The Posterior Aspect of the Shoulder

An Anatomic Study Using Plastinated Cross-Sections

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The aim of this study was to evaluate the topography of the main neurovascular bundle located in the posterior aspect of the shoulder and to establish a relatively safe area for a low-risk arthroscopic approach through a posterior portal. A slice anatomy study, using plastinated transparent shoulder joint sections, was performed on ten non-degenerative right shoulder body specimens. Measurements were performed at the level of the suprascapular notch, the coracoid process, and the acromion. The suprascapular nerve was 38.2 ± 0.1 mm, the suprascapular artery 39.4 ± 0.2 mm, and the circumflex scapular artery was 24.8 ± 0.5 mm away from the posterior rim of the acromion at the level of the suprascapular notch. At the level of the coracoid process the suprascapular artery was 34.2 ± 0.5 mm, and the circumflex scapular artery was 50.9 ± 0.3 mm away from the posterior rim of the acromion. Combined measurements of both arteries offered an average distance of 19.8 ± 0.3 mm. The mean distance to the posterior circumflex humeral artery and the axillary nerve was 47.7 ± 1.5 mm and 50.9 ± 0.9 mm, respectively. The present study suggests that, a posterior arthroscopic approach at a level of 4.5 to 5 cm below the posterior rim of the acromion and above the midline of the glenoid joint space poses a low risk for injuries to the neurovascular structures.

Keywords: Plastinated cross-sections, arthroscopy, shoulder, axillar nerve

Since its introduction, arthroscopy of the shoulder has provided a better understanding of the diagnosis and treatment of shoulder joint disorders. Over the past few years, the complexity of the techniques, as well as the number of surgeries performed, has risen significantly. Arthroscopy allows not only a shorter rehabilitation period and an improved outcome but also provides a functional exploration of the joint compared to open surgery [1, 2]. Therefore, proper portal placement and a good anatomical knowledge are necessary to prevent injuries to anatomic structures. The posterior portal of the shoulder is the preferred approach for diagnostic and therapeutic arthroscopy. It basically serves as a portal for arthroscopic visualization and usually represents the initial approach to the shoulder joint. The location is situated inferior and slightly medial to the posterolateral angle of the acromion at the so-called "soft spot" of the posterior shoulder, described by Andrews et al. [3] and Wolf [4]. The main neurovascular bundle of the arm passes the shoulder joint on the medial and anterior region on its way to the periphery, innervating neural branches and providing the vascular supply to the muscles on the shoulder's posterior aspect. In particular, the axillary nerve and the posterior circumflex humeral artery run from the lateral triangular space around the inferior border of the teres minor muscle on the reverse side of the shoulder, and therefore, are at increased risk of injury [5, 6]. Furthermore, the course of the suprascapular nerve and accompanying suprascapular artery into the infraspinatus fossa should be known to ensure appropriate portal positioning [7-9].

Anatomic dissection has been used to investigate the posterior aspect of the shoulder for endoscopic surgery [10-15]. The technique of sheet plastination produces transparent body slices with all structures in an uncollapsed state, without any artifacts caused by dissection. This technique is unique as transparent body slices with intact structures and transparent connective tissues can be easily processed morphometrically [16-21].

The purpose of this study was therefore to confirm the topographic landmarks that can be used consistently to delineate a secure and safe region for posterior portals. The location of posterior neurovascular structures was determined using the sheet plastination without moving any structures, as would be the case with dissection, to delineate a safe zone in where to establish a posterior portal. Therefore bony landmarks, the axillary nerve, the suprascapular nerve, the suprascapular artery, the circumflex scapular artery, and the circumflex humeral artery were investigated, as well as their relationship to each other.

Experimental part

Ethical approval was received from the Ethical Committee of the Medical University of Vienna, following the ICH-GCP standards of good clinical practice (number of approval 157/2011).

