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Image guided laryngoscopy versus laryngectomy surgery: Patient safety and system review

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Abstract: Laryngectomy, open surgery on the neck, is an invasive therapeutic procedure with serious potential of constraints in everyday life, such as the loss of voice. The use of minimal invasive transoral and transnasal approaches for local treatment of laryngeal cancer could ensure better preserving of organs. Direct laryngoscopy, a widely used endoscopic procedure that requires general anesthesia is presented as well as transnasal optical fiber approaches that require only local anesthesia and would allow a deeper insertion of instruments. In this paper we present and review the different endoscopic approaches in combination with cold cutting and hyperthermal approaches for laryngeal tumor treatment with the conventional open surgery approaches. Minimal invasive surgery could provide advantages for patients and surgeons. Further improvements include robotic and other manipulation systems.

Subjects: Biomedical Engineering; Medical Devices; Medical Imaging

Keywords: image guided surgery; larynx; laryngoscopy; cold cutting; laser; minimal-invasive

1. Introduction

The American Cancer Society estimated that approximately 29,000 new cases of cancer in the pharynx and larynx will be diagnosed in the United States in 2015 (American Cancer Society, 2015). Smoking, excessive drinking of alcohol, an unhealthy diet and infections with the human papillomavirus can increase the risk of suffering from laryngeal cancer (National Cancer Institute, 2014).

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PUBLIC INTEREST STATEMENT

The American Cancer Society estimated that approximately 29,000 new cases of cancer in the pharynx and larynx were diagnosed in the United States in 2015. Complexity and the narrow space inside the throat require removal of cancerous tissue with minimal damage of healthy tissue. Usage of minimal invasive procedures improves the outcome of cancer removal in the larynx. In this review paper, different methods of endoscopic imaging and different minimal invasive surgery approaches for laryngeal cancer removal are compared from a technical perspective. Hyperthermal approaches seem to be more superior to cold cutting techniques, due to its possibility of hemostasis. But introduction and control of these instruments are still focus of research.

There are several approaches for treating laryngeal cancer, for example surgical approaches, Radiation Therapy (RT) or chemoradiation therapy. But especially conventional RT and chemotherapy are often associated with severe late toxicities (Semrau et al., 2013; Tuan et al., 2012). The complex anatomy and the tight working space in the area of the throat represent a challenge for the surgeon. Nevertheless a precise operation must be guaranteed. A complete removal of the tumor must be ensured, otherwise a relapse can be developed. Also, complications can lead to loss of voice.

Image Guided Interventions (IGI) and Surgery (IGS) are developed, which assist the surgeon during the complicated procedures. Transoral and transnasal approaches promise to treat cancer in the larynx without the incision in the neck (Snow, Wackym, & Ballenger, 2009). Therefore optical and fiberoptical methods are used for visualization of the operational environment (Snow et al., 2009). Further advantages of intraoperative imaging are an increased accuracy during the intervention and a facilitation to respond to complications. Interventions inside the throat requires instruments and systems which guarantees precise and accurate removal of the tumor. The usage of transoral laser microsurgery and transoral robotic surgery (TORS) can preserve the functionality of the organs (Radosevich, 2013).

An overview of possible IGI and IGS systems used in tumor therapies is discussed in this paper. Furthermore, a particular attention is given to the limitations of these used methods. Finally will be improvements given of the systems for a future outlook.

2. Intraoperative imaging

Imaging allows diagnosis of diseases, achieves an overview over the operating environment and helps to guide instruments during an intervention. To implement this, MRI and CT can be used (Joshi, Wadhwa, & Mukherji, 2012). But both systems are relatively expensive and they are sensitive to distortions. Imaging based on X-rays should be avoided as the thyroid glands are particularly sensitive to ionizing radiation (Leung, Tipnis, Spampinato, Hungerford, & Huda, 2015).

The proximity to the mouth and nose area permit transoral and transnasal approaches to visualize the pharynx and larynx (Snow et al., 2009). These are mainly based on endoscopic and fiberoptical devices. One method to visualize the vocal folds and glottis is the laryngoscopy. Although laryngoscopy is a very old technique, it is still a very common method used for visualization in the throat and can be distinguished between direct and indirect laryngoscopy (Snow et al., 2009).

