PARTIAL POSTEROMEDIAL OLECRANON RESECTION: A KINEMATIC STUDY

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Background: The posteromedial aspect of the olecranon process is a site of impingement and subsequent osteophyte development in throwing athletes. Treatment with débridement, with resection of osteophytes and varying amounts of normal olecranon bone, is common. We found no reports in the literature concerning the effects of resecting different amounts of normal bone from the posteromedial aspect of the olecranon. We hypothesized that excessive resection would increasingly alter elbow kinematics and that an optimum amount of olecranon resection could be identified.

Methods: We investigated the kinematic effects of increasing valgus and varus torques and posteromedial olecranon resections, in twelve cadaveric elbows, with use of an electromagnetic tracking device. Two valgus and two varus torques were applied, and three sequential resections were performed in 3-mm steps from 0 mm to 9 mm. Statistical analyses included paired t tests, 95% confidence intervals, a one-factor analysis of variance with repeated measures, and a post hoc test when significance was established.

Results: Sequential partial resection of the posteromedial aspect of the olecranon resulted in stepwise increases in valgus angulation with valgus torque. Clear differences were seen at each level of resection. A pattern of increased valgus angulation also was seen in association with increased valgus torque. Increased valgus torque resulted in a trend toward increased axial internal rotation of the ulna, whereas increased osseous resection resulted in a decrease in the absolute degree of internal rotation or, in some specimens, increased external rotation.

Conclusions: Although no single critical amount of olecranon resection was identified, valgus angulation of the elbow increased in association with all resections, with a marked increase occurring in association with a 9-mm resection. Our findings challenge the rationale of removing any amount of normal olecranon bone in throwing athletes as doing so may increase strain on the medial collateral ligament. The implications for the professional throwing athlete are important, and we recommend that bone removal from the olecranon be limited to osteophytes, without the removal of normal bone.

Elbow injury is a well-recognized problem among throwing athletes. Elbow stresses generated by excessive valgus torques result in posteromedial olecranon impingement, which in turn causes pain, osteophytes of the olecranon process and fossa, and loose bodies[1] (Fig. 1). The commonly associated condition, of which the above findings are a part, is the valgus extension overload syndrome[1], in which a concomitant medial collateral ligament injury is often underappreciated and hence undertreated[2].

Surgical débridement, either open or arthroscopic, has become a standard technique for the treatment of the osseous elements of the condition[3]. In common surgical practice, the osteophytes are débrided, along with varying amounts of the olecranon, with a variable angle of resection. The function of the posterior part of the olecranon was addressed in two previous studies[4,5]. McKeever and Buck concluded that the olecranon was unimportant for stability[4]. However, An et al. observed a 50% reduction in valgus restraint following removal of its proximal quarter[5]. We found no specific data concerning the amount of the posteromedial aspect of the olecranon that can be removed without compromising elbow stability and/or altering elbow kinematics. We hypothesized that, because of the normal balance of osseous and ligamentous constraints, resection of any amount of normal bone from the olecranon would alter the kinematics of the elbow under valgus torsional loading conditions, with greater effects being observed as more bone was removed. We further hypothesized that a critical amount of resection that places the medial collateral ligament at particular risk could be identified.

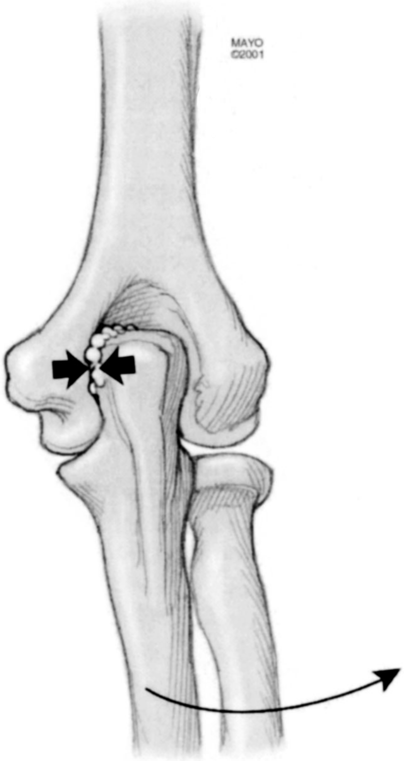

Fig. 1

Illustration depicting posteromedial olecranon impingement and reciprocal olecranon and humeral osteophytes with valgus loading. (With permission of the Mayo Foundation.)

