# Determining Humeral Retroversion with Computed Tomography

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**Background:** The purpose of this study was to develop and standardize a technique in which computed tomography images are used to determine the humeral torsion angle with landmarks that can be used during surgery.

**Methods:** One hundred and twenty cadaveric humeri were studied. The retroversion of these anatomical specimens was measured on a computed tomography scan and compared with the direct measurements of the specimens. The retroversion of the humerus was measured by determining the orientation of the proximal articular surface of the humerus with respect to the transepicondylar line of the distal part of the humerus and the forearm axis. To evaluate this method of measuring retroversion, the protocol was tested in patients before and after shoulder arthroplasty.

**Results:** The degree of reproducibility of the measurements made on the computed tomography scan was evaluated by determining the interclass correlation coefficient. The interclass correlation coefficient was considered good (between 0.85 and 0.90) for the measurements of the normal humeri when the orientation of the articular surface measured in the distal part of the humeral head, the epicondylar axis, and the ulnar axis were used as references. There was a significant difference ($p < 0.01$) between the mean angular orientation of the proximal articular surface with respect to the epicondylar axis (17.6°) and the mean angular orientation of the proximal articular surface with respect to a line perpendicular to the forearm axis (28.8°). Despite a wide variation in the humeral torsion angle among the specimens from the different cadavera, the angle varied little between the two normal humeri of the same individual (mean side-to-side difference, 2.1°).

**Conclusion:** This study demonstrated that retroversion of the proximal part of the humerus can be reliably measured with computed tomography.

**Clinical Relevance:** Determining retroversion with computed tomography is more accurate than palpating the epicondylar axis or using the forearm as a goniometer during surgery. Computed tomography is useful for measuring the amount of rotation of humeri with a malunited fracture or severe arthritic deformity.

Anatomical studies have shown that retroversion of the proximal part of the humerus is highly variable, ranging in some series from −6° to 50°[1-6]. When shoulder arthroplasty is performed, the axis of the articular surface is usually appreciable. However, the retroversion angle of the humeral osteotomy may be difficult to evaluate intraoperatively when the humeral head is deformed. Evaluation is equally difficult when there is a fracture of the proximal part of the humerus since the usual landmarks cannot be identified.

Computed tomography has been used to measure tibial and femoral torsion by calculating the angle between defined axes of the proximal and distal metaphyses of those bones[7,8]. To our knowledge, this technique has rarely been applied to the measurement of torsion of the humerus[9], and when it has been, the orientation of the distal articular surface of the humerus was the osseous landmark used for measurement[10]. This surface is not palpable and cannot be used by the surgeon during surgery. We hypothesized that the humeral torsion angle could be measured on axial computed tomography images with use of the epicondylar axis or the forearm axis for reference since these osseous landmarks can be seen during surgery.

## Materials and Methods

### *Measurements of Anatomical Specimens*

#### Selection of Specimens

In the first series, twenty paired humeri with the elbow joints intact were obtained from ten fresh cadavera, and all soft tissues were dissected. The mean age of the donors (five men and five women) at the time of death was seventy years (range, sixty-three to eighty-one years). These twenty paired specimens, which had no structural abnormality, were used to determine whether the forearm could be used as a goniometer with the elbow flexed 90° during shoulder arthroplasty.

In the second series, forty paired humeri were obtained from twenty fresh cadavera; all soft tissues were removed, and care was taken to avoid damage to the articular cartilage. The mean age of the donors (eight men and twelve women) at the time of death was seventy-two years (range, sixty-five to eighty-two years). Two pairs of specimens demonstrated a unilateral deformity that was consistent with a previous fracture. These two pairs were not excluded but were studied to compare the pathological side with the normal side.

In the third series, sixty unpaired humeri without structural abnormality were obtained from dry cadaver specimens. The gender or exact ages of the donors of the sixty specimens were not known, but the ages were estimated[11-13] to be between forty-five and seventy years.

### Determination of Reference Axes and Osseous Landmarks

Full-length computed tomography scans were made of the first ten specimens to study the cross-sectional morphology of the humerus and to identify landmarks for measurement. Measurements of the other specimens were made on 3-mm-thick scanner sections through the first 6 cm of the proximal part of the humerus and on 3-mm-thick scanner sections through the entire length of the distal epiphysis (the last 5 cm of the distal part of the humerus).

After review of the initial full-length scans, we agreed on the selection of proximal and distal reference axes. The orientation of the proximal articular surface of the humerus was first measured on the section passing through the center of the head of the humerus (Fig. 1), with use of a line perpendicular to the chord of the diameter of the articular surface at the level of the margin of the cartilage. Without arthro-computed tomography, it is difficult to identify the cartilaginous part of the humerus on the section passing through the center of the humeral head in patients (Fig. 1) as well as in anatomical specimens. However, the cartilaginous part is easy to recognize at the distal part of the humeral head because its spherical shape is different from the shape of the humeral neck.

The fundamental problem with this method of measuring the angles at the proximal part of the humerus derives from the irregular geometry of the margin of the cartilage, which means that this line may vary between a slice passing through the center of the humeral head and a slice passing through the distal part of the humeral head. Consequently, to calculate the possible error, measurements were made on serial images of the humeral head with 3 mm between each section. The slice containing the center of the humerus was defined as the slice in which the diameter of the humeral head was the greatest. The slice designated as "0 mm" was the slice corresponding to the apex of the humeral head.

