The Effect of Humeral Rotation on Elbow Range-of-Motion Measurements

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Abstract

In 84 patients (85 elbows), a standard goniometer was used to measure elbow flexion and extension with the forearm in 2 positions: full supination (humeral condyles parallel to floor) and neutral forearm rotation (ulnohumeral joint in relative internal rotation). All measurements were made by the same surgeon with a standardized technique.

Mean absolute difference in elbow extension measurements was 8°. There was no difference in flexion between measurement positions. Mean difference between neutral and supinated measurements was 6° in extension. There was no difference in flexion for patients with contractures between 0° and 29°. In patients with flexion contractures of more than 30°, mean difference between neutral and supinated measurements was 12° in extension; there was no difference in flexion. Elbow goniometer extension measurements taken in neutral humeral rotation underestimated the degree of elbow hyperextension and elbow flexion contracture.

We recommend taking elbow flexion arc measurements in the true plane of motion, with the humerus externally rotated by fully supinating the forearm, such that the distal humeral condyles are parallel to the floor.

Elbow motion is crucial for activities of daily living and full function of the upper extremity.[1] Measuring the elbow flexion arc accurately and consistently is an important part of the physical examination of patients with elbow pathology. Orthopedic surgeons rely on these measurements to follow patients over time, and they often base their treatment decisions on the range and progression/regression of motion arc.

In the clinical setting, elbow range of motion (ROM) is commonly measured with a handheld goniometer.[2,3] The literature also suggests that goniometric measurements are highly reliable in the clinical setting and that intrarater reliability of elbow ROM measurements is high.[2-4] Despite the routine use and clinical importance of flexion arc assessment, there is no universal recommendation regarding optimal measurement position. Textbooks and journal articles commonly do not specify arm position at time of elbow ROM measurements,[5-8] and a literature review found no studies directly addressing this issue.

From a biomechanical standpoint, humeral rotation is often affected by forearm pronosupination position. Although forearm pronosupination is a product of the motion at the radioulnar joints, forearm position during elbow flexion arc measurement can influence the relationship of the distal humeral intercondylar axis to the plane of measurement. Full forearm supination rotates the distal humeral intercondylar axis externally to a position parallel to the floor and in line with the plane of measurement. Humeral rotation with the forearm in neutral pronosupination places the humeral condyles internally rotated relative to the floor. Therefore, for the purposes of this study, we defined full humeral external rotation and true plane of ulnohumeral motion as full forearm supination, and relative humeral and ulnohumeral joint internal rotation as neutral pronosupination.

Because of the potential for elbow ROM measurement changes caused by differences in the motion plane in which measurements are taken, some have advocated taking flexion arc measurements with the arm in full supination to allow measurements to be taken in the true plane of motion. We hypothesized that elbow flexion arc measurements taken with the forearm in neutral rotation would underestimate the extent of elbow flexion contractures compared with measurements taken in full supination.

Materials and Methods

This study received institutional review board approval. Eighty-four patients who presented with elbow dysfunction to a single shoulder and elbow orthopedic surgeon enrolled in the study. Skeletally immature patients and patients with a fracture or other disorder that prohibited elbow ROM were excluded. A standard goniometer was used to measure elbow flexion and extension with the humerus in 2 positions: full external rotation and neutral rotation.

All goniometer measurements were made by the same surgeon (to eliminate interobserver reliability error) using a standardized technique with the patient sitting upright. The goniometer was positioned laterally with its center of rotation over the lateral epicondyle, aligned proximally with the humeral

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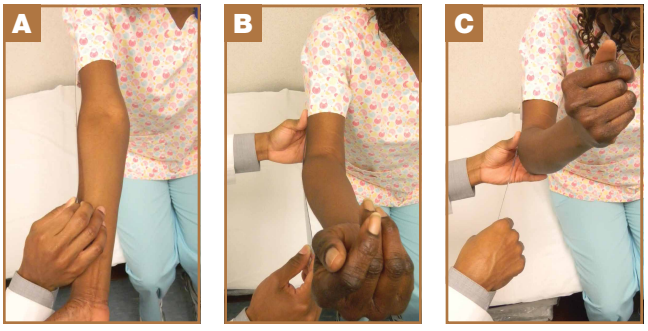

Figure 1. Methods of measuring elbow range of motion: (A) goniometer over axis of rotation on lateral epicondyle; (B) with humerus externally rotated, measurements can be made in plane of motion; (C) with humerus in neutral rotation, measurements were out of plane.

head and distally with the center of the wrist. Measurements were obtained sequentially with the hand in both positions. For external rotation measurements, the patient's arm was fully supinated to bring the humeral condyles parallel to the floor. For neutral positioning, the patient's arm was placed in the "thumb-up" position with the hand perpendicular to the horizontal axis of the floor (**Figures 1A–1C**).

