Arthroscopic transosseous rotator cuff repair: how to avoid damaging the axillary nerve—a cadaveric study

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Arthroscopic transosseous rotator cuff repair: how to avoid damaging the axillary nerve—a cadaveric study

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Abstract

Introduction Arthroscopic transosseous rotator cuff repair can be performed with an external guide, although the proximity to the axillary nerve raises safety concerns. The aim of this study is to determine the safety of different drilling angles regarding the axillary nerve.

Materials and methods We performed a bone tunnel in the greater tuberosity in 17 fresh frozen shoulders, using an external guide at four different angles: 40°, 50°, 60°, and 70°. At each angle, we measured the distance between the drill and the axillary nerve, the distance from the acromion to the skin incision point, and the perimeter of the arm at the axilla.

Results The distance to the axillary nerve was safe with the guide at an angle of 40°, 50° and 60°, but not at 70° ($p = 0.001$). We found significant differences between all four angles ($p < 0.05$). Regression analysis demonstrated the influence of the guide angle in all measurements assessed ($p < 0.001$). There was no association between the measurements taken and the axillary perimeter ($p > 0.5$).

Conclusions Arthroscopic transosseous rotator cuff repair with an external guide does not pose a risk for the axillary nerve using angles of 60° or less.

Keywords Rotator cuff · Transosseous repair · Shoulder arthroscopy · Axillary nerve · External guide

Introduction

Transosseous repair of the rotator cuff has proven to have advantages over suture anchors in terms of both footprint repair, higher pressure of the tendon against the bone [1, 2], less stress concentration inside the tendon, and reduced motion at the tendon–tuberosity interface [3, 4]. Biomechanical studies have found similar pullout strength and stability between suture anchors and transosseous tunnels [5–7]. Blood flow, as assessed using contrast-enhanced ultrasound in the postoperative period, has also been shown to be greater in bone tunnels after transosseous repair as compared with suture anchor-based repair [8]. Other advantages have been the cost savings, since they do not require the use of anchors, with no significant difference in operative time compared with transosseous equivalent rotator cuff repair [9, 10]. Although initially performed in open surgery, the technique has recently begun to be carried out arthroscopically with good postoperative outcomes [11, 12].

To execute arthroscopic transosseous repair, surgeons have used curved needles [13, 14], external guides similar to those used in the reconstruction of knee ligaments [12, 15, 16], and disposable devices such as the Arthro-Tuneler TunnelPro System (Wright, Memphis, USA) [17]. All of these techniques create bone tunnels between the lateral cortex of the greater tuberosity and the medial margin of the footprint, allowing suture passing to fix the rotator cuff.

The axillary nerve (AN) is reported to be one of the most commonly injured nerves during surgical procedures of the shoulder (6–10% of all the brachial plexus injuries)

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[18, 19]. No axillary nerve injuries have been reported with the arthroscopic transosseous rotator cuff repair technique, but the literature is limited up to date, and it is still considered as a potential complication [20].

Complete understanding of the course of the axillary nerve, is critical for performing open and arthroscopy shoulder surgery safely. Originated from the posterior cord of the brachial plexus, the axillary nerve descends inferolaterally over the subscapularis muscle, gives off a branch for the shoulder joint, and splits into anterior and posterior divisions within the quadrangular space. The anterior branch goes around the surgical neck of the humerus and penetrates into the deltoid muscle. The posterior branch gives a branch for the teres minor, another for the posterior part of the deltoid muscle and continues as the superior lateral brachial cutaneous nerve [21, 22]. Many variations in the origin of the different muscular, articular, or cutaneous branches have been reported [18, 19, 21].

In respect of the muscular branching pattern of the axillary nerve, Uz et al. [21] stated that the innervation of the teres minor and both the clavicular and the acromial part of the deltoid was done in all cases by the posterior and anterior branches, respectively. In contrast, the innervation pattern of the posterior part of the deltoid is more variable, and can depend on the anterior trunk, the posterior trunk, or both [21–24].

