

# Height marker and shoulder hemi arthroplasty in fracture cases: Measurement of the distance between the apex of the humeral head / pectoralis major

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**Introduction:** Functional results following a shoulder transplant in fracture cases are closely linked to the correct height position of the implant. If fracture markers can help, then there are today usable pre-operative measurements which are more reliable such as the distance between the apex of the humeral head / upper edge of the pectoralis major. We analysed this distance on 200 shoulder scans so as to carry out a wide ranging study on these measurements so as to use them for the delto-pectoral route and the supero-external route.

**Materials and methods:** We analysed 200 consecutive scans of 88 women and 112 men with an average age of 49.79 years (15-93). On the 137 scans where the sternal head tendon of the pectoralis major muscle was identifiable, we measured the distances separating the tangent on the upper edge of the tendon to: the apex of the humerus, the upper edge of the greater tubercle, the change in curvature of the upper side of the humerus and medial edge of the anatomical neck.

**Results:** The distance between the pectoralis major and the apex was 67.606 mm (SD: 9.988mm), between the pectoralis major and the trochiter it was 57.825 mm (SD: 10.317mm), between the pectoralis major and the change in curvature of the external edge of the humeral neck was 28.701mm (SD: 9.029mm) and the anatomical neck: 34.146mm (SD: 9.697mm). The men presented predominantly with distances greater than 7 mm for the pectoralis major apex and pectoralis major trochiter measurements than the women.

The ratio between the pectoralis major-change in curvature / pectoralis major-anatomical neck distances was 0.851 (SD: 0.166). The ratio pectoralis major-trochiter/ pectoralis major-change in curvature was 0.489 (SD : 0.098). The ratio pectoralis major-trochiter/ pectoralis major-change in curvature was 0.584 (SD : 0.102).

**Discussion:** Height measurements should assist the surgeon in placing unshortened “fracture” shoulder prostheses. In 3 cadaver studies, Murachovsky in 2006 (2x20 shoulders sex ratio 1), Torrens in 2008 (N=20 sex ratio =1) and Hasan (N=38) in 2009, the pectoralis major/apex distance was found to be equal to 5.5 cm +or – 5mm, so smaller than here (6.7 cm) but with more men in our sample. Greiner (2008) and Lascar (2012) found better clinical results in this after introducing this marker. However, it is only possible to take this measurement by the anterior route. Using the supero-external route and under an image intensifier, the knowledge of a new parameter (the distance between the pectoralis major and the change in curvature), of nearly 3 cm, allowed gross errors to be avoided. It is possible to maintain a single height marker, whatever the primary route: the prosthetic head should be placed 6 cm away from the upper edge of the pectoralis m. and 3 cm away from the lateral curvature change in the humeral neck.

**Introduction :**

Functional results following a shoulder transplant in fracture cases are closely linked to the correct height position of the implant [1-3]. If fracture markers can help, then there are today usable pre-operative measurements which are more reliable such as the distance between the apex of the humeral head / upper edge of the pectoralis major [4-6]. We analysed this distance on 137 shoulder scans so as to carry out a wide ranging study on the measurements reported in anatomical studies.

**Materials and methods:**

200 consecutive shoulder scans taken between 2010 and 2011 of adult patients who did not present with post-traumatic lesions were analysed retrospectively, this being 88 women and 112 men with an average age of 49.79 years (15-93).

The population studied comprised 88 women and 112 men with an average age of  $49.8 \pm 18.5$  years (18 - 93 years). 17.5% of those examined showed signs of arthrosis (35/200) and 28.5% presented with a transfixated rupture of the rotator cuff (57/200).

All of the examinations were read by the same multiplane reconstruction technician on a PACS post treatment console. For each of the 200 scans (64 slice CT device, 140KeV, 350mAs, rotation time 1s, slice thickness 1mm, obtaining 64 slices/0.6, pitch 0.8) only 137 were able to show a definitive analysis of the sternal head of the pectoralis major. On the 137 scans where the sternal head tendon of the pectoralis major was identifiable (figure 1), 4 morphological study measurements were able to be made. We measured the distances separating the tangent at the upper side of the tendon to: the apex of the humerus, the upper edge of the greater tubercle, the change in curvature of the upper side of the humerus and medial edge of the anatomical neck (figure 2).