Data collected included demographics, diagnosis, hand dominance, affected side, and elbow ROM measurements with the hand in the 2 positions. These data were compiled and analyzed for all patients and then stratified into 3 groups by extent of elbow flexion contracture in the supinated position (group 1, hyperextension; group 2, 0°-29° elbow extension; group 3, ≥30° flexion contracture).

Statistically, paired t tests were used to identify differences between the 2 elbow ROM measurement methods. $P < .05$ was considered significant.

Results

Eighty-four (44 male, 40 female) consecutive patients (85 elbows) met the inclusion and exclusion criteria. Mean age was 51 years (range, 19-84 years). Seventy-six patients were right-handed, 7 were left-handed, and dominance was unknown in 1 patient. The right elbow was affected in 45 patients, the left in 38, and both in 1 patient. There were 25 different diagnoses, the most common of which was lateral epicondylitis; 7 patients had multiple disorders (**Table**).

The first set of data, elbow ROM measurements, was taken with all 84 patients analyzed as a single group. In neutral humeral rotation, mean elbow extension was 14° (range, 10°-72°), and mean elbow flexion was 134° (range, 72°-145°). In external rotation, mean elbow extension was 20° (range, 12°-87°), and mean elbow flexion was 134° (range, 72°-145°). For the group, mean absolute difference in elbow extension was 8° (range, 0°-30°; $P < .0001$); there was no difference between external rotation and neutral rotation in flexion (**Figure 2**).

The data were reanalyzed after being stratified into 3 groups based on extent of elbow flexion contracture measured in supination.

Table. **Study Patients' Elbow Disorder Diagnoses (N = 25), From Most to Least Common**

Lateral epicondylitis	37
Osteoarthritis	8
Posttraumatic arthritis	6
Medial epicondylitis	5
Rheumatoid arthritis	4
Olecranon bursitis	3
Ulnar collateral ligament strain	3
Elbow contusion	3
Distal biceps tendinopathy	2
Distal biceps tendon rupture	2
Radial head fracture	1
Posterior interosseous nerve syndrome	1
Synovitis	1
Triceps strain	1
Triceps avulsion	1
Elbow plica	1
Congenital radial head dislocation	1
Arthrofibrosis	1
Elbow pain of uncertain etiology	1
Soft-tissue infection after open reduction and internal fixation	1
Septic bursitis	1
Distal humeral nonunion	1
Humeral shaft delayed union	1
Symptomatic hardware	1
Traumatic elbow muscle loss	1

The 9 elbows in group 1 (hyperextension) had mean extension of –2° (range, 10°-2°) and mean flexion of 141° (range, 130°-145°) in the neutral position. In external rotation, mean extension was –9° (range, –12° to –1°), and mean flexion was 141° (range, 130°-145°). When the 2 measurement positions were compared, group 1 had mean elbow ROM differences of –6° (range, –14° to 0°; $P = .0033$) for elbow extension and 0° for elbow flexion (**Figure 3A**).

The 50 elbows in group 2 (0°-29° flexion contracture) had mean extension of 7° (range, 0°-20°) and mean flexion of 138° (range, 100°-145°) in the neutral position. In external rotation, mean extension was 13° (range, 0°-26°), and mean flexion was 138° (range, 100°-145°). Mean difference between neutral and external rotation measurements was 6° (range, 0°-20°; $P < .0001$) in extension and 0° in flexion (**Figure 3B**).

The 26 elbows in group 3 (≥30° flexion contracture) had mean extension of 33° (range, 0°-72°) and mean flexion of 124° (range, 72°-145°) in the neutral position. In external rotation, mean extension was 45° (range, 30°-87°), and mean

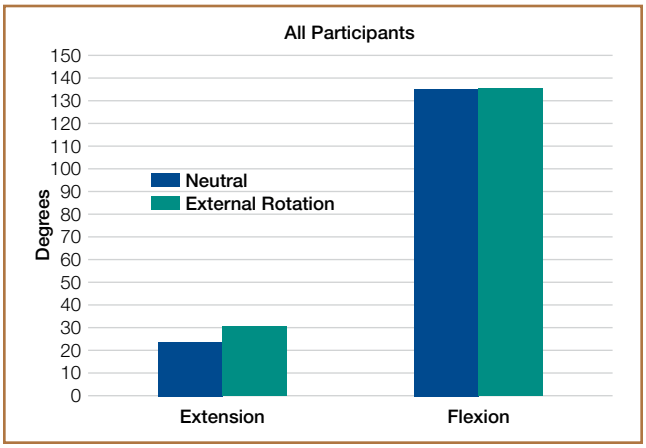

Figure 2. Mean difference in elbow extension measurements between neutral position and externally rotated position was about 8°. There were no significant differences in elbow flexion measurements based on humeral position.

flexion was 124° (range, 72°-145°). Mean difference between neutral and external rotation measurements was 12° (range, 0°-30°; $P < .0001$) in extension and 0° in flexion (**Figure 3C**).