Many researchers have tried to identify safe zones to avoid the injury of the axillary nerve, with variable results. The distance from the nerve to the tip of the acromion has been reported to be approximately 5–7 cm [18, 25, 26], and 5–6 cm inferior to the top of the humeral head [18, 22, 27]. Cetik et al. [28], characterized a quadrangular "safe zone" inferior to the acromion for the placement of hardware based on the ratio of arm length. Another safe zone was determined by Cheung et al. [29] in a vertically neutral shoulder position for hardware placement up to 5 cm distal from the mid-acromion. Rowles et al. [30] recommended, when doing percutaneous pinning, to locate the distal lateral pins no beyond twice the length of the humeral head. However, variations may occur particularly in arms that are above or below average in size [18]. Otherwise, different "safe distances" to neurovascular bundles have been established in cadaveric studies about various shoulder surgical procedures, ranging from 10 to 15 mm [31–33].

The risk of axillary nerve injury, when doing arthroscopic transosseous rotator cuff repair with an external guide, has been reported using magnetic resonance imaging (MRI) [12, 20], but no cadaveric studies have supported the data obtained up to date. The aim of this study is to determine the safety of an external guide at different drilling angles regarding the risk of damaging the axillary nerve.

Materials and methods

We performed an experimental anatomical study on 17 fresh frozen shoulders, after excluding those with traumatic injury, clear deformities, or signs of previous surgery. The anatomical specimens used included the shoulder joint, the scapula, the clavicle, and the proximal half of the humerus. Each specimen was fixed onto a support simulating beach chair position (Fig. 1) for the study. All dissections were done by the same orthopedic surgeon.

We first measured the perimeter of the arm at the axilla with a tape and subsequently made an incision of approximately 10 cm, using a longitudinal transdeltoid approach in the middle of the muscle, handling carefully the soft tissues to avoid distorting the anatomy. Then we located the axillary nerve, crossing the distal third of the deltoid incision. This approach to expose the axillary nerve was found to be more reliable than doing the dissection after drilling with the external guide, as we had observed when preparing the protocol. Finally we detached the supraspinatus tendon from its footprint until exposing the cartilage of the humeral head.

To reproduce the technique of transosseous repair of the rotator cuff, we used an external guide designed specifically for the purpose (Fig. 2), which enabled perforation of the humerus at different angles. We chose four angles for this study: 40°, 50°, 60°, and 70°. Once the cannulated distal mobile arm of the guide was blocked in the selected angle, with the handle of the guide aligned with the humerus, we placed the proximal fixed arm at a 90° angle to the humeral shaft axis, placing the blunt guide tip at the junction between the articular surface and the footprint of the supraspinatus insertion. The perforation was performed with a drill pin of 2.4 mm from the lateral cortex of the humerus to the point marked with the blunt

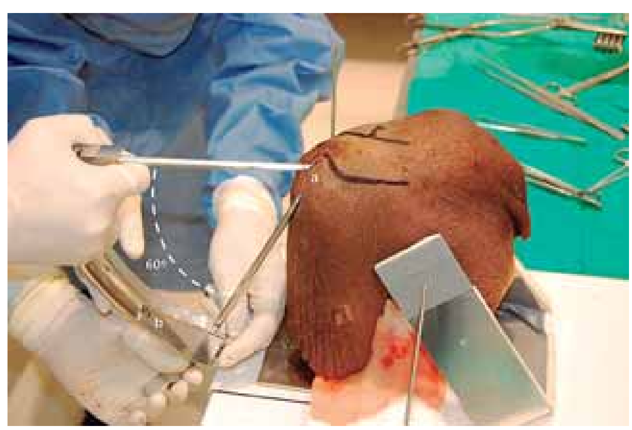

Fig. 1 Fresh frozen shoulder, fixed on a support. **a** Skin incision, **b** external guide fixed at 60°

