Anat Morphol. 2025;1(2):36-47 Received: 2025-03-04 / Accepted: 2025-04-18

Cadaveric Anatomical Simulation in Risk Management and Prevention of Adverse Events in Procedures for Airway and Ventilation

Agustín D. Algieri[1], María Milagros Bellía Mendiguren[2], Carolina C. Brofman[3], Juan Pablo Fernández[4], María Soledad Ferrante[5] & Rubén D. Algieri[6]

[1] Médico. Auxiliar Docente. Tercera Cátedra de Anatomía, Facultad de Medicina, Universidad de Buenos Aires (UBA), Argentina.

[2] Auxiliar Docente. Tercera Cátedra de Anatomía, Facultad de Medicina, Universidad de Buenos Aires (UBA), Argentina.

[3] Médica. Especialista en Cirugía General. Jefe de Trabajos Prácticos, Tercera Cátedra de Anatomía, Facultad de Medicina, Universidad de Buenos Aires (UBA), Argentina.

[4] Médico. Especialista en Cirugía General.

[5] Médica. Especialista en Cirugía General. Jefe de Trabajos Prácticos, Tercera Cátedra de Anatomía, Facultad de Medicina, Universidad de Buenos Aires (UBA), Argentina. Docente Adscripto en Cirugía General (UBA).

[6] Médico. Especialista en Cirugía General y en Emergentología. Doctor en Medicina (UBA). Docente Autorizado, Cirugía General (UBA). Profesor Adjunto Regular de Anatomía, Tercera Cátedra de Anatomía, Facultad de Medicina, Universidad de Buenos Aires (UBA), Argentina. Jefe del Servicio de Emergencias, Hospital Municipal de Morón. Ex Presidente de la Asociación Argentina de Anatomía. Ex Presidente de la Asociación Panamericana de Anatomía.

Correspondence
Rubén D. Algieri
Tercera Cátedra de Anatomía
Facultad de Medicina
Universidad de Buenos Aires (UBA)
Buenos Aires, Argentina

E-mail: rdalgieri08@hotmail.com

ALGIERI AD, BELLÍA MENDIGUREN MM, BROFMAN CC, FERNÁNDEZ JP, FERRANTE MS, ALGIERI RD. Cadaveric anatomical simulation in risk management and prevention of adverse events in procedures for airway and ventilation. *Anat Morphol.* 2025; 1(2):36-47

ABSTRACT: Medical knowledge and skills must start from a basic anatomical knowledge. This work is developed after identifying the occurrence of adverse events in clinical and surgical procedures due to ignorance of anatomical bases. The purpose is to evaluate the implementation of simulating the necessary skills to carry out these procedures in formalin-fixed cadaveric dissections during an annual rotation course with undergraduate students. We performed a statistical, retrospective, and observational analysis of the technique and adverse events that occurred in the procedures of placement of oropharyngeal cannula, placement of mask with reservoir, orotracheal intubation, puncture of the cricothyroid membrane, chest puncture, placement of a chest tube, in formalin-fixed cadaveric dissections with the participation of 73 students during the annual rotation course at the School of Medicine at the Universidad de Buenos Aires from March to December 2022. Out of the students who performed the procedures, 95.89 % performed a satisfactory placement of an oropharyngeal cannula in the first attempt. 98.63 % practiced the placement of a mask with reservoir and oropharyngeal device simultaneously correctly in the first attempt. 47.95 % of presented no adverse events in puncture of the cricothyroid membrane on the first attempt. Regarding orotracheal intubation, 10.96 % presented no adverse events on the first attempt; 89.04 % who had adverse events made a second attempt. 86.3 % performed a successful chest puncture on the first attempt. Finally, chest tube placement was successfully performed in 28.77 % on the first attempt. Anatomical knowledge is essential for its application in clinical and surgical skills ensuring the prevention, reduction of risk and development of a culture of safety and quality in patient care.

KEY WORDS: education; airway; ventilation; clinical and surgical procedures; teaching anatomy.

INTRODUCTION

University medical education in Argentina began in 1821 with the founding of the University of Buenos Aires. At present, its educational model is based on a tutorial teaching–learning process with integration between teaching and service delivery (Santas, 1968; Berra, 2022). In 1890, William Halsted, Chief of Surgery at Johns Hopkins, introduced medical training under the residency model, in which the physician in training assumed a central role in patient care in order to teach procedural skills (Arribalzaga & Jacovella, 2006; Algieri, 2011; Laroche & Vacher, 2014). This tutorial model has been maintained to this day but has been criticized in terms of the safety it provides to patients seeking care in the health system (Corrigan *et al*., 1999; Aranaz *et al*., 2008; Algieri *et al*., 2010; Rodríguez-Herrera *et al*., 2019).