Materials and Methods

Twelve fresh-frozen cadaveric upper extremities without signs of osseous or soft-tissue abnormalities were used in this study. There were seven right and five left limbs. The specimens were obtained from eight male and four female donors who had been an average of seventy-five years old (range, forty-five years to eighty-nine years old) at the time of death. All specimens were stored at −20°C beginning at the time of retrieval and were thawed overnight at room temperature prior to testing, thereby undergoing a single freeze-thaw cycle.

Each specimen was transected through the middle part of the humerus and was disarticulated at the radiocarpal joint without compromising the integrity of the distal radioulnar joint. The medial collateral ligament complex was exposed with use of a flexor pronator mass-splitting approach. The biceps brachii was transected at the mid-humeral level, and the humeral origins of the brachialis and triceps muscles were released subperiosteally to the proximal level of the elbow capsule. The humeral shaft was embedded in a Plexiglas tube filled with polymethylmethacrylate dental resin and then was placed in a fixture that maintained the humerus parallel to the floor[6]. Loosening the fixture allowed the elbow to be oriented in any of three test positions: the neutral test position (forearm motion in the vertical plane), the valgus test position (forearm motion in a horizontal plane with the medial epicondyle uppermost), and the varus test position (forearm motion in a horizontal plane with the lateral epicondyle uppermost). The positions were maintained by retightening the fixture. The forearm was freely mobile about the elbow joint in both pronation and supination as preliminary tests revealed no change in motion patterns when the forearm bones were fixed together, corroborating the findings of Pribyl et al.[6].

An electromagnetic tracking system (3Space Fastrak; Polhemus, Colchester, Vermont) was used to record the kinematics of elbow motion and to track the three-dimensional relationship of the ulna relative to the humerus at a sampling rate of 30 Hz. A transmitter source was mounted on the testing table, adjacent and proximal to the humerus. Two receiving sensors were attached to the distal aspect of the lateral part of the humerus and the distal aspect of the medial part of the ulna. Although the stated accuracy of the system is ±0.5°, the stated resolution of the sensors is ±0.025°[7]. The stated accuracy of the system was based on a large field of view with movable sensors[8]. Our sensors were fixed to bone and were confined to a small space, which should have improved the accuracy of the system. The accuracy of the system is known to be affected by extraneous ferromagnetic sources[9]; hence, any such interference was minimized by eliminating all ferromagnetic materials from the testing field.

The biceps brachii, brachialis, and triceps muscles were attached to weights that produced loads of 20 N, 20 N, and 40 N, respectively, representing a single level muscle load simulation[6,10]. These loads represent 10% of the maximal potential force of these groups[6,11]. They were chosen because smaller loads representing 5% of maximal muscle force

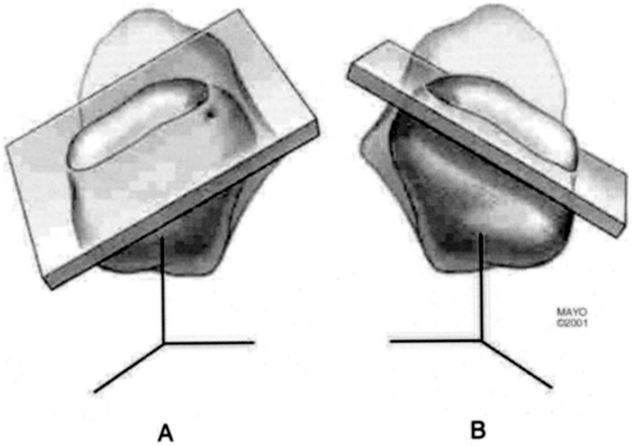

Fig. 2

Illustrations depicting the orientation of the posteromedial olecranon osteotomy. *A,* Osteotomy oriented 45° to the subcutaneous border of the ulna. *B,* Commonly performed osteotomy oriented parallel to the subcutaneous border of the ulna. (With permission of the Mayo Foundation.)

