

An Anatomical Feasibility Study of Rotator Cuff Sparing Approaches for Total Shoulder Arthroplasty

Tressa Amirthanayagam, Andrew A. Amis FREng, Peter Reilly, Roger J. H. Emery.

Work done at Imperial College London

Address for correspondence:

Prof RJ Emery,

Dept Surgery and Cancer,
Level 10 QEQM building,
Imperial College London School of Medicine,
St Mary's Hospital.
London W2 1NY

r.emery@imperial.ac.uk

Running short title: "Rotator cuff sparing surgical approaches"

Introduction

The incidence of total shoulder arthroplasty has been rising in the last decade¹ and there has been a trend towards smaller implants and more minimally invasive approaches². As demonstrated by the joint registries³ the most common approaches in current practice are the deltopectoral and antero-superior approaches, both of which violate the subscapularis tendon and can lead to long term dysfunction⁴⁻⁷. As a result, there has been a move towards rotator cuff sparing approaches. In addition to reducing post-operative cuff dysfunction, another advantage of such approaches is the reduction of post-operative restrictions and the facility for early active mobilization. This would have a positive impact on the time and costs of rehabilitation and may result in an earlier return to work.

Lafosse has described an approach for shoulder arthroplasty entirely through the rotator interval with early promising results. However, this approach is limited in terms of access to the inferior joint for osteophyte removal and referencing for humeral component placement which can result in implant malpositioning^{2,8}. Similarly, a number of authors have proposed subscapularis sparing approaches involving either a split⁹ or partial tenotomy^{9,10} of the subscapularis. The subscapularis splitting approach is commonly utilized for open anterior stabilization¹¹ and Laterjet procedures and its use in shoulder arthroplasty was described as being experimental in 2013⁹. Glenoid wear is more prevalent posteriorly, a region difficult to access with both anterior and superior approaches. Historically, the posterior approach to the shoulder for arthroplasty has involved deltoid mobilization and acromion osteotomy, such as that described by Kocher in 1902 and utilized by Engelbrecht in the 1970s¹²⁻¹⁵, or complete detachment of the posterior deltoid and external rotator tenotomy^{16, 17}. However, Brodsky¹⁸ and later Jerosch¹⁹ both described a posterior subdeltoid approach that aimed to preserve all the rotator cuff attachments. This involves superolateral retraction of the posterior deltoid with subsequent development of the inter-nervous interval between the infraspinatus and teres minor. This approach has been performed for

posterior shoulder pathology such as instability but, like the subscapularis splitting approach, it remains to be seen whether it can provide sufficient access to the glenohumeral joint for total shoulder arthroplasty. From this review of the literature, the subscapularis splitting, rotator interval and inter-nervous posterior approaches represent the most feasible minimally invasive approaches to the shoulder that do not involve any form of tenotomy of the rotator cuff.

All medical devices have to undergo a formal risk assessment procedure to determine whether, on the basis of accepted data, a reasonable risk in a given context has been achieved. Although no such requirements exist for novel surgical approaches or procedures it was felt that this systematic process would be an effective method to minimize potential risk to patients from less commonly used surgical approaches.

The first part of a risk assessment involves analyzing potential risks and then taking steps to mitigate these risks to safe levels. In this case, this involved a detailed literature review of potential complications of total shoulder arthroplasty and how the surgical approach can affect them. The main three complications: implant failure (usually secondary to suboptimal implant position or soft tissue imbalance), glenohumeral instability, and rotator cuff dysfunction²⁰⁻²² are inextricably linked, with each one having the potential to impact on the other²³. Another significant risk, intra-operative neural injury, is rare but has serious consequences for long-term function.

The factors within a surgical approach that contribute to these complications include the proximity of neurovascular structures, whether the access afforded is sufficient for instrumentation and adequate orientation of the implant, and whether the force through the rotator cuff during retraction could be high enough to result in muscular dysfunction. Thus, this cadaveric study design focused on the quantification of these factors for each rotator cuff sparing approach. If the risks are deemed acceptable following this study, the next stage of the assessment would involve in vivo testing of the approach with pilot studies.

The aim of this study was to compare the three minimally invasive approaches to the glenohumeral joint in terms of ease of access and proximity to neurovascular structures that can be at risk during surgery, with a view to total shoulder arthroplasty with modern implants and instrumentation.