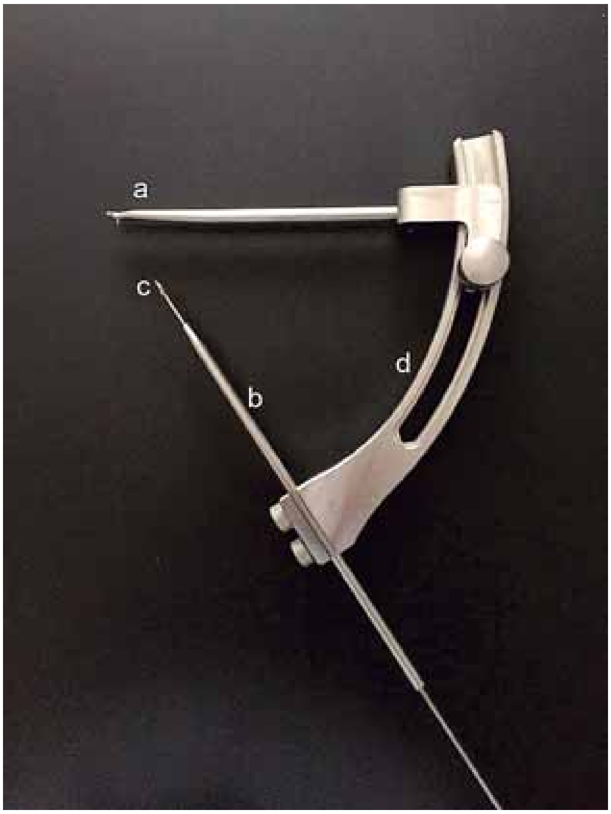

Fig. 2 External guide, purpose designed for this study. **a** Proximal fixed arm for rotator cuff footprint reference, **b** cannulated distal mobile arm of the guide, **c** drill pin, **d** variable angle handle

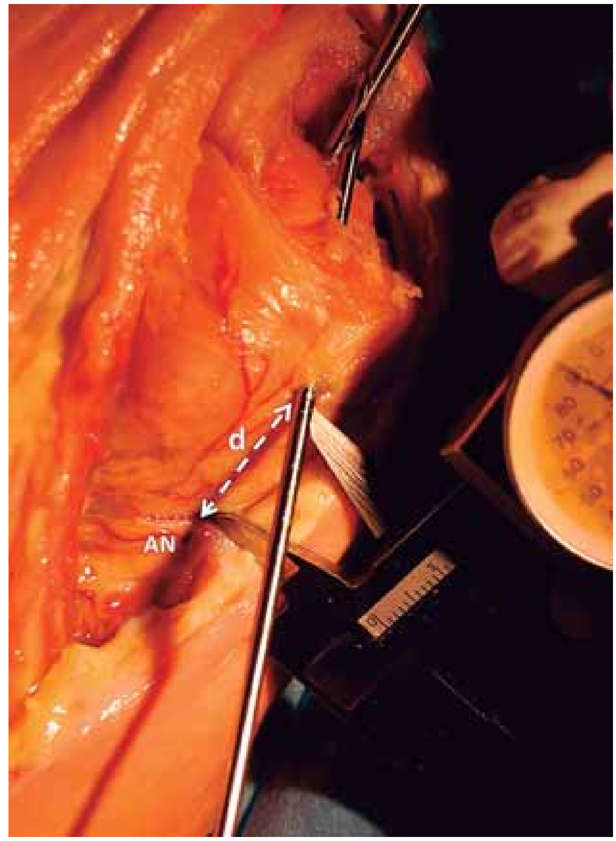

Fig. 3 Measurement of distance from drill pin to superior border of the axillary nerve. *AN* axillary nerve, *d* distance measured with caliper gauge

tip in the cartilage–footprint junction. Leaving the pin inside the bone, we removed the external guide and took two measurements.

The first measurement was the distance in centimeters from the lateral edge of the acromion to the guide's entry point in the skin. The second, taken with a caliper gauge in millimeters, was the shortest distance from the drill entry point in the lateral cortex to the axillary nerve (Fig. 3). We considered 15 mm to be the threshold for a safety distance, basing this judgement on previous reports in the literature [31] and the possible anatomical variations between specimens.

This process was repeated similarly with each specimen, and perforations were performed in each with the external guide at 40°, 50°, 60°, and 70°.

Data were processed and analyzed with SPSS 21.0 software (Statistical Package for Social Services, Chicago, IL). Non-parametric statistical tests were used. The Mann–Whitney *U* test was applied for hypothesis tests between the measurements obtained at the different angles proposed in the study. To define the optimal perforation angle, we undertook an analysis of the measurements considered safe versus unsafe according to our study criteria, employing McNemar's test. We used simple linear regression to study the relationship that perforation angle and axillary perimeter had on the measurements taken. We considered *p* values of less than 0.05 to be statistically significant.