In the initial evaluation and care of a patient, airway patency must be confirmed by ruling out signs of obstruction. However, airway patency does not guarantee proper ventilation, as adequate lung function and chest wall movement also play a role. For this reason, it is important that the attending physician possess basic skills (Arribalzaga & Jacovella, 2006; Algieri, 2011; Laroche & Vacher, 2014) for airway management and ventilation, in order to correctly place the different devices.

Training future physicians during their undergraduate education is vital, as human error or adverse health events rank as the third leading cause of in-hospital mortality worldwide (Corrigan *et al*., 1999; Cahill *et al*., 2000; Aranaz *et al*., 2008; Algieri *et al*., 2010; Beltramino, 2010; Arribalzaga *et al*., 2012; Berra, 2022). An adverse health event is defined as harm caused to the patient not by the underlying condition of their disease but by improper management by the attending physician, resulting in delayed discharge, prolonged hospital stay, or disability, and which may threaten the patient's life or cause death (Arribalzaga & Jacovella, 2006; Aranaz *et al*., 2008; Algieri *et al*., 2010; Algieri, 2011; Arribalzaga *et al*., 2012).

Medical knowledge and manual skills must be grounded in a basic anatomical understanding essential for practice in all specialties (Flexner, 1910; Corrigan *et al*., 1999; Beltramino, 2010; Sugand *et al*., 2010; Arribalzaga, 2011; Algieri, 2011; Arribalzaga *et al*., 2012; Rodríguez-Herrera *et al*., 2019). For this reason, and following the identification of adverse events occurring during airway management and ventilation procedures due to a lack of anatomical knowledge, this study aims to evaluate the implementation of simulation-based training for the necessary skills to perform these techniques on cadaveric specimens during the annual rotating internship for undergraduate students.

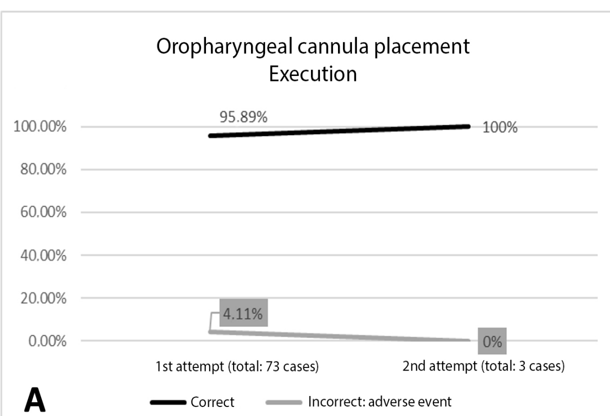
MATERIAL AND METHOD

A retrospective, observational statistical analysis was conducted on the techniques and adverse events that occurred during the following procedures performed on cadaveric specimens: insertion of an oropharyngeal airway, placement of a reservoir mask and oropharyngeal airway, orotracheal intubation, puncture of the cricothyroid membrane, puncture of the pleural space, and insertion of a chest drainage tube. The study involved the participation of 73 students from the annual rotating internship program of the Faculty of Medicine, University of Buenos Aires, between March and December 2022.

RESULTS

Of the students who performed the procedures, 95.89 % successfully inserted the oropharyngeal airway on the first attempt. The remaining 4.11 % required a second attempt, which was completed successfully in 100 % of cases (Fig. 1A).

Among those who required a second attempt (4.11 %), the potential adverse events were, in all cases (100 %), due to incorrect insertion of the device, failing to pass the tongue to reach the oropharynx (Fig. 1B).



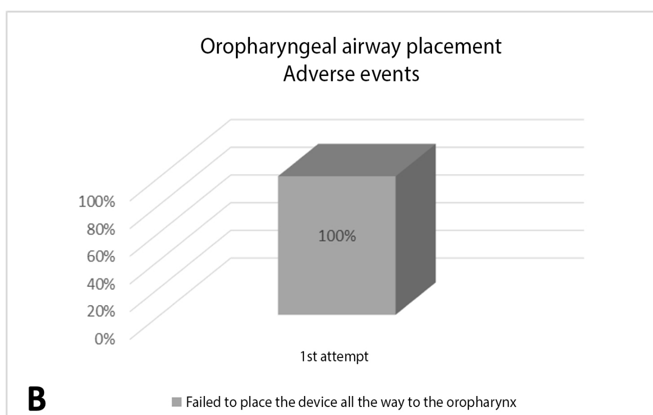


Fig. 1. Placement of an oropharyngeal airway in cadaveric specimens. A. Execution outcomes showing correct placement rates on the first and second attempts. B. Adverse events in the first attempt, with all cases (100 %) due to failure to advance the device beyond the tongue to reach the oropharynx.

After placement of the oropharyngeal device, 98.63 % of cases successfully placed a reservoir mask and inserted the oropharyngeal airway simultaneously on the first attempt. The remaining 1.37 % required a second attempt, which was successful in 100 % of cases (Fig. 2A). The only maneuver incorrectly performed on the first attempt was placing the reservoir mask without covering the nose (Fig. 2B).