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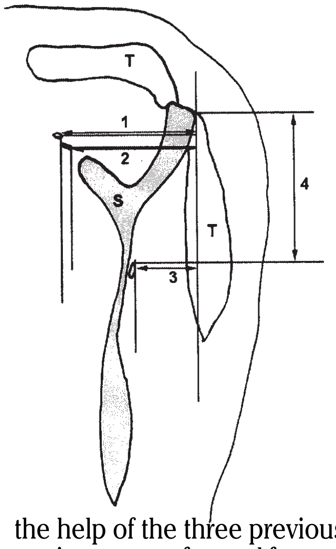

Fig. 1. Sample diagram indicating the sites at which the measurements were taken at the level of the suprascapular notch. 1 - Distance between the spina scapulae and the suprascapular nerve; 2 - Distance between the spina scapulae and the suprascapular artery; 3 - Distance between the spina scapulae and the circumflex scapular artery; 4 - Distance between the spina scapulae and the circumflex scapular artery; S – Scapula; T - Trapezius muscle.

Ten, intact right upper body extremities were used. Exclusion criteria for selection were severe arthritic joint destruction, healed fractures or defects of the participating bones, as well as previous medical condition, that would alter the normal anatomy. All body specimens ages ranged between 67 and 83 years with a mean age of 74.2 years. The bodies were placed into the lateral decubitus position, with anterior flexion (10 to 15 degrees) and slight abduction (30 to 70 degrees) of the arm. They were then deep-frozen for five days at a constant temperature of -80°C, and then each upper extremity was sawed off at the lateral two thirds of the clavicle and at the level of the fifth rib of the chest wall. This position of removal preserved all topographical structures, such as the connective tissue around the neurovascular bundle of the arm. Each specimen was subsequently cut into slices with a mean thickness of 1.5 +/- 0.3 mm and the sawing direction parallel to the adjusted joint surface. Before sawing, three markers were inserted in each frozen specimen at a 90 degree angle for removal.

To preserve the original size of the frozen slices their caudal surface was scanned with an Epson GT-10000+ Color Image Scanner (Epson America, Long Beach, CA), and the mean thickness of each slice was determined by four fixed positions: 5.0 mm from the anterior, posterior, right, and left borders of the slices. For dehydration, the slices were pre-cooled overnight at -25°C, and subsequently submerged into cold acetone (-25°C) series and degreased with methylene chloride for one week. Impregnation with an E-12 epoxy resin composition (Biodur, Heidelberg, Germany) began at +5°. Each slice was placed between two tempered glass plates with a flexible gasket used as a spacer (2.0 mm), and filled up with the resign composition. After bubble removal, the sheets were stored horizontally (15°) at room temperature for one day, then placed into an oven to cure the polymer for four days at +45°C. The finished plastinated slices were once again scanned at the bottom with the Epson GT-10000+ Color Image Scanner to determine the shrinkage rate between the fresh and plastinated slices. These comparative calculations were considered in the measurements. A scale was placed on each slice for the purpose of calibration and to guarantee accurate measurements. The measurements of the neurovascular and topographic structures were obtained using the UTHSCSA Image Tool software for Windows, version 3.0 (University of Texas Health Science Centre at San Antonio, San Antonio, TX). Measurements were taken from three selected slices, representative of the main landmarks of the shoulder joint and to localize the posterior aspect of the shoulder (fig.1). Each measurement was repeated three times, and the mean value was calculated. Descriptive statistics was used to calculate the means and SDs and for further statistical analyses, we used SPSS software for Windows, version 11.0 (SPSS, Chicago, IL).

