Intramedullary reaming for press-fit fixation of a humeral component removes cortical bone asymmetrically

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Periprosthetic humeral fractures are major complications of shoulder arthroplasty. Bone removal during surgical reaming is a risk factor for these fractures. Although it is recognized that the endosteal surface of the humerus is asymmetrical whereas the reamers are symmetrical, to our knowledge, the effect of cylindrical reaming on the pattern of cortical bone removal during reaming has not been previously studied. The medullary canals of 10 cadaveric humeri (mean age, 73 years) were reamed in a manner similar to that used during humeral arthroplasty. Cortical dimensions were obtained from computed tomography scans before and after reaming. In unreamed humeri, the anterior-posterior endocortical diameter was 20% smaller than the medial-lateral diameter. The average medial-lateral diameter (15.6 ± 2.3 mm) was significantly greater than the anterior-posterior diameter (12.5 ± 1.9 mm) at 13 cm distal to the tuberosity (P < .00005). Successive cylindrical reaming preferentially thinned the anterior and posterior cortices. This bone loss would not be apparent on anterior-posterior radiographs. Intramedullary reaming to obtain substantial cortical contact asymmetrically removes cortical bone in a manner that may increase the risk of periprosthetic fracture. (J Shoulder Elbow Surg 2008;17:150-155.)

Shoulder arthroplasty is commonly used to manage glenohumeral arthritis and posttraumatic conditions. Surgeons often prefer to secure the humeral components with a press fit to avoid the use of cement. The press fit must be sufficiently snug so that the risk of implant loosening is minimized. Because the stems of humeral prostheses are generally cylindrical, current arthroplasty technique includes reaming of the endosteal diaphyseal cortex to achieve a cylindrical shape to enhance the fit of the prosthetic stem. The endosteal surface of the diaphyseal cortex has been noted to be elliptical in cross section, with varying orientation of the elliptical major axis.[10]

Figure 1 Radiograph of the left shoulder of a 62-year-old man with a periprosthetic fracture after a fall.

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Figure 2 A cylindrical intramedullary reamer.

Because the cross sections of the medullary canal are not symmetrically aligned, the path taken by a cylindrical reamer is determined by the shape and density of the endosteal bone at each segment all along its length. As a result, cylindrical reaming is likely to remove bone asymmetrically from the diaphyseal endosteal surface. Asymmetric cortical bone removal is a recognized risk factor for humeral periprosthetic fracture, either at surgery or with later trauma.[4,7,9]

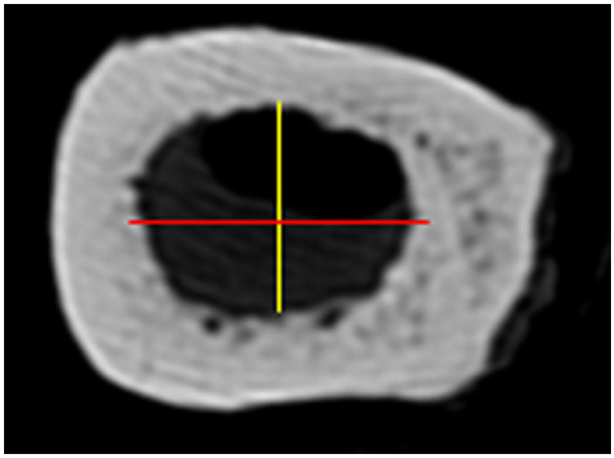

Figure 3 Measurements of the anterior-posterior (up-down) and medial-lateral (right-left) diameters of unreamed humerus of specimen 7, 15 cm distal to proximal aspect of the greater tuberosity.

Periprosthetic fractures account for 20% of all complications associated with shoulder arthroplasty.[11] The incidence of fractures in association with prosthetic humeral replacement has been reported at 1% to 2.3%.[3,6,12-14] Such fractures often require more extensive or repeat surgery and compromise the rehabilitation program. A recent review by Bohsali et al[1] indicates that the frequency of these periprosthetic fractures may be increasing and that they now are the third most common complication of shoulder arthroplasty after loosening and instability. Risk factors for fracture include osteopenia, osteoporosis, rheumatoid arthritis, inadequate operative exposure resulting in excessive manipulation, and overzealous reaming or impaction.[2,5] Boyd et al[3] reported 7 cases and noted that the fracture pattern involved the humeral shaft at the distal tip of the prosthesis, where the amount of bone removed with cylindrical reaming would be greatest (Figure 1).