2.1. Direct laryngoscopy

Direct laryngoscopy is based on a direct line of sight from the eye of the surgeon to the patients trachea and enables a visualization of laryngeal soft tissue structures (Collins, 2014). During the examination, the patient lies on a table and the head is typically raised in the so called "sniffing position" (Collins, 2014). This position allows that the laryngeal axis aligns with the oral axis. With the alignment of the axes and a displacement of the tongue with a laryngoscope blade, it is possible to achieve a direct line of sight to the glottis (El-Orbany, Woehlck, & Salem, 2011; Snow et al., 2009).

The blade is hereby used on one side as a retractor and on the other side as an illuminator (Glick, Cooper, & Ovassapian, 2012). Different kinds of laryngoscope blades exists. The most common used blades are the curved Macintosh and the straight Miller blade (Collins, 2014). Other blades are for example the McCoy, Wisconsin, Belescope or the Siker blade (Collins, 2014). The straight blades are more narrow and they have a rounded tip to lift the epiglottis (Margolis, 2004).

Whereas, the curved blades have a broad flange for moving the tongue (Margolis, 2004). The tip of the curved blades are designed to fit into the vallecula (Margolis, 2004). The curved blade is often favored for a better tongue control and an easier intubation (Collins, 2014). Whereas, the straight blade has a smaller displacement volume and is more suited for patients with smaller displacement space like children (Collins, 2014).

It is uncommon that during the operation the surgeon carries the laryngoscope in one hand and in the other hand the cutting device. For that special laryngoscope holders are used, which are fixed either over or directly on the patient's chest (Ekberg, 2012, p. 397). Direct laryngoscopy allows guiding of instruments under direct visualization (Margolis, 2004). Furthermore, direct laryngoscopy is more cost effective than other imaging modalities (Glick et al., 2012).

This system is more robust and does not depend on fragile fiberoptics (Glick et al., 2012). But, there are also some drawbacks when using direct laryngoscopy. An alignment of the laryngeal axis is necessary for successful laryngoscopy. If it is not possible to position the patient in the sniffing position, for example because of a trauma or the patient have a high misalignment of the axis since birth, it will be very difficult to see the glottic opening (Margolis, 2004). Improper usage of the laryngoscope can lead to dental and mucosal damages (Margolis, 2004). A too deeply placed laryngoscope into the mouth can lead to a gag reflex.

This for the patient unpleasant procedure and to avoid movements or gag reflexes by the patient during the procedure make a general anesthesia necessary. The anesthesia requires an endotrachial tube, which allows a gas exchange of oxygen and carbon dioxide in the lungs. During the intervention the tube can get in the way (Eastern Virginia Medical School, 2015).

2.2. Indirect laryngoscopy

Using indirect laryngoscopy a direct line-of-sight is not necessary for visualizing the larynx (Snow et al., 2009, pp. 955–962). The images are acquired by reflection or using lens systems with the patient head in a comfortable neutral position. For indirect mirror laryngoscopy the doctor inserts a mirror through the mouth of the patient (Ponka & Baddar, 2013). With an external light source he is then able to visualize the vocal cords and glottis (Snow et al., 2009). To prevent fogging of the mirror it is possible to heat the mirror (Snow et al., 2009). The drawback of this very cheap and simple method is the restricted field of view and movement possibilities inside the throat (Snow et al., 2009).

Another method for indirect laryngoscopy uses Rod-Lens Telescopes (RLT) (Snow et al., 2009). Those systems consists of relatively long rod lenses but small air spaces (Smith, 2007). Compared to a conventional glass lens endoscope, RLT has a greater light transmission, better image resolution, wider field of view and image magnification (University of Georgia: College of Veterinary Medicine, 2015). Using RLT it is possible to connect the telescope with a light source (Snow et al., 2009). Compared to mirror laryngoscopy, RLT allows a better adjustment of the viewing direction thereby it provides an "all-round vision" and it has a much better patient tolerance (Karl Storz-Endoskope, 2015; Snow et al., 2009).

