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ORIGINAL ARTICLE

A morphovolumetric study of head malposition in proximal humeral fractures based on 3-dimensional computed tomography scans: the control volume theory

Raffaele Russo, MD[a,*], Antonio Guastafierro, MD[b], Livia Renata Pietroluongo, MSc[c]

[a]*Department of Orthopedic Surgery, Hospital dei Pellegrini, Naples, Italy*
[b]*Department of Medical and Surgical Specialties and Dentistry, University of Campania "Luigi Vanvitelli", Naples, Italy*
[c]*E-LISA s.r.l., Naples, Italy*

Background: This study regards a volumetric analysis of proximal humeral fractures. The main purpose was to investigate the head displacement in relation to the shaft and its link to volume reductions ("bone loss") of the anatomic segments interposed between the head and the shaft: the tuberosities and the calcar. We call this area "control volume."
Methods: In 20 fractures, we used 3-dimensional virtual reconstruction to create a reference system that divides geometrically the control volume and allows the evaluation of displacement angles of the humeral head. We calculated the volumetric reduction of control volume segments for each fracture through a specific mathematical protocol.
Results: The measurement of the head displacement angles in 20 fractures led to following results: in the coronal plane, 10 varus, 6 valgus, 4 neutral; in the sagittal plane, 6 anterior tilt, 9 posterior tilt, 5 neutral position. There was a reduction of control volume in 19 of 20 fractures. Only in 1 fracture was the control volume intact and the fracture was nonimpacted. In 19 impacted fractures, the volume reduction was variable (4% minimum loss, 98% maximum loss). In head varus position, loss was greater in the medial area than in the lateral area. There was generally a clear correspondence between the positions assumed by the head and the volumetric losses of the respective control volume segments.
Conclusions: The control volume is an important anatomic and functional area of the proximal humerus. A morphovolumetric 3-dimensional approach improves knowledge about pathomorphology of proximal humeral fractures.
Level of evidence: Anatomy Study; Imaging

Keywords: shoulder; third proximal humerus; control volume; calcar; 3D reconstruction; complex fractures; bone loss

To better understand the pathomorphology of proximal humeral fractures (PHF), the use of 3-dimensional (3D) volume rendering has become increasingly frequent.[17] According to some authors, the reliability of existing classifications is

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*Reprint requests: Raffaele Russo, MD, Department of Orthopedic Surgery, Hospital dei Pellegrini, 41 Portamedina, I-80134 Naples, Italy.
E-mail address: raffrusso@tin.it (R. Russo).

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not improved with this technique,[1,4,21] being linked only to the orthopedic surgeon's experience.[3] In other studies, volume-rendering computed tomography (CT) scans have instead improved the reliability of existing classifications, particularly in complex fractures.[5,6,15] There are different classifications of PHF, such as the most popular Neer and AO (Arbeitsgemeinschaft für Osteosynthesefragen), but they have low intraobserver and interobserver reliability.[10,20,21]

However, volume-rendering CT has been used to analyze the pathomorphology of PHF,[11] and new classifications have been designed. These classifications are more complete, valid, and reliable[14] because they are more analytical and succeed in a better description of fracture pathomorphology.[9]

Resch et al[18] analyzed the position of the humeral head in relation to the shaft in the coronal and sagittal planes, building up a pathomorphologic classification with 3D volume rendering. Although their study is interesting and the classification is reliable, some pathomorphologic aspects are missing, and there is no link between the type of fracture and the surgical treatment. In particular, less attention is given to calcar fracture. The extent to which the calcar is compromised is one of the factors that influences malposition, the impact of the humeral head in relation to the shaft, and above all, the healing of the fracture.[8,16]

The Hertel classification[22] instead classifies fractures considering the number of main fragments and the way they are combined to describe the pathologic anatomy of the lesion schematically. As regards ischemia and necrosis of the head, the Lego classification assesses the possibility to add to the different classification models an analysis of calcar length,[2,12] which must be close to 8 mm to allow reliable reconstruction of the head. However, calcar analysis continues to be linked to 2D evaluation, and many pathomorphologic and volumetric aspects of the fracture are not considered.[13] The position of the humeral head in relation to the shaft plays a relevant role in pathologic analysis of fractures[7]; what is relevant is not the degree of head displacement but the mechanical causes leading to these displacement degrees.

Our hypothesis is that humeral head malposition in relation to the shaft, particularly in impacted fractures, is a direct consequence of bone loss in the anatomic topographic region, situated between the head and humeral shaft, that we have defined "control volume" (CV). This anatomic part, as we pointed out in a previous publication[19] only for the calcar region, requires an analytical CT study to understand many other aspects of the pathomechanics of the fragments displacement. Thus, it is important to analyze whether there is a real possibility of measuring the seriousness of head displacement and whether there is a link between its position after the fracture and loss of bone mass in the underlying parts.

The objective was to prove that CT 3D analysis of impacted vs. nonimpacted PHF in bone loss (loss of control volume) and displacement is feasible and reliable. In particular, we wished to study whether different patterns of head displacement in relation to the shaft are linked to different involvement of anatomic segments interposed between the head and shaft. The second goal was to show that the concept of CV loss is in accordance with established biomechanical concepts and can serve as the basis for a new classification of PHF that has an effect on clinical decision making.

Materials and methods

Experimental design

We set up a study based on a collaboration among 3 surgeons (R.R., A.G., and G.D.R.), 2 engineers (L.P., P.M.), and 1 software expert (F.F.). We identified an anatomic volume between the humeral head and shaft in the 3D reconstruction of a normal 64-slice CT scan (Somatom Sensation 64 CT; Siemens Healthcare, Erlangen, Germany). We described this zone as the "CV," which is included between 2 parallel planes: plane α, corresponding to the anatomic neck, and the second plane β, parallel to the first and intersecting the surgical neck (Fig. 1).

This area, similar to a cylinder with a height between 20 and 25 mm and with a diameter corresponding to the humeral head, was intersected at right angles by 2 planes, 1 frontal and 1 sagittal, described respectively as λ and δ. Plane λ divides the whole volume in a lateral zone and a medial zone: the lateral area contains the tuberosities, divided by the bicipital sulcus, whereas the medial area contains the calcar (Fig. 2). Plane δ divides the whole volume in the anterior and posterior zone, and we consider it as a plane cutting across only the medial area, thus identifying the anterior and posterior calcar (Fig. 3). In this way, the CV contains 4 sections: anteromedial (anterior calcar [Ca]), posteromedial (posterior calcar [Cp]), anterolateral (lesser tuberosity [Lt]), and posterolateral (greater tuberosity [Gt]; Fig. 4).

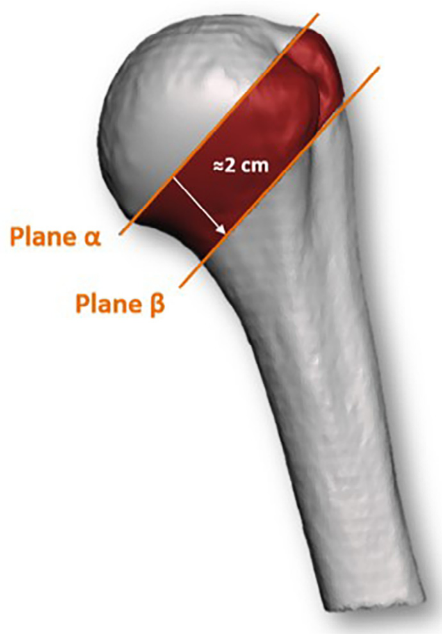

Figure 1 Coronal view: planes α and β are the extremes of the control volume. The distance between them is approximately 2 cm.