TABLE I Valgus and Varus Angulation with the Elbow Positioned at 90° of Flexion in the Valgus and Varus Test Positions*

	Muscles Alone	Muscles + 5% Torque	Muscles + 10% Torque
Valgus angulation in the valgus test position *(deg)*			
Intact	0.99 (1.36)	2.08 (1.10)	3.08 (1.07)
3-mm cut	1.08 (1.45)	2.42 (1.24)	3.5 (1.37)
6-mm cut	1.4 (1.59)	2.89 (1.44)	4.09 (1.51)
9-mm cut	2.77 (2.00)	4.3 (2.09)	5.92 (2.68)
Varus angulation in the varus test position *(deg)*			
Intact	−1.62 (0.94)	−3.51 (1.37)	−5.25 (2.20)
3-mm cut	−1.40 (0.85)	−3.55 (1.56)	−5.16 (2.25)
6-mm cut	−2.59 (1.02)	−3.91 (1.76)	−5.08 (2.41)
9-mm cut	−1.50 (0.90)	−4.21 (2.66)	−5.85 (3.37)

*The values are given as the mean, with the standard deviation in parentheses. Positive values indicate valgus angulation, and negative values indicate varus angulation.

have been shown to stabilize the elbow joint in vitro[6] and because they did not cause suture-pullout failure during preliminary testing. Passive elbow extension from a position of full flexion, in the plane of the flexion arc, was controlled by two taut nylon cords that were attached to the base of the ulnar styloid. This method allowed a relatively constant angular velocity and minimized the tendency toward valgus or varus displacement that occurs when the forearm is moved by hand. In the valgus and varus test positions, a weighted bag filled with saline solution was attached to the distal part of the radius to account for the weight of the resected hand, which was calculated to be 50% of the weight of the forearm.

The valgus and varus torques that were applied to the forearm in both the valgus and varus test positions were based on the maximal varus torque that is generated to oppose the estimated 64 Nm of valgus torque that occurs across the elbow in baseball pitchers[12]. The medial collateral ligament is responsible for 54% of the resistive varus torque[13], thereby producing 34.6 Nm of torque[12]. Five percent (1.73 Nm) and 10% (3.46 Nm) of this torque was applied sequentially to the distal part of the radius, in the form of bags of saline solution, when the specimen was in the valgus and varus test positions. These torque values were chosen on the basis of data from pilot studies, in which 15% of the throwing torque was found to cause catastrophic failure of the anterior band of the medial collateral ligament.

Testing began with the intact elbow oriented in the neutral test position, with the humerus parallel to the floor and the forearm perpendicular to the floor when positioned in 90° of flexion. The elbow was passively moved from full flexion to full extension by moving the nylon cords with the muscle loads applied. Each testing stage was performed in duplicate. The elbow was then oriented in the varus test position (with the humerus and forearm parallel to the floor, with the ulna inferior and the radius superior). The testing sequence was repeated with the muscles loaded and then with the application