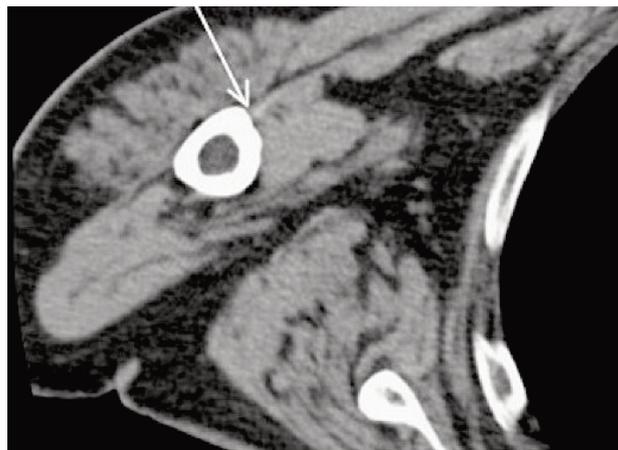


Figure 1: Scan view of the upper limit of the pectoralis major on a horizontal slice

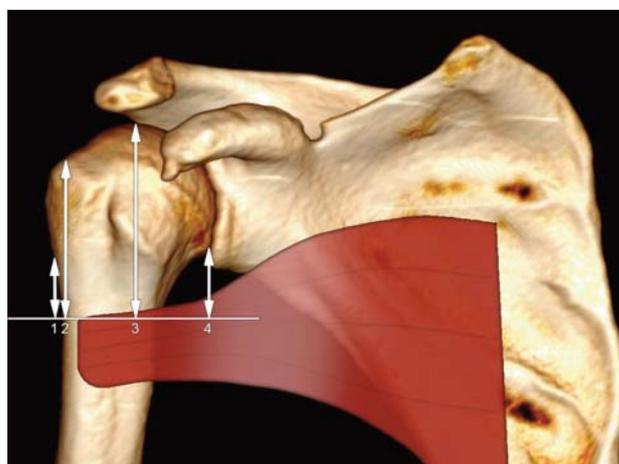


Figure 2: The 4 measurements taken from the upper edge of the pectoralis major

**Results (figure 3):**

The distance between the pectoralis major and the apex was 67.606 mm (SD: 9.988mm), between the pectoralis major and the trochiter it was 57.825 mm (SD: 10.317mm), between the pectoralis major and the change in curvature of the external edge of the humeral neck was 28.701mm (SD: 9.029mm) and the anatomical neck: 34.146mm (SD: 9.697mm).

The Apex-Pectoralis Major distance was  $62.95 \pm 7.9$  mm for the women and  $70.7 \pm 10$ mm for the men. There is a very significant difference in this distance due to the sex of the patient: an average of 7.8mm more for the men ( $p < 0.001$ ). The Trochiter-Pectoralis Major distance was  $53.3 \pm 7.8$ mm for the women and  $60.9 \pm 10.7$ mm for the men. There was also a very significant difference according to the sex of the patient: the average difference was 7.6 mm greater for the men ( $p < 0.001$ ). In addition, there was a statistically significant correlation between the maximal width and the Pectoralis Major-Trochiter distance ( $p = 0.003$ ).

The ratio between the pectoralis major-change in curvature / pectoralis major-anatomical neck distances was 0.851 (SD: 0.166). The ratio pectoralis major-trochiter/ pectoralis major-change in curvature was 0.489 (SD: 0.098). The ratio pectoralis major-trochiter/ pectoralis major-change in curvature was 0.584 (SD : 0.102).