To our knowledge, the effect of humeral reaming on cortical bone thickness has not been previously studied. This investigation tested the hypothesis that cylindrical intramedullary reaming removes substantial diaphyseal cortical bone in an asymmetrical manner. We further hypothesized that there would be substantial variability among humeri so that a standard approach to humeral reaming would have different effects on different humeri. Finally, we hypothesized that the degree of cortical thinning would not be apparent to the surgeon on a traditional anterior-posterior radiograph, typically taken after shoulder arthroplasty.

MATERIAL AND METHODS

Because the path taken by a reamer is determined by the endosteal anatomy of the humerus along the entire course of

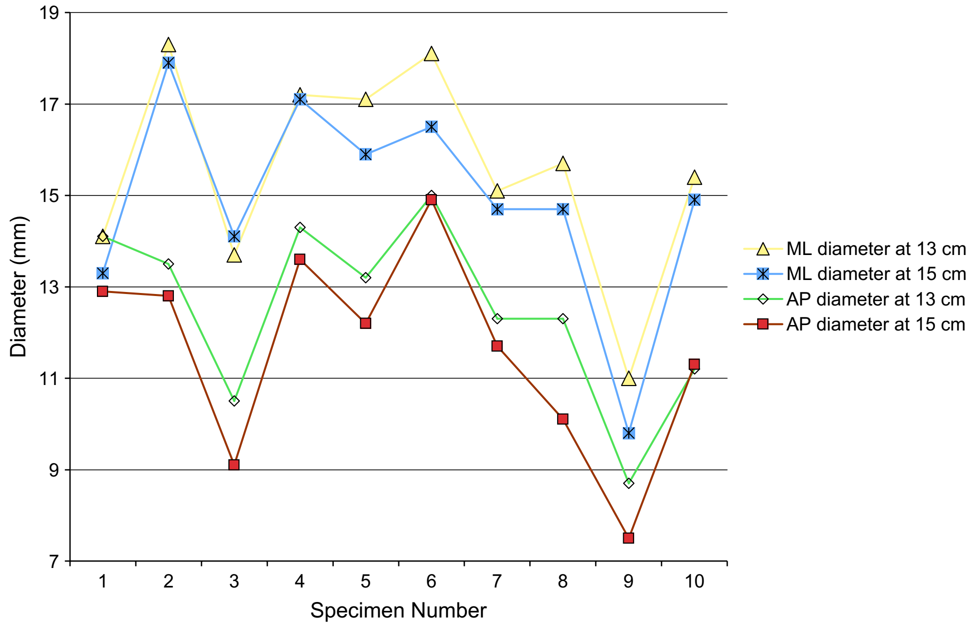

Figure 4 Medial-lateral *(ML)* and anterior-posterior *(AP)* diameters of the 10 different humeri 13 and 15 cm distal to the proximal tuberosity

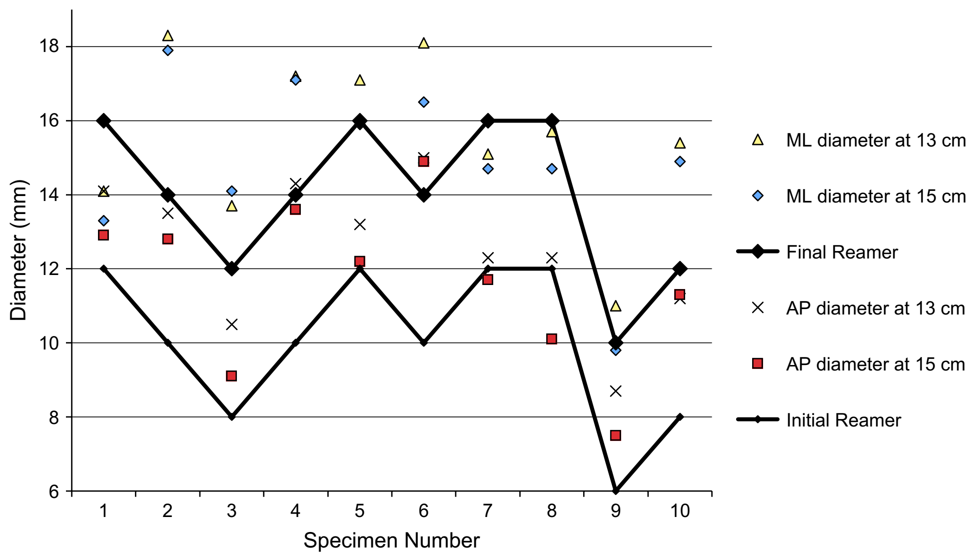

Figure 5 Relationship of reamer size to endocortical diameters in the 10 humeri. The *lower line* shows the diameter of the reamers achieving the first bite in each of the 10 humeri in relationship to the anterior-posterior *(AP)* and medial-lateral *(ML)* diameters 13 and 15 cm distal to the proximal greater tuberosity. The *upper line* shows the diameter of the reamers 4 mm larger than the reamers achieving the first bite.