Using microlaryngeal instruments for tumor dissection in combination with mirror or RLT systems is cumbersome because of the limited mobility. Another disadvantage of the mirror and rod-lens laryngoscopy is that by touching the pharyngeal wall or tongue base, a gag reflex can occur which could lead to severe accidents during the intervention (Ponka & Baddar, 2013).

To avoid such problems it is possible to use fiberoptic transnasal endoscopy (Snow et al., 2009). Thereby a flexible endoscope is passed through the nasal cavity and enables a more deeper view of the larynx compared to mirror and RLT laryngoscopy. The flexible endoscope can be equipped with a working channel which allows the insertion of small forceps or laser waveguides for surgery (Levine, Govindaraj, & DeMaria, 2013, p. 166).

Because of the relative complicated pathway through the nose, transoral endoscopy is easier to manage for the surgeon than transnasal endoscopy (Craig, Hanlon, Dent, & Schoeman, 1999).

Table 1. Comparison of different intraoperative imaging modalities for throat surgery

	Pro	Con
Direct laryngoscopy	• Direct line of sight • Robust	• Uncomfortable position for patient • General anaesthesia necessary
Transoral rigid Endoscopy	• Imaging is easy to manage	• Gag reflex • Intervention is cumbersome
Transnasal flexible endoscopy	• Deeper view than rigid endoscopy • More tolerated by patients • Flexible	• Relative complicated pathway • Flexible[a]
Video laryngoscopy	• Better view	• Expensive

[a]Flexibility is advantageous when steering an instrument in a complicated pathway. But during an intervention it is more appropriate to have a stiff imaging modality.

Large diameter fiberscopes can also damage blood vessel inside the nose (Craig et al., 1999). But studies show that transnasal approaches are more comfortable and better tolerated by the patients than transoral approaches (Kadayifci et al., 2014).

Bending of glass fibers for light transport causes loss of light. This leads to a reduced image magnification and a higher rate of image distortions compared to rigid endoscopy (Radosevich, 2013, p. 145).

2.3. Video laryngoscopy
Increased distance from the glottis to the laryngoscopist decreases the field of view (Collins, 2014). Attaching a small video chip on the tip of the laryngoscope promises a better view on the glottis compared to a direct line-of-sight or optical approaches (Collins, 2014).

Teaching the insertion of the different laryngoscopes is very cumbersome and is based on an error-and-trial approach. The usage of an external monitor for viewing can improve the learning curve for trainees significantly (Collins, 2014). Also the possibility of saving the images can be beneficial for documentation and teaching purposes (Collins, 2014). But for high resolution images expensive camera systems are necessary, which increase the cost of the procedure.

Table 1 compares the introduced imaging modalities for intraoperative imaging of the larynx.

3. Surgical techniques for removing throat cancer

3.1. Cold cutting approaches

3.1.1. Open surgery and closed microlaryngeal surgery
Open surgery for laryngeal cancer is done when neither radiotherapy, chemoradiotherapy or other approaches are possible to treat the cancer. Those procedures are highly invasive and mostly the functionality of swallowing and breathing are impaired (Radosevich, 2013).

One possible intervention in the region of the larynx is the so-called laryngectomy. Depending on the cancer stage, it is possible to divide the laryngectomy into total laryngectomy and partial laryngectomy (Radosevich, 2013). Total laryngectomy is done in cases when the cancer is in an advanced stage. Thereby, an U-shaped incision in the anterior neck is made for direct visualization and the larynx is completely removed (Bernier, 2011, p. 478). After removal of the larynx, the patient loses the ability of speaking (Radosevich, 2013, p. 541). The separation of the airway from the oral and nasal cavity also requires the placement of a tracheotomy tube, through which the patient is able to breathe (Radosevich, 2013). Partial laryngectomy promises a better preservation of the functionality of the organs. Thereby, only a part of the larynx will be removed. But still complications are common during or after the procedure which favor non-open surgery approaches (Radosevich, 2013).

The usage of microlaryngeal instruments while guidance with laryngoscopy through oral or nasal openings promise a better preservation of the functionality of internal organs. The instruments used must be long and thin so that the insertion into the throat and the guidance via laryngoscopy is possible. And the tips of the tool must also be very small for handling the tiny laryngeal structures (Eastern Virginia Medical School, 2015).

