Morphological landmarks of proximal humerus with impact in post-traumatic outcome

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Abstract
As one of the fundamental requirements for an optimal function of the locomotive system is the integrity of the skeleton, the morphology of proximal humerus is crucial for upper limb performance. Not only that the bone is the support for muscle insertion, but its particular form is responsible especially for the complex movement of the shoulder joint, so that any pathological features of this morphology results in different degrees of dysfunction. Since trauma is the most frequent cause for morphological changes of this area, this paper studies the anatomical landmarks, which are affected by proximal humeral fractures and must be targeted when treating these injuries, for they influence the functional outcome. Evaluating the results from a Level 1 Trauma Centre, the authors underline the importance of these anatomical landmarks in approaching proximal humeral fractures and aim to establish a morphology-based therapeutic algorithm, crucial for optimal functional restoration.

Keywords: proximal humerus morphology, proximal humerus fractures, functional restoration, therapeutic algorithm.

Introduction
The morphology of the proximal humerus has a major role in the biomechanics of the upper limb; certain morphological elements are responsible not only for the function of the shoulder, but for the whole kinetic chain arm–forearm–hand due to their implication in joint stability and mobility.

Besides the elements enhancing the stability of the shoulder – the capsule-ligamentous structures and the labrum, which increases the depth of the glenoid fossa with up to 50% [1–3], certain morphological elements are vital for the optimal function of the joint, the most significant being: the retroversion of the humeral head (10–31º), [4], the integrity of the subacromial space (normally 7–11 mm) [3] and the caput-collum-diaphysis angle (CCD angle, the angle between the axis of the diaphysis axis and that of the humeral neck, approximately 135º) [5–7], closely related to the medial periosteal hinge; this structure is crucial not only for the mechanical support, but especially for maintaining the vessels originating in the posteromedial system, which represent the ultimate vascular resource of the humeral head when fractures disrupt those originating from the anterolateral (arcuate) branch of the anterior humeral circumflex artery [8–11].

These landmarks are severely disrupted by trauma, especially by proximal humeral fractures (PHFs); due to the lack of correlations between the currently used classifications of PHFs, based on the measurements of displacements, and the outcome of the fracture treatment, research focused on finding other criteria for establishing therapeutic indications; an example is the morphological approach, which considers not only displacements as criteria for a certain therapy, but these morphological landmarks with considerable functional impact.

The purpose of this study is to establish if there is any correlation between the restoration of morphology and the functional outcome after PHF, so as to consider the main morphological landmarks of proximal humerus as predictive factors and use them as criteria for therapeutic algorithms.

Patients and Methods
In order to identify the morphological elements of proximal humerus, which influence the outcome after fractures, a retrospective study was performed upon the patients operated for PHF in the Clinic of Orthopedics and Traumatology, Clinical Emergency Hospital, Bucharest, Romania.

The inclusion criteria were: skeletally mature patients, who signed the informed consent, with isolated closed uncomplicated PHF, operated using ORIF (open reduction internal fixation), with full medical records for 18 months after surgery; the exclusion criteria were: complicated PHF (open fractures, vascular injuries associated), fractures on pathological bone (metastasis, systemic diseases determining bone alterations), other surgical methods (arthroplasty, closed reduction and fixation) and loss of follow-up.

From the total number of 124 patients operated for PHF using ORIF, in our Hospital, between 01.01.2012–01.01.2015, 64 sustained all the inclusion criteria, without matching any of the exclusion ones. The study was performed according to the European Communities Council
and osteosynthesis, when morphological restoration is
on the probability of morphological restoration, reduction
reduction and internal fixation (CRIF) with nails can be
Figure 2a, which presents the following situations: if
method to restore functional anatomy, as shown in
lization also depends on the possibility offered by each
nuted that the parts cannot be repositioned and fracture
is considerable; the type of the plates depended on the
phological landmarks, especially when the displacement
required; due to the fracture characteristics of the study
group, ORIF was more suitable for restoring the mor-
comminuted fractures, restoring morphological landmarks
by reduction and fixation being increasingly challenging
when the number of parts is higher. The study group also
includes three patients with fracture-dislocations, which
were separately counted, as the morphological disturbances
are enhanced by the vascular damage of the humeral
head because of dislocation.