Regarding orotracheal intubation, 10.96 % experienced no difficulties in the first attempt. The 89.04 % who experienced adverse events subsequently performed a second attempt, in which 69.23 % completed the technique without complications, while the remaining 30.77 % required a third attempt, successfully performing the maneuvers in 100 % of these cases (Fig. 3A).

Among the events detected in the 89.04 % of first-attempt cases, 53.85 % resulted from placing the endotracheal tube in the esophagus, 7.69 % failed to check the cuff before tube insertion, 23.08 % advanced the tube into the right main bronchus, and 15.38 % failed to insert the tube due to incorrect positioning of the laryngoscope outside the epiglottic vallecula. In the second attempt, among the 30.77 % who required it, 25 % placed the laryngoscope outside the epiglottic vallecula, 41.67 % inserted the endotracheal tube into the esophagus, and 33.33 % advanced the tube into the right main bronchus (Fig. 3B).

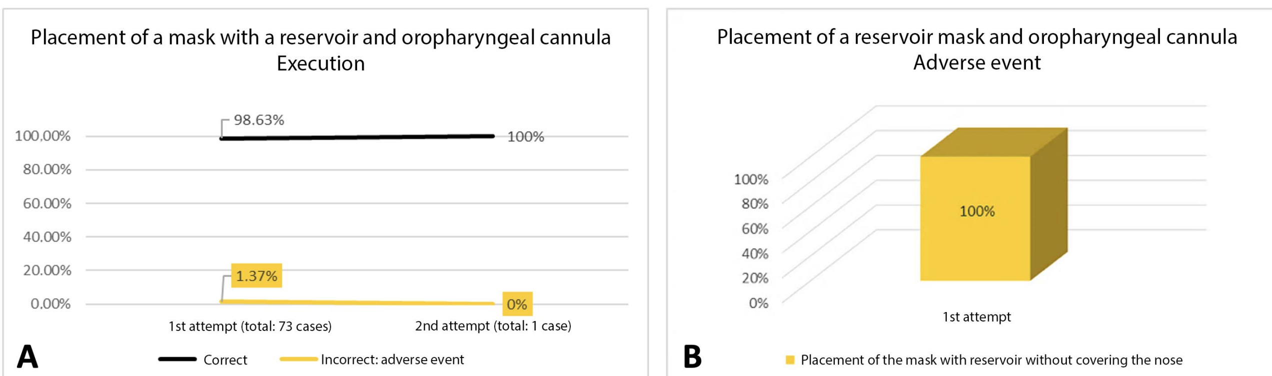


Fig. 2. Placement of a reservoir mask over an oropharyngeal airway in cadaveric specimens. A. Execution outcomes showing correct placement rates on the first and second attempts. B. Adverse events in the first attempt, with all cases (100 %) due to incorrect placement of the reservoir mask without covering the nose.

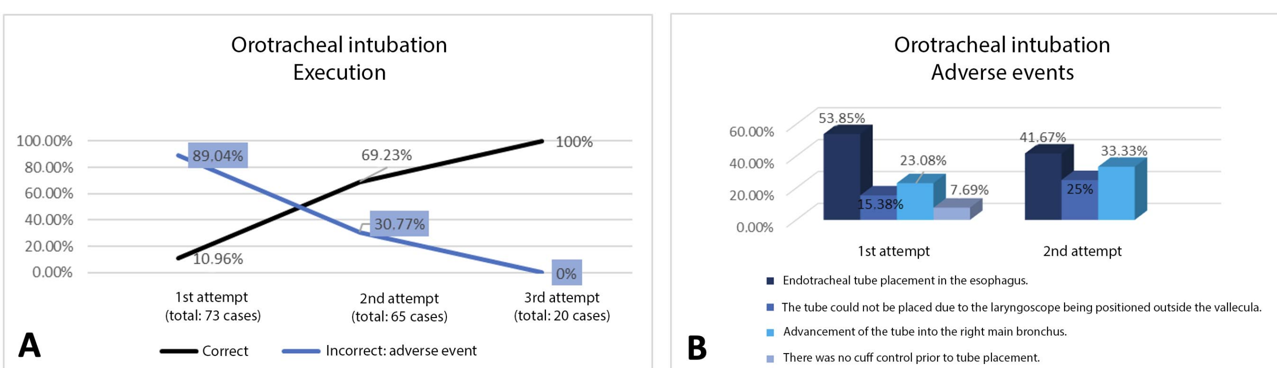


Fig. 3. Orotracheal intubation in cadaveric specimens. A. Execution outcomes showing correct performance rates across first, second, and third attempts. B. Adverse events by attempt: in the first attempt, endotracheal tube placement into the esophagus (53.85 %), failure to insert the tube due to laryngoscope positioning outside the vallecula (15.38 %), tube progression into the right main bronchus (23.08 %), and absence of cuff inflation check before insertion (7.69 %); in the second attempt, tube placement into the esophagus (41.67 %), laryngoscope positioning outside the vallecula (25 %), and tube progression into the right main bronchus (33.33 %).