Materials & Methods

As part of the risk analysis detailed above, a study was designed to quantify the following factors for each approach: access to the pathological parts of the joint (i.e. the osteophytes), access to surgical landmarks for orientation and implantation, access for surgical instruments and implantation, quantification of the minimum force required for adequate access through the rotator cuff during retraction, and the proximity of neurovascular structures to the approach.

Specimens and testing sequences

Twelve fresh frozen forequarter cadaveric specimens were used from 9 North American individuals. Of the specimens 6 shoulders were left sided, 6 right sided, 6 from males and 6 from females. The mean age was 71 (range 57 - 83) and the mean weight was 67 kg (range 47 – 109 kg) with 11 from Caucasian and 1 from Afro-Caribbean heritage.

The cadavers were divided into three groups of four specimens: male right, male left, female right and female left forequarters. In the first group the subscapularis splitting approach (SS) was performed first, in the second group the interval approach (RI) and in the final group the posterior approach (POS). The specimens were rotated systematically so that all three approaches were performed in each cadaveric specimen, with the six possible sequences of testing applied to two specimens each, to avoid bias arising from previous use. All skin incisions were 10cm in length and the capsule and rotator cuff split were repaired with size 2 Ethibond sutures (Ethicon, Johnson & Johnson, New Jersey) after each approach to reduce any effect on subsequent approaches. If a statistically significant difference was identified between each approach when it had been performed first and when

performed as a second or third procedure, only the data from the first approaches were considered.

Access to Osteophytes

During total shoulder arthroplasty, adequate removal of the surrounding osteophytes helps to minimize impingement of soft tissues and optimize range of motion. In this study, the three minimally invasive approaches were compared in terms of the percentage of circumferential access to osteophytes that was achieved.

Intra-operatively, an osteotome or bone nibbler would be used to remove osteophytes but in this study a straight pair of Kelly surgical forceps, with their narrow tip, were used to assess access to osteophytes due to their enhanced ability to identify a specific point. The forceps were placed at the proximal and distal extremes of the surgical incision and the amount of the glenoid and humeral articular margin that could be accessed with the instrument was recorded on a graphical representation of the joint. The superior aspect of the joint was taken to be 0° and going clockwise in a circle starting from superior to anterior, inferior then posterior, the articular margins of the glenoid and humerus were divided into 5° sections (Figure 1). The sections where the margin and thus any potential osteophytes could be accessed for removal were recorded.

Surgical Access & Force on Rotator Cuff

Using a similar method to that described by Fischer et al ^{24, 25}, a Gelpi self-retaining retractor was equipped with strain gauges using a full Wheatstone bridge configuration and calibrated using an Instron materials testing machine (Instron Limited, High Wycombe, UK) to enable measurement of the force in Newtons exerted by the retractor onto the tissues of the rotator cuff during retraction. The retractor was opened until no further improvement in access could be achieved. Given the non-linear viscoelastic mechanical properties of resting muscle^{24, 26, 27}, the peak readings (prior to substantial stress relaxation)

during maximal retraction for each of the three surgical approaches were taken. This was performed with the retractor placed perpendicularly at the mid-point of the rotator cuff split.

During the three surgical approaches, digital photographs were taken at a distance of 200 mm in the direction that afforded the best image of the joint line. The photographs were taken with the camera on maximum zoom to minimize lens distortion. The photographs were taken in seven positions: with the shoulder in neutral, 45° abduction neutral rotation, 45° flexion 45° abduction neutral rotation, maximal internal rotation neutral rotation, maximal internal rotation 45° abduction, external rotation neutral abduction and external rotation 45° abduction. The photographs were then processed with digital imaging software (Adobe Photoshop CS6 Extended ^{28, 29}). In similar methodology to Bellamy et al ⁹ the digital imaging software was used to compare a known distance from a metric ruler in each photographic image with the actual number of pixels and subsequently calculate the maximum height (superior to inferior) and width (medial to lateral) as well as the surface area of the skin opening and rotator cuff opening (Figure 2).

A pilot study was performed measuring the depth from the skin incision to the glenohumeral joint in each of the seven positions using digital calipers. As there was no statistically significant difference between these readings the remaining measurements of depth were performed with the shoulder in the neutral position.

The volume of the space afforded for surgical instrumentation, i.e. the space from the skin incision to the rotator cuff split was calculated using the formula for the volume of a frustum of a cone, $V = \frac{1}{3}(A_1 + A_2 + \sqrt{A_1 A_2})h$. The wide base of the frustum (A_1) is taken to be the skin incision, the narrow base (A_2) the rotator cuff split and the height of the frustum (h) the depth from the skin incision to the joint (figure 3).