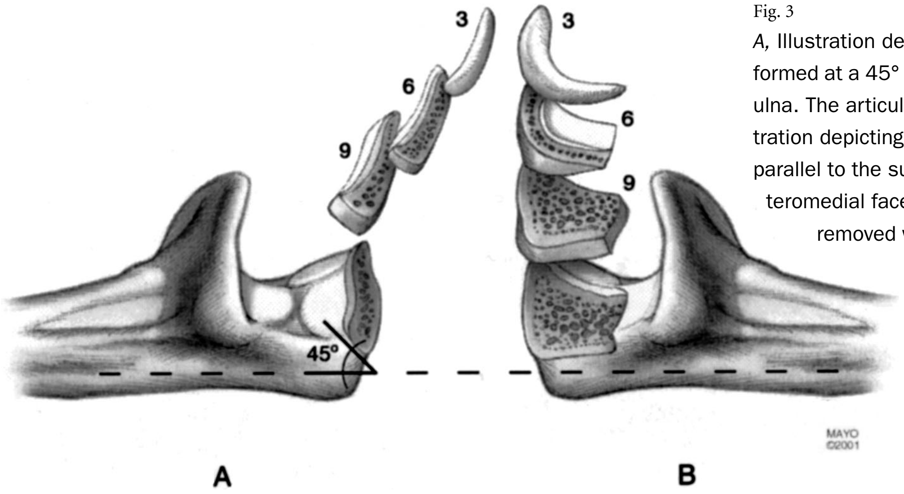

Fig. 3
A, Illustration depicting sequential 3-mm resections performed at a 45° angle to the subcutaneous border of the ulna. The articular cartilage is well preserved. *B,* Illustration depicting sequential 3-mm resections performed parallel to the subcutaneous border of the ulna. The posteromedial facet of the articular cartilage is completely removed with a 6-mm resection. (With permission of the Mayo Foundation.)

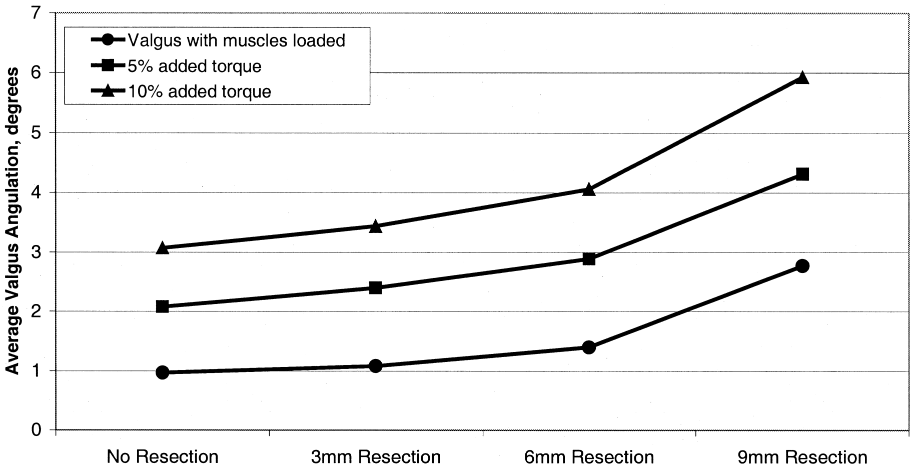

Fig. 4
Illustration depicting valgus angulation with increasing torques and resection, with the elbow positioned in 90° of flexion in the valgus test position.

of the 5% and 10% varus torques. Finally, the elbow was oriented in the valgus test position (with the humerus and forearm parallel to the floor, with the radius inferior and the ulna superior). The testing sequence was repeated with the muscles loaded and then with the application of the 5% and 10% valgus torques. The baseline valgus and varus angulations, used for subsequent analysis, were taken to be those measured with the arm in either the valgus or varus test position with only the weight of the hand attached.

Following testing of the normal (intact) elbow, three sequential 3-mm resections of the olecranon were performed. Each resection was followed by the testing sequence described above. The 3-mm resection thickness was chosen on the basis of clinically relevant measurements in that débridement beyond 9 mm is not common practice yet sequential 3-mm resections can be adequately gauged both arthroscopically and during an open procedure. Each resection was performed with a 9-mm-wide, 0.4-mm-thick oscillating saw blade (Hall Oscillator; Zimmer, Warsaw, Indiana). The resection was aligned at a 45° angle to the sagittal, coronal, and transverse planes (referable to the anatomic position of the olecranon). In comparison, the original resection plane during pilot studies was aligned at a 45° angle between the sagittal and transverse planes and parallel to the coronal plane (that is, parallel to the subcutaneous border of the ulna) (Figs. 2 and 3). It was clear during the pilot study that the original plane of resection was not appropriate as this is not the orientation of the resection typically performed and because a 6-mm resection resulted in the complete removal of the entire chondral surface of the posteromedial articular facet.

The final stage of experimentation was the disarticulation of the elbow joint and digitization of the articular surfaces of the elbow and the distal part of the humeral shaft. These data were used to create a coordinate system based on the osseous anatomy consistent with Matlab software (MathWorks; Natick, Massachusetts). Each experimental condition was tested twice. We observed a small and consistent increase in angulation values between the first and second tests and hence chose the values from the latter for subsequent analysis.