The surgical method and implant are chosen depending
on the probability of morphological restoration, reduction
and osteosynthesis, when morphological restoration is
possible, or arthroplasty, when the fracture is so commi-
nuted that the parts cannot be repositioned and fracture
healing is improbable. The type of reduction and stabi-
ization also depends on the possibility offered by each
method to restore functional anatomy, as shown in
Figure 2a, which presents the following situations: if
reduction can be obtained by external maneuvers, closed
reduction and internal fixation (CRIF) with nails can be
used (four patients); since they need a strong intact
proximal part for locking, nails are mainly indicated in
two part fractures; if the morphology needs to be restored
by direct manipulation of each fragment, then open
reduction and internal fixation (ORIF) with plates is
required; due to the fracture characteristics of the study
group, ORIF was more suitable for restoring the mor-
phological landmarks, especially when the displacement
is considerable; the type of the plates depended on the
bone stock, conventional plates being used for big frag-
ments and good bone quality, while altered bone stock
due to comminution or to osteoporosis usually require
angular stability implants.

It must also be commented the fact that the study
group also includes 12 patients with four-part fractures
operated by ORIF, fractures which sometimes require
arthroplasty. The correlation between the type of surgery
and the age of the patients applies in this situation,
because all the patients having four-part fractures in the
study group were less than 55 years old, thus limiting
the indication of arthroplasty.

The outcome of the patients was evaluated using:
• the late complications – represented by: three implant
failures (requiring re-intervention) and two cases of avas-
cular necrosis (further proposed for arthroplasty);
• the functional Constant–Murley score, which includes
both subjective (pain, level of activity) and objective
(range of motion, muscular strength) criteria.

The functional results were evaluated following two
criteria: the initial classification of the fractures according to Neer criteria and the post-operative morphological restoration.

According to Neer criteria, the outcome was strongly influenced by the fracture type, fair and poor results being associated with comminution and dislocation. The proportion of excellent results was higher in two-part fractures (81.81%), while the percentage is lower for three-part (52%) and four-part (40%) fractures (Figure 2b). On the opposite, poor results appeared in 40% of the patients with four-part fractures and in only 8.3% in the group with two-part fractures.

In order to identify the impact of anatomical restoration, the functional outcome was analyzed in correlation with the degree of restoration of the main morphological landmarks, identified on the postoperative radiological evaluations (Table 1).

Table 1 – The impact of proximal humerus morpho-

logy upon shoulder function; morphological restoration is associated with excellent and good results, while poor outcome is correlated with impaired morpholo-

gical landmarks, including the local complications (*)

<table>
<thead>
<tr>
<th></th>
<th>Excellent</th>
<th>Good</th>
<th>Fair</th>
<th>Poor</th>
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<tbody>
<tr>
<td>CCD angle 120–135°</td>
<td>36</td>
<td>14</td>
<td>6</td>
<td>1*</td>
</tr>
<tr>
<td>CCD angle &lt;120°</td>
<td>2</td>
<td>2</td>
<td>3*</td>
<td>(two avascular necrosis)</td>
</tr>
<tr>
<td>Medial hinge undisplaced or displaced &lt;2 mm</td>
<td>33</td>
<td>11</td>
<td>5</td>
<td>0</td>
</tr>
<tr>
<td>Medial hinge displaced &gt;2 mm</td>
<td>3</td>
<td>4</td>
<td>5</td>
<td>3* (implant failure)</td>
</tr>
<tr>
<td>Metaphyseal extension &gt;8 mm</td>
<td>34</td>
<td>10</td>
<td>3</td>
<td>0</td>
</tr>
<tr>
<td>Metaphyseal extension &lt;8 mm</td>
<td>2</td>
<td>6</td>
<td>6</td>
<td>3* (two avascular necrosis)</td>
</tr>
<tr>
<td>Subacromial space &gt;50%</td>
<td>36</td>
<td>15</td>
<td>4</td>
<td>0</td>
</tr>
<tr>
<td>Subacromial space &lt;50%</td>
<td>1</td>
<td>5</td>
<td>3</td>
<td></td>
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CDD: Caput-collum-diaphyseal.

The CCD angle on the fractured operated side was compared with the normal value of the healthy one; considering that the normal value of this angle is 135°; varus deviations were described up to 120° or more. While over 50% of the patients (36/57) with CCD over 120° had excellent functional results, no excellent functional results appeared in patients with CCD angle less than 120°; more than that, varus collapse was associated in 67.34% of the cases with excellent results (33/49), while over 50% (8/15) of the patients with displacements >2 mm had fair or poor results. More than that, the displaced medial cortex and the varus collapse were associated, in the study group, with implant failure, secondary to medial overloading (Table 1).

An important morphological landmark is the medial hinge, which is closely related not only to the post-traumatic vascular supply, but also, similar to the proximal femur, the calcar zone is crucial for the resistance of this area, so the medial cortex should be carefully addressed; undisplaced or displaced up to 2 mm medial hinge was associated in 67.34% of the cases with excellent results (33/49), while over 50% (8/15) of the patients with displacements >2 mm had fair or poor results. More than that, the displaced medial cortex and the varus collapse were associated, in the study group, with implant failure, secondary to medial overloading (Table 1).