Bony Landmarks and Proximity to Neurovascular Structures

Using digital calipers, the distances of the significant neurovascular structures from the skin incision and bony landmarks were measured for each of the three approaches with the shoulder in the neutral position. It was also noted whether the bony landmarks commonly used for surgical referencing during arthroplasty were either visible, palpable or both during each approach.

Statistical Methods

Statistical analysis was performed with use of the Statistical Package for the Social Sciences software (version 22.0; SPSS, Chicago, Illinois). The normality of the distribution of the data was confirmed using the Shapiro-Wilk test. Two-way repeated-measures analyses of variance (ANOVA) were performed to analyze the differences among the three surgical approaches with regard to surgical access and mixed ANOVA were performed to assess if the order of the approaches had any impact on the results. The Mauchly test was used to test the assumption of sphericity. Post hoc pairwise comparison tests with Bonferroni correction were used to test the differences between group means. The level of significance for all univariate and multivariate analysis was set at $p < 0.05$.

Results

Parametric data are reported as mean $\pm$ standard deviation (minimum - maximum).

Access to Osteophytes

The posterior approach permitted direct linear access to 60 ± 8 (39-69) % of the humeral and 59 ± 4 (53-65) % of the glenoid joint circumference compared with 39 ± 7 (25-50) % and 42 ± 9 (31-57) % for the subscapularis splitting approach and 37 ± 7 (28-49) % and 28 ± 9 (19-44) % for the rotator interval approach (figure 4).

Surgical Access and Force on Rotator Cuff

The order in which the approaches were performed did not have a statistically significant effect on the size of the skin and rotator cuff openings or the volume of access ($p>0.05$). Therefore, the data from all three approaches for the twelve cadavers were considered.

There was a statistically significant correlation between the body weight of the cadaveric donor and the depth of the approach (distance from skin incision to glenohumeral joint) with the subscapularis splitting ($p=0.001$) and posterior approaches ($p=0.004$) but not with the rotator interval approach ($p=0.101$). Similarly, arm position affected access in the subscapularis splitting and posterior approaches but not the rotator interval approach. Access through the rotator cuff was greatest in external rotation and 45° abduction in the subscapularis splitting approach and least with internal rotation and 45° abduction (Figure 5). With the posterior approach, internal rotation with neutral abduction afforded the best view of the glenohumeral joint whereas external rotation limited the view. For all approaches, arm position had no significant effect on the size of the skin opening. The area afforded by the skin incision was greatest through the subscapularis splitting approach and access through the rotator cuff was greatest through the posterior approach in all arm positions. There was no significant difference in the volume of access between the three approaches.

The mean force of retraction required on the rotator cuff to achieve optimum visualization was 2.8 ± 1.1 (0.8 - 4.3) N with the posterior approach, 2.7 ± 1.2 (1.2 - 4.6) N with the rotator interval and 4.7 ± 2.6 (1.2 - 10.8) N with the subscapularis splitting approach (Figure 6). The rotator interval and posterior approaches exerted significantly less force on the rotator cuff at the tool-tissue interface than the subscapularis splitting approach ($p<0.05$).

Bony Landmarks and Proximity to Neurovascular Structures

The distances of the main neurovascular structures from the rotator cuff opening and from bony landmarks identifiable during surgery are shown in Table 1 and Figure 7.

With the subscapularis splitting approach, the axillary nerve was 32 ± 10 (10 - 53) mm from the split in the rotator cuff whereas it was 55 ± 8 (46 - 76) mm from the rotator interval split and 23 ± 8 (15 - 47) mm from the infraspinatus/teres minor split (Figures 7a and 7b). Care must be taken with retractor placement as the axillary nerve was only 13 ± 6 (7 - 22) mm from the glenoid rim when measured posteriorly and 17 ± 10 (9 - 43) mm from the anterior approach.

Discussion

This paper demonstrates that the inter-nervous posterior approach may be a viable option for a non-dislocating surgical approach to the glenohumeral joint. Osteophytes contribute to restricted range of motion and function in osteoarthritis and adequate removal of osteophytes is an integral part of total shoulder arthroplasty³⁰. In previous unpublished work looking at computerized tomography scans of pre-operative total shoulder arthroplasty patients, this group found that the majority of osteophytes were located in the antero-inferior and postero-inferior aspects of the glenoid and humeral articular margins, which is in keeping with Neer's findings³¹. Of the three approaches investigated in this study, the posterior approach afforded the best access to the inferior aspect of the joint where the majority of osteophytes are found (figure 5), in addition to providing access to a greater percentage of the overall articular margin. This is beneficial not only for the removal of osteophytes but also for access to the joint for instrumentation during arthroplasty surgery.