For cricothyroid membrane puncture, 47.95 % encountered no difficulties on the first attempt. Among the 52.05 % who did experience difficulties, a second attempt was performed, with 92.10 % completing the technique without complications, while the remaining 7.9 % required a third attempt, which was successful in 100 % of cases (Fig. 4A).

In the first-attempt adverse events for the 52.05 % of cases, 76.32 % injured the esophagus during puncture, and 23.68 % failed to identify the anatomical plane of the cricothyroid membrane. In the second attempt, the 7.9 % with complications all (100 %) experienced esophageal injury (Fig. 4B).

Pleural space puncture was performed successfully in 86.3 % of cases on the first attempt, while 13.7 % required a second attempt, which was completed correctly in 100 % of cases (Fig. 5A).

Among the findings in the 13.7 % of first-attempt cases, 30 % punctured at the first intercostal space and 70 % at the infraclavicular level, both due to a lack of anatomical knowledge to locate the second intercostal space at the midclavicular line (Fig. 5B).

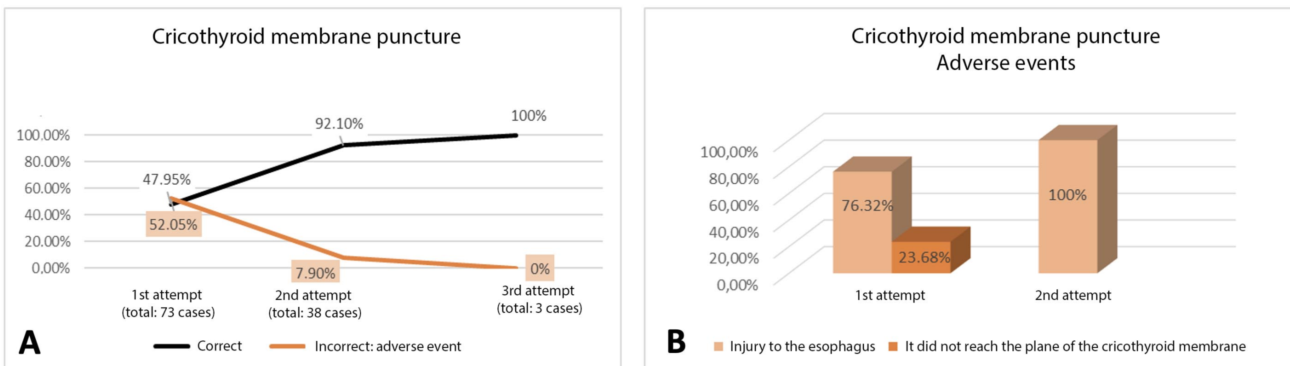


Fig. 4. Cricothyroid membrane puncture in cadaveric specimens. A. Execution outcomes showing correct performance rates across first, second, and third attempts. B. Adverse events: in the first attempt, esophageal injury (76.32 %) and failure to identify the anatomical plane of the cricothyroid membrane (23.68 %); in the second attempt, all adverse events (100 %) corresponded to esophageal injury.

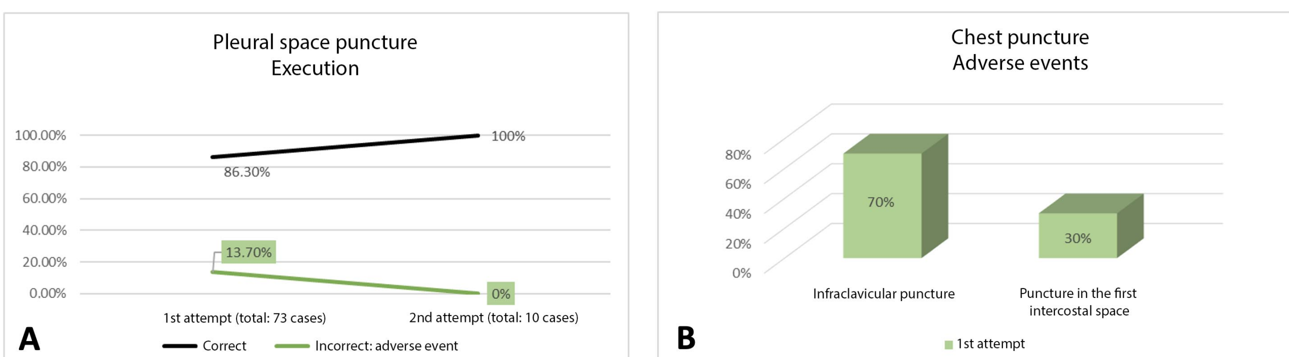


Fig. 5. Pleural space puncture in cadaveric specimens. A. Execution outcomes showing correct performance rates on the first and second attempts. B. Adverse events in the first attempt, including puncture at the infraclavicular region (70 %) and puncture at the first intercostal space (30 %), both due to lack of anatomical knowledge to locate the second intercostal space at the midclavicular line.