Discussion

Elbow flexion arc measurements are crucial for patient outcomes and activities of daily living. Commonly cited as functional ROM, the 30°-to-130° flexion arc often is used to guide clinical decisions in patients with elbow disorders.[1] However, our data indicate that humeral position can alter elbow ROM measurements. Specifically, because of neutral forearm pronosupination, measurements made with the humerus in neutral rotation underestimate both the extent of elbow hyperextension and the degree of flexion contracture (**Figures 4A, 4B**). The more severe the flexion contracture, the more values are altered by measurements taken in this position. The same does not apply for elbow flexion measurements, as varying humeral rotation did not significantly affect those values.

Our results indicate that patients evaluated with the arm in neutral humeral rotation had flexion contractures underestimated by a mean of 8°, while there was a negligible difference in flexion measurements. Stratifying our data into 3 groups, we found that neutral humeral rotation kept elbow extension measurements closer to 0° for patients with both hyperextension and contractures. With increasing severity of flexion contractures in groups 2 and 3, the measurement errors were magnified. The differences in extension measurement values between these 2 groups based on humeral rotation increased more than 4°—an indication that, as flexion contracture severity increases, so does the degree of measurement error when elbow extension is measured with the humerus in neutral rotation rather than external rotation.

Our literature review found no studies on ROM value differences based on position of humeral rotation. Most texts, in their descriptions of elbow ROM and biomechanics, make no reference to position of pronosupination at time of flexion