At the distal part of the humerus, two methods of defining the distal axis were studied. One method was based on the orientation of the transepicondylar line (Fig. 2) as measured on the scanned section in which the epicondyles appeared to be the most prominent. This method was evaluated because the orientation of the epicondylar line can be assessed during surgery since the epicondyles are palpable. The measurements

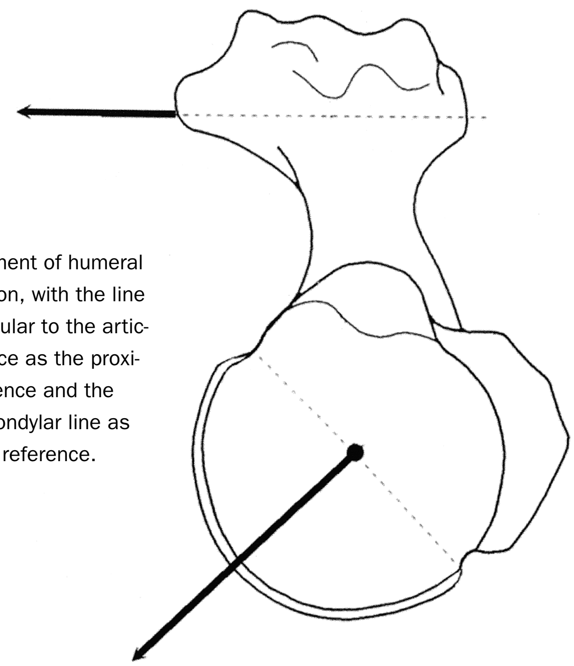

Fig. 1

Measurement of humeral retroversion, with the line perpendicular to the articular surface as the proximal reference and the transepicondylar line as the distal reference.

were also made on different levels (two above and two below this line), with use of the horizontal line as a reference line, with the humerus lying with the anterior articular surface of its distal part downward and horizontal.

In the study of the twenty paired specimens that included the elbow joint and the forearm, the long axis of the ulna was placed vertically in the scanner and the elbow was flexed 90°. This allowed us to determine the angle between the proximal articular surface of the humerus and a line perpendicular to the long axis of the ulna. The long axis of the ulna was represented by a line extending from the medial part of the olecranon process to the distal part of the styloid process (Fig. 2). This method was evaluated because some surgeons use the forearm as a goniometer to measure retroversion. The orientation of the forearm is the result of what is called the *carrying angle* of the elbow joint[14-16]. The angle between the transepicondylar line and the line perpendicular to the axis of the ulna was called the *angle Theta*.

### Direct Measurements of Anatomical Specimens

Direct anatomical methods of measurement on bone have ranged from direct inspection[2,4] to point measurements on the surface of the bone with use of a circular protector[17] or with coordinate machines[1,18]. Since the aim of the present study was to evaluate humeral retroversion in a way directly applicable to replacement arthroplasty of the proximal part of the humerus, the anatomical method of measurement consisted of evaluation of the retroversion in relation to the plane of the articular surface, as previously reported[19]. A pin was transfixed across the distal epicondyles, and the border of the articular surface was marked with a wire loop. The humerus was rotated about its longitudinal axis and was inspected under fluoroscopy so that the mark approximated a straight line. In all