Insertion of the chest drainage tube was successful in 28.77 % of cases on the first attempt. The remaining 71.23 % performed a second attempt, in which 61.54 % executed the procedure correctly, while 38.46 % still performed it incorrectly. Those with incorrect second attempts performed a third attempt, achieving correct technique in 100 % of cases (Fig. 6A).

Among the adverse events in the first attempt, 3.84 % were due to lack of anatomical knowledge regarding placement site, 25 % to poor dissection techniques of the thoracic wall, 48.08 % to injury of the intercostal neurovascular bundle, and 23.08 % to incorrect tube positioning toward the mediastinum. In the second attempt, 35 % injured the intercostal neurovascular bundle, and 65 %

advanced the tube incorrectly toward mediastinal structures, perforating the mediastinal pleura (Fig. 6B).

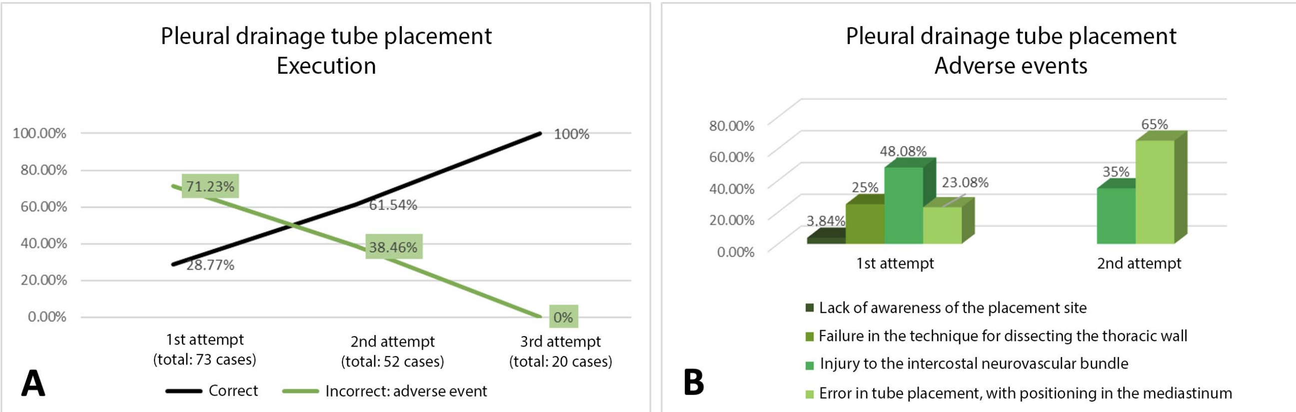


Fig. 6. Chest tube placement in cadaveric specimens. A. Execution outcomes showing correct performance rates across first, second, and third attempts. B. Adverse events: in the first attempt, lack of anatomical knowledge regarding placement site (3.84 %), inadequate thoracic wall dissection technique (25 %), injury to the intercostal neurovascular bundle (48.08 %), and incorrect tube positioning toward the mediastinum (23.08 %); in the second attempt, injury to the intercostal neurovascular bundle (35 %) and incorrect tube progression toward mediastinal structures, perforating the mediastinal pleura (65 %).

DISCUSSION

Anatomy is one of the basic sciences of medicine. Its lack of knowledge, poor description, or misinterpretation can lead to patient safety issues in both diagnosis and treatment (Corrigan *et al*., 1999; Aranaz *et al*., 2008; Algieri *et al*., 2010; Sugand *et al*., 2010; Algieri, 2011; Arribalzaga *et al*., 2012; Rodríguez-Herrera *et al*., 2019). The study of Anatomy requires careful observation and highly precise manipulation of the structures that make up the human body, as well as their relationships. For this reason, the use of cadaveric material is essential, allowing students to consolidate theoretical knowledge through its practical application on the cadaver (Cahill *et al*., 2000; Beltramino, 2010; Sugand *et al*., 2010; Arribalzaga, 2011; Arribalzaga *et al*., 2012; Molina Martínez *et al*., 2012; Rodríguez-Herrera *et al*., 2019).

In 1999, the Institute of Medicine, National Academy of Sciences, published *To Err is Human: Building a Safer Health System*, which highlighted the impact of medical errors on public health (Corrigan *et al*., 1999; Algieri *et al*., 2010). Following its publication, patient safety emerged as a new challenge in achieving high-quality healthcare. Since then, efforts have focused on preventing or reducing harm through the implementation of strategies and tools aimed at minimizing adverse events in healthcare, both in pre-hospital and hospital settings, on a continuous and routine basis (Corrigan *et al*., 1999; Aranaz *et al*., 2008; Algieri *et al*., 2010; Arribalzaga, 2011).