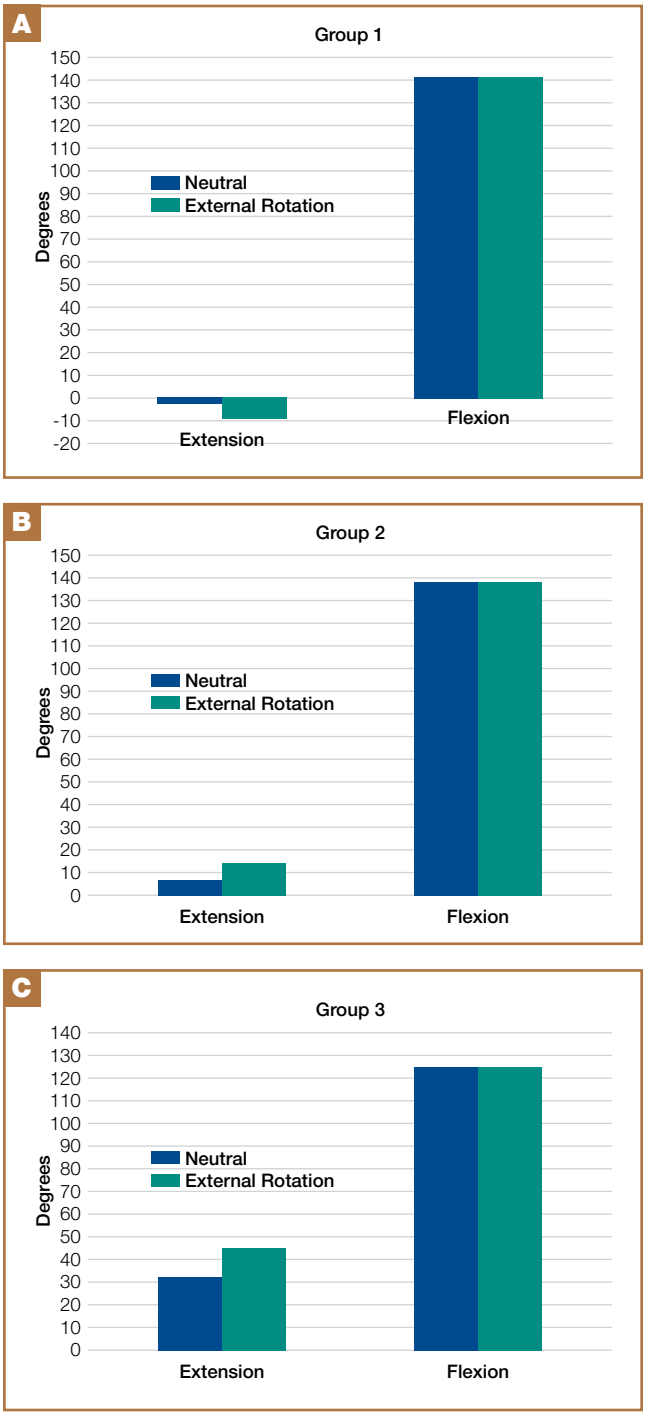

Figure 3. Differences in elbow extension measurements: (A) In group 1, neutral position underestimated hyperextension by about 6°; (B) in group 2, neutral position underestimated flexion contracture by about 6°; (C) group 3 (flexion contracture, ≥30°) had largest difference (12°) between extension measurements.

arc measurement.[5-8] Although many elbow authorities recommend taking elbow ROM measurements in full external rotation, we found no corroborating evidence.

Other investigators have evaluated the reliability of goniometer measurements.[2,3] Rothstein and colleagues[3] concluded

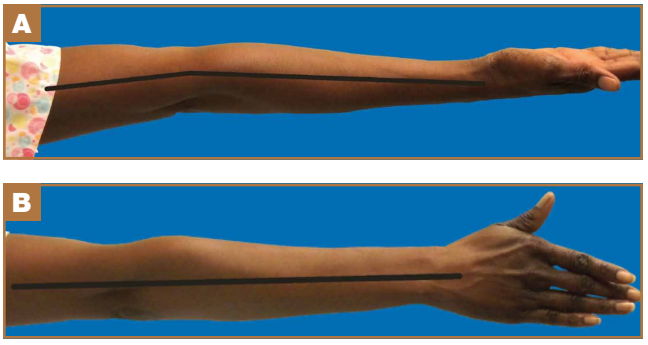

Figure 4. Full extent of elbow hyperextension can be better appreciated with (A) humerus fully externally rotated than with (B) humerus in neutral rotation.

that elbow and knee goniometric measurements are highly reliable in the clinical setting when taken by the same person. In particular, intratester reliability for elbow extension measurements was high. Armstrong and colleagues[2] specifically examined intratester, intertester, and interdevice reliability and found that intratester reliability was much higher than intertester reliability for universal goniometry. In our study, all patients were measured with the same technique by the same orthopedic surgeon to eliminate any intertester reliability error. Armstrong and colleagues[2] also found that intratester changes vis-a-vis extension measurements are meaningful when goniometric differences are more than 7°. In our study, the difference in extension measurements between the 2 humeral positions averaged 8° overall and 12° in group 3. This suggests that the data reported here reflect a true difference dependent on humeral rotation and are not a result of goniometer intratester variability.

Other studies have examined measurement devices other than the standard universal goniometer. Cleffken and colleagues[4] found that the electronic digital inclinometer was reliable for elbow ROM measurements. Blonna and colleagues[9] used digital photography–based goniometry to measure patient outcomes without doctor–patient contact at tertiary-care centers and found it to be more accurate and reliable than clinical goniometry in measuring elbow flexion and extension. Chapleau and colleagues[10] compared the validity of goniometric elbow measurements in radiographic methods and concluded that the maximal error of goniometric measurements in extension was 10.3°. However, they also found high intraclass correlation coefficients for goniometric measurements. With the accepted clinical reliability of universal goniometry,[2-4,10] we believe it to be the best clinical tool for this study because of its availability, minimal cost, and ease of use.

In the clinical setting, elbow flexion arc measurements are a major factor in treatment decisions and often dictate whether to proceed with operative interventions such as capsular release. In addition, ROM measurements are crucial in determining the success of treatments and the progression of disease. Erroneous elbow extension measurements can have significant consequences if they falsely indicate functional ROM when taken in neutral position. This is particularly true for patients with elbow flexion contractures of more than 30°, in whom differences in humeral rotation resulted in about 12° of variance between measured values. For instance, a patient with a true 40° flexion contracture in the externally rotated position could be determined to have functional ROM based on measurements made in the neutral position.

Limitations of this study include those involving goniometer reliability and intraobserver variability (already described) and the validity of goniometer measurements compared with radiographic measurements.

Conclusion

Because elbow goniometer extension measurements taken in neutral humeral rotation underestimate both the degree of elbow hyperextension and the degree of elbow flexion contracture, we recommend taking elbow flexion arc measurements in the true plane of motion, with the humerus externally rotated by fully supinating the forearm, such that the distal humeral condyles are parallel to the floor.

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This paper will be judged for the Resident Writer's Award.