the reamer, the pattern of bone removal can be only studied by actually performing the reaming of humeri on bones of approximately the same age as patients having shoulder arthroplasty.

This study used 10 unmatched human cadaveric humeri with a mean age of 73 years. All humeri were free of fracture or evident bone disease. Soft tissues were removed before testing. The humeri were cut at 16 cm distal to the proximal aspect of the greater tuberosity, and the humeral head was excised at the anatomic neck.

Scanning

The baseline cross sectional geometry of the humeral cortex was defined by computed tomography (CT) using the Lightspeed vCT scanner (General Electric, Fairfield, CT) at

0.62-mm intervals. Particular attention was directed to the cross-sectional anatomy at 13 and 15 cm distal to the proximal tip of the greater tuberosity, where the distal tip of a humeral component is characteristically placed.

Reaming

The humerus was reamed by hand using cylindrical reamers (Figure 2) as performed in surgical practice. Although no standard technique for reaming has been established, it is evident that positioning of the prosthetic stem requires that the diaphysis at the prosthetic tip be shaped to fit the prosthetic stem. In our protocol, reamers were inserted to 15 cm, the depth necessary to accommodate a humeral prosthesis. Starting with the smallest size, reamers of progressively larger diameter were inserted until endocortical contact was first achieved. Because this first bite would provide fixation for only the distal tip of the prosthesis, reaming was repeated with reamers of a diameter 2 mm and then 4 mm greater than the one to first achieve a bite on the endosteal surface. CT scans were again obtained after the reaming.

Data analysis

Analysis of the cortical anatomy was conducted using the OsiriX medical imaging software program (http://homepage.mac.com/rossetantoine/osirix/). The anterior-posterior and medial-lateral endocortical diameters were measured 13 and 15 cm distal to the tuberosity before and after reaming (Figure 3). The significance of the difference in the anterior-posterior and medial-lateral diameters at each level was determined using the 2-tailed Student *t* test for paired samples. The diameters of the humeral diaphysis were compared with the geometry of the initial and final reamers selected on the basis of their bite on insertion. The amount of thinning of each of the anterior, posterior, medial, and lateral cortices at 13 cm distal to the tuberosity was determined by subtracting the cortical thickness in each of these directions before and after reaming. The significance of the difference in these thicknesses was determined using the 2-tailed Student *t* test for paired samples. The level of significance was set at $P < .05$.

RESULTS

Geometry of diaphysis

The average medial-lateral endosteal diameter (15.6 ± 2.3 mm) was significantly greater than the anterior-posterior diameter (12.5 ± 1.9 mm) at 13 cm distal to the tuberosity ($P < .00005$; Figure 4). Similarly the average medial-lateral diameter (14.9 ± 2.3 mm) was significantly greater than the anterior-posterior diameter (11.6 ± 2.2 mm) at 15 cm distal to the tuberosity ($P < .0001$). This indicates that endocortical contact in the medial-lateral direction cannot be achieved without removal of substantial anterior-posterior cortical bone. If circumferential cortical contact were to be obtained for the 13- to 15-cm segment, the 11.6 ± 2.2-mm anterior-posterior diameter at 15 cm would have to be increased by at least 4 mm to the 15.6-mm medial-lateral diameter at 13 cm. Because reamers are manufactured in 1- or 2-mm increments, the amount of bone removed could be even greater if reaming were carried out to an integral diameter.