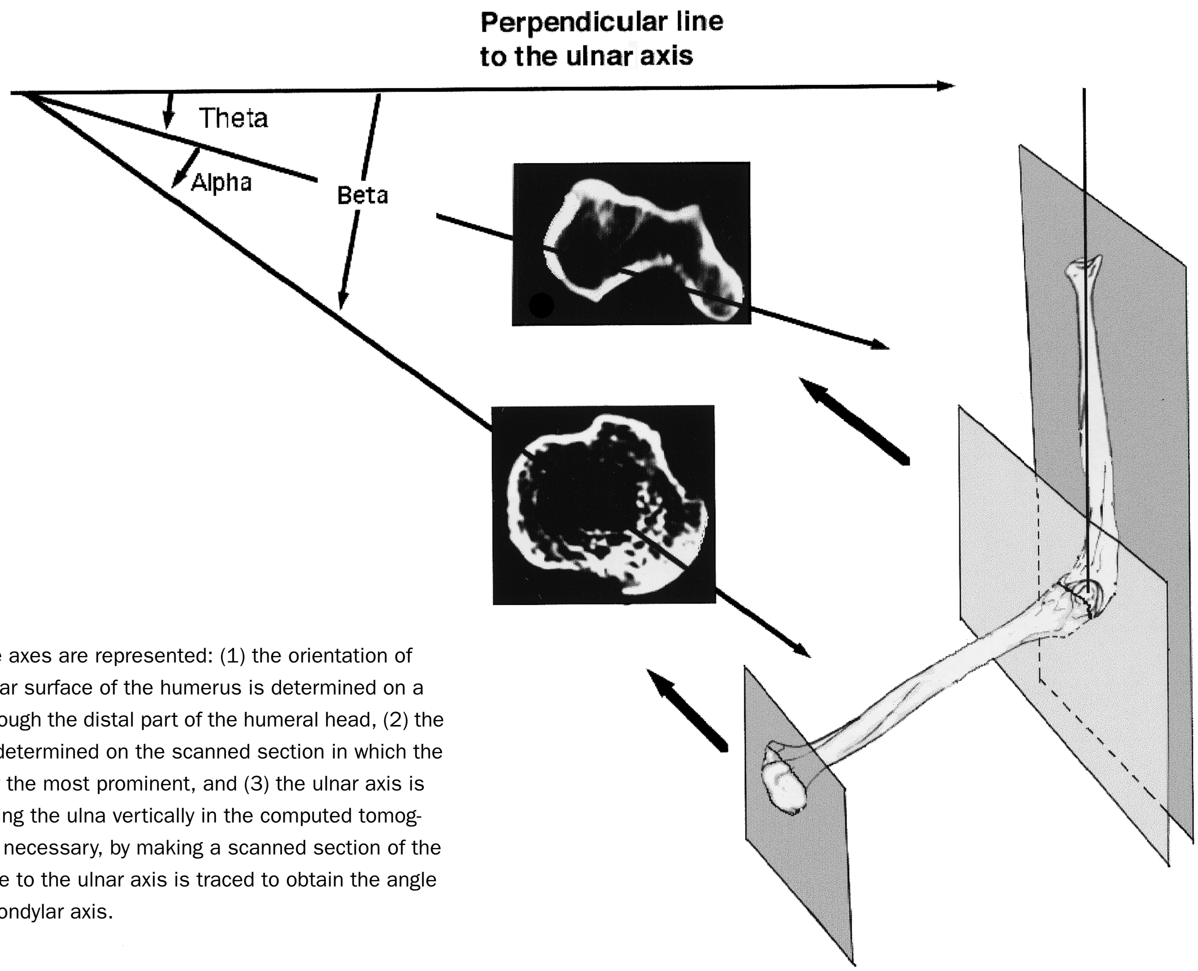


Fig. 2

The three reference axes are represented: (1) the orientation of the proximal articular surface of the humerus is determined on a section passing through the distal part of the humeral head, (2) the epicondylar line is determined on the scanned section in which the epicondyles appear the most prominent, and (3) the ulnar axis is determined by placing the ulna vertically in the computed tomography scanner or, if necessary, by making a scanned section of the ulna. The right angle to the ulnar axis is traced to obtain the angle Theta with the epicondylar axis.

but the anatomical position of retroversion, the mark appeared as a part of an ellipse. Retroversion of the articular surface relative to the distal pin was then measured with a goniometer aligned to the pin. In the study of the twenty specimens with the elbow joint intact, the retroversion of the proximal articular surface was measured relative to the ulnar axis with the elbow flexed 90°. Two measurements were made on each humerus at different times.

### *Measurements in Patients*

The patient was positioned so that the shaft of the humerus was parallel to the long axis of the scanner. The elbow was flexed 90° with the ulna vertical. To prevent motion of the forearm in this position, it was supported with wedges of foam rubber. The forearm was vertical in the gantry for measurements of the distal part of the humerus. Theoretically, if the patient is able to maintain the forearm vertical, a section passing through the forearm is not necessary as the vertical line on the computed tomography section represents the forearm axis. When a patient has an acute proximal humeral fracture, this position can of course be safely maintained only on the contralateral side. After generation of an anteroposterior digital radiograph, the position of the several computed tomography images was selected. The orientation of the proximal articular surface of the humerus was measured on the section passing through the distal part of the humeral head (at 33 ± 3 mm from the top of the humerus), with use of the line perpendicular to the chord of the diameter of the articular surface, at the level of the margin of the cartilage or at the level of the osteophytes for a shoulder with that pathological condition. The vertical line was the axis of the forearm representing the ulna. The epicondylar line was determined by drawing a line between the epicondyles where they appeared to be the most prominent. This technique provided a cross section of bone through the humeral head to define the proximal rotation of the humerus as well as a distal humeral section with the elbow flexed 90° and the ulna vertical to provide information on the rotational variation in the distal part of the upper limb, allowing the surgeon to use either mark (the epicondylar axis or the forearm axis) for assessment of retroversion during surgery. Another section through the whole forearm was sometimes added to obtain the axis of the ulna. This appeared necessary since some patients could not maintain the forearm in a vertical position in the gantry. Differences between the normal and pathological sides were examined statistically.

Retroversion of both humeri was measured preoperatively in twenty-three consecutive patients with a unilateral pathological condition. Shoulder arthroplasty was performed for the treatment of osteoarthrosis in thirteen patients, for the treatment of a recent proximal fracture of the humerus in six, and for the treatment of a malunited proximal fracture of the humerus in four. The thirteen patients with osteoarthrosis also had measurements made during surgery. The articular surface axis was identified intraoperatively, and prior to osteotomy the humeral retroversion was measured with a goniometer in relation to the epicondylar axis identified by palpation and in relation to the forearm axis (ulnar axis). Preference was given to the computed tomography measurements when decisions were made regarding prosthetic implantation. The data obtained with the preoperative computed tomography were used during the arthroplasty with the hope that the anatomical reconstruction could be tailored according to this preoperative evaluation. For implantation of the humeral stem, retroversion was determined by using the forearm as a goniometer. Great care was taken to be certain that the elbow was flexed to 90° since the carrying angle of the human elbow joint changes with flexion of the elbow joint[14]. After surgery, the retroversion of the humeral head was again measured with computed tomography. The patient was positioned so that the stem of the humeral prosthesis was parallel to the long axis of the scanner. The orientation of the articular surface of the prosthesis was measured with use of the neck of the stem in the section (Fig. 3). In the six patients with severe comminution of the proximal part of the humerus, the technique of measuring retroversion could not be used reliably on the pathological side because of loss of anatomical landmarks. In these cases, the orientation of the articular surface on the contralateral side was used during the arthroplasty. Retroversion of the humeral head was also measured with computed tomography after the shoulder arthroplasty and was compared with that on the contralateral side in seven other patients who had not had preoperative computed tomography.