After plastination, the shoulder joint with the neurovascular bundle of the arm was reconstructed three-dimensionally (fig. 2) based on the technique described by Sora et al., [20]. Each slice was scanned twice at the inferior and superior surfaces using a Color Image Scanner (Epson GT-10000+) at 600 dpi; thus, we obtained two images from each slice in bmp format. The data set was loaded into a surface reconstruction program (WinSURF, version 4.2; SURFdriver Software, Kailua, HI) and digitally processed based on the technique described by Lozanoff et al. [22], Moszkowicz et al. [23] and Sora et al. [24]. The program combines the outlines of each anatomical structure and calculates the exact distance between the slices. The exact alignment of all slices was managed with the help of the three previously inserted markers. Manual tracing was performed for each structure from the monitor. Once all contours were identified and marked digitally, the whole shoulder could be visualized in three dimensions. The available measuring tool recorded the height, the width, and the depth measurements from the model. All reconstructed objects were exported into Adobe Photoshop to actualize them all in one single data file (PDF) as one 3D model (fig. 2).

Results and Discussions

Thin slices measuring 1.5 mm were obtained (figs. 3 and 4) and there was no contamination with sawdust or any small parts of the tissue, including air bubbles. All plastinated E-12 slices were transparent and hard, with good optical quality providing outstanding detailed anatomy down to the microscopic level (figs. 3 and 4). To delineate the area of the axillary space (fossa) and the posterior shoulder region three general slices for every specimen were chosen; 1) at the level of the suprascapular notch, 2) the coracoid process and 3) the acromion.

The data from the topographical measurements obtained through plastination of ten shoulder joints can be seen in table 1, as well as tables 2 and 3. The rate of shrinkage of the slices during the plastination procedure amounted to 2.9%, and the measured values were adjusted accordingly. Due to the high resolution of the plastinated

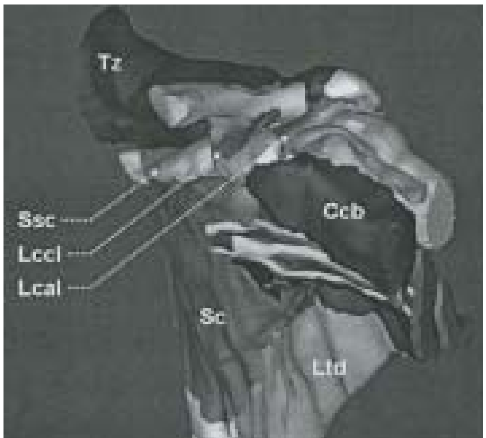

Fig. 2. 3D reconstruction of the shoulder, anteromedial view. Ccb - Coracobrachial muscle; Lcal - Coracoacromial ligament; Lccl - Coracoclavicular ligament; Ltd - Latissimus dorsi muscle; Sc - Subscapular muscle; Ssc - Suprascapular muscle; Tz - Trapezius muscle

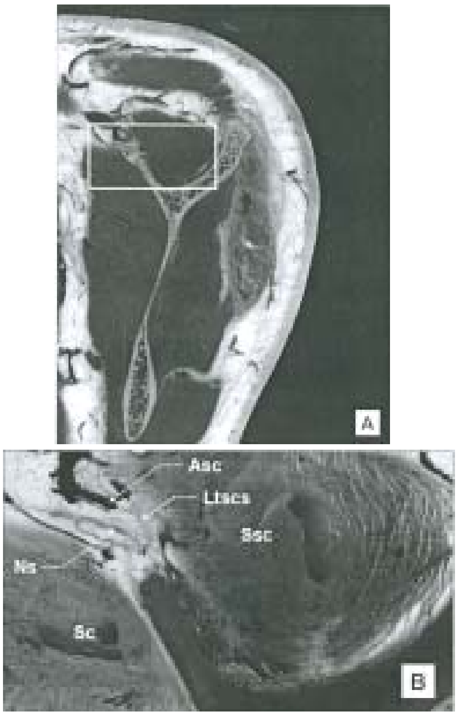

Fig. 3. Plastinated section in the sagittal plane at the level of the suprascapular notch (A). The detail (B) shows the suprascapular nerve, which passes below, and the suprascapular artery passing above the superior suprascapular ligament to enter the suprascapular fossa. Asc - Suprascapular artery; Ns - Suprascapular nerve; Sc - Subscapular muscle; Ssc - Suprascapular muscle; Ltscs - Superior suprascapular ligament