Results

This study included 17 fresh frozen shoulders (9 right and 8 left); 8 were from men and 4 from women, with the sex unknown in the 5 remaining specimens.

Table 1 shows the measurement values obtained. There were statistically significant differences between the four angles assessed ($p < 0.05$). The mean distance from the drill to the axillary nerve was less than 15 mm only when the guide was at a 70° angle. We did not detect contact between the drill pin and axillary nerve in any of the perforations carried out in the greater tubercle with the external guide, regardless of the angle used.

Table 2 shows the analysis of data according to the 15 mm defined as safe distance from the drill entry point in the lateral cortex to the axillary nerve. At 40°, we observed

Table 1 Distances from acromion to skin incision point and from drill pin to axillary nerve at different angles tested

Distance (mm)	Angle																P value
	40°				50°				60°				70°				
	Mean	SD[a]	Min[b]	Max[c]	Mean	SD	Min	Max	Mean	SD	Min	Max	Mean	SD	Min	Max	
Acromion—skin incision point	45.1	9.2	35	70	52.8	10.5	40	75	62.4	12.4	45	85	75,6	16,3	50	100	p=0.001
Drill pin—axillary nerve	28.5	7.0	16.9	45.2	24.1	6.1	13.7	35.5	20.1	5.7	6.6	30.8	14,3	6,2	2,3	30,2	p=0.001

[a]Standard deviation

[b]Minimum

[c]Maximum

Table 2 Analysis of measurements according to safety distance to the axillary nerve

Distance drill pin—axillary nerve (angle)	Distance ≥ 15 mm n (%)	Distance < 15 mm n (%)	p value
40°	13 (100%)	0	$p=0.001$
50°	16 (94%)	1 (6%)	
60°	15 (88%)	2 (12%)	
70°	6 (35%)	11 (65%)	

valid measurements in 13 shoulders, but in the other 4, the drill either made contact with the upper edge of the greater tuberosity or passed over it without allowing perforation of an adequate bone tunnel. In the 13 shoulders with valid measurements, the distance to the axillary nerve was 15 mm or more. At a perforation angle of 50°, 16 specimens (94%) obtained safe drilling distances to the axillary nerve, while only 1 (6%) was categorized in the zone at risk of damage to the nerve. When we increased the angle to 60°, in 15 cases (88%), the cortex was safely perforated at more than 15 mm from the axillary nerve, while the distance was less than 15 mm in just 2 cases (12%). Finally, at a perforation angle of 70°, the safety distance to the axillary nerve was insufficient (< 15 mm) in 11 specimens (65%) and sufficient in 6 (35%).

Statistical analysis demonstrated that most perforations at 40°, 50°, and 60° ($p=0.001$) are safe for the axillary nerve, but at 70°, the distance was under 15 mm in most of the measurements.

We used simple linear regression to analyze crude associations between perforation angle and each of the study variables, observing strong associations ($p<0.001$) with the distance from the drill to the axillary nerve ($R^2=0.386$), and the distance from the acromion to the drill guide's entry point in the skin ($R^2=0.476$).

Axillary perimeter (mean 27.1 cm; SD 3.2; range 22–34), showed no relationship in the linear regression model with the distance from the drill to the axillary nerve, nor with the distance from the acromion to the skin incision ($p>0.5$).

Discussion

Traditional transosseous suture of the rotator cuff has shown several biomechanical advantages over suture anchor techniques. Apreleva et al. [1] compared the contact area obtained with different types of sutures, finding that none of the techniques evaluated were able to completely restore the original insertion area, but that simple transosseous suture achieved 20% more coverage. Park et al. [2] compared transosseous suture with two different types of suture anchors, concluding that the contact area was significantly larger with the transosseous technique (67.7 $mm^2 \pm 5.8$ versus 34.1 $mm^2 \pm 9.4$ versus 26.0 $mm^2 \pm 5.3$). In the same study, the pressure exerted by the suture in the reinsertion area was highest with the transosseous sutures (0.32 MPa ± 0.05 versus 0.26 MPa ± 0.04 versus 0.24 MPa ± 0.02).

Authors like Kuroda [12], Kim [15], and Shea [16] have used external guides to perform different types of arthroscopic transosseous rotator cuff repair. The perforation of tunnels and the instrumentation at the level of the lateral cortex of the proximal humerus carry some risk of damage to the axillary nerve, a fact which motivated the conception of this study.

