Video Article

Learning Modern Laryngeal Surgery in a Dissection Laboratory

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Abstract

Surgery for laryngeal malignancies requires millimetric accuracy from the different endoscopic and open techniques available. Practice of this surgery is almost completely reserved to a few referral centers that deal with a large proportion of this pathology. Practice on human specimens is not always possible for ethical, economic, or availability reasons. The aim of this study is to provide a reproducible method for the organization of a laryngeal laboratory on ex vivo animal models where it is possible to approach, learn, and refine laryngeal techniques. Porcine and ovine larynges are ideal, affordable, models to simulate laryngeal surgery given their similarity to the human larynx in their anatomical layout and tissue composition. Herein, the surgical steps of transoral laser surgery, open partial horizontal laryngectomy, and total laryngectomy are reported. The merging of endoscopic and exoscopic views guarantees an inside-out perspective, which is vital for the comprehension of the complex laryngeal anatomy. The method was successfully adopted during three sessions of a dissection course "Lary-Gym". Further perspectives on robotic surgical training are described.

Video Link

The video component of this article can be found at https://www.jove.com/video/60407/

Introduction

In recent years, the field of laryngeal oncology has seen the introduction and spread of organ sparing protocols such as chemoradiotherapy (CRT), function sparing procedures like transoral laser microsurgery (TLM) and partial laryngectomies, and mainly open partial horizontal laryngectomies (OPHLs). Due to the current general propensity to give greater priority to a patient's quality of life after treatment, this strategy change was necessary in order to avoid, when possible, the burdensome consequences of the total laryngectomy (TL) procedure, which still remains the standard treatment for locally advanced laryngeal cancer. However, despite surgical and technical innovations, TL remains the ideal treatment for advanced stage laryngeal cancer (LC) and for patients who cannot tolerate a conservative protocol because of age or important comorbidities. Therefore, TL has to be properly included in the armamentarium of a complete laryngeal surgeon.

A relevant problem in learning about LC treatment is the relatively rare incidence of the pathology (~13,000 new diagnoses per year in the USA), against the wide spectrum of possible alternatives[1,2]. Moreover, as clearly stressed by Olsen in one of his editorials, the misinterpretation of studies that satisfy the standard of care leads to several unintended consequences[3]. One such consequence was the abandonment of TLM and OPHLs, because they were not included in those studies and in the cost-benefit evaluation, and therefore are no longer taught to residents and young surgeons[3]. As a result, there is a significant paucity of centers in which it is possible to actively learn a surgical technique demanding a high level of accuracy, where the difference between a conservative and an extirpative procedure is quantifiable in the order of millimeters.

In response to this background and to meet the need for dissemination of these surgical procedures, the European Laryngological Society has worked to standardize and classify both TLM and OPHL techniques[4,5,6]. The tremendous result of these classifications was to introduce the possibility of a modular treatment for LC, customized by the real tumor extent and always remaining inside the field of 'partial' surgery and function sparing treatment.

As emphasized in recent work, surgical ability (as a matter of fact, the success of a procedure requires millimetric accuracy) and strict patient selection are mandatory for good results[7,8,9]. In good hands, and if applied to the proper patients and diseases, TLM and OPHL exhibit solid surgical and survival outcomes.

The practice and evolution of these surgical procedures took place almost exclusively in referral centers for pathology, due to the relatively high number of patients, which allowed the surgeons to develop the essential expertise to successfully treat even locally advanced LCs. Trying to summarize the current scenario, laryngeal surgery can be applied to a relatively small number of patients and consists of different procedures that are not available and viable in every center. To preserve laryngeal function and equally reach the oncological radicality, perfect comprehension of the geometrical anatomy, technical accuracy, and concern for the tissues, are mandatory. For all these reasons, simulations on models are nowadays necessary to successfully approach this type of surgery. Faithful, detailed simulations are required to consolidate

the comprehension of the laryngeal framework, manage tissue manipulation with different techniques, and to learn the exact and precise sequence of movements required by a single procedure. Therefore, to learn TLM and OPHL techniques, it is appropriate to be able to practice in a dedicated laboratory. Where there is no possibility to train on human specimens, for ethical, economic, or availability reasons, it is necessary to find an alternative and affordable ex vivo model. Porcine and ovine larynges, waste animal products in the meat supply chain, are ideal and affordable models to simulate laryngeal surgery given their similarity to the human larynx in anatomical layout and tissue composition[10,11].