Although dynamic data were collected throughout the entire flexion arc, only one position of flexion, 90°, was used for statistical comparison. This position was selected because

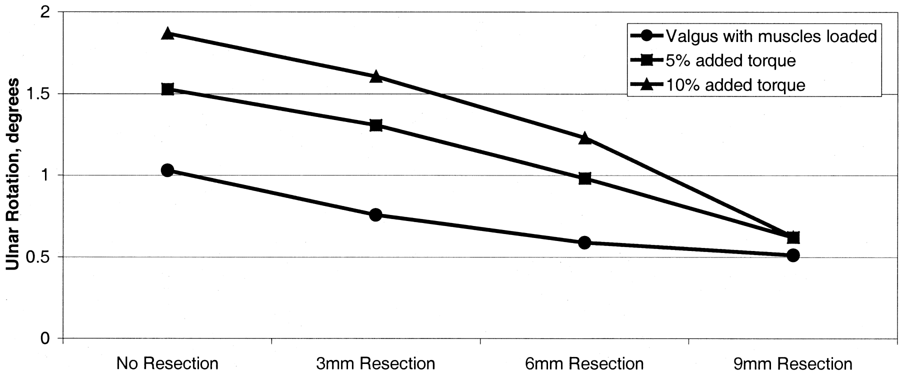

Fig. 5
Illustration depicting ulnar rotation with increasing torques and resection, with the elbow positioned in 90° of flexion in the valgus test position.

TABLE II Axial Rotation of the Ulna with the Elbow Positioned at 90° of Flexion in the Valgus and Varus Test Positions*

	Muscles Alone	Muscles + 5% Torque	Muscles + 10% Torque
Axial rotation in the valgus test position *(deg)*			
Intact	1.02 (2.33)	1.52 (2.21)	1.86 (2.31)
3-mm cut	0.75 (2.58)	1.30 (2.43)	1.60 (2.49)
6-mm cut	0.58 (2.60)	0.98 (2.60)	1.22 (2.75)
9-mm cut	0.51 (2.23)	0.62 (2.43)	0.62 (2.68)
Axial rotation in the varus test position *(deg)*			
Intact	−1.44 (2.05)	−4.00 (3.33)	−5.15 (4.07)
3-mm cut	−0.93 (1.75)	−3.80 (3.71)	−4.89 (4.33)
6-mm cut	−0.84 (2.03)	−3.72 (3.61)	−4.76 (4.14)
9-mm cut	−1.52 (2.25)	−3.58 (4.60)	−4.33 (5.17)

*The values are given as the mean, with the standard deviation in parentheses. Positive values indicate internal rotation, and negative values indicate external rotation.

it represents the position of maximal torque across the elbow during pitching. Statistical analysis consisted of a one-factor analysis of variance with repeated measures for each resection performed. If significance was found, the least-significant-difference method was used as a post hoc test to assess the difference between the variables. Paired t tests were performed to define the significance of the first 3-mm resection under the different loading conditions. Ninety-five percent confidence intervals were calculated to describe the projected effects of 3-mm and 6-mm resections as compared with the intact state.

Results

The paired t test analysis of the intact and 3-mm-cut preparations revealed differences in valgus angulation during all of the loading conditions, with significant differences noted after the addition of 5% torque ($p < 0.004$) and 10% torque ($p < 0.008$). The 95% confidence interval that defined the expected change in angulation due to a 3-mm cut with the elbow in the valgus test position was 0.11° to 0.62° with 10% torque applied. The 95% confidence interval that defined the expected change in angulation due to a 6-mm cut with the elbow in the valgus test position was 0.63° to 1.35° with 10% valgus torque applied, showing an increase in angulation compared with the values associated with the 3-mm cut.

The mean valgus angulation increased for all specimens in association with increased valgus torque (Fig. 4 and Table I). For the intact elbows, valgus angulation increased approximately 1° for each 5% increase in valgus torque. Partial posteromedial olecranon resection resulted in stepwise increases in valgus angulation (Fig. 4). For example, with 10% applied torque, valgus angulation averaged 3.1° for the intact specimens, 3.5° after a 3-mm resection, 4.1° after a 6-mm resection, and 5.9° after a 9-mm resection. This pattern of increase was seen in association with every loading and resection condition.