Eakin et al. [32] studied the distance between the axillary nerve and the arthroscopic capsulolabral sutures in anterior gleno-humeral stabilization, considering them to be safe at a distance of 12 mm or more. Woolf et al. [33] measured the proximity of the superior-medial Neviaser portal to the suprascapular nerve, establishing a safety distance of 10 mm. Marsland et al. [31] undertook a study on the arthroscopic fixation of glenoid fractures, estimating a safety distance of 15 mm between the K-wires and the nearest neurovascular structures. In our study, we considered it prudent to choose the greatest safety distance proposed in these previous studies, that is, 15 mm.

Following the perforation of the bone tunnels, we verified that none of the drill pins damaged the axillary nerve upon penetrating the lateral cortex of the proximal humerus at any of the angles assessed. As expected, however, we did observe that the drill got closer to the axillary nerve as the guide angle increased. From the baseline 28.5 mm at 40°, mean distance to the axillary nerve gradually decreased as the angle widened, reaching 14.3 mm when the guide was at 70° (Table 1, Fig. 4). The only perforations that would be inadvisable due to safety concerns for the axillary nerve (< 15 mm of safety distance) would be those performed with the guide at a 70° angle.

The data obtained allow us to conclude that at angles equal or smaller than 60° there is a wide safety margin with respect to the axillary nerve. Drillings performed with the guide at a 70° angle should be avoided.

Some authors have established associations between anthropometric parameters and diverse measurements to devise corrective factors for the latter. In a cadaveric study, Cetik et al. [28] determined the distance between the anterior and posterior edge of the acromion and the axillary nerve pathway, finding a significant correlation between both distances and arm length, with a ratio of 0.20 in the anterior margin and 0.16 in the posterior margin. In the specimens included in our study, it was not possible to measure arm length, as only the proximal half of the humeral shaft was preserved. We, therefore, used the axillary perimeter as a possible representative parameter for the size of the arm, similarly to other studies focusing on the treatment and follow-up of pathologies such as lymphedema of the upper limbs [34–36]. We did not observe a correlation between

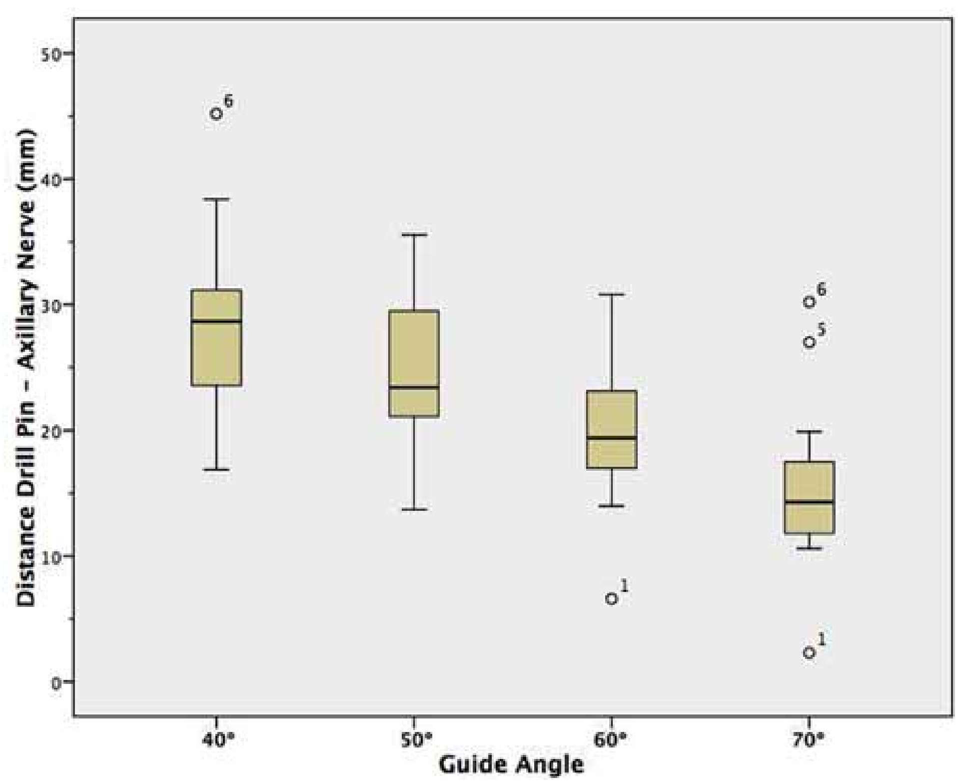

Fig. 4 Boxplots showing the results of measurements taken from drill pin to the axillary nerve at the different angles tested

axillary perimeter and the rest of the variables studied in the linear regression model ($p > 0.5$).