Several groups have reported their experiences with porcine larynx used as a model for TLM[11,12,13,14]. Despite the different dimensions of the cartilaginous skeleton with larger arytenoids and the inability to distinguish between arytenoid, corniculate, and cuneiform cartilage, the glottic plane is very similar to its human counterpart: the arytenoid cartilage has an analogous articulation with the cricoid and similar geometric proportions[15]. When compared to other animal species, the porcine larynx has a defined laryngeal ventricle with well represented false vocal cords, while the glottic plane is characterized by short arytenoid vocal processes, long vocal folds, and the absence of a proper vocal ligament[14]. Furthermore, from the histologic point of view, Hahn and colleagues have reported a comparable elastin distribution within the lamina propria between porcine and human glottic planes[16,17,18].

On the other hand, other studies have described the utilization of lamb larynx for both TLM and open surgeries[10,19,20]. In detail, Nisa et al. confirmed the strong similarity between ovine and human larynges, with the exception of a differently shaped hyoid bone and arytenoid cartilage, a lower position of the anterior commissure (placed at the inferior border of the thyroid cartilage), and near-complete tracheal rings[21]. Despite these small differences, those authors outlined the great utility of this model for training and practice of laryngotracheal surgical procedures[21]. Moreover, the same model was also used to simulate the percutaneous tracheostomy procedure[22].

The aim of the present study is to illustrate how to prepare and organize a reproducible laboratory for laryngeal surgery on affordable and closely similar ex vivo animal laryngeal models. The authors' experience in setting up such a laboratory was acquired during years of training on surgical simulation in a laboratory of experimental laryngeal surgery called "Lary-Gym" – at the FPO-IRCCS Cancer Institute of Candiolo, Turin, Italy.

Protocol

1. Collection of the Specimens

1. Take lamb and porcine innards from animals slaughtered for meat products.
   NOTE: Innards should be supplied by a reliable butcher who has complied with current health standards.
2. Collect the larynx together with the base of the tongue and the first five tracheal rings, in order to give stability to the specimen. Leave the remaining innards with the butcher, especially the brain and spinal cord, to avoid infective tissue.
3. Thoroughly wash the specimen and put it in a numbered box for tracking.
4. Use the specimen right away or freeze it at -18 °C and defrost it at least 24 h before the dissection.

2. Preparation of the Laboratory

1. If possible, use a sector table with a proper sink, easily washable before and after use.
2. Procure a surgical light or a traditional lamp providing sufficient illumination.
3. Put a barrier across the table at the halfway point to split it into two stations.
   NOTE: This allows for more apprentices to work at the same time and protects them from the laser beam.
4. Procure a special waste container where the specimen and used parts will eventually be discarded. Close the container, label it with the specific European Waste Catalogue (EWC) code, and dispose of it according to the institution's protocols.
5. Optionally, set the air conditioning to offset heat from all of the machinery working and maintain a steady temperature in the room.