A structure with crucial importance for post-fracture morphological restoration is the vascularity, which was evaluated according to Hertel criteria, by the metaphyseal extension; values more than 8 mm were associated with excellent results in 72.3%, while 53% of the patients with metaphyseal extensions less than 8 mm developed fair or poor outcome.

It is also to be noticed that certain morphological elements were more frequent associated with avascular necrosis of the humeral head, a late complication which totally disrupts the morphology of the proximal humerus, and, secondary, that of the shoulder joint. These are varus collapse (CCD angle <120°) and metaphyseal extension <8 mm, therefore confirming the considerable impact of the morphological postoperative restoration upon the function of the shoulder.

The main morphological landmarks with a physiological aspects are presented in Figure 3, which also suggests that different methods of assessing the morphology offers the complete aspect: the CT with three-dimensional (3D) reconstruction reveals a metaphyseal extension longer than 8 mm (Figure 3a); the clinical intra-operative evaluation revealed the anatomical restoration of the medial cortex, with an undisplaced medial hinge as shown in Figure 3b (the dotted line); intra-operative

Figure 2 – The type of the implant was chosen depending on the requirements of morphological restoration; nails for simple two-part fractures and plates for the other types; angular stability implants are used when morphology has a complex disturbance (a); the functional result was influenced by the fracture type, comminuted fractures being associated with lower functional outcome, concordant with increased morphological damages (b).
fluoroscopy on an AP reveals an intact medial hinge (yellow line) and the restoration of the articular surface (blue) and subacromial space (green). The humeral axis and the axis of the humeral head where drawn (red lines), resulting the CCD angle which is here within normal limits.

The reverse situation, when the morphology remains severely disrupted, significantly affect the function, is reflected by the case presented in Figure 5; initial X-ray shows a fracture-dislocation of the shoulder (Figure 5a); surgery was urgently performed with optimal reduction and stabilization with an angular plate. Four months after surgery, the Constant–Murley score showed poor results, correlated with failed morphological landmarks (Figure 5b): lack of subacromial space (green), which is practically occupied by the proximal end of the plate, obviously displaced medial hinge (purple lines), metaphyseal extension less than 8 mm and varus collapse of the humeral head, with decreased CCD angle almost 90° (red lines).

It is to be underlined that this was one of the cases complicated with avascular necrosis, which required re-intervention, thus demonstrating the importance of reconstructing morphology after PHF.

As it can be seen, the situations when the anatomical elements were restored after surgery are associated with excellent and good functional results, which underlines the importance of morphologically guided treatment for these fractures. The radiological evaluation (if properly executed) gives accurate information about medial hinge, subacromial space and CCD, thus allowing to easily identifying these elements.

A practical example is presented in Figure 4, where the a comminuted fracture with a metaphyseal extension >8 mm is showed in the initial X-ray (Figure 4a) and CT (Figure 4b); postoperative X-ray (Figure 4c) reveals an optimal subacromial space (green) and articular surface (blue), with a proper CCD angle (red) and undisplaced medial hinge (yellow). Due to this optimal restoration of morphology, the functional result was excellent, as shown in Figure 4, proving that anatomical restoration is the premises for a favorable outcome, therefore underlining the place of the morphological landmarks for clinical practice.
Discussion

Proximal humeral fractures are the most frequent humeral fractures (45%) and the second most frequent fractures of the upper limb, that is why fundamenting methods able to ensure early functional recovery is of great interest for modern orthopedic practice [12].

The nowadays used systems of classifying PHF are based on the number of the fragments and their displacement, only, therefore generating situations when report regarding the outcome of the fractures provide controversial data; the AO (Arbeitsgemeinschaft für Osteosynthesefragen) system [13] is complicated and frequently replaced by the classical Neer classification; although this is more facile, it still does not result in clear indications for conservative or operative treatment, thus several criteria (Neer, Lill, etc.) with different standard values are still used, none of them with prognostic significance [14, 15].

On the opposite, several anatomical elements have been discussed as having a stronger connection with the post-traumatic outcome, as they directly influence fracture healing, regardless its type.

The position of the humeral head is strongly influencing the mobility of the shoulder, due to the reduced contact between the head and the glenoid fossa, let alone the changes of the geometry of the forces; the humeral head retroversion to the frontal axis represents the angle between the frontal plane and the line bisecting the articular margins of the head at the level of the anatomical neck, with a mean value of 10–31° [4]. Studies showed that reduced retroversion angle is related with impaired external rotation of the arm [16, 17], thus demonstrating the importance of restoring this parameter after PHF.