Some previous anatomical, clinical, and radiological studies have focused on the axillary nerve relationship to percutaneous pinning in the proximal humerus [12, 30]. These studies have not assessed the distance from the acromion to the skin incision. In our study, we considered this to be a useful external reference for the surgeon. From our data, the skin entrance in the lateral area of the shoulder should take place at less than or equal to 6 cm (SD 1.2; range 4.5–8.5) from the lateral edge of the acromion. However, this distance may change depending on arm position and soft tissue thickness over the proximal arm [37]. Cheung et al. [29] found that shoulder abduction was the main determinant of axillary nerve position, with respect to the acromion. Burkhead et al. [26] studied the distance of the axillary nerve to the mid-acromion with the arm in neutral and at 90 of abduction and found it to be 61 and 45 mm, respectively. To solve this problem, an external guide is a reliable method since the distance from the entry point of the drill in the lateral cortex to the axillary nerve, at any angle, will not be affected by the position of the arm or the muscle and subcutaneous fat thickness [20].

Kuroda [12] described an arthroscopic transosseous suture technique using an external guide, similar to the model used in our study. He utilized an angle of 55°, without specifying the criteria followed for choosing this measure. However, he did present measurements taken post-operatively through magnetic resonance imaging (MRI), which showed that the mean distance obtained from the edge of the greater tuberosity to the tunnel entry in the lateral cortex was 17.7 mm (range 6–34 mm), but no direct measures to the axillary nerve were reported. With regard to the axillary nerve safety, Kuroda reviewed all patients and had a pre and post-op electromyographic study made in 262 of them, without finding any nerve damage. The data obtained in our study help to explain the absence of neurological complications with Kuroda's technique, as they confirm the existence of a safe distance of more than 15 mm with regard to the axillary nerve when using an external guide at an angle of 60° or less.

Our results also agree with those reported by Gupta et al. [20]. They simulated humeral drillings with an external guide on MRI images and measured the distance between the drill pin and the axillary nerve. They concluded that angles above 60° have a risk of damaging the axillary nerve. Moreover, in this study, a safe distance to the axillary nerve is considered to be only 5 mm, based on the work of Cho et al. regarding facial nerve vulnerability during otologic surgery [38]. Our measurements have demonstrated a safe distance superior to 15 mm with 60° guide angle, more similar to other anatomical reports on shoulder arthroscopy procedures.

The present study has several limitations. It is a cadaveric study, so measurement errors cannot be ruled out, especially considering the neurovascular structures being examined. To minimize this aspect, we followed a systematic procedure in the dissection and were meticulous when handling the tissues to avoid distorting the anatomical structures under study. Additionally, during the arthroscopy, the swelling of the shoulder due to continuous perfusion of liquids may also alter the anatomy. We could not control this variable in our study.

Conclusions

Arthroscopic repair of the rotator cuff via external guides can be undertaken without risk to the axillary nerve at angles of 60° or less, as our data show. The different angles of perforation are related to the distance between the drill and the axillary nerve, and with the distance from the acromion to the skin incision. We did not observe a relationship between arm perimeter at the level of the axilla and the other variables studied.

Author contributions All authors contributed to the study conception and design. Material preparation, data collection, and analysis were performed by JABD, LA, DM and MM. The first draft of the manuscript was written by JABD and all authors commented on previous versions of the manuscript. All authors read and approved the final manuscript.

Compliance with ethical standards

Conflict of interest José A. Blas-Dobón, Luis Aguilella, Daniel Montaner-Alonso and Maria Morales-Suárez-Varela declare that they have no conflict of interest.

Ethical approval This article does not contain any studies with live human participants or animals performed by any of the authors. This study fulfilled all the ethics requirements of the dissection room and Anatomy Department.

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