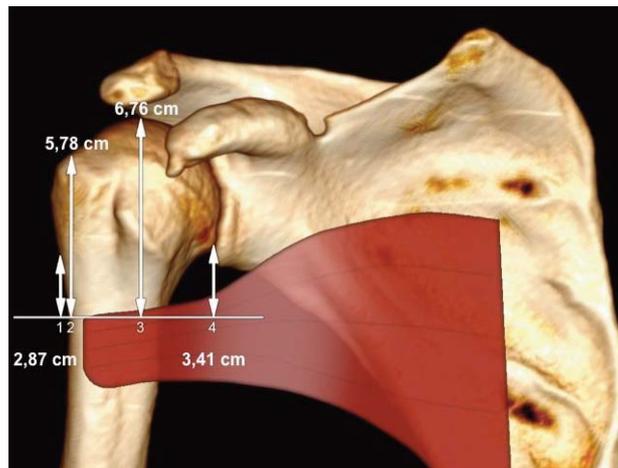


Figure 3: Results of the 4 measurements

**Discussion:**

**Criticisms**

Our study presents a biased view. While the humeral height measurements are only visible in 137 cases, it is because it has not always been possible to see the tendon on the sternal head of the pectoralis major, either because the scanner's acquisition helix was too limited or because the muscle could not be identified with certainty. Conversely, on a cadaver, or during an operation, it is easy to find the upper edge of the pectoralis major via the delto pectoral route (figure 4). Moreover, we have never taken the measurements in patients and therefore have not been able to correlate this distance to either the patient's own measurements or to the contralateral humerus.

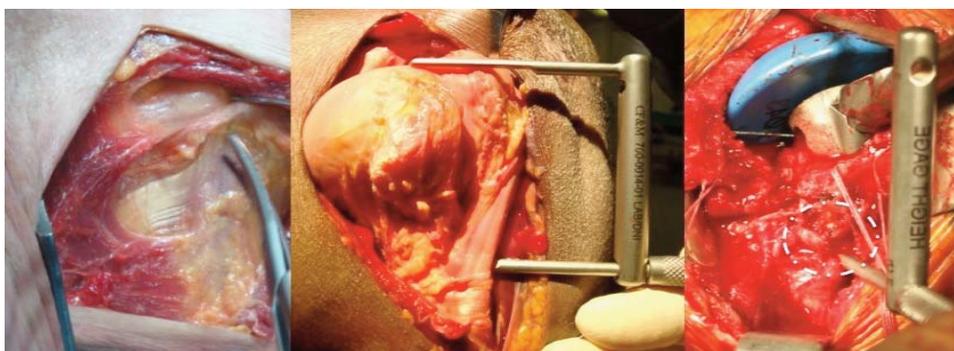


Figure 4: 3 examples on left shoulders of the distance apex of the humeral head / upper edge of the pectoralis major: On the left, it is easy to find the upper edge of the pectoralis major on this anatomical dissection, in the centre, one can see the scale of a specific measurement tool (with an arbitrary spread of 5.5 cm) measuring the distance between the apex of the humeral head / upper edge of the pectoralis major, on the right, a per-operative view of the positioning of the implant at a good distance from the upper edge of the pectoralis major (circled in white).

### **Why look for « height » markers?**

Functional results in hemiarthroplasty in complex cephalotuberosity fractures correlate with the height position of the implant and the anatomical consolidation of the tuberosities (1-3).

If the position of the humeral stem is correct, the tuberosities will also be at a correct height. The optimum tuberosity position should be looked at in 3 planes in space, but their respective size, which is variable from one fracture to another, makes it difficult to establish a reproducible technique which would fit every patient and in every situation. A number of studies exist which correlate results for tuberosity consolidation and the height of the stem. In the Sofcot series, out of 175 fractures there was 64% positioning error and in a group of 66 patients, Boileau found 50% tuberosity malposition by showing that there was a correlation between excessive length of the implant and tuberosity malposition [1].

More recently, in a retrospective multi-centre analysis of 102 patients, Reuther found 66% with tuberosity pseudarthrosis, with women presenting with a risk 11 times higher of non-consolidation [2]. Kralinger noted in a group of 167 fractures treated with 5 types of prosthesis, a rate of between 6 and 56% for tuberosity pseudarthrosis. In addition to these pseudarthroses, there was also a malunion in tuberosities (consolidation with a height discrepancy greater than 5mm) in between 8 and 30% of cases. With 4 types of prostheses there were less than half of the cases where the tuberosities consolidated with less than 5mm displacement [3]. Therefore, tuberosity fixation is primarily linked to height adjustment in the implant.