Those systems can acquire a precise surgical incision, but an effective bleeding control is not possible (Somogyvári, Gerlinger, Lujber, Burián, & Móricz, 2015).

3.1.2. Microdebrider
A Microdebrider (MD) consists of three parts: a blade, a hand piece and a control console (Lunn & Ernst, 2008). The blade is a hollow metal tube, which can be used only once in an intervention and is coupled to a suction system (Lunn & Ernst, 2008). The hand piece drives the blade with an electrically powered motor (Lunn & Ernst, 2008). And the console controls the speed and the direction of the blade via a foot pedal (Lunn & Ernst, 2008). The MD sucks tissue into the hollow tube, which cuts the tissue (Polley, 2007). This allows a simultaneously removal of tissue and blood to improve a better view of the surgeon. The usage of a non-thermal approach includes that airway fires are completely avoided and the risk of severe damages are reduced (Lunn & Ernst, 2008). Furthermore there will be no smoke, which can mist the imaging instruments and impair the operational view. The implementation of a suction and a cutting device in one device offers higher freedoms during the intervention compared to traditional methods, where the surgeon needs three instruments for interventions in the airway: an optical visualization instrument, a cutting system and a suction device (Polley, 2007). By using MD only two instruments are necessary. In the one hand the surgeon holds a MD and in the other hand a visualization instrument (Polley, 2007). Repetitive switching between the instruments is avoided, which could disturb the intervention and concurrently time can be saved.

But the usage of MD have some drawbacks. Typically such a MD has a diameter of 4 mm and is very rigid. So it is not amenable to flexible endoscopy and therefore, rigid endoscopy or a direct laryngoscopy have to be used (Lunn et al., 2005). There is also the possibility of a mistakenly cutting of healthy tissue. So the surgeon should use the powered instrumentation with caution, to reduce the risk of injuring the vocal folds and impairing the functionality of the organ (Howell et al., 2014; Mortensen & Woo, 2009).

3.2. Hyperthermal approaches

3.2.1. Transoral laser surgery
Beginning with the introduction of CO_2 laser in laryngology in the early 1970s, Transoral laser surgery (TLS) has become an effective alternative to cold-cutting techniques, open laryngectomy and radiation therapy in today's medicine (Bernier, 2011). There exist a broad variety of lasers in medicine like the Pulsed Dye Laser (PDL) and the Potassium Titanyl Phosphate laser (KTP) (Radosevich, 2013). Compared to most other laser types, the CO_2 laser can be more focused and consequently allows a minimal damage of the surrounding tissues (Yan et al., 2009). It is necessary to achieve in combination with a microscope a straight line between the beam and the cancer cells for a successful intervention (Yan et al., 2009).

Also it is possible to use a micro-manipulator mirror system for CO_2 laser delivery (Radosevich, 2013, p. 632). But these would need direct laryngoscopy approaches which require a general anesthesia.

A fiberoptical approach requires only a local anesthesia and enables an office-based intervention (Yan et al., 2009). But classical fiberoptical approaches are not used for transmission of CO_2 laser (Yan et al., 2009). Under specific circumstances, there is a possibility that a very high focused CO_2 laser beam can lead to especially high power densities inside the fibers (Katzir, 1993, p. 220). This could cause severe damages to the optical fiber which lead to severe accidents during the intervention (Katzir, 1993). But developments are underway using special hollow fiber guides, which make a CO_2 laser transmission possible (Tichindelean, 2015).

Typically laser types like PDL, KTP and thulium lasers offer a better possibility for fiberoptical transmission of the laser beam. Furthermore, PDL and KTP provide better hemostatic effects than the CO_2 laser (Yan et al., 2009).

Coupling the CO_2 laser to an operating microscope increases the accuracy of the surgical intervention (Adelstein, 2005, p. 43). Because the laser light of the CO_2 laser is not visible, often a helium-neon laser is mounted on the microscope (Adelstein, 2005).

Using laser systems for throat surgery have several