The subacromial space is normally 7–11 mm wide, which is maintained due to multiple landmarks: normally, the centre of the humeral head is offset 7 mm medially and 2 mm posteriorly relative to the humeral axis [1–3] and the greater tuberosity is position so that its upper level is 8–10 mm lower related to the articular surface [3]. Practically, the intact subacromial space allows full abduction, while its’ narrowing results in painful limitation of this movement; due to the position of the rotator cuff, external rotation is also affected by any abnormality in the subacromial space, thus the absolute necessity of its restoration after PHF.

The CCD angle represents the angle between the diaphysis axis and the humeral neck axis, drawn as a perpendicular to the base of the head [5, 6]. The normal value of CCD is approximately 135°; varus malalignment especially after trauma is not well tolerated, with functional impairment. A CCD angle of 120° or less is a predictor of secondary varus collapse, especially when medial support is missing; therefore, it is considered that varus deformities more than 20° are not acceptable especially after surgery and they might need surgical correction if generating functional disturbances [18–20]. In our study group, failure to regain the normal valgus impaired the functional score and increased the stress of the implant, thus being associated with implant failure. This is concordant with the literature, which describes limitations of shoulder mobility, especially of the abduction, due to varus deformation of the humeral head [21].

The main vascular source of the humeral head is the anterolateral (arcuate) branch of the anterior humeral circumflex artery, running along the long head of the bicipital tendon and then adjacent to the lateral wall of the intertubercular groove ascending up to the level where this groove continues with the greater tuberosity, when it enters the humeral head [22, 23]. Separate from the vessels of the tuberosities and the metaphyseal vessels, another system has been described, that of the posterior-medial vessels originating from the posterior circumflex artery. These vessels represent the ultimate vascular resources when the ascendant branch is injured, so their status is important for fracture healing [24, 25].

According to the criteria described by Hertel, the landmarks suggestive for the vascular status of the humeral head are the metaphyseal head extension and the medial hinge; the first one is a radiographic measurement of the articular fragment from the head–neck junction to the inferior extent of the medial cortex; the second, the medial hinge, consists of a strong periosteal structure, maintaining the medial cortex; the situations that protect the posterior-medial vessels are represented by a metaphyseal extension wider than 8 mm and an intact medial hinge, that is an intact medial cortex, which should normally be displaced up to 2 mm (ideally non-displaced) – the so-called medial gap [8–11], situations which, in our study group, were associated with excellent or good results, while metaphyseal extension <8 mm and medial displacement >2 mm were followed by a poor outcome of the patients.

Multiple studies referred to the modalities of restoring the anatomy after PHF, with two essential aspects: proper reduction and optimal stabilization; reduction restores not only the medial cortex and the CCD angle, but also the proper gleno-humeral contact, as they are strongly related and directly influence the position of the proximal humeral articular surface; while normally, the glenoid cartilage is in contact with the entire cartilage of the humeral head, the contact will be limited at its lower part, if the humeral head is in valgus and with its upper part if it’s in varus, with a secondary impaction of the dense diaphysis in the humeral head; since both these situations cannot be detected by clinical evaluation solely (as the medial cortex may be intact, but with a wrong CCD angle), fluoroscopic examination is mandatory for proper anatomical restoration, with both AP and lateral views. Correct reduction of the medial cortex and CCD angle must be followed by optimal placement of the implant, as it can impact the morphological landmarks by several aspects, such as: an abnormal proximal position of the plate will affect the subacromial space, while failure to support the medial cortex (by properly placed calcar screws with optimal length) will result in medial gap and varus collapse, all these with severe functional consequences.

The purpose of this study was to identify the components of the proximal humerus morphology, which, due to their importance in post-traumatic outcome, must be included in the therapeutic outcome, as a “check-list” for orthopedic surgeons when performing PHF treatment, as they have not only a guiding role, but a prognostic value, too.

The strongest limitation of this study is its retrospective character; together with the fact that multi-observer evaluations were used; this underlines the necessity of randomized prospective studies with increased objectivity by multicentre cooperation; these studies need to provide
an objective-guided therapeutic algorithm, as well as a unified classification with curative and prognostic value.

Conclusions

The morphology of proximal humerus is complex and ensures not only the movements of the shoulder joint, but also the global function of the upper limb; PHF severely impair this morphology, thus requiring proper treatment as to obtain maximum functional recovery. Due to the inconsistencies between the currently used therapeutic algorithms based on displacement solely and the clinical outcome, research focused on identifying different criteria for treatment and prognosis and several morphological landmarks have been demonstrated to be more valuable than the displacement for this purpose. This paper sustains the idea that it is the functional anatomy restoration that matters more than the displacement for this purpose. This paper sustains the idea that it is the functional anatomy restoration that matters more than the displacement for this purpose.

Conflict of interests

The authors declare that they have no conflict of interests.

References


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