Retractors can compress muscle fibers: work done by Taylor et al³² on paraspinal muscles suggested that there can be loss of muscle function from ischaemia secondary to pressure from the retractors. In his study, Taylor used

an Intra-Compartment Pressure Monitor (Stryker UK, Newbury) to record the intramuscular pressures in-vivo. In this cadaveric study, force feedback was used as a means to compare the force exerted by the three approaches on the rotator cuff. The retractor exerted significantly less force on the tissue in the rotator interval and posterior approaches than the subscapularis splitting approach. The forces were comparable to those reported in laparoscopic bowel surgery studies by De Visser and others, which were approximately 2.5 N to 5 N^{33, 34}. The forces measured in this study are useful for comparative purposes but their absolute values are likely to underestimate the force during live surgery given the increased resting muscle tension of living tissue.

The three approaches provided comparable volumes for surgical access. Although the subscapularis splitting approach, which utilized the deltopectoral interval superficially, had the greatest area of skin opening, the posterior approach was far superior in terms of deeper access to the glenohumeral joint itself. With the subscapularis splitting and rotator interval approaches, the opening in the rotator cuff was essentially in continuity with the capsule. However, with the posterior approach, medially the cuff and capsule are two distinct planes. Thus for the posterior approach, the opening in the rotator cuff was used rather than the capsulotomy opening as in practical terms it is the muscular structures that tend to limit surgical access rather than the malleable capsule. In a similar study design, Bellamy et al compared the amount of exposure of the humeral head and identification of landmarks for shoulder arthroplasty with the subscapularis splitting, partial subscapularis tenotomy and complete subscapularis tenotomy⁹. Unsurprisingly they showed that the exposure of the humeral head increased sequentially as more of the subscapularis tendon was cut. They were unable to place instrumentation for resurfacing or total shoulder arthroplasty through the subscapularis splitting approach and were able to visualize $200 \pm 59 \text{ mm}^2$ of the glenoid and $320 \pm 216 \text{ mm}^2$ of the humeral head. This was in line with the present findings of reduced access through the rotator cuff opening with the subscapularis splitting approach of $136 \pm 13 \text{ mm}^2$ compared to $155 \pm 17 \text{ mm}^2$ for the rotator interval and $377 \pm 38 \text{ mm}^2$ for the posterior approach.

The axillary nerve was found to be as close as 7 mm (13 ± 6 (7 - 22) mm) to the inferior glenoid rim. This is similar to a cadaveric study by Ball et al, who measured the posterior branch of the axillary nerve to be 10 (2 -17) mm from the inferior glenoid rim³⁵. They also found the nerve to teres minor to be 18 (11 - 25) mm from the inferior glenoid rim whereas this study found it to be 11 ± 5 (5 - 19) mm.

Direct anatomical comparisons of the rotator cuff sparing approaches to the shoulder have not been published before. The study was designed with a view to mitigating potential risk for the patient and involved a large number of measurements on each specimen. A reproducible method has been described and measures were taken to eliminate bias of sex and side. However, there are inherent limitations in a cadaveric study. Fresh frozen cadavers were used and alteration in the qualities of the tissue in vivo is unavoidable. The study size was limited to 12 specimens, and 11 of these were from Caucasians, which may have resulted in an ethnic bias. The measurements were all performed by one observer and there were no measures of inter- or intra-observer reliability. However, the findings are consistent with similar studies. Photographs provide a two dimensional image of a three dimensional structure. When surgery is performed, the surgeon moves around the patient to optimize visualization and access. Thus, the data from the two-dimensional images may under represent the access in vivo⁹.

This study demonstrates that the posterior inter-nervous approach may be a viable option for total shoulder arthroplasty with new implant designs and minimally invasive instrumentation. It provides better access to pathology such as posterior glenoid wear and osteophytes, and allows better visualization of the glenohumeral joint compared to other minimally invasive cuff sparing approaches. By preserving the rotator cuff, such approaches should allow early active immobilization, reducing the need for involved postoperative rehabilitation programs and potentially an earlier return to full function. The next stage of the risk assessment process would be to perform an in vivo pilot study with intra-operative neuromonitoring.