### *Statistical Investigations*

To detect a difference in the humeral torsion angle between the different methods of selecting the reference axes, the differences between two groups of data were analyzed with the Mann-Whitney U test. Comparative relationships between different methods of measurement were examined with the Spearman rank correlation test (Rs values). The level of significance was set at $p < 0.05$, and when the relationship was found to be significant with the Spearman test, a linear regression analysis was used to explore the relationship; the result was given as an r value (Pearson) and by the equation of the regression line. To determine if the direct anatomical measurements could be approximated with computed tomography values, the deviations between the first and second estimations derived by direct anatomical measurements were used as a reference against which the accuracy of the computed tomography values was evaluated. The absolute difference, the absolute percentage deviations, and the systematic percentage between the two different methods of measurement were calculated and assessed with the Mann-Whitney U test[20].

The absolute side-to-side differences in each parameter evaluated in the paired specimens were examined statistically (Mann-Whitney U test). In addition, to investigate any association between the magnitude of the parameter and the difference between sides, a scatterplot of the torsion angles on the right and left sides of the normal specimens and the absolute side-to-side (right-left) differences was examined visually both through simple linear regression analysis and through the Spearman rank test.

To determine the reliability of the technique of computed tomography measurement of specimens, three inde-

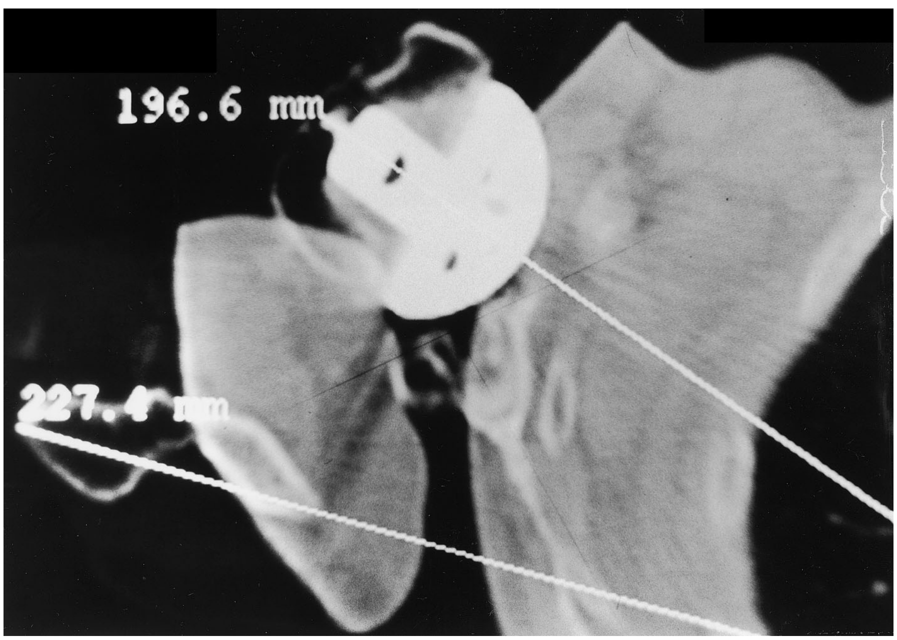


Fig. 3

Measurement of retroversion of the prosthesis, with the epicondylar line used as the reference axis.

**TABLE I Comparison of Retroversion* Measured with Computed Tomography and That Measured on Anatomical Specimens**

| | Mean and Standard Deviation *(deg)* | | |
|---|---|---|---|
| Angle Alpha (120 specimens) | | | |
| Computed tomography scan (first review) | 17.1 ± 8.1 | p = 0.796 | |
| Computed tomography scan (second review) | 18.6 ± 8.3 | p = 0.892 | p = 0.646 |
| Anatomical measurement (first review) | 19.2 ± 9.7 | | |
| Anatomical measurement (second review) | 18.4 ± 9.5 | p = 0.878 | |
| Angle Beta (20 specimens) | | | |
| Computed tomography scan (first review) | 28.8 ± 6.4 | p = 0.816 | |
| Computed tomography scan (second review) | 29.5 ± 6.1 | p = 0.884 | p = 0.792 |
| Anatomical measurement (first review) | 29.7 ± 6.3 | | |
| Anatomical measurement (second review) | 30.1 ± 5.9 | p = 0.846 | |

*The retroversion was measured as the angle between the articular surface and the epicondylar line (angle Alpha) or the line perpendicular to the axis of the ulna (angle Beta). The p values were obtained with the Mann-Whitney U test.

pendent observers measured twenty-two angles (with sixteen variations in the orientation of the proximal articular surface, five variations in the epicondylar axis, and one ulnar axis) on each of the first ten humeri at three different times; thus, there were 1980 ($22 \times 10 \times 3 \times 3$) individual measurements. A two-way random effect (variance components) analysis of variance was used to determine the reliability of each measurement. The reliability coefficient (interclass correlation) was measured[21,22]. That value can range from 0 to 1, with values close to 1 indicating high reliability of measurements.

## Results

### *Measurements of Anatomical Specimens*

**Reliability of Computed Tomography Measurements (Ten Specimens)**

The reliability coefficient (interclass correlation) ranged from 0.65 to 0.90 for the twenty-two angles measured on the scans of the first ten humeri. Those interclass correlations were significant ($p < 0.001$). The better reproducibility was for the ulnar axis (0.89 to 0.90) and the epicondylar axis (0.85 to 0.89). Also, the reproducibility was better for measurements on sections passing through the distal part of the humeral head (0.87 to 0.90) than it was for those on sections passing through the center of the humeral head (0.77 to 0.82) or through the proximal part of the humeral head (0.65 to 0.76).

