Quantifying the Center of Elbow Rotation: Implications for Medial Collateral Ligament Reconstruction

HAND
2019, Vol. 14(3) 402–407
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DOI: 10.1177/1558944717743599
hand.sagepub.com

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Abstract

Background: Medial collateral ligament (MCL) reconstruction of the elbow mandates precise characterization of where the centerline of elbow rotation projects onto the medial epicondyle (ME). A muscle-splitting approach allows the flexor-pronator muscles to remain attached to the ME and facilitates visualization of the MCL remnant, the sublime tubercle, and the ulnohumeral joint line. Knowledge of where the centerline of rotation intersects the ME relative to the ulnohumeral joint line may assist the surgeon during placement of the proximal drill hole. **Methods:** Models were created from the computed tomography scans of 29 normal elbows. The centerline of rotation, center of the trochlea, sublime tubercle, and ulnohumeral joint line were identified. Measurements were taken from the ulnohumeral joint line to the center of the trochlea and to the centerline of rotation in the sagittal view and along the course of the MCL. **Results:** The centerline of rotation intersected the ME in a consistent location. With the elbow flexed 90°, the trochlea center and the centerline of rotation are essentially in line with each other. There are significant differences between the distances from the ulnohumeral joint line to the center of the trochlea and to the centerline of rotation in both the sagittal view and along the course of the MCL. **Conclusions:** The centerline of rotation is located 14.31 mm (1.70) from the ulnohumeral joint line in the sagittal view and 16.54 mm (2.09) from the ulnohumeral joint line along the course of the MCL.

Keywords: center of rotation, medial, ligament, MCL, reconstruction, elbow

Introduction

Elbow stability is conferred through static and dynamic stabilizers that create a well-constrained joint.^{1,3,5,12,16,18,21} The major ligamentous contributor to valgus elbow stability is the medial collateral ligament (MCL) complex.^{6,11,14,23,25} MCL stability can fail in overhead throwing athletes, and for these patients, a ligament reconstruction may be performed.^{8,15,17}

A muscle-splitting approach has been advocated as this is less traumatic to the flexor-pronator muscle mass and decreases immediate morbidity after surgery.^{24,26} The proposed muscle-split through the common flexor bundle extends from the medial humeral epicondyle to a point distal to the tubercle of the ulna. A “safe zone” extends from the medial humeral epicondyle to approximately 1 cm distal to the insertion of the MCL on the tubercle of the ulna.²⁵ The drawback of this approach is that it limits visualization of the medial epicondyle when compared with efforts that elevate and then reattach the flexor-pronator mass.

Graft placement in a location where isometric or nearly isometric motion occurs will minimize the length changes and thus tension in the graft. Nonisometric motion may

cause impingement, stiffness, stretching, and subsequent failure of the graft.^{1,2,9,13,15,18,20,26} To restore elbow kinematics, humeral drill hole placement is best performed at the centerline of ulnohumeral rotation, which is represented by the geometric centerline of the 3-dimensional trochlea.^{1,18}

External landmarks may be used to find the axis of ulnohumeral rotation; however, these are difficult to visualize in an elbow that is not grossly unstable and where the full articular surface of the entire trochlea is poorly seen.^{4,18,19,22}

If, at the time of surgery, the anterior bundle of the medial collateral ligament (AMCL) footprint is clearly seen, then its geometric center should be used to place the graft drill hole. If the footprint cannot be defined, then drilling the hole toward the base of the medial humeral

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Figure 1. Anteroposterior view of the distal humerus with the trochlea in blue (a), axial view (b), and 11 parallel planes offset in 1-mm increments through the trochlea centered on the lowest depression of the trochlea (c).

epicondyle is suggested because the attachment of the AMCL is anterior and inferior on the medial epicondyle.³

The footprint location has been characterized using 3-dimensional mapping in cadaver elbows as 13.4 mm from the medial epicondyle and 19.6 mm from the humeral cartilage edge.¹⁰ Another mapping study quantified its location as 19 mm from the trochlear joint margin on an anteroposterior (AP) view and 10 mm from the coronoid on the lateral view.⁷

When performing a ligament reconstruction through a muscle-splitting approach, the surgeon must rely on what can be seen through this direct view of the medial elbow. What must be identified is the sublime tubercle of the ulna, the ulnohumeral joint line, the AMCL ligament remnant, and its footprint on the medial epicondyle. Given the importance of not dissecting the soft tissues unnecessarily, visualization of the medial epicondyle is limited on purpose. For that reason, it is of value to know the distance between the ulnohumeral articulation and the drill hole along the course of the AMCL remnant. There are 2 methods by which the location of the centerline of rotation can be found during surgery. Either a ruler is placed in parallel with the AMCL and a measurement taken from the joint line or the ruler is held in a sagittal plane and the measurement approximated without placing the ruler obliquely into the joint.