Table I Thinning of cortices of humeral diaphysis 13 cm distal to the tuberosity resulting from reaming to a size 4 mm greater than the reamer obtaining the first bite

Specimen	Anterior thinning, mm	Posterior thinning, mm	Medial thinning, mm*	Lateral thinning, mm†
1	1.6	0.7	1.1	1.8
2	0.2	0.2	0.2	0.0
3	1.3	1.0	−0.4	0.6
4	0.0	0.0	0.1	0.0
5	0.5	0.0	0.0	0.2
6	0.5	0.2	−0.1	0.2
7	2.2	1.8	0.3	0.5
8	0.9	2.1	−0.1	0.1
9	0.6	1.8	0.0	0.3
10	0.1	0.0	0.0	0.0
Average	0.8	0.8	0.1	0.4

*On average, significantly less than anterior thinning ($P < .02$).
†On average, significantly less than anterior thinning ($P < .05$).

It is noteworthy that the endocortical anatomy varied widely among the specimens, as suggested by Figure 4. The medial-lateral diameter was 0% to 56% larger than the anterior-posterior diameter. This result is important because it indicates that a standard approach to humeral preparation may have substantially different effects on different humeri.

Relationship of selected reamer size to diaphyseal dimension

The initial reamer size selected was the reamer that first obtained a bite in the distal endosteal cortex. The diameter of this reamer was close to the anterior-posterior diameter of the humerus 15 cm distal to the tuberosity (Figure 5). This suggests that it is the distal anterior-posterior dimension at the tip of the prosthetic stem that limits the size of stem that can be inserted with minimal reaming. The diameter of the average final reamer, which was 4 mm greater than the initial reamer in this study, was less than that of the medial-lateral diameter at 13 or 15 cm distal to the tuberosity, suggesting that medial-lateral cortical contact would not have occurred, even if the diameter of the reamer were increased 4 mm over that of the initial reamer (Figure 5).

Cortical thinning at 13 cm distal to the tuberosity

When the diaphysis was reamed to a diameter 4 mm greater than that of the reamer that first obtained a cortical bite, the greatest amount of bone was