3. Preparation of the Endoscopic Station

1. Put the specimen on a proper support, positioning the laryngoscope at the end of the surgical table (**Figure 1**).
   NOTE: The stand support is the one proposed by Delfo Casolino and Andrea Ricci Maccarini and is made of a metal folding structure with adjustable transverse bars[23]. The stand support is equipped with a holder for a laryngoscope and a chassis for specimen positioning.
2. For the safety of the attendants, position an open wood box around the station in order to absorb potential improperly directed laser beams.
   NOTE: Recently the literature has reported a new validated station, approved for CO_2 laser surgery, called LarynxBox. This transparent structure is entirely made by polycarbonate resin, which can safely absorb all the misdirected laser beams[14,24] and could be a replacement for the wooden structure described above.
3. Insert the laryngoscope inside the specimen, expose the desired surgical target (i.e., supraglottic, arytenoid, glottic plane, etc.) and fix the laryngoscope to the support by tightening the proper screw.
   NOTE: Be sure for safety and for the precision of the surgery to firmly fix both the laryngeal specimen and the laryngoscope to the metal structure. If not, use dedicated needles or tape to steadily secure the specimen to the station.
4. Choose the proper laryngoscope for the selected laryngeal region. For example, use a wide and curved laryngoscope for the supraglottic region (i.e., Lindholm operating laryngoscope), a straight and narrow one for the vocal folds (i.e., Dedo operating laryngoscope).
5. For exposure of the vocal folds in the porcine specimen, embed the tip of the laryngoscope anterior to the arytenoid cartilages, pushing these structures in a lateroposterior direction, in order to open and put tension on the vocal folds.
6. Place a suction system inside the specimen, from above or below, in order to extract the laser fumes.
7. Put and fix in position a wet gauze inside the inferior tracheal extremity of the larynx, in order to avoid the emission of CO_2 laser from the inferior part of the specimen. In the same way, place a wet gauze at the superior border of the larynx in order to protect the areas not involved in the dissection.
8. Connect the operating microscope to the CO_2 laser, and place it on the right side of the table.

9. Ensure that the surgeon and all the participants wear safety goggles before turning on the CO_2 laser.
10. Put the endoscope or the exoscope in front of the laryngeal specimen in order to guarantee that the attendants get the same perspective as that of the first operator.
    NOTE: Make sure to put the endoscope or the exoscope above the CO_2 laser source in order to avoid a collision between the laser and the instrumentation.
11. Use an endoscope holder to maintain the optic system in place. Ensure that all the components are fixed and stable in their position for safety and for the surgical dissection.
12. Put the 4k or full high definition (FHD) monitor on the left side of the table, linked to the microscope or to the endoscopic camera.
13. Prepare a microlaryngoscopy set of surgical instruments on a table, beside the first surgeon.
    NOTE: The set should at least contain laryngeal forceps, scissors and spreader, telescope with light cable, ball end suction device, laryngeal hook, laryngeal needle, gauzes.
14. Start the dissection.

4. Preparation of the Open Surgery Station

1. Place the specimen on the other end of the sector table, inside an open box.
2. Prepare the open laryngeal surgery set on a table beside the operating field.
   NOTE: The set should at least be composed of scissors, a pair of forceps (traumatic and atraumatic), dissector, scalpels, pin cutter, hook, needle holder, and stitches.
3. Adjust the surgical light so it is on the surgical field.
4. Optionally, set the CO_2 fiber laser device.
5. Optionally, put a conventional two-dimensional (2D) camera or a three-dimensional (3D) exoscope above the surgical field and connect it to a 2D/3D monitor.
   NOTE: The tutor and the other surgeons can watch what the operator is doing and provide guidance while wearing polarized glasses.

5. (Optional) Broadcast the Dissection

1. Set up an ambient camera, capable of filming all of the room.
2. Link the two monitors, used in the dissections, to a workstation.
3. Broadcast the signal to an external room to extend the procedure to the public, to make comments, or guide the dissection remotely.

6. Endoscopic Dissection

1. Start with a bilateral vestibulectomy in order to improve the view on the glottic plane. Turn on the CO_2 laser and use a 6−10 W power, SuperPulse or UltraPulse mode, a length of 0.8−1.5 mm and a depth of 1−2 points. Use the micromanipulator in order to move the laser pointer and micro forceps in order to grab the mucosa while performing the vestibulectomy.
2. Once the vestibulectomy is performed, inject 2 mL of a NaCl solution (0.9%) into Reinke's space in order to highlight the mucosa.
3. Perform the superior cordotomy: using the CO_2 laser or the microscissors incise the mucosa longitudinally along the superior and lateral aspect of the vocal cord. Grasp the mucosa with forceps and dissect Reinke's space in order to identify the underlying vocalis muscle.
4. Perform a bilateral cordectomy, from type I to V, based on the goal of the dissection, according to the European Laryngological Society (ELS) classification by Remarcle et al.[25].
   NOTE: If a porcine model is used for endoscopic dissection, it is not possible to perform a type II cordectomy, because the vocal ligament is absent. Cordectomies can be performed both by CO_2 laser (4−6 W, Super or Ultrapulse mode, a length of 0.8−1.5 mm, and a depth of 1−2 points) or by cold surgical instrumentations (endoscopic microforceps and microscissors).
5. Once the cordectomy is performed, extract the surgical specimen and place it on a working table. Try to define the anatomical landmarks (e.g., anterior, posterior, and deep aspects).
6. Approach the paraglottic spaces and dissect the region for any anatomical purpose, paying attention to the anatomical landmarks and limits.
7. Perform supraglottic laryngectomies from I to IVb according to the classification of Remacle et al.[26] and approach the pre-epiglottic space.
   NOTE: It must be kept in mind that porcine larynges have larger arytenoids and a smaller epiglottis than in humans.