Our hypothesis is that the centerline of ulnohumeral rotation bisects the medial epicondyle at a reproducible location. This point may be different than the geometric center of the trochlea when viewed intraoperatively from the medial side. This research was conducted to identify a distance between the intersection of the centerline of ulnohumeral rotation with the medial epicondyle and the ulnohumeral joint line along the course of the AMCL. We will record the radius of curvature of the medial trochlea in all specimens to quantify the range of elbows studied.

Material and Methods

After Institutional Review Board approval was obtained, 63 computed tomography (CT) scans of elbow joints obtained for clinical care were reviewed for inclusion in the study.

The CT scans were analyzed for arthritis that would affect normal morphology. Two orthopedic surgeons (K.S.G. and R.A.K.) and a radiologist (S.G.) independently graded the scans according to joint space, osteophyte size and location, sclerosis, and subchondral cysts. Elbows determined to be arthritic by any of the graders were excluded from the study. Twenty-nine CT scans were selected to be included in the study. Twenty-one elbows were from male specimens and 9 from female specimens. The average age was 35 years old (range: 18-57 years old).

Images from each CT scan were imported into 3D Slicer (National Alliance for Medical Image Computing) to segment the humerus, ulna, and radius at the elbow. Segmented data were imported into Rapidform XO (JMR Systems, Derry, New Hampshire) to create a corresponding model. For each model, the distal humerus was isolated and then smoothed to minimize stair stepping effects created by the CT scans.

Once the model was created, the lowest depression on the AP view within the trochlea was identified. The model was rotated on end to the axial view. From this perspective, the maximum anterior and posterior depression within the trochlea was identified. These 3 points were then connected to generate a plane, which was offset in medial and lateral directions in five 1-mm increments to generate 11 parallel planes (Figure 1).

A curve was created at the intersection of each plane with the outer surface of the trochlea. These curves were trimmed where the trochlea merged proximally with the distal humerus. The center of each curve was identified, and a best fit line to these 11 points was created. This line characterized the centerline of rotation for the ulnohumeral articulation (Figure 2). The location where this centerline of rotation intersected the cortex of the medial epicondyle of the humerus was identified. This was termed the center of rotation.

The outline of the trochlea from the sagittal view was created, and the center of this outline was projected onto the medial epicondyle. This was termed the center of the trochlea. The location of the sublime tubercle was identified with the elbow flexed 90°. Two lines were created, one

Figure 2. Curves created at the intersection of each plane with the outer surface of the trochlea (a) and best fit line to the centers of each curve representing the centerline of rotation for the ulnohumeral articulation (b).

Figure 3. Point of interest as viewed in the sagittal plane (A: sublime tubercle, B: ulnohumeral joint line, C: center of the trochlea, and D: center of rotation).

connecting the sublime tubercle with the center of rotation and the other with the center of the trochlea. This was done with the elbow flexed 90° as this is a position at which ligament reconstruction would be performed. The ulnohumeral joint line was identified as the intersection of these lines with the outline of the trochlea (Figure 3).

Distance measurements were taken from the ulnohumeral joint line. Two length measurements were taken as a projection onto the sagittal plane. The distance between the joint line to the center of rotation (L) and to the center of the trochlea (R) were measured (Figure 4a). These measurements are of value when the surgeon chooses to hold a ruler parallel to the sagittal plane. Two additional length measurements were taken of the AMCL along its actual course: one measurement from the joint line to the center of rotation

(L3D) and the other to the center of the trochlea (R3D) (Figure 4b). These measurements assist the surgeon who places a ruler adjacent to the AMCL.

Statistical analysis was performed using a paired Student *t* test to determine whether there were statistical differences between the 2 sets of measurements.

Results

Our results show a consistent area where the centerline of rotation of the elbow intersects the medial epicondyle (Figure 5).

The measurements were taken to recreate intraoperative conditions assuming surgery performed with the elbow flexed 90° . This places the sublime tubercle at approximately 60° of flexion with respect to the humeral shaft. At this angle, the trochlea center (C) and the center of rotation (D) are essentially in line with each other with only a 1.51° average difference with respect to the sublime tubercle (A) (Table 1).

In the sagittal view, the center of rotation is 14.31 mm (SD, 1.70) from the ulnohumeral joint line (L). The center of the trochlea to the ulnohumeral joint line (R) is 13.20 mm (SD, 1.66). There is a significant difference between these 2 measurements ($P = .001$; Table 1).

The distance between the center of rotation and the ulnohumeral joint line (L3D) is 16.54 mm (SD, 2.09) along the AMCL. The center of the trochlea is 14.46 mm (SD, 2.13) (R3D) from the ulnohumeral joint line along the AMCL. There is a significant difference between these 2 measurements ($P = .001$; Table 1).