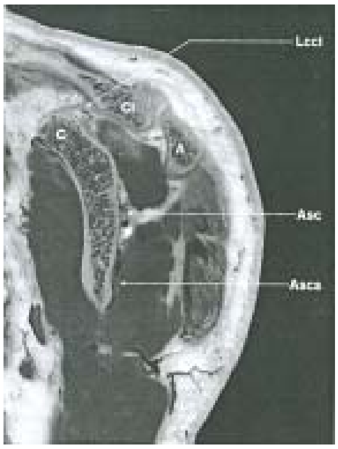

Fig. 4. Plastinated section of a right shoulder in the sagittal plane, at the level of the coracoid process, showing muscles of the rotator cuff and their associated neurovascular structures. A – Acromion; Asc - Suprascapular artery; Ascs - Circumflex scapular artery; C - Coracoid process; Cl – Clavicula; Lccl - Coracoclavicular ligament

slices, it was easy to identify the anatomic structures of the shoulder (e.g., ligaments, muscles, bones, vessels, and nerves) and the borders were traced rapidly and reliably.

Based on measurements, outlining the coracoid process, the joint space, the posterior border and lateral angle of the acromion a posterior portal was established. The average distance between the posterior border of the acromion and the suprascapular nerve was found to be 38.2 ± 0.1 mm. The suprascapular artery was 39.4 ± 0.2 mm, and the circumflex scapular artery was 24.8 ± 0.5 mm, and the average distance from the skin to the posterior circumflex humeral artery was 47.7 ± 0.7 mm. At the level of the coracoid process, the average distance between the posterior border of the acromion and the suprascapular artery was 34.2 ± 0.5 mm and the average distance to the circumflex scapular artery was 50.9 ± 0.3 mm. The combined measurement of the suprascapular and circumflex scapular arteries provided an average distance of 19.8 ± 0.3 mm. From the skin, the suprascapular artery and the circumflex scapular artery were found to have an average distance of 47.7 ± 0.7 mm and 51.8 ± 0.4 mm respectively. From the posterolateral corner of the acromion the average distance to the posterior circumflex humeral artery (47.7 ± 1.5 mm) and the axillary nerve (50.9 ± 0.9 mm) were measured.

The reconstructed three-dimensional shoulder model displayed a first-rate morphology that corresponded qualitatively to the body specimen. The generated 3D-images were of high quality and allowed several perspectives from different spatial positions and depicted the complicated adjacent relations of various shoulder structures.

Compared to open surgery, arthroscopy is less invasive and provides shorter rehabilitation times in patients with shoulder disorders. The numbers of shoulder arthroscopies has continued to increase within the last several decades, as this is a popular diagnostic and therapeutic procedure. However, an overall complication rate has been reported that ranges from 5.8 to 9.5%, with the most frequent injuries to neurologic and vascular structures and an overall complication rate to neurologic structures up to 30% [25]. Neurovascular injuries of the larger nerves or vessels are often caused by traction and compression, or direct trauma during the intervention. For this reason, a fundamental anatomical knowledge of the whole region is necessary, not only for careful patient positioning, but also for accurate portal placement and handling of the rigid instruments, particularly the trocars.

Several studies have examined the anatomy to assess the risk of establishing arthroscopic portals for the shoulder joint [12, 13]. In this study we identified a more secure area in relation to the main topographical landmarks for posterior shoulder arthroscopy. All measurements were performed at three representative levels bordering the posterior aspect of the shoulder joint and included bony landmarks for orientation (fig.1). The medial border was

Table 1
MEASUREMENTS OF THE DISTANCE AT THE LEVEL OF THE SUPRASCAPULAR NOTCH
(n = 10).