7. Open Dissection I (OPHL)

1. Dissect the strap muscles along the midline using scissors and forceps.
2. Remove the prelaryngeal tissue.
3. For larynx skeletonization, rotate the larynx contralaterally and perform, using scissors or a scalpel, an incision of the inferior constrictor muscle bilaterally along the lateral aspect of the thyroid cartilage. This procedure can also be performed with a CO_2 fiber laser[27], if available. Protect the superior laryngeal pedicle by retracting the larynx medially and downwards, then section the thyrohyoid ligament. Bilaterally dissect the pyriform sinus from the thyroid cartilage and the paraglottic space, as far as the inferior cornu of the thyroid cartilage.
4. Dissect the cricothyroid muscle and section the inferior cornu of the thyroid cartilage bilaterally to protect the recurrent laryngeal nerve.
5. Manually fracture the thyroid cartilage along the midline. Push with the thumbs on the laryngeal prominence while pulling forward the lateral laminae of the cartilage.
6. Using a scalpel, make the superior access along a line parallel to the superior border of the thyroid cartilage through the pre-epiglottic space. Remove the pre-epiglottic space. Modify the superior access according to the selected type of OPHL, following the ELS classification[6].
7. Using a scalpel, make the inferior access between the cricoid ring and the first tracheal ring. Modify the inferior access according to the selected type of OPHL, following the ELS classification[6].

8. Complete the dissection: using scissors or scalpel perform bilaterally the vertical incisions in order to connect the superior and the inferior accesses. Cut the ary-epiglottic folds, the false vocal cords, the true vocal cords, and the subglottic region. Modify the lines of incision according to the selected type of OPHL, following the ELS classification[6].

9. Perform the pexy: apply four polyglactin 910 stitches for OPHL types I and II, and six for OPHL type III, of which one median double, between the cricoid cartilage and the hyoid bone, passing through the base of the tongue. Ensure to make the passage of the lateral stitches adherent to the superior aspect of the hyoid bone in order to not damage the lingual artery.
   NOTE: The inferior structure will vary based on the type of OPHL performed (thyroid cartilage for OPHL type I, cricoid cartilage for OPHL type II, first tracheal ring for OPHL type III).

10. Optionally, check the result in the inside-out technique using a 0° endoscopic telescope.

8. Open Dissection II (Total Laryngectomy)

1. Remove the infrahyoid muscles using the scissors.
2. Divide the thyroid gland isthmus and move the lobes off the trachea, cricoid, and inferior constrictor muscles.
3. Rotate the larynx contralaterally and incise the inferior constrictor muscle along the lateral aspect of the thyroid cartilage using scissors or scalpel. Expose the pyriform sinus bilaterally. Release the greater cornu of the thyroid cartilage on both sides.
4. Dissect bilaterally the pyriform sinus from the thyroid cartilage and the paraglottic space.
5. Dissect the suprahyoid muscles from the hyoid bone following the superior border of the bone.
   NOTE: Because in human patients the hypoglossal nerve and lingual artery are located at a depth below the greater cornu of the hyoid bone, simulate the maneuver by cutting the muscle insertion close to the medial aspect of the cornu.
6. Perform the pharyngotomy through the valleculae, the pyriform sinus, or the postcricoid area. The choice of entry point is based on the size of the tumor. Use the scissors or the scalpel for this step.
7. For inferior access, use the scalpel to incise the trachea between two tracheal rings and extend the tracheal incision posterolaterally.
8. To perform the laryngectomy in the craniocaudal direction, begin from the epiglottis and proceed through the pharyngotomy. Using the scissors, cut the aryepiglottic folds then proceed through the lateral wall of the pyriform sinus. Incise the postcricoid mucosa transversely, dissecting the plane between the trachea and the esophagus. Remove the larynx.
9. To perform the laryngectomy in a retrograde manner, use the scissors to transect the posterior membranous tracheal wall, dissecting above the trachea from the anterior esophageal wall. Incise the hypopharyngeal mucosa below the upper border of the cricoid lamina. Extend the incision to the pyriform sinus and remove the larynx.
10. Perform the primary closure of the pharynx using interrupted absorbable sutures or barbed sutures in the horizontal direction.
   NOTE: The sutures should be located submucosally on the external surface in order to avoid granulation and possible fistulas. The primary closure of the defect can be achieved easily if at least 2 cm of pharyngeal mucosa is preserved, otherwise a flap has to be harvested.