Axial rotation of the ulna varied little under all test conditions in the valgus test position. The mean value for internal rotation ranged from 0.51° to 1.86°, with no significant differences noted between conditions (Table II). However, increased valgus torque resulted in a trend toward increased internal rotation (Fig. 5) whereas increased resection resulted in a decrease in the absolute degree of internal rotation or, in some specimens, increased external rotation.

Two specimens sustained a complete rupture of the anterior band of the medial collateral ligament when tested after a 9-mm resection with application of the 10% torque in the valgus test position. The specimens were from eighty-seven and eighty-nine-year-old male donors. In both cases, the medial collateral ligament origin was avulsed from the epicondyle. The results prior to failure were included in the subsequent analysis, with exclusion of the results from the final test condition. Thus, the sample size was reduced by two for the analysis of the effect of a 9-mm resection with 10% valgus torque.

No significant differences were found after any resection with the elbow in the varus test position, confirming that posteromedial olecranon resection almost purely affects valgus angulation.

Discussion

During high-level baseball pitching, the speed of elbow motion exceeds 300°/sec[14] and the valgus torque across the joint has been calculated to be 64 Nm[12]. The medial collateral ligament has been estimated to bear 54%[12,13] of this torque, and the radiocapitellar joint has been estimated to bear 33%[13]. The valgus stresses generated during the arm-cocking and acceleration phases of baseball pitching[12] cause wedging of the olecranon process into its fossa[1], resulting in posteromedial and posterior olecranon tip osteophytes with reciprocal lesions of the fossa[1]. The treatment of posterior elbow impingement includes surgical débridement, which involves the removal of adjacent normal articular olecranon bone in an effort to reduce the possibility of further impingement. The aim of the present study was to investigate the hypothesis that removing articular olecranon bone would increasingly alter joint kinematics.

Until the early 1980s, removal of as much as 80% of the olecranon process was a generally acceptable practice in the treatment of comminuted proximal ulnar fractures, especially in patients more than fifty years old, as previous research had shown that doing so had little effect on stability[4]. Only one subsequent study investigated the effects of partial olecranon removal; the findings of that study demonstrated that ulnohumeral joint constraint was directly proportional to the area of the remaining articulation[5]. A progressive decrease in the constraint moment for resisting valgus displacement resulted from removal of the proximal part of the ulna. With the elbow at 0° the resisting moment decreased by >30%, whereas with the elbow flexed to 90° the resisting moment decreased by 50%[5]. These findings clearly highlighted the importance of the proximal quarter of the olecranon in resisting valgus and varus displacements in both elbow positions. However, until recently, the removal of the posteromedial corner of the olecranon in the throwing athlete was governed by the perception that "the more, the better."

In addition to the extent of removal, current surgical débridement techniques vary with regard to the orientation of the resection. One common practice appears to involve a horizontal osteotomy across the olecranon tip, parallel to the subcutaneous border of the ulna, with removal of both the posteromedial and the posterolateral margin. With the increasing realization of the importance of this region, the impact of an osteotomy parallel to the posteromedial olecranon border was recognized. Data from our pilot study further defined that. A resection parallel to the posteromedial border of the olecranon and parallel to the subcutaneous border of the ulna resulted in the removal of excessive amounts of the articular surface (Figs. 3 and 4). A resection that was oriented 45° to the coronal, sagittal, and transverse planes of the olecranon appeared to be least destructive to the bearing surface.