Conclusion

The rotator interval approach is not affected by body weight or arm position and is furthest away from neurovascular structures but it provides poor access to joint pathology, particularly inferior osteophytes. The subscapularis splitting approach provides the largest skin opening but exerts the greatest retraction force on the rotator cuff. Of the three, the inter-nervous posterior approach provides the greatest access to the shoulder joint whilst minimizing damage to the rotator cuff. However, care must be taken during retractor placement due to the proximity of the axillary nerve in this approach.

Source of Funding

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Fig 1

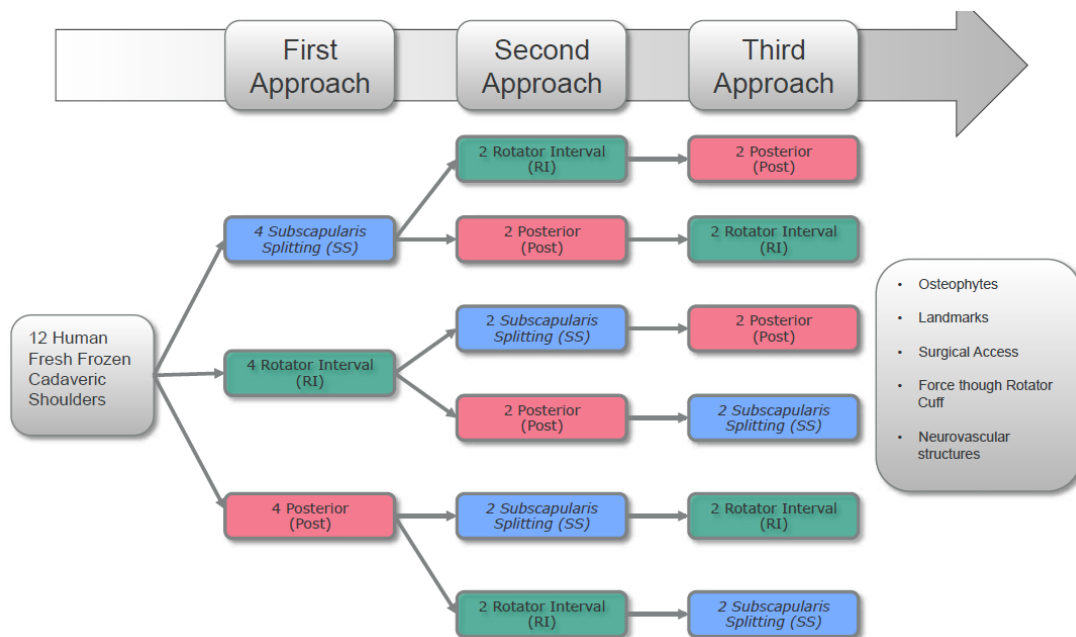


Fig 2

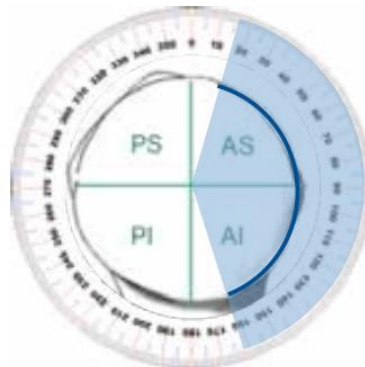


Figure 2: Diagrammatic representation of humeral articular surface
 AS – anterior superior. AI – anterior inferior,
 PS – Posterior inferior, PS – Posterior superior