The degree of reproducibility of measurements made with use of the ulnar axis, the epicondylar axis, and the orientation of the proximal articular surface measured in the distal part of the humeral head (with the slice levels ranging from 30 to 39 mm from the top of the humerus) was considered sufficiently reliable to be used in measurement applications.

We examined, with use of the method of tolerance limits[23], the importance of a variation in computed tomography measurement caused by observer error in the evaluation of humeral torsion in anatomical specimens. The impact of this variation due to observer error (based on the inversion of the tolerance limit calculations) was that one could be 95% confident that 99% of the time the observer measurement error would be <10° and that 84% of the time the observer measurement error would be <5°.

The boundary of the articular surface of the humeral head was studied on sections situated between 15 and 39 mm from the top of the humerus. Calculation of the angle between the transepicondylar line and the articular surface in the different sections of the humeral head in the 120 specimens showed a difference of only 1.8° between the average measurements of the most different values (those measured with the articular surface situated 18 mm from the top of the humerus and those measured with the articular surface at 30 mm). This difference was not found to be significant ($p = 0.491$) with the Mann-Whitney U test, and retroversion measured with the section passing through the distal part of the humeral head can be considered to be not different from the value measured with the section passing through the center of the humeral head. The section passing 33 mm from the top of the humeral head was chosen as the reference section for the proximal articular surface.

The effect of the section level of the epicondylar axis was also analyzed. The average variation between the angles measured with the epicondylar axis in the proximal section and those measured with the epicondylar axis in the distal section (with the sections separated by 12 mm) was 0.2°, which was not significant ($p > 0.05$).

**Comparison Between Computed Tomography and Anatomical Measurements**

The retroversion measured on the computed tomography scans, with the orientation of the proximal articular surface determined in the section 33 mm from the top of the humeral head, was compared with the retroversion measured directly on specimens with the help of fluoroscopy. The retroversion of the articular surface relative to the epicondylar line (angle Alpha on Fig. 2) averaged 17.1° on the first review of the computed tomography scan. The mean values did not differ significantly according to the sex of the donor ($p = 0.09$) or

**TABLE II Computed Tomography Measurement of Retroversion with the Epicondylar Axis (Angle Alpha) or the Ulnar Axis (Angle Beta) as Reference**

| | | Retroversion *(deg)* | | |
|---|---|---|---|---|
| Angle | No. of Specimens | Mean and Standard Deviation | Minimum | Maximum |
| Alpha | 20 | 17.6 ± 12.3 | 1 | 32 |
| Beta | 20 | 28.8 ± 6.41 | 20 | 37 |
| Theta | 20 | 11.1 ± 5.2 | 7 | 19 |

**TABLE III Side-to-Side Variability of Retroversion**

| | | Mean Side-to-Side Variation* *(deg)* | |
|---|---|---|---|
| Angle | No. of Specimens | Computed Tomography Measurements | Anatomical Measurements |
| Alpha | 56 | 2.1 (p = 0.64) | 2.3 (p = 0.61) |
| Beta | 20 | 1.9 (p = 0.35) | 2.2 (p = 0.31) |
| Theta | 20 | 1.9 (p = 0.35) | 1.8 (p = 0.35) |

*The p values indicate the significance of the differences between sides as evaluated with the Mann-Whitney U test.

between the right and left sides of the cadavera ($p = 0.09$).

The difference between the angle Alpha measured with the computed tomography method and that measured with the anatomical method (Table I) was not significant ($p = 0.646$), and the relationship (evaluated with the Spearman rank test) between the values was strong ($Rs = 0.991$; $p < 0.001$). Regression analysis showed a strong linear relationship between the retroversion measured with computed tomography and that ascertained with direct anatomical measurement ($r = 0.998$). The variation between the first and second computed tomography estimations was not significantly greater than that between one computed tomography estimation and one anatomical measurement or that between two anatomical measurements. The level of significance of these comparisons was $p > 0.139$ for the absolute difference, the absolute percentage deviation, and the systematic deviation. The same results were observed (Table I) when the angle of the proximal articular surface relative to the line perpendicular to the ulnar axis was measured (angle Beta on Fig. 2).

### Difference Between Measurements Made with the Epicondylar Axis as the Reference and Those Made with Use of the Forearm as a Goniometer (Twenty Specimens)

There was a significant difference ($p < 0.01$; Mann-Whitney U test) between angle Alpha and angle Beta (Fig. 2) (Table II). This difference is represented by the angle between the transepicondylar line and the line perpendicular to the axis of the ulna (angle Theta). The average angle Theta (and standard deviation), measured with the elbow flexed 90°, was 11.1° ± 5.2° (range, 7° to 19°).

We decided to look for functional relationships between the torsion of the proximal part of the humerus (proximal to the epicondylar axis) and the torsion of the distal part of the upper limb (distal to the epicondylar axis). We therefore examined the relationship between angle Alpha (measured between the orientation of the proximal articular surface and the epicondylar axis) and angle Theta (measured between the epicondylar axis and the line perpendicular to the ulnar axis with the elbow in 90° of flexion). An inverse relationship was found between angle Alpha and angle Theta at 90° of elbow flexion ($Rs = -0.741$; $p < 0.001$). When the proximal articular retroversion (angle Alpha) increases, the carrying angle of the elbow decreases. This probably explains why the variation in angle Beta is smaller than the variation in angle Alpha (Table II). This may also explain why the clinical rotation measured in the shoulders of patients is not highly variable, in contrast with the variable degrees of retroversion measured directly on humeral specimens.