### **Markers for correct height positioning**

Various techniques have been described to obtain a precise humeral length. The distance between the upper centre of the prosthesis and the upper edge of the trochiter must be equal to 5mm... but it is difficult during surgery to check this value in so far as the tuberosities align after the stem is fixed. Dines reported a test where after reduction of the implant, an attempt at subluxating the humeral head downwards, using lower traction should not uncover more than a quarter or at the maximum, half of the glenoid [7]. Equally, other authors have underlined the importance of having a transfer of 50% of the test humeral implant on the glenoid on the front and the back [8,9]. These per-operative tests should be looked at but they bring up several problems: Good stability in the test implant is required or an adjustable fixation in the actual implant, and then without fixing the tuberosities, what does this type of displacement mean? Flatow [9], Compito [10] and Boileau [1] described a reconstruction method which depended on medial calcar markers, which is difficult to apply to cases of severe comminution. Boileau also suggested the use of an external support with planning using contro-lateral humerus which has been shown to be reproducible, but not used frequently by other teams as is rather difficult to adapt without removing a degree of uncertainty [11]. Others have suggested hemiarthroplasty procedures where the height adjustment is modifiable per operatively: Thomazeau and the GUEPAR group using the Ulyss implant [12], and the FX solutions group with the Humelock implant [13]. Thus, after the initial disappointing results caused by a lack of height markers in particular in fracture-led hemiarthroplasties, the anatomical studies on them have appeared to be necessary. And the use of the apex distance from the humeral head / upper edge of the pectoralis major seems to have become “the” trusted marker.

### **Published anatomical studies**

Even though this distance is an interesting point for surgeons now, it is difficult to find a published “anatomical” note for this distance. Ollier [14] seems to be the first person to describe this distance on a cadaver. On a man with « greater than average » height, he measured the humerus at 365mm with an apex/pectoralis major distance of 65mm [14]. The Warner team was the first one in 2001 to report the useful results from this measurement from Anne Gerber and Philippe Clavert whose studies were reviewed and published by Murachovsky [4]. In a cadaver study, Gerber created a digital model in 3D to calculate the distance between the upper part of the pectoral tendon and the apex of the humeral head with a result of 5.19 cm [15]. In 3 cadaver studies, Murachovsky in 2006 [4], Torrens in 2008 [5] and Hasan in 2009 [6], found a pectoralis major - apex distance of around 5.5 cm +or – 5mm, which is smaller than in our study (6.7 cm) (see table 1). This difference can be explained by the limited number of samples (none having more than 40) and also as our larger study sample contained more men. Indeed, our study shows a significant difference in this distance according to the sex of the subject ( $p < 0.001$ ): it is significantly 7.8 mm longer in men. In the Murachovsky study the average distance was 5.6 cm (5.0-7.0 cm; SD, 0.5 cm), 36/40 shoulders « were » between 5.0 and 6.0 cm, but in 3 cases (6 shoulders) the distance was equal to or greater than 6 cm, in 3 men with heights over 1.68 m. Only 4 cases (8 shoulders) had an identical measurement to the distance between the sides of a similar cadaver. Torrens' scan measurement study [5] on cadavers also found a distance equal to 5.64 cm (5.29-5.99) but above all showed that this distance represented 17.55% (16.70-18.39) of the total length of the humerus.

Taking this distance as a marker would allow there to be an error of less than 1 cm in 85% of cases. In Hasan's cadaver study carried out over 31 shoulders (38 cadavers), 2 scan measurements were correlated: the distance apex/pectoralis major (HP), and pectoralis major/ lateral epicondyle (PL). HP was measured at 5.77 cm (standard deviation 6.10 mm), but with 11 shoulders (8 different cadavers) where the HP distance was greater than 6 cm and 2 shoulders with a distance of less than 5 cm. In this study, Hasan shows that a constant relation exists between the 2 distances measured and this depends on the unique anatomy of each patient. The formula for this relationship is simple and easy to use pre-operatively. The distance of the lateral epicondyle at the upper edge of the insertion can be measured and the formula ( $PHP = 0.2323 \times PL$ ) used to estimate the apex / pectoralis major distance. The average prediction error of 4.11 mm is very acceptable. Hasan notes that a lengthening of 5 mm and a shortening of 1 cm of the humerus are tolerated [6].