Fig 3

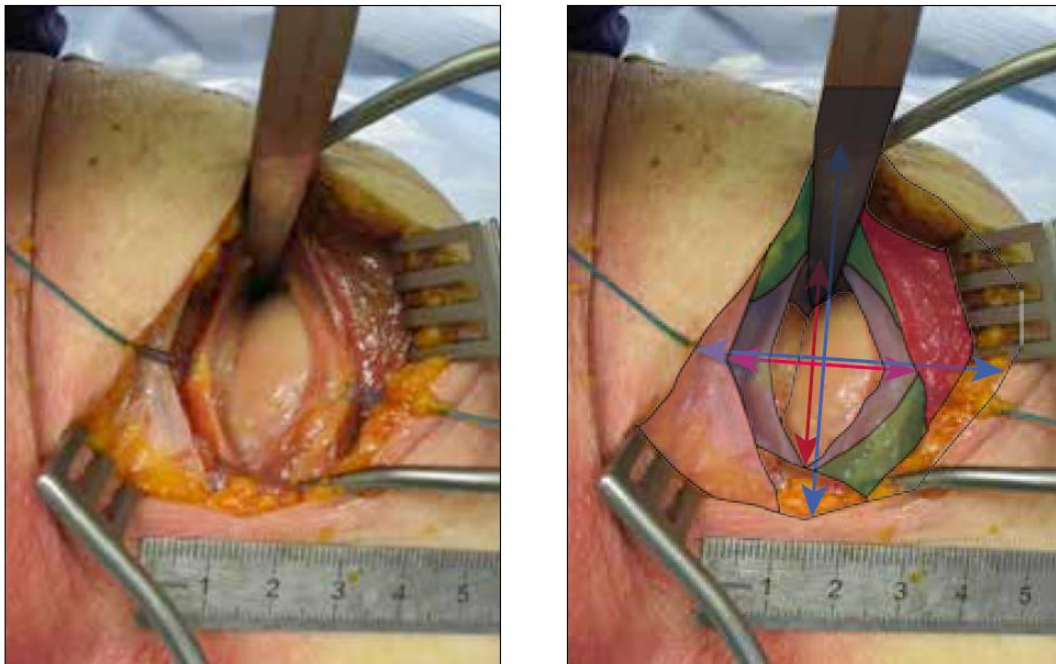
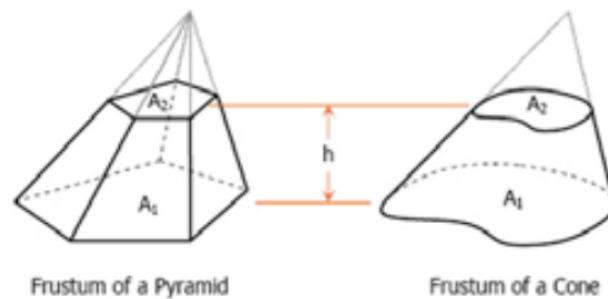


Fig 4

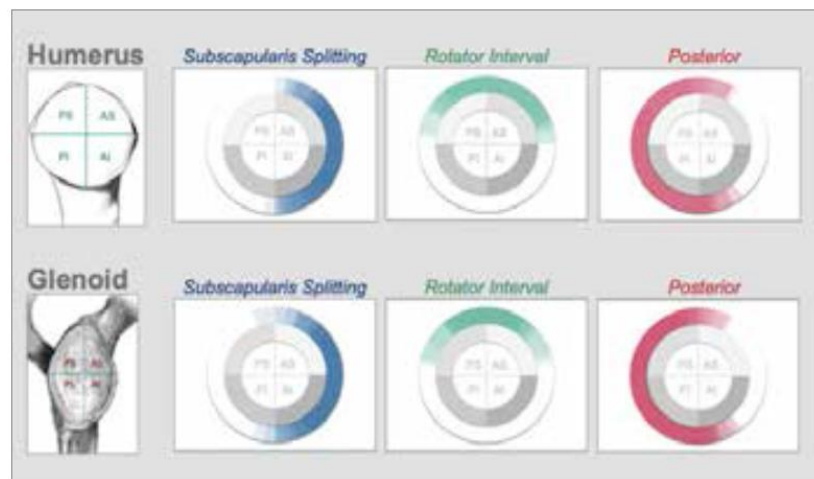


Formula for Volume of a Frustum

The volume of a frustum is equal to one-third the product of the altitude and the sum of the upper base, the lower base, and the mean proportional between the bases. In symbols:

$$V = \frac{1}{3}(A_1 + A_2 + \sqrt{A_1 A_2})h$$

Fig 5

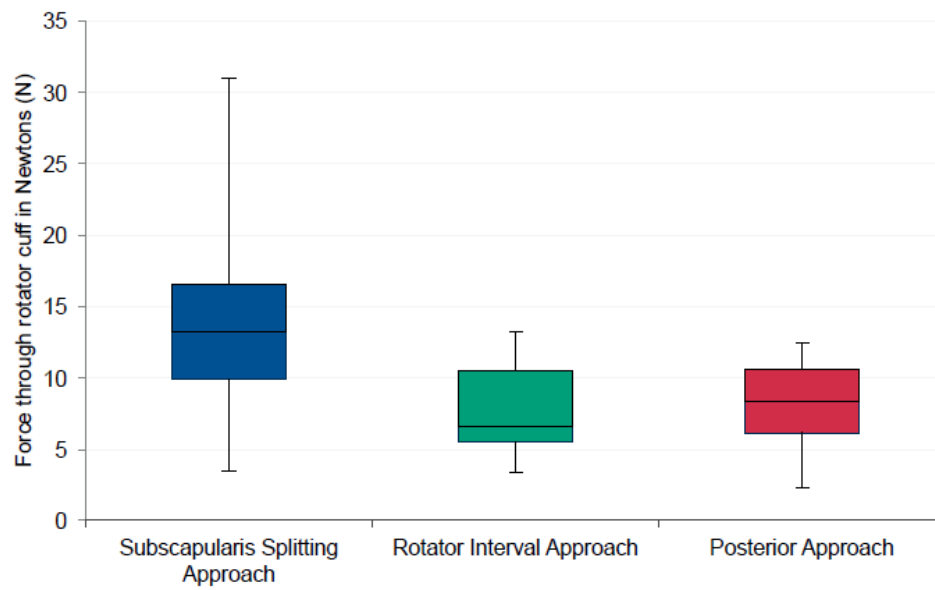


Outer circle – the darker the color the larger the number of specimens where access to this area could be achieved
 Inner circle – the darker the grey, the higher the incidence of osteophytes in this quadrant in the osteoarthritic shoulder

Fig 6



Fig 7



Maximum force exerted on cuff by retractors.