Clinical simulation has thus emerged as an educational tool with an exceptional learning methodology, as it recreates real clinical scenarios in which students can develop and improve the techniques and skills they have acquired (McLaughlin *et al*., 2002; Dutta *et al*., 2006; Vázquez-Mata & Guillamet-Lloveras, 2009; Jakimowicz & Jakimowicz, 2011; Molina Martínez *et al*., 2012; Cobián *et al*., 2021). Skills must always be practiced under the supervision of an experienced instructor who can correct and guide the student.

It is important that the teaching of Anatomy focuses on the anatomical landmarks required for the development of technical skills in the future (Algieri, 2011; Arribalzaga, 2011; Arribalzaga *et al*., 2014; Cobián *et al*., 2021). For this reason, it is essential for the instructor to perform these maneuvers on the cadaver so that the student can integrate the knowledge and technique, and then attempt to replicate it. This simulation allows the student to consolidate knowledge through as many repetitions as necessary to gain sufficient confidence before performing these procedures on a real patient (Ludojovski, 1967; Weed, 1997; McLaughlin *et al*., 2002; Vázquez-Mata & Guillamet-Lloveras, 2009; Jakimowicz & Jakimowicz, 2011; Molina Martínez *et al*., 2012; Laroche & Vacher, 2014) (Fig. 7).

Fig. 7. Exhibition of the materials required to perform the different procedures for the students.

The practical session with students began with a demonstration of oropharyngeal airway placement. The appropriate size was selected by measuring from the corner of the mouth to the earlobe. The device was inserted with the concavity facing upward until it contacted the soft palate, then rotated 180° to direct the concavity downward, sliding the airway along the upper surface of the tongue until it reached the isthmus of the fauces, or until the flanges of the airway rested against the lips. The isthmus of the fauces is the entry point to the oropharynx and the anatomical site where the device must be seated (Fig. 8).

Fig. 8. Demonstration of the correct placement of an oropharyngeal airway. A. Soft palate. B. Isthmus of the fauces. C. Oropharynx.

Next, students were instructed on placing a reservoir mask after inserting the oropharyngeal airway as part of the same procedure. The correct mask size for the patient's face was chosen, and after placing it, a firm seal was ensured to guarantee adequate ventilation (Fig. 9).

Once mastered, the orotracheal intubation technique was taught with the cadaver placed in the supine position. The endotracheal tube was selected according to the nasal opening diameter. The mouth was opened using the right hand's index finger and thumb on the right upper and lower molars. The blade of the laryngoscope was inserted toward the right tonsillar pillar until reaching the epiglottic vallecula, contacting the oropharynx, and with the handle pointing toward the left nipple. The tongue was positioned within the groove of the laryngoscope blade. Once in place, the handle was lifted upward, taking care not to damage the upper incisors. This maneuver allowed visualization of the true vocal cords, after which the endotracheal tube was inserted, ensuring the cuff's proper function beforehand. The laryngoscope was removed, the cuff inflated, and the correct tube placement in the trachea was verified, ensuring it was not in the esophagus or the right main bronchus. Finally, the tube was secured with gauze or adhesive tape (Figs. 10-12).

Fig. 9. Demonstration of the correct placement of a reservoir mask over an oropharyngeal airway.

Fig. 10. Orotracheal intubation correctly performed on two cadaveric specimens. A. Airway.

Fig. 11. Orotracheal intubation incorrectly performed on two cadaveric specimens due to placement of the endotracheal tube in the esophagus. B. Digestive tract.

Fig. 12. Orotracheal intubation incorrectly performed due to selective intubation of the right main bronchus. A. Trachea. B. Right main bronchus.

Training continued with puncture of the cricothyroid membrane, with the cadaver in supine position to identify, by surface anatomy, the cricothyroid membrane located between the thyroid and cricoid cartilages in the anterior cervical region. The operator, positioned at the head of the cadaver, punctured the membrane at a 45° caudal angle using a 14-gauge catheter, aspirating saline with a syringe to detect bubbling caused by air upon entering the larynx below the vocal cords (in the subglottic space) and into the trachea. The needle was removed, leaving the cannula in place to allow insertion of a guide for connecting the device to an oxygen source for ventilation (Figs. 13 & 14).

The surgical cricothyrotomy technique was also demonstrated, performed solely by the instructor. After identifying the thyroid cartilage, cricoid cartilage, cricothyroid membrane, and sternal manubrium, a transverse skin incision was made with a scalpel, cutting through the cricothyroid membrane to access the laryngeal lumen. The opening was dilated with a Halsted forceps, and a ventilation device was inserted (Fig. 15).

For pleural space puncture, the cadaver was placed in the supine position, and the puncture was performed toward the back in the second intercostal space along the midclavicular line, at the upper margin of the lower rib to avoid injury to the intercostal neurovascular bundle (Feller-Kopman *et al*., 2007; Beckett *et al*., 2011; Clemency *et al*., 2015; Aho *et al*., 2016) (Fig. 16). The puncture site at the fifth intercostal space was also described, between the anterior and mid-axillary lines, posterior to the pectoralis major muscle to avoid injury, and anterior to the latissimus dorsi muscle, again on the upper margin of the lower rib.