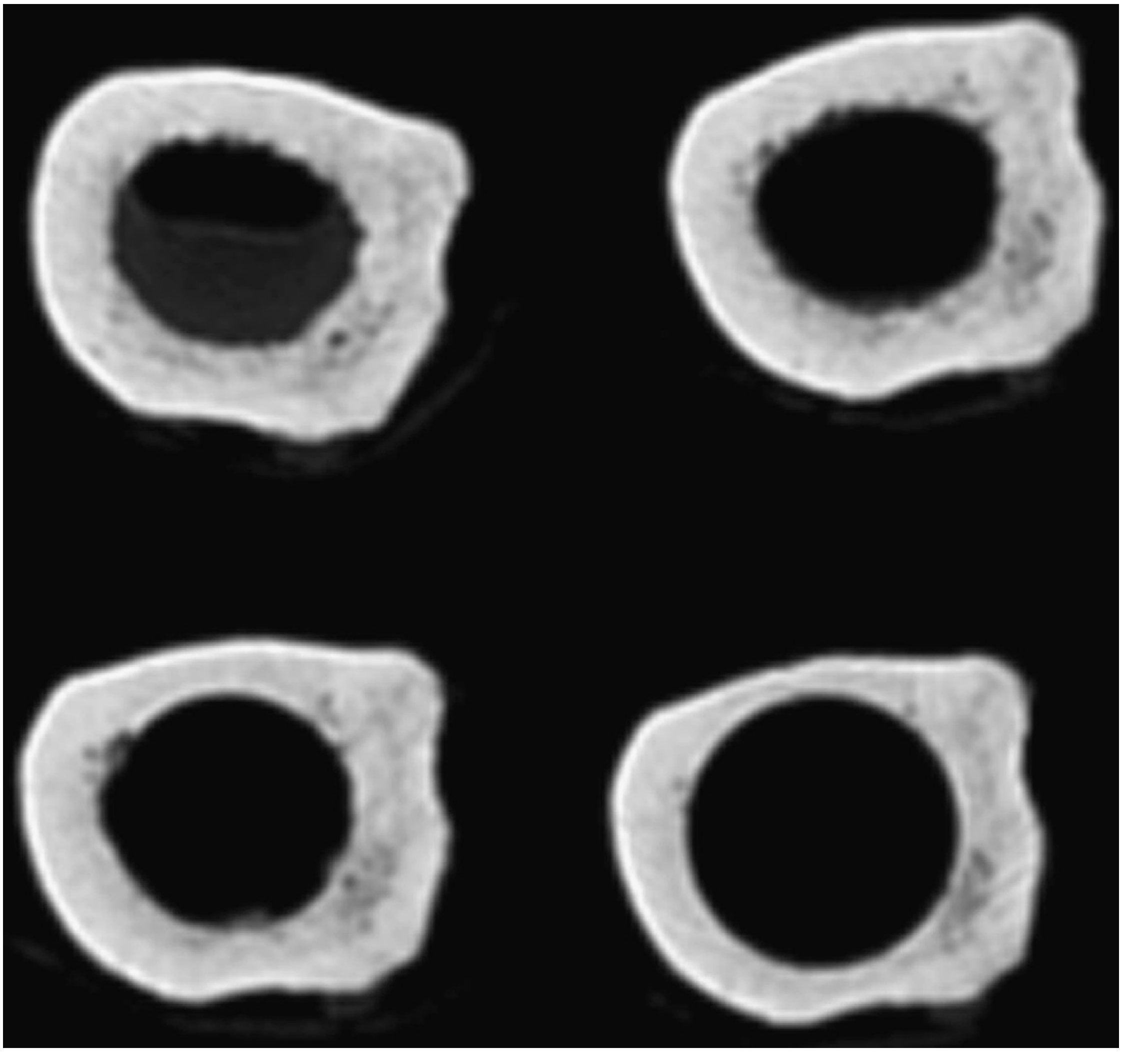

Figure 6 Preferential thinning of the anterior and posterior cortices with sequential reaming of humerus No. 7 at 15 cm distal to the proximal aspect of the greater tuberosity. **Top left,** unreamed; **top right,** reamed to 12 mm; **bottom left**, reamed to 14 mm; **bottom right,** reamed to 16 mm.

removed from the anterior and posterior endocortical surfaces (average 0.8 mm each) and least from the medial cortex (average 0.1 mm; Table I). Good endocortical contact in the medial-lateral direction could not be achieved without removing substantial bone from the anterior-posterior cortices. The loss of bone from the anterior and posterior surfaces would not be apparent on standard anterior-posterior radiographs (Figure 6).

DISCUSSION

In preparation for shoulder arthroplasty, surgeons often use the anterior-posterior radiograph to template the size of the humeral prosthetic stem that will fit the humerus without substantial cortical reaming. This study demonstrates that this traditional method of templating may cause the surgeon to overestimate the size of the ideal humeral stem. The average medullary canal diameter seen in the plane of the anterior-posterior radiograph at 13 cm and 15 cm distal to the proximal aspect of the greater tuberosity was 3.1 and 3.3 mm greater than that which would be seen on the lateral radiograph at these locations. When Campbell et al[5] examined periprosthetic fractures that occurred at the distal tip of the prosthesis, they verified that in 2 of 4 cases, the original endosteal diaphyseal diameter was smaller than the diameter of the distal stem of the prosthesis. It is recognized that intraoperative periprosthetic fractures can be caused by overzealous reaming, impaction, or manipulation.[2]

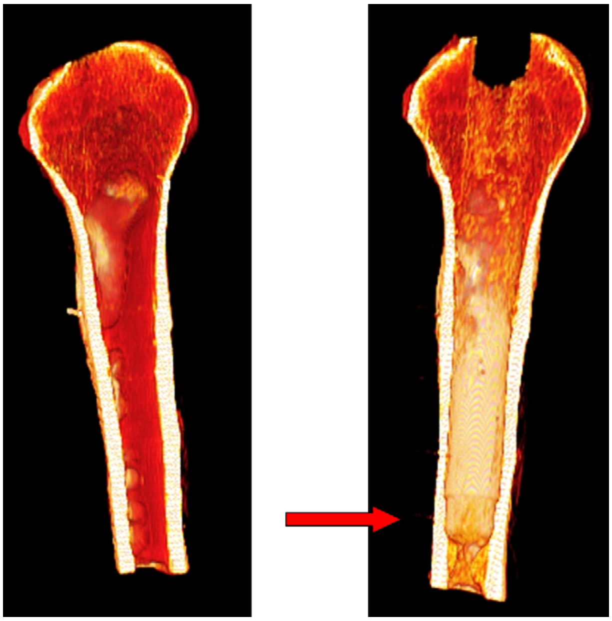

Figure 7 Anterior-posterior endosteal notching *(arrow)* caused by reaming as seen on the lateral projection in a 3-dimensional reconstruction of humerus No. 7. **Left,** unreamed; **right,** reamed.