The angular data presented here support the notion that the geometric angular orientation of the proximal part of the humerus relates functionally to the orientation of the distal forearm axis. These data have surgical implications: it appears that the forearm can be used as a goniometer with the elbow flexed as an alternative to palpating the epicondylar axis intraoperatively, but that method does not have exactly the same reliability as does the method employing epicondylar axis.

### Side-to-Side Variability in the Results of Computed Tomography and Anatomical Measurement (Fifty-six Specimens)

Analysis of the fifty-six paired normal specimens revealed a mean side-to-side difference of 2.1° for the computed tomography measurements of the retroversion angle between the articular surface and the epicondylar axis (angle Alpha) (Ta-

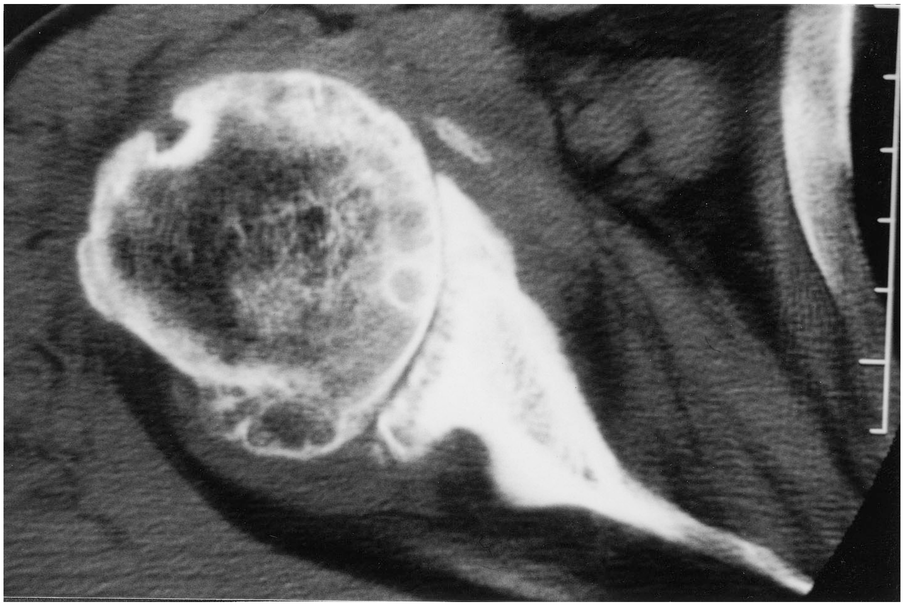

Fig. 4

In a patient with glenohumeral osteoarthrosis, the level of the margin of the cartilage is not an easily identifiable osseous landmark at the central part of the humeral head.

ble III), with the retroversion more marked on the right side. This side-to-side difference was not significant ($p > 0.05$). The scatterplots did not reveal any association between the torsion angle on either the right or the left side of each normal pair and the difference between the two humeri of the pair. Also, no relationship was found between the mean torsion of each normal pair and the difference between the two humeri of the pair. The mean side-to-side variability of the measurements performed directly on the bone specimens (2.3°) was not significantly different from the mean side-to-side difference in the measurements obtained with computed tomography ($p > 0.05$). The same results were observed for angles Beta and Theta (Table III).

***Results in Patients Who Underwent Computed Tomography Measurement Measurements Made Before Shoulder Arthroplasty (Twenty-three Patients)***

For the thirteen patients with unilateral glenohumeral osteoarthrosis, the limits of the articular surface were difficult to trace at the proximal and central parts of the humeral head (Fig. 4). Osteophytes were present at the distal part of the humeral head, but the limits of the osteophytes were easy to trace at this level. Using the epicondylar axis and measuring the retroversion on the pathological side at the limits of the osteophytes at the distal part of the humeral head (Fig. 5), we calculated a mean side-to-side difference in the torsion angle of 2.4° for the thirteen patients (Table IV), which was not sig-

Fig. 5

Measurement of retroversion at the limits of the osteophytes in the distal part of an osteoarthritic humeral head.