The current study revealed that increasing torque, with the elbow in the valgus test position and in 90° of flexion, increased valgus angulation in regular increments. Resection of the posteromedial part of the olecranon in 3-mm increments also increased valgus angulation. Our results revealed that the resection of 3 mm of normal olecranon bone led to a significant change in valgus angulation with any load greater than gravity. However, this degree of valgus angular change was clinically unimportant and was approximately within the range of accuracy of our testing system. In contrast, a 6-mm cut produced a clinically appreciable increase in valgus angulation. It should be noted that only 10% of the typical in vivo torque was applied to the specimens in this study because of limitations of the cadaveric tissue. We noted a nearly linear increase in the effect of additional torque on valgus angulation. It can, therefore, be extrapolated that normal in vivo loading would result in a much more meaningful and highly measurable increase in angulation at the elbow. We can infer that increasing valgus angular changes increase the load borne by, and the subsequent strain within, the medial collateral ligament. Given the repetitive loads and high valgus loads generated during throwing sports, a small increase in strain may be significant. Hence, small and clinically imperceptible changes in valgus angulation of the elbow resulting from even small amounts of resection may have substantial consequences for the throwing athlete.

In previous studies, removal of the proximal quarter of the olecranon was reported to have a minimal effect on the resistance to axial internal and external rotational displacement at both 0° and 90° of flexion[5]. The greatest change (representing more than a 10% decrease) was noted in the resistance to internal rotation at 0°, but the overall effect was minor. In the present study, no significant changes in axial rotational displacement were noted in association with any of the test conditions but a clear trend emerged in the valgus position. Increasing the applied load increased the internal rotation of the ulna, whereas increasing the amount of resection decreased the amount of internal rotation.

The present study had a number of recognized limitations. Cadaveric elbows from elderly donors are far from optimal, and the age-related changes in the bones and ligaments should be kept in mind when these data are extrapolated to a younger athletic population. Another issue associated with the use of cadaveric specimens concerns the integrity of the ligaments as a function of repeated testing and the possibility of stretching. This problem cannot be completely excluded without resorting to a large number of cadavera in order to test a single step of a single resection at a single additional level of torque. We partially accounted for this testing flaw by using the baseline valgus/varus displacement at each experimental stage as that displacement when the arm was in the valgus/varus test position with the arm weight applied at the beginning of each resection stage. The flexor-pronator mass is thought to provide dynamic, load-sharing support to the medial collateral ligament either by producing tension in the muscle mass during active supination[15] or by producing contractile tension during active pronation. The dynamic stabilizing effect of the flexor pronator mass was not taken into account during the present study, although it has been documented to aid in the resistance to valgus loads[12]. The "preload" protection realized by contracting muscles was imperfectly simulated. Valgus moments that were known to be considerably less than physiological moments caused gross rupture of the anterior band of the medial collateral ligament in two specimens during this study. This observation was attributed to the two study limitations described above. The experimental design utilized passive loading and passive motion. We thought that it was important to visualize the anterior band of the medial collateral ligament directly, through a predominantly muscle-splitting, and minimally resecting, approach through the flexor pronator mass. This disturbance may have increased the load borne by the anterior band of the medial collateral ligament.

We have attempted to define the kinematic effects of posteromedial olecranon resection. In current clinical practice, which often is not based on documented biomechanical data, varying amounts of olecranon are removed, with the resection extending beyond the osteophytic margin and into the normal olecranon anatomy. Whereas this may be of little consequence in low-demand and older patients, much of the interest in this subject arises from its relevance to the throwing athlete. For instance, baseball pitchers can experience extremely large torques across the elbow that are close to the in vitro failure threshold of the anterior band of the medial collateral ligament. These throwing athletes are especially prone to chronic overuse of the elbow because of the high-performance and repetitive nature of activity in their profession. It is these features that predispose the elbow, following partial olecranon resection, to fatigue failure of the anterior band of the medial collateral ligament, with potential exacerbation of the preexisting injury. This sequence of events may lead to further substantial derangement of joint kinematics and may result in a career-ending injury.

In conclusion, we found that increased posteromedial olecranon resection led to increased valgus angulation and decreased axial internal rotation of the ulna about the humerus in the valgus test position. Increased applied torque, regardless of the amount of resection, led to increased valgus angulation and internal rotation in the valgus test position. A 6-mm resection of the posteromedial part of the olecranon resulted in immediate and measurable kinematic changes. We concluded that, in throwing athletes, posteromedial olecranon resection should not extend beyond the abnormal osteophytes to include normal olecranon bone. ■

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