Representative Results

This protocol proved to be useful for setting up a surgical training laboratory focused on laryngeal surgery using basic instruments and animal waste innards from the meat supply chain. The goal is mostly instructive, but it could be used by less experienced surgeons to improve their anatomical knowledge and surgical skills.

The protocol was adopted in three sessions of the authors' dissection course organized in the 'Lary-Gym' and in the second session of the Head and Neck Surgery Course named "Better than live", where the laboratory dissections were accompanied by teaching sessions by skilled surgeons in this field, and it was greeted enthusiastically by the participants. Overall, 228 colleagues took part in both courses. Twenty-eight attended the Lary-Gym course, and 200 attended the 'Better than live' course. In the Lary-Gym course's last two sessions, the satisfaction of 14 participants was determined through a dedicated questionnaire where participants responded to questions about their experience in the course. The questionnaire and the results are reported in **Table 1**. The animal models chosen proved to be very similar to the human counterpart, with a comparable tissue composition. The possibility to use both the endoscopic and open procedures guaranteed comprehensive understanding of the anatomical layout and surgical techniques. In fact, this inside-out vision could clarify the complex laryngeal anatomy and the implications of the surgical maneuvers in terms of extirpative and reconstructive procedures (e.g., the anastomosis technique in OPHL). In the last session of the course, human specimens and a surgical robot were successfully used to show various transoral robotic surgery (TORS) procedures. The setting of the room was similar to that described, showing that this protocol has good flexibility and can be adapted to equipment and space available in a particular institution.
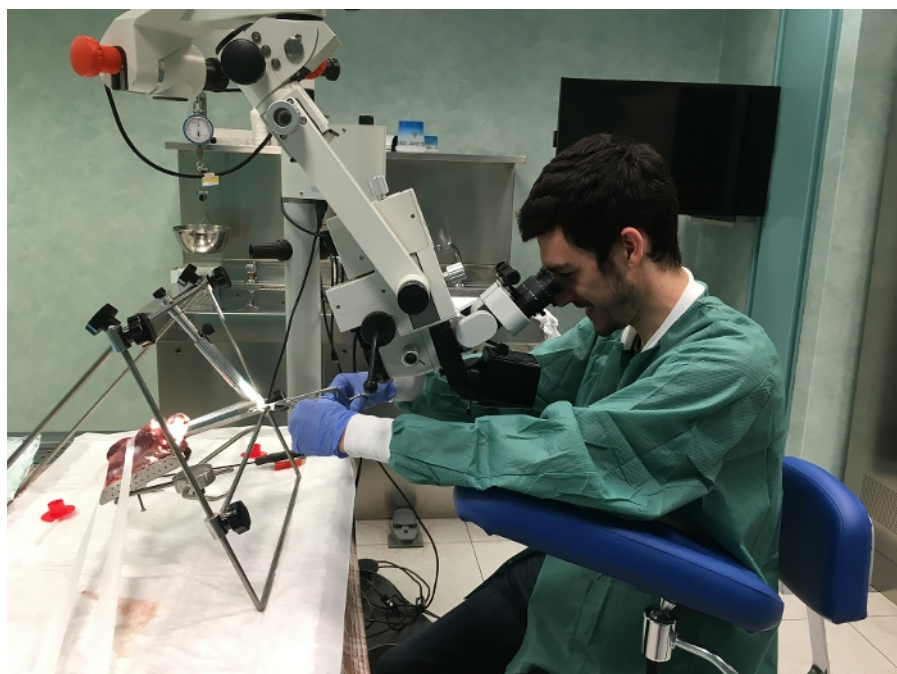
Figure 1: Endoscopic dissection. A young surgeon working in our endoscopic station on an animal specimen. Please click here to view a larger version of this figure.