The results of our study confirm that the endocortical morphology of the humerus is variable, as pointed out by Robertson et al.[10] Intramedullary reaming with a rigid cylindrical reamer preferentially removed cortical bone from the anterior and posterior surfaces of the diaphyseal cortex. This creates notching of the endosteal cortex that may not be recognized on the conventional anterior-posterior radiograph (Figure 7).

This study should be interpreted in light of certain limitations. We only used 10 unmatched cadaveric humeri; thus, our sample may not demonstrate the full range of humeral morphology. Nevertheless, the great variability found among these 10 specimens indicates that no anthropomorphic rules of thumb can be safely applied. Although we did not confirm the quantitative effect of cortical thinning on humeral bone strength, it seems intuitive that thinning and notching, as shown in Figure 7, would increase the risk of humeral fracture.

Despite these limitations, we concluded that intramedullary reaming to achieve snug cortical fit of the stem at 13 to 15 cm distal to the tuberosity selectively removes bone from the anterior and posterior cortices and that this bone removal ends abruptly, leaving a notch. The degree of thinning depends on the initial shape of the humeral endosteal surface; cylindrical canals, such as in one of the humeri included in this study, would be thinned less than elliptical or conical shaped canals, represented by most of the humeri studied. Finally, the amount bone loss may not be evident on a conventional anterior-posterior radiograph. Asymmetrical thinning may increase the risk of periprosthetic facture, especially when combined with the abrupt change in material properties that would occur at the point of transition from notched cortex with a prosthesis to the unreamed cortex just below it.

In summary, the initial fit of a humeral component can be achieved by cementing, by reaming, and broaching to a secure fit, or by the use of impaction intramedullary grafting.[8] If the surgeon wishes to avoid cement, bone preserving techniques, such as impaction grafting, may provide initial snug fit while avoiding the risk associated with asymmetrical bone loss from reaming.

REFERENCES

1. Bohsali KI, Wirth MA, Rockwood CA Jr. Complications of total shoulder arthroplasty. J Bone Joint Surg Am 2006;88:2279-92.
2. Bonutti PM, Hawkins RJ. Fracture of the humeral shaft associated with total replacement arthroplasty of the shoulder. A case report. J Bone Joint Surg Am 1992;74:617-8.
3. Boyd AD Jr, Thornhill TS, Barnes CL. Fractures adjacent to humeral prostheses. J Bone Joint Surg Am 1992;74:1498-504.
4. Cameron B, Iannotti JP. Periprosthetic fractures of the humerus and scapula: Management and prevention. Orthop Clin North Am 1999;30:305-18.
5. Campbell JT, Moore RS, Iannotti JP, Norris TR, Williams GR. Periprosthetic humeral fractures: Mechanisms of fracture and treatment options. J Shoulder Elbow Surg 1998;7:406-13.
6. Chin PY, Sperling JW, Cofield RH, Schleck C. Complications of total shoulder arthroplasty: Are they fewer or different? J Shoulder Elbow Surg 2006;15:19-22.
7. Choo AM, Hawkins RH, Kwon BK, Oxland TR. The effect of shoulder arthroplasty on humeral strength: an in vitro biomechanical investigation. Clin Biomech (Bristol, Avon). 2005;20:1064-71.
8. Hacker SA, Boorman RS, Lippitt SB, Matsen FA 3rd. Impaction grafting improves the fit of uncemented humeral arthroplasty. J Shoulder Elbow Surg 2003;12:431-5.
9. McDonough EB, Crosby LA. Periprosthetic fractures of the humerus. Am J Orthop 2005;34:586-91.
10. Robertson DD, Yuan J, Bigliani LU, Flatow EL, Yamaguchi K. Three-dimensional analysis of the proximal part of the humerus: Relevance to arthroplasty. J Bone Joint Surg Am 2000;82:1594-602.
11. Rockwood CA Jr, Matsen FA 3rd, Wirth MA. Lippitt SB. The shoulder. Philadelphia, PA: W.B. Saunders; 2004.
12. Sperling JW, Cofield RH. Case reports: shoulder arthroplasty in transplant recipients: a report of five cases. Clin Orthop Relat Res 2006;442:273-5.
13. Worland RL, Kim DY, Arredondo J. Periprosthetic humeral fractures: management and classification. J Shoulder Elbow Surg 1999;8:590-4.
14. Wright TW, Cofield RH. Humeral fractures after shoulder arthroplasty. J Bone Joint Surg Am 1995;77:1340-6.