Finally, chest tube placement was demonstrated. A skin incision was made between the fourth and fifth intercostal spaces, between the anterior and mid-axillary lines. Blunt dissection was performed down to the muscle plane, which was then separated over the upper margin of the lower rib until the parietal pleura was reached and perforated digitally to confirm entry into the pleural cavity. The chest tube was inserted using a hemostatic clamp to hold its tip and was directed posterosuperiorly within the pleural cavity. The tube was inserted until a few centimeters beyond the last fenestration, marked on the skin by a suture placed 2–3 fingerbreadths distal to it, depending on the patient's adipose tissue. The tube was then secured to the skin, covered with gauze, and connected to an underwater seal drainage system to prevent air entry into the thorax (Figs. 17 & 18).

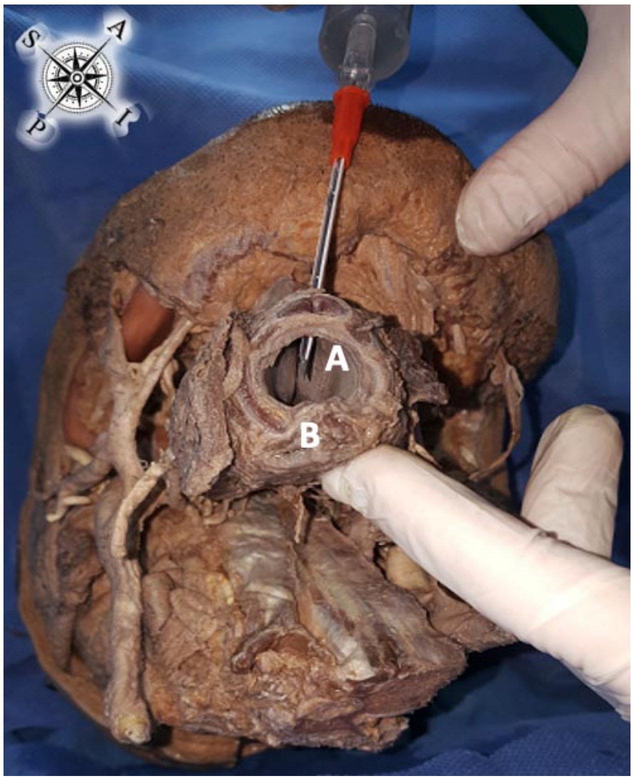


Fig. 13. Correct puncture of the cricothyroid membrane. A. Trachea; B. Esophagus.

Fig. 14. Incorrect puncture of the cricothyroid membrane due to esophageal perforation. A. Trachea; B. Esophagus.

Fig. 15. Demonstration of surgical cricothyroidotomy. A. Mandible. B. Hyoid bone. C. Cricothyroid membrane.

Fig. 16. Demonstration of correct thoracic puncture in the second intercostal space, midclavicular line, on a cadaveric specimen.