Distance between anatomical structures (mm)	Abbreviations	Range (mm)	Mean ± SD (mm)
Distance between the spina scapulae and the suprascapular nerve	Sc – Ns	34.3 – 42.1	38.2 ± 0.1
Distance between the spina scapulae and the suprascapular artery	Sc – Asc	37.5 – 40.9	39.4 ± 0.2
Distance between the spina scapulae and the circumflex scapular artery (antero-posterior direction)	Sc – Ascs	19.5 – 31.2	24.8 ± 0.5
Distance between the spina scapulae and the circumflex scapular artery(in the caudal direction)	Sc – Ascs	38.7 – 47.4	43.7 ± 0.7

Distance between anatomical structures (mm)	Abbreviations	Range (mm)	Mean ± SD (mm)
Distance between the acromion and the suprascapular artery	A – Asc	30.2 – 36.4	34.2 ± 0.5
Distance between the acromion and the circumflex scapular artery	A – Ascs	45.9 – 55.7	50.9 ± 0.3
Distance between the suprascapular artery and the circumflex scapular artery	Asc – Ascs	17.3 – 21.9	19.8 ± 0.3
Distance between the skin and the suprascapular artery	Sk – Asc	45.5 – 50.0	47.7 ± 0.7
Distance between the skin and circumflex scapular artery	Sk – Ascs	48.7 – 55.4	51.8 ± 0.4

Table 2
MEASUREMENTS OF THE LEVEL OF THE CORACOID PROCESS (N = 10)

Distance between anatomical structures (mm)	Abbreviations	Range (mm)	Mean ± SD (mm)
Distance between the posterior border of the acromion and the posterior circumflex humeral artery	A – Achp	40.1 – 51.7	47.7 ± 1.5
Distance between the posterior border of the acromion and the axillary nerve	A – Nx	45.3 – 54.7	50.9 ± 0.9
Distance between the skin and the posterior circumflex artery	Sk – Achp	50.2 – 58.3	53.8 ± 1.3
Distance between the skin and the axillary nerve	Sk – Nx	49.6 – 57.2	54.7 ± 2.7

Table 3
MEASUREMENTS OF THE LEVEL OF THE POSTERIOR RIM OF THE LATERAL END OF THE ACROMION (N = 10)

chosen at the level of the suprascapular notch to investigate the suprascapular nerve and artery, as well as the circumflex scapular artery. In the middle, topography was measured at the level of the coracoid process, which can be palpated clinically during surgery and is one of the main landmarks for the establishment of arthroscopic portals. The lateral border represents the level of the acromion, which includes its posterior corner, also an important bony landmark when developing arthroscopic approaches to the shoulder joint. These borders are used because the surgeon uses these landmarks for orientation and establishment of the “soft-point” portal and the central posterior portal [3, 4, 11-13, 26]. At the level of the coracoid process, the suprascapular artery is situated at mean distance of 34.2 ± 0.5 mm from the posterior border of the acromion, and the circumflex scapular artery is situated 50.9 ± 0.3 mm from the posterior border of the acromion. The axillary nerve was found to be at mean distance of 50.9 ± 0.9 mm from the posterolateral corner of the acromion at the level of the lateral end of the acromion. Meyer et al. [13], performed a body study of twelve different portals and derived a mean distance between the posterior portal and the axillary nerve of 49mm, between the posterior portal and the suprascapular artery a mean distance of 27 mm, and measured 29 mm between the posterior portal and the suprascapular nerve [13]. Lo et al. [10] reported an average distance of 36.4 mm, with a range of 31 to 44 mm between the axillary nerve and the posterior portal and suggested that, in all cases, the nerve was over 30 mm away. Nottage [27], described an average distance of approximately 20 to 40 mm between the cannula and the axillary nerve and the accompanying posterior humeral circumflex artery [27]. For the suprascapular nerve and artery, a distance of approximately 1cm lateral to the posterior portal was reported. The distance between anatomic neurovascular structures was measured and an arthroscopic approach through anatomic dissection was established. By using the E-12 plastination technique, morphometric measurements can be performed easily and accurately, because the tissue is preserved in a non-collapsed and non-dislocated state so that all anatomical-topographical structures as well as the connective tissue remain in their natural position [19]. By slicing the shoulder joint in 1.5 mm steps, detailed and exact information about the main neurovascular bundle and its branches in the upper extremity can more accurately be obtained, compared to anatomic dissection which was described in previous studies [10 - 13]. These dissection studies measured the distances from the inserted trocars or cannulas to the adjacent anatomic structures that had been altered by dissection, and therefore, could not be precise or objective. As we measured the preserved topographical structures from bony landmarks, our data is more accurate and reproducible in clinical practice, compared to the dissection method. On the basis of our anatomic data and morphometric measurements, the safe area for an arthroscopic posterior portal is located in a range of 4.5 to 5.0 cm below the posterior border of the acromion, above the midline of the glenoid joint space. Any arthroscopic approach that is situated below this area increases the likelihood of neurovascular injury of the axillary nerve, the posterior circumflex humeral artery, and the circumflex scapular artery. The posterior arthroscopic portals for accessing the inferior glenohumeral recess, termed the “accessory” posterior and the 7-o’clock portal, are placed in this dangerous area. In an anatomical study performed by Bhatia et al. [10], it was recommended an axillary pouch portal, located approximately 2 cm lateral at the level of the central posterior portal, as a safer alternative to the posteroinferior portals. This inferior glenohumeral recess portal is located 2 to 2.5 cm directly inferior to the posterior acromial corner [10]. In addition, our results show that a safe area for this inferior glenohumeral recess portal would be in the range of up to 4cm greater than that recommended by Bhatia et al [10].