Fig 8a

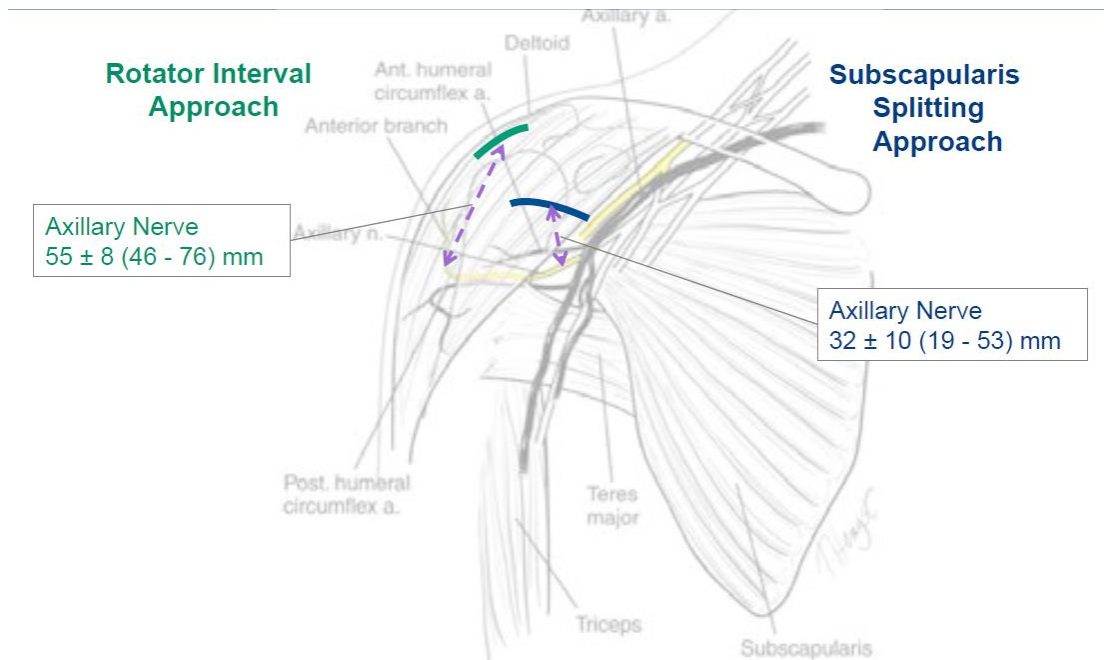


Fig 8b

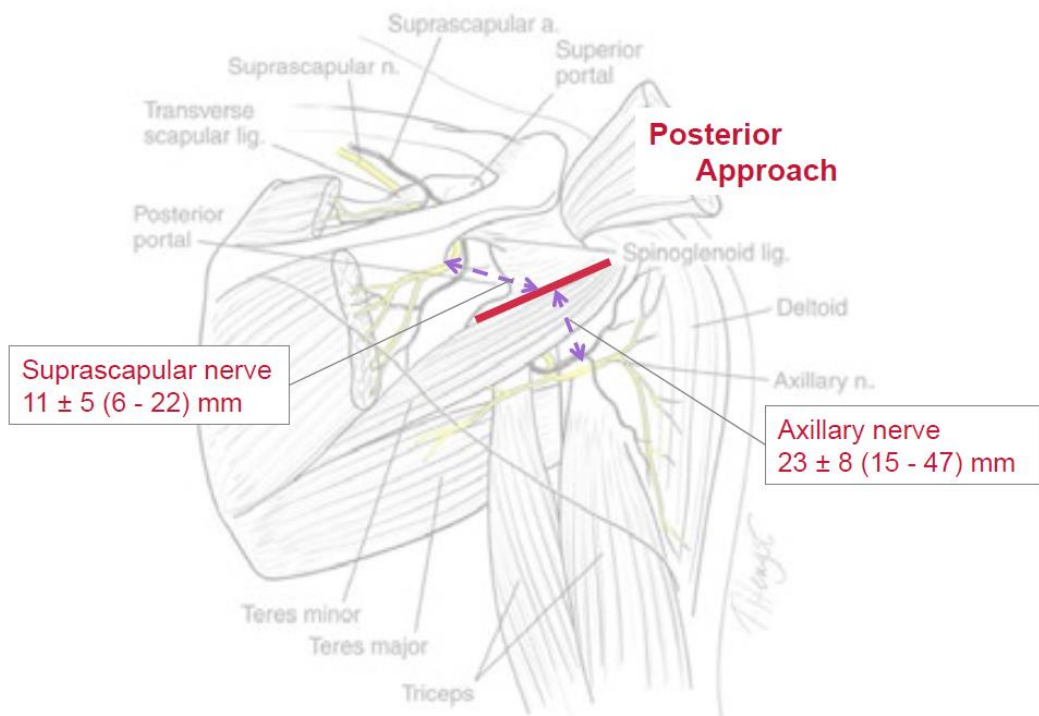


Table 1a

Subscapularis Splitting Approach

Distance of Axillary Nerve from:	Mean	SD	Min	Max
Anteromedial coracoid tip	54	12	29	70
Lat border of subscapularis (shortest distance)	38	8	25	55
Subscapularis split (shortest distance)	32	10	19	53
Glenoid rim: superior	47	8	36	60
Glenoid rim: middle	32	10	16	51
Glenoid rim: inferior	17	10	9	43
Distance of Musculocutaneous Nerve from:	Mean	SD	Min	Max
Anteromedial coracoid tip	37	10	20	50
Lat border of subscapularis (shortest distance)	33	6	22	42
Subscapularis split (shortest distance)	16	6	6	28
Anterior Circumflex Humeral Artery	Mean	SD	Min	Max
From subscap split	27	10	16	55

Table 1b

Rotator Interval Approach

Distance of Axillary Nerve from:	Mean	SD	Min	Max
Anterolateral acromial tip	68	8	58	82
Rotator Interval split (shortest distance)	55	8	46	76
Distance of Musculocutaneous Nerve from:	Mean	SD	Min	Max
Anterolateral acromial tip	58	7	46	69
Rotator Interval split (shortest distance)	96	177	33	658
Acromial br of thoraco-acromial artery	Mean	SD	Min	Max
From rotator interval split	54	11	32	79

Table 1c

Posterior Approach

Distance of Axillary Nerve from:	Mean	SD	Min	Max
Posterolateral acromial tip	55	9	43	74
Infraspinatus -teres minor split	23	8	15	47
Genoid rim: top	43	6	33	54
Glenoid rim: middle	28	7	17	43
Glenoid rim: bottom	13	6	7	22
Distance of br to teres minor from:	Mean	SD	Min	Max
Lateral border teres minor	28	5	21	36
Inferior glenoid rim	11	5	5	19
Distance of Suprascapular Nerve from notch to:	Mean	SD	Min	Max
Length of nerve from notch to infraspinatus	11	5	6	22
Lateral border of infraspinatus	30	8	20	40
Genoid rim: superior	22	6	14	38
Glenoid rim: middle	22	8	14	41
Glenoid rim: inferior	28	7	15	44
Posterior Circumflex Humeral Artery	Mean	SD	Min	Max
From incision	28	6	21	41