Question	1	2	3	4	5
How do you value the relevance of the treated topic in respect of your need to update your surgical skills?	0	0	0	1 (7%)	13 (93%)
How do you value the educational quality of this course?	0	0	0	1 (7%)	13 (93%)
How do you value the utility of this course?	0	0	0	1 (7%)	13 (93%)
Absence of conflict of interest.	0	0	0	0	14 (100%)

Table 1: The Lary-Gym course: satisfaction questionnaire and responses. The score ranges from 1 (very dissatisfied) to 5 (very satisfied). Percentages are reported in brackets.

Discussion

This paper aims to describe the organization of a laboratory dedicated to laryngeal surgery and the choice of equivalent ex vivo animal models that can be used to simulate several surgical procedures in an economical but faithful manner. When human specimens are not available, it is necessary to find an accurate animal model to be used as a substitute. If there is no anatomy department that can provide specimens from body donations, the average price for a human model is about $1,300–1,500. On the other hand, for an animal slaughtered for meat products, the equivalent ex vivo animal models are about $8 or less. Here, the experiences of setting up the dedicated space, individual training sessions, and the organization of surgical dissection courses are reported. Based on the literature, it was decided to use porcine and ovine laryngeal models, mainly for laser and open surgery, respectively[10,14,15,19,20,21]. Both the animal models described are easily available and affordable since they are animal waste products in the meat supply chain. Moreover, these ex vivo models are easily managed and stored, with no risk for the operators. Even if slightly different from the human larynx and removed from the normal context of the neck, the anatomical proportions and tissue composition of the animal substitutes are very similar, allowing a step-by-step reproduction of TLM, OPHL, and TL techniques. The large number of specimens available for a very reasonable price guarantees the possibility to repeat the procedure many times. In this way, surgeons can not only improve their precision and accuracy in surgical procedures, but they can also increase their speed of execution, principally during the less important surgical steps of the procedures.

The contemporary use of microscopes/endoscopes for the endolaryngeal view, together with the external view, enhanced in this case by the 3D exoscope, allows an inside-out perspective to be gained, which can help surgeons to fully understand the complex laryngeal anatomy and the importance of each surgical step. Moreover, the use of a camera and screen to share the dissection allows the tutor and the other surgeons to monitor the same field of view as the first operator, increasing the training potential of the system. In this way the tutor can guide the procedure, correct mistakes, and answer any questions or comments.

This type of set-up can be easily replicated, as it is modular and flexible based on the instruments and devices available. Naturally, possible limitations of the animal models can be found in the intrinsic differences between the model and the human larynx and in working on a single prepared organ in the absence of the normal relationships with the surrounding anatomical structures. In detail, the porcine larynx has different

arytenoids conformation, which requires a good glottic exposure. Moreover, the absence of the vocal ligament in the porcine specimen prevents a completely realistic type II cordectomy. On the other hand, these differences are somewhat overshadowed by the availability and cost of the animal models, which are very similar substitutes in tissue consistency and structure. Once the surgeon has acquired sufficient ability, the natural step forward is to switch to simulation to the more expensive human specimens.

A laryngeal training center with the features described is an ideal set-up for training in this precision surgery, for technical refinement, and for teaching purposes. Moreover, the same laboratory can be used to test novel head and neck surgical techniques. For example, the growing diffusion of transoral robotic surgery for oropharyngeal and supraglottic tumors requires time for individual training on the robotic console and to experience tissue manipulation and movements. All of these exercises can be easily simulated and repeated inexpensively in a training laboratory organized as described, without moving surgical facilities and instruments.

Disclosures

The authors have nothing to disclose.

Acknowledgments

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