used to measure humeral retroversion strictly follow this definition, values obtained by these techniques vary and may be biased by morphologic variations of the humerus. The purpose of this study was 2-fold: to validate a method to define the axis of the distal humerus with a virtual cylinder and to establish the reliability of 3-dimensional (3D) measurement of humeral retroversion by this cylinder fitting method.
Methods: Humeral retroversion in 14 baseball players (28 humeri) was measured by the 3D cylinder fitting method. The root mean square error was calculated to compare values obtained by a single tester and by 2 different testers using the embedded coordinate system. To establish the reliability, intraclass correlation coefficient (ICC) and precision (standard error of measurement [SEM]) were calculated.
Results: The root mean square errors for the humeral coordinate system were <1.0 mm/1.0° for comparison of all translations/rotations obtained by a single tester and <1.0 mm/2.0° for comparison obtained by 2 different testers. Assessment of reliability and precision of the 3D measurement of retroversion yielded an intratester ICC of 0.99 (SEM, 1.0°) and intertester ICC of 0.96 (SEM, 2.8°).
Discussion and conclusion: The error in measurements obtained by a distal humerus cylinder fitting method was small enough not to affect retroversion measurement. The 3D measurement of retroversion by this method provides excellent intratester and intertester reliability.
Level of evidence: Basic Science Study, Anatomy Study, Imaging.

Keywords: Humeral retroversion; three-dimensional measurement; cylinder fitting; computed tomography; baseball players; reliability

The Institutional Review Board of Hiroshima International University approved the protocol of this study: No. H09-025.

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The concept of humeral retroversion is often used to understand disorders of the throwing shoulder and elbow. Retroversion angle is generally defined as the angular difference between the orientation of the proximal humeral head and the axis of the elbow at the distal humerus,[27] although the reference axis used has been a topic of debate.[12,13,18,25,40] In baseball players and other throwing athletes, humeral retroversion is greater in the dominant arm than in the nondominant arm.[7,19,20,22,26,35,38-40] This increased humeral retroversion has been linked to upper extremity disorders including throwing-related shoulder and elbow injuries.[20] Humeral retroversion as well as posterior capsule thickness has a considerable influence on shoulder range of motion, including decreased glenohumeral internal rotation.[19,26,31] Baseball players exhibiting a decrease in passive internal rotation $\geq 25°$ in the dominant shoulder were approximately 4 to 5 times at greater risk of an upper extremity disorder than were players with $<25°$ decrease in passive internal rotation.[29]

Various methods using radiography,[22,26] computed tomography (CT),[2,7,18] or ultrasonography[18-20,23,32,34-36,38-40] have been proposed to measure the humeral retroversion angle; however, no widely accepted standard method exists.[2,18,25] Establishing a valid and reliable method is challenging work for several reasons, including the definition of humeral retroversion, range of imaging methods in use, and validity of anatomic landmarks or reference axes used to determine humeral retroversion. The cartilage/metaphyseal interface[2,18] and bicipital groove,[18-20,23,32,34-36,38-40] identified from 2-dimensional CT or ultrasound images, are commonly used to define the proximal axis of the humerus. However, the retroversion angle measured with these anatomic landmarks varies, depending on the level at which it is measured in the axial plane.[12,13] The results indicate that the more proximal cartilage/metaphyseal interface or groove we select as reference in the axial plane, the greater the value obtained for the humeral retroversion angle. The humeral epicondyles[2,18] and ulna[18-20,23,32,34-36,38,39] are used as reference points for the distal humeral axis (transepicondylar axis by the CT method, and forearm axis by indirect ultrasound assessment, respectively). However, morphologic variability in the medial epicondylar epiphyses and some degree of elbow valgus laxity have been observed in the dominant elbows of baseball players,[1,6,11] which may reduce the reliability of conventional methods using CT slices or indirect ultrasound technique. To overcome these limitations, a 3-dimensional (3D) measurement of humeral retroversion is required.

CT technology now allows 3D measurement of bone morphology, including femoral anteversion[5] and humeral retroversion.[13,24,25] A 3D volume-rendering CT technique was shown to provide accurate and reproducible measurements of humeral retroversion.[25] To analyze femoral neck anteversion, a virtual cylinder was fitted to 3 regions (femoral neck, diaphysis, and condyle), and the angle between the femoral neck and condyle vectors projected onto a plane perpendicular to the diaphysis vector was calculated.[5] The authors stated that this angle is consistent with the definition of femoral neck anteversion as it is the angle between the neck axis and the condylar line projected onto a plane perpendicular to the shaft axis.[5] Similarity in geometric shapes between femur and humerus allows us to fit the cylinder to humeral regions, suggesting that the cylinder fitting method by 3D CT would provide a reliable estimate of the humeral retroversion angle in baseball players.

The purpose of this study was 2-fold: to validate a method defining the axis of the distal humerus with a virtual cylinder and to establish the reliability of a 3D measurement of retroversion by this cylinder fitting method.

Materials and methods

Participants

Fourteen male baseball players participated in this study (age, 21.4 ± 1.5 years; height, 171.8 ± 6.3 cm; weight, 72.0 ± 7.3 kg; mean ± standard deviation). Both pitchers and position players with current shoulder pain in their throwing arms were enrolled. Three of the 14 players had a prior history of elbow injury, and 11 were without shoulder or elbow injury. We excluded patients with a history of shoulder surgery or shoulder condition that may have affected humeral retroversion. All participants read and signed the informed consent forms approved by a local Institutional Review Board before participation. Bilateral upper extremities were assessed in each participant; therefore, 28 extremities were included in our analysis of humeral retroversion.

Procedures

Patients underwent CT scans (Asteion Super 4, TSX-021 B/4A; Toshiba, Tokyo, Japan) at 1.0-mm slice pitch for the bilateral humeri. Geometric bone models of the humerus were created with a commercial software program (3D-Doctor; Able Software Corp., Lexington, MA, USA).[21] A 3D coordinate system was embedded onto the distal humerus by a cylinder fitting method similar to that described by Eckhoff et al[9] for the distal femur. A set of 2 virtual cylinders sharing a co-axis was manipulated in virtual space, positioning and enlarging the cylinders to achieve a good fit, leaving only a small rim of the capitulum and trochlea bone outside the cylinder (Fig. 1). The x-axis (flexion-extension axis of the elbow joint) was defined as the co-axis of the cylinders. The z-axis was perpendicular to the x-axis and parallel to the humeral shaft projected onto the sagittal plane. The y-axis was a cross product of the x- and z-axes.

A projected line of the proximal humerus onto the xy plane of the distal humerus was defined by Rapidform software (Geomagic, Morrisville, NC, USA). First, the articular surface of the humeral head was virtually painted so that the best-fit sphere was automatically generated[13] (Fig. 2). The humeral shaft was painted, and the best-fit cylinder was automatically generated. The line connecting the spherical center of the humeral head and the proximal end of the longitudinal axis of the cylinder (humeral