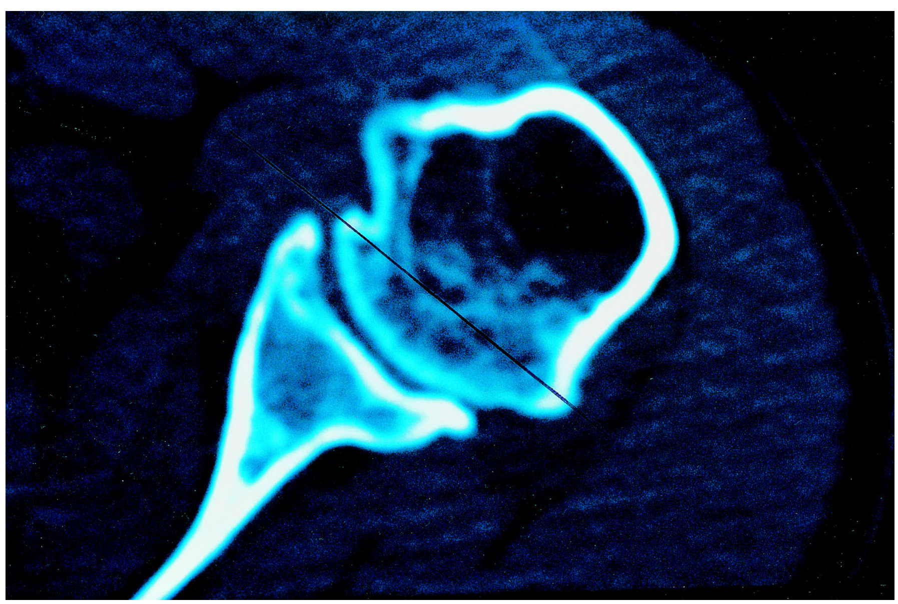

**TABLE IV Mean Retroversion* (and Standard Deviation) on the Preoperative Computed Tomography Scans, at the Operation, and on the Postoperative Computed Tomography Scans in Thirteen Patients with Unilateral Glenohumeral Osteoarthrosis**

| | Pathological Side | | | Normal Side (Computed Tomography Scan) |
|---|---|---|---|---|
| | Preop. Computed Tomography Scan | At Op. | Postop. Computed Tomography Scan | |
| Retroversion measured relative to epicondylar axis *(deg)* | | | | |
| Mean | 16.1 ± 12.3 | 25.3 ± 15.2 | 15.9 ± 12.7 | 18.5 ± 11.4 |
| Side-to-side difference | 2.4 | 6.8 | 2.6 | |
| Retroversion measured relative to ulnar axis *(deg)* | | | | |
| Mean | 27.5 ± 6.7 | 33.5 ± 11.4 | 26.9 ± 6.1 | 29.3 ± 5.6 |
| Side-to-side difference | 1.8 | 4.2 | 2.4 | |

*Reliability coefficient = 0.81 to 0.86. With the method of tolerance limits, it was determined that one could be 95% confident that 80% of the time the observer measurement error would be <5°.

nificantly different ($p > 0.05$) from the value of 2.1° obtained from the analysis of the fifty-six paired normal humeri from the cadavera. This finding suggests that the limits of the osteophytes at the distal part of the humeral head can be used to measure humeral retroversion when the normal articular surface landmarks cannot be traced.

The side-to-side difference in the torsion angle of the articular surface of the humerus was also determined in the four patients with a malunited fracture of the proximal part of the humerus with increased internal rotation of the shoulder. The mean side-to-side difference in these four patients as well as in the two cadavera with a unilateral malunited fracture (a total of six pairs) averaged 21.2°. The difference between this value of 21.2° and the value of 2.1° in the group of fifty-six paired normal humeri was highly significant ($p < 0.0001$). The preoperative examination of the four patients with a malunited fracture demonstrated that it was impossible to correct the insufficient external clinical rotation of the shoulder with a humeral osteotomy at the stem-head angle of the prosthesis without violating the greater tuberosity and the insertion of the rotator cuff.

### Measurements Made During Shoulder Arthroplasty (Thirteen Patients)

The measurements of retroversion made during surgery in thirteen patients with osteoarthrosis (Table IV) were compared with the measurements made on the preoperative computed tomography scans of the pathological side and those made on the computed tomography scans of the contralateral, normal side. When the measurements were made with the epicondylar axis as a reference (Fig. 6), the mean side-to-side difference in the values determined on the preoperative computed tomography scans (2.4°) was significantly smaller ($p = 0.02$) than the mean side-to-side difference of the values determined at the time of surgery (6.8°). This finding suggests that preoperative calculation of retroversion on computed tomography is more accurate than measurement during surgery. This was also true for the measurements made with use of the forearm as the reference axis (Table IV).

As demonstrated by the Spearman rank test, the relationship between the retroversion measured during surgery and that measured with computed tomography with use of the ulna as the distal reference (Rs = 0.986) was stronger than the same relationship between the measurements obtained with the epicondyles used as the distal reference (Rs = 0.914). When the forearm axis was used as the distal reference, the mean dif-

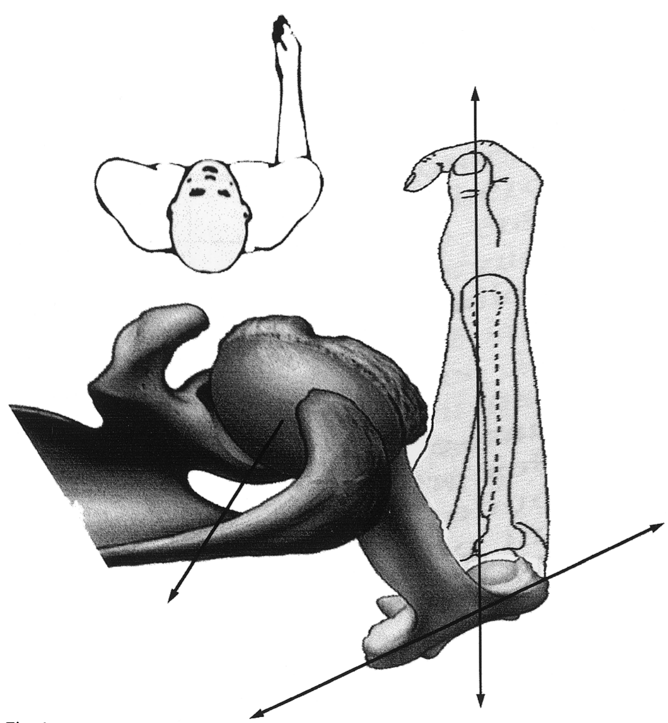

Fig. 6

Intraoperative measurement of the retroversion of the articular surface of the shoulder with the forearm used as a goniometer and with the epicondylar axis as the reference.

ference (6°) between the retroversion measured during surgery and that measured with computed tomography was significantly smaller ($p = 0.02$) than the difference (9.2°) when the epicondylar axis was used as the reference. This observation suggests that measurement of retroversion during surgery is less accurate when it is based on epicondylar palpation than when it is determined with the forearm axis as a reference.