Discussion

Identifying the AMCL insertion site on the humerus is imperative to ensure a successful reconstruction. A muscle-splitting approach does not facilitate intraoperative visualization of the trochlea, however. During a muscle-splitting approach,

Figure 4. Distance measurements from the ulnohumeral joint line taken in the sagittal plane (a), taken along the course of the anterior bundle of the medial collateral ligament (AMCL) (b) (A: sublime tubercle, B: ulnohumeral joint line, C: center of the trochlea, D: center of rotation, L: distance between ulnohumeral joint line and center of rotation in the sagittal view, R: distance between ulnohumeral joint line and center of the trochlea in the sagittal view, L3D: distance between ulnohumeral joint line and center of rotation along the AMCL, and R3D: distance between ulnohumeral joint line and center of the trochlea along the AMCL).

Figure 5. Sagittal view of range, average $\pm$ standard deviation, of where the center of rotation and the center of the trochlea intersect the medial aspect of the humerus (a) and oblique view of the same (b) (C: center of the trochlea and D: center of rotation).

Table 1. Distance Measurements Taken From the Ulnohumeral Joint Line to Points of Interest.

Measurement (from joint line to)	Center of rotation L3D, actual length	Center of trochlea R3D, actual length	Center of rotation L, sagittal view	Center of trochlea R, sagittal view
Distance, mm, mean (SD)	16.54 (2.09)	14.46 (2.13)	14.31 (1.70)	13.20 (1.66)

Note. L = distance between ulnohumeral joint line and center of rotation in the sagittal view; R = distance between ulnohumeral joint line and center of the trochlea in the sagittal view; L3D = distance between ulnohumeral joint line and center of rotation along the AMCL; R3D = distance between ulnohumeral joint line and center of the trochlea along the AMCL.

Figure 6. Average distance from the ulnohumeral joint line to the center of rotation with ruler in the sagittal plane is 14.36 mm (SD, 1.70) (a), and along the course of the AMCL, it is 16.54 mm (SD, 2.09) (b).

both the AMCL remnant and the sublime tubercle as well as the ulnohumeral joint line are reliably visualized, however. Knowledge of the distance from the joint at which the drill hole should be placed may be of value to the surgeon.

The purpose of this study was, therefore, to use CT scan modeling of the trochlea to characterize the ulnohumeral centerline of rotation. We aimed to establish where the centerline of rotation bisected the medial epicondyle. The distance between this point and the ulnohumeral joint line was measured. The goal was to provide a guide for drill hole placement based on landmarks that are readily visualized during a muscle-splitting approach. The measurements were taken from the distal extent of the CT scanned humeri and did not include the cartilage thickness. Our intraoperative measurement recommendations should, therefore, occur from the cartilage edge of the distal humerus.

When approaching the medial elbow through a muscle-splitting approach, the footprint of the native MCL is sometimes seen and can be used as a landmark for drill hole placement. On occasion, the footprint may not be reliably visualized. If it is not well appreciated, then the hole may be placed roughly 14 to 15 mm proximally and posteriorly along the course of the AMCL remnant with the ruler placed in parallel to the ulna or between 16 and 17 mm when the ruler is adjacent to what remains of the AMCL (Figure 6). Even if the footprint is seen, the location of the drill hole guide wire can be verified using this measurement once it has been placed.

The methodology that we employed to characterize the center of rotation is dependent on manually finding the points of maximal depression and using these points to create a plane that characterizes the trough of the trochlea groove. A potential limitation of this study relates to the error that is implicit in manually identifying points of greatest depression within the trochlea.

Furthermore, although the elbows were visually inspected for radiographic changes consistent with osteoarthritis, a wide age range was noted. Older specimens may exhibit cortical thinning and bony changes that could potentially influence the centerline of the trochlea.

Further study is needed to determine whether placement in the location determined by this study would allow the graft to experience near isometric length changes throughout the arc of flexion comparable with the native AMCL. Particularly when the elbow experiences external forces, a screw deviation axis describes the centerline of rotation variation due to arm position.⁵ Further study is needed to quantify how a graft would react in these “real-life” dynamic situations.

Ethical Approval

This study (IRB #PR015030065) was approved by the University of Pittsburgh Institutional Review Board.

Statement of Human and Animal Rights

All procedures followed were in accordance with the ethical standards of the responsible committee on human experimentation (institutional and national) and with the Helsinki Declaration of 1975, as revised in 2008 (5).

Statement of Informed Consent

No personal identifying information was used in this article. Informed consent was obtained from all patients for being included in the study where required.

Declaration of Conflicting Interests

The author(s) declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

Funding

The author(s) received no financial support for the research, authorship, and/or publication of this article.

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