#### **Clinical studies applied:**

In 2010 Rouchy [16] reported a short clinical study where a hemiarthroplasty was positioned using this marker and the length of the operated humerus was then compared to the healthy humerus: there was a maximum difference of 3%. Greiner's study in 2008 [17] and Lascar's in 2012 [18] found better clinical results after using the distance between the apex of the prosthetic head / pectoralis major. Greiner compared the results of 30 patients with an average age of 73 years, who were seen for follow-up at an average of 22 months [15]. 21/30 had been operated on using the apex/pectoralis major distance (measuring between 5.1 and 5.4 cm) to position the hemiarthroplasty. The use of this distance allowed for an improvement in the Constant score of 15 points and of 20 points in the Dash score. Lascar reported a dual study, a preliminary anatomical study on 11 cadavers and a prospective multi-centre clinical one of 30 patients (31 cases) operated on with a dedicated prosthesis, the Humélock FX stem [18]. The anatomical and clinical studies allowed a distance between the head apex /pectoralis major to be found that was very close to the published data, validating the height adjustment tool (compass distance 5.5 cm) for this implant (figure 4). However, it is only possible to take this measurement by the delto pectoral route. Via the superoexternal route and with image intensifier, the knowledge of a new parameter (distance between the pectoralis major and the change in curvature), of nearly 3 cm, helps to avoid basic errors and offers yet another checking tool to obtain correct prosthesis position. It is possible, whichever route is chosen, to maintain a simple height marker which will avoid errors: the prosthetic head should be placed 6 cm from the upper edge of the pectoralis major and 3 cm from the change in lateral curvature of the humeral neck, if this has not been damaged by the fracture and is visible on the image intensifier.

#### **Conclusion**

Functional results following a shoulder hemiarthroplasty in fracture cases are closely linked to the correct height position of the implant. The distance between the apex of the humeral head / upper edge of the pectoralis major is a useful measurement, with some consistency, and characteristic to the individual even while it may be different from one side to the other. The various published anatomical studies and our scan analysis will allow the surgeon to position the top of the prosthetic head of a humeral implant used in fracture cases at least 6 cm from the upper edge of the pectoralis major. If the patient is male, and if he is « tall » (over 1.8 m), then this distance will be closer to 7cm. Measuring the controlateral humerus and Hasan's formula will also help to avoid an error of more than 5mm. In addition, this measurement lets other per operatory markers increase the chances of obtaining acceptable functional results, which are also acceptable to the patient who chose to have neither the fracture or the need for a new shoulder.

Study	N cadavers N shoulders	H/F	Age/ Height	Measure- ments	Notes
Murachovsky JSES 2006	N =20 cadavers / 40 shoulders	11 M, 9F	1.62 m (1.45- 1.78)	5.6 cm (5.0-7.0 cm; SD, 0.5 cm	36 shoulders «were» between 5 and 6 cm. In 4 cases (10%) the distance exceeded 6 cm. The humerus bones in the same patient are not always equal in length.
Torrens C JSES 2008	N =20 cadavers / 40 shoulders X-ray measurements	12 M, 8F	68 years (54-96) height not reported	5.64 cm (5.29-5.99)	In 2 cases the distance was 4.47 and 3.96 cm and in one case 7.35. This distance represents 17.55% (16.70-18.39) of the total length of the humerus. If one uses this distance the error will be less than 1 cm in 85% of cases.
Hasan Orthopedics 2009	N = 31 cadavers /38 shoulders Pectoralis major measurement (HP) compared with humeral length	?	Unreported	HP =0.2323xPL	More non-twinnd shoulders, therefore more unbiased results. The pre-operative measurement of the controlateral humerus allows for the distance apex/pectoralis major to be extrapolated with a margin of error of 4.11 cm.
Greiner SH JSES 2008	Clinical study N=30 comparative with 2 groups of protheses with and without the use of distance		73 years	5,1 à 5,4 cm	Using this marker allows for a long-lasting fixation of tuberosities with a Constant score above 15 points and a Dash score over 20 points.
Rouchy Trucs et Astuces 2010	Clinical study N = 9 Using distance	3M, 6F	1.68 m (1.55-1.78) M :1,76 F :1,64	5,46 cm (5-6)	Measurement of the relative gap/healthy side. No correlation reported with the clinical functional results.
Lascar T OTSR 12	N= 11 cadavers 11 shoulders Clinical study with and without the use of distance	?	Unreported	5,5 cm (5-6)	Validation of an ancilliary for placement of a custom implant. Best results in abduction and ante-elevation if the prosthesis is positioned «at least 5.5 cm» from the pectoralis major.
Peyron C OTSR S 13	N=137 x-ray images /200 shoulders	112 M 88 F	Height not measured 49.79 years (15-93)	6,7 cm H : 7 cm F : 6,3 cm	First study with more precise scanner measurements, on a larger scale, which shows a difference between men and women.

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