**Measurements Made After Shoulder Arthroplasty (Twenty-six Patients)**

In the seven patients without preoperative computed tomography, the mean side-to-side difference in the postoperative torsion angle (15.3°) was significantly different ($p < 0.001$) from the value for the paired normal cadaveric humeri (2.1°). Injury of the posterior part of the greater tuberosity by the osteotomy was observed on the computed tomography scans of three patients. In the thirteen patients who had had computed tomography before the shoulder arthroplasty (Table IV), the mean difference (0.2°) between the average preoperative value (16.1°) and the average postoperative value (15.9°) on the pathological side was not significant ($p = 0.79$).

For the six patients with a fracture and comminution of the proximal part of the humerus, the orientation on the contralateral side as seen on the preoperative computed tomography scans was used as a reference during surgery. The mean side-to-side difference (3.2°) in the postoperative torsion was not significantly different ($p = 0.16$) from that in the paired normal cadaveric humeri. This finding suggests that preoperative computed tomography scans may be useful to the surgeon during the implantation of a humeral prosthesis.

## Discussion

There have been several reports describing retroversion of the humerus. Technical difficulties and the lack of precision of earlier methods of measuring torsion[24,25] led to the recent use of axial radiographs[26] or computed tomography[9]. However, the distal osseous landmark has been the anterior aspect of the distal humeral articular surface, which cannot be used intraoperatively by the surgeon. Also, we are not aware of any study documenting the reproducibility of that method in a large series of bones. We believe that our technique for measuring humeral retroversion can help the surgeon to replicate the individual retroversion of each humerus during shoulder arthroplasty (Fig. 6).

In our study, four patients could not maintain the forearm in a vertical position in the gantry because of an interior rotation contracture, pain, or a body habitus too large for the diameter of the gantry. This situation was addressed by obtaining an additional section of the whole forearm to determine the axis of the ulna. In two other cases, it was not possible to position the axis of the humerus parallel to the long axis of the scanner. The sections were not perpendicular to the axis of the humeral shaft but were reformatted according to the bone axis to obtain sections perpendicular to it. Retroversion cannot be determined on sections that are not perpendicular to the long axis of the bone. Following arthroplasty, the best way to measure retroversion if the stem is not parallel to the long axis of the scanner is to reformat the sections along the axis of the stem.

Proximal humeral morphometry with use of the described technique has limitations. It is difficult to trace the osseous landmarks under certain circumstances, such as when the humeral head is nonspherical, has voluminous osteophytes, or has osteolysis. The technique also cannot be used reliably when there is a severely comminuted fracture of the proximal aspect of the humerus because of the loss of anatomical landmarks. Despite a wide variation in the data among the different cadaveric specimens in our study, the data varied little between the two normal humeri of the same individual. On the basis of these as well as other findings[27], it appears that, in patients with a unilateral pathological condition of the shoulder, the geometry of the affected humerus can be determined reliably by measuring the contralateral, normal humerus. Our findings and conclusions are similar to those reported in studies of torsion of the tibia, femur, and radius[7,8,28]. When a patient has bilateral glenohumeral osteoarthrosis with major deformities of both shoulders, the limits of the osteophytes at the distal part of the humeral head can be used to define the orientation of the proximal humeral articular surface.

Retroversion of the proximal part of the humerus is highly variable, ranging from −6° to 50°[1-6]. Theoretically, anatomical reconstruction of the retroversion angle during arthroplasty should be tailored to the individual. The osteotomy should not violate the greater tuberosity (particularly its posterior part that is not under visual control) because of the vulnerability of the insertion of the rotator cuff[29]. Pearl and Kurutz[30] demonstrated that the normal anatomy often cannot be replicated exactly with a prosthetic system because of a limited inventory of implant sizes and geometries. In most situations, the choice of the osteotomy site, the size of the prosthesis, and the amount of prosthetic version represents a compromise among the different parameters. It may be important for the surgeon to know preoperatively whether the original retroversion angle of the humeral head was more or less than the usual angle recommended by most surgeons (30° to 40°)[31-33] to avoid a nonanatomical reconstruction that displaces the articular surface too much either posteriorly or anteriorly, damages the rotator cuff, or compromises the metaphyseal bone stock.

The degree of precision needed to reconstruct the proximal part of the humerus is unknown. The results obtained in this study may help surgeons to understand the problems involved in treating malunited fractures and severe arthritic deformity of the humerus. It is too early to interpret these results as indicating that preoperative measurement of the humeral geometry is necessary in the majority of routine cases. It is probably not essential to restore absolutely normal geometry of the proximal part of the humerus to obtain a good clinical result. Also, surgical experience and judgment are required[34-37]. Furthermore, in many circumstances, replacement of the glenoid is also indicated and the glenoid version also has to be taken into account to recreate normal version of the gleno-humeral joint. Variation in both the size of the humeral head and the stem-neck angle and changing the soft-tissue balance between anterior and posterior structures may also affect the results[38,39]. ■

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