The measured values obtained on plastinated slices are more objective and reproducible than those obtained by the dissection method or measurements between the inserted trocars and neurovascular structures, as tissue components remain unchanged, and there are none of the artifacts associated with dissection on the topographical anatomy. Furthermore, the use of the bony landmarks as the origin of measurements compared to arthroscopic surgery ensures the good quality and is reproducibility in setting the safe area for posterior portal placement. The slice anatomy study had no modifications or deformations of anatomic tissue, thereby making this technique a valuable tool in the evaluation of topographic relations.

Another possibility for the visualization of the topographic compartments and neurovascular structures of the posterior aspect and the shoulder joint itself is the three-dimensional reconstruction of the shoulder using plastinated cross-sections. The quantitative measurements from the model, obtained with the available measuring tool in the reconstruction software, confirmed that the overall morphology was retained. The ability to reconstruct individual and combined images of shoulder structures, and view them from different surgical angles, offers several possibilities. It serves as a great teaching tool for a better understanding of the topographic anatomy in dissection class or in residency education, and is applicable to the arthroscopic surgery and cross-sectional training course in visualizing the regional topography. In addition, surgeons and researchers are using digital models to develop and plan new approaches and new techniques for shoulder surgery, thus further optimizing these types of models.

Several potential limitations should be considered in the interpretation of our results. First, due to a limited sample of specimens, the results and the validity of the study may be weaker when compared to a larger study. Second, although we considered the general shrinkage rate for each slice in our results, artifacts are still possible due to the different tissue types. Finally, position changes are not easily accomplished if the tissue is already fixed with formalin or frozen therefore the results could be improved if the specimen could be precisely positioned before the fixation or plastination procedure.

Based on our measurements for further validation and evaluation of our findings, a clinical arthroscopy study will be performed.

Conclusions

This re-evaluation of the posterior aspect of the shoulder identified a greater and safer posterior area for portal placement, when compared to previous anatomic studies. In addition to the high quality of visualization of anatomic structures with sheet plastination, exact measurements of anatomic structures with relation to the bony landmarks are guaranteed. This will also ensure a high reproducibility rate for each posterior portal placement and risk reduction to damage neurovascular structures. Thus a better understanding of the regional topography of the shoulder is necessary to reduce the risk of injury to the adjacent neurovascular structures through the exact positioning of the posterior portal.

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Manuscript received: 12.02.2014