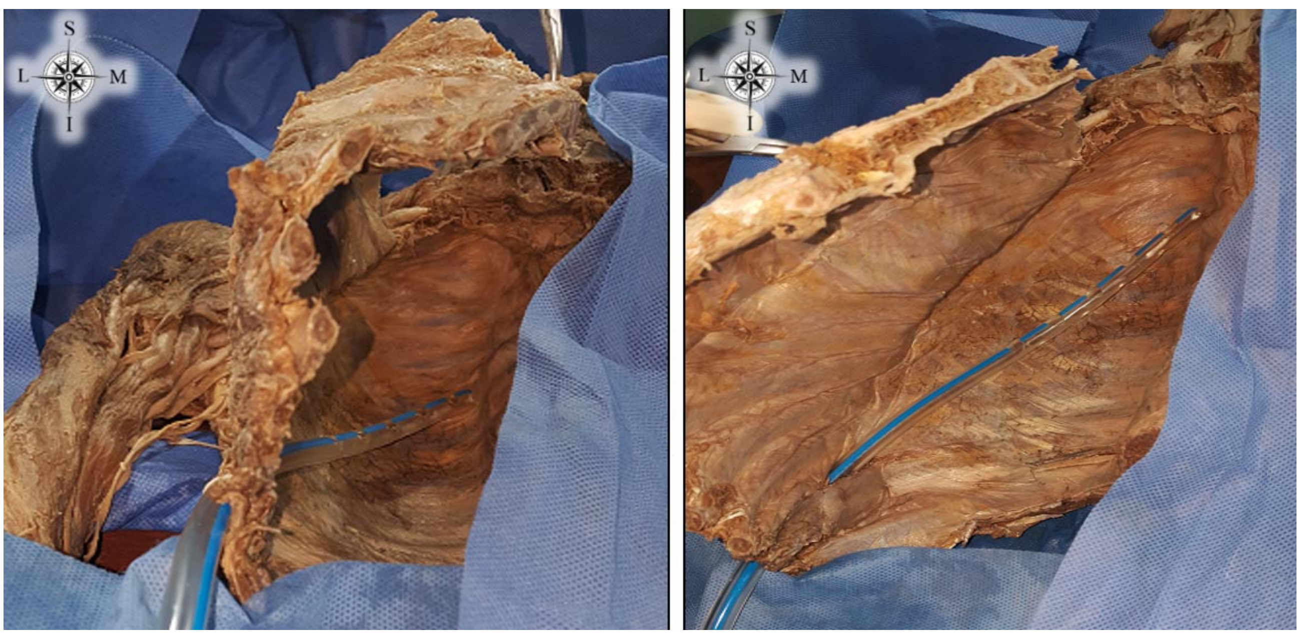


Fig. 17. Correct placement of a chest tube on a cadaveric specimen.

Through cadaver-based simulation practice of these procedures, we observed that anatomy is highly relevant to medical education in achieving proper and progressive professional development. Various factors can lead to adverse events resulting from healthcare delivery rather than from the underlying disease. The absence or incorrect knowledge of Anatomy is a crucial factor that undermines patient safety and can even endanger the patient's life.

CONCLUSION

Anatomical knowledge is essential for its application in clinical-surgical skills, ensuring prevention, risk reduction, and the development of a culture of patient safety.

As educators, our role is to provide study tools that enable ethical, safe, and efficient learning through the teaching of Applied Anatomy. The strategies employed should be closely aligned with the student's needs to increase motivation and responsibility in their autonomous and continuous learning, while establishing the anatomical foundations necessary for performing basic procedures in the medical care of urgent and scheduled conditions.

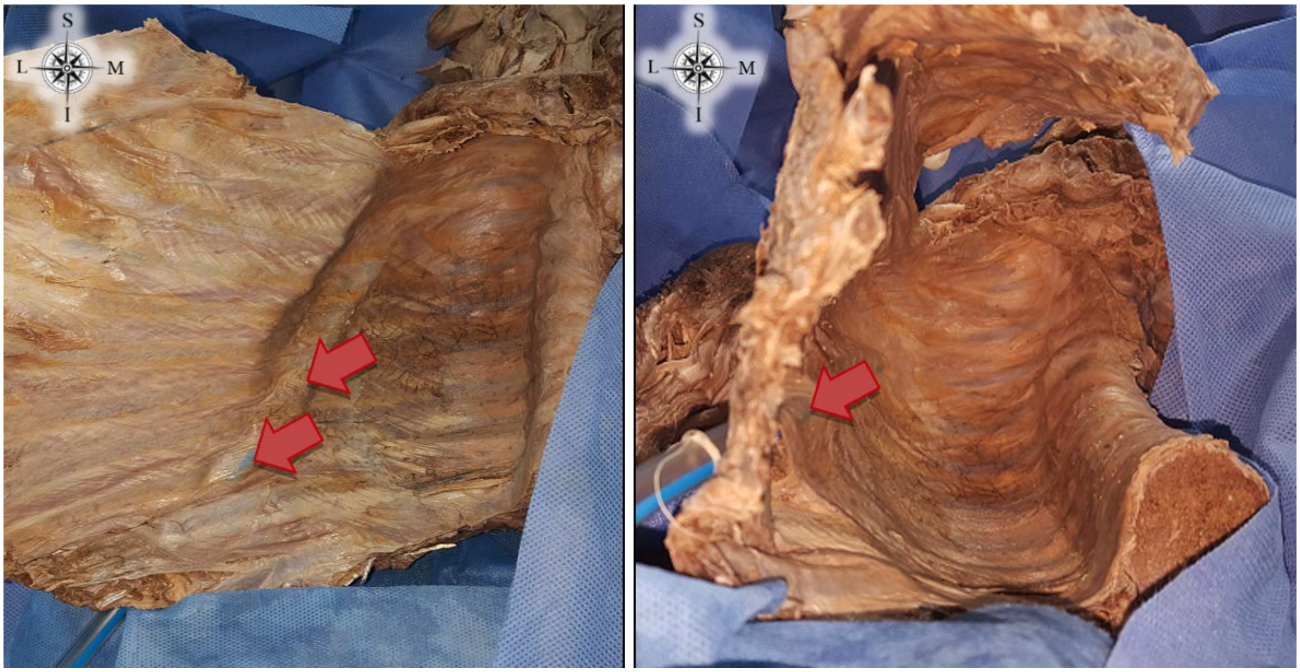


Fig. 18. Incorrect placement of a chest tube on a cadaveric specimen due to failure in the dissection of the chest wall and error in the tube placement plane (red arrows).

ACKNOWLEDGMENTS

The authors sincerely thank the individuals who selflessly donated their bodies to science, making possible the progress of anatomical research. The insights obtained from these studies can significantly deepen medical knowledge and contribute to improving patient care. For this reason, the generosity of these donors and their families is profoundly valued and merits the highest recognition (Iwanaga *et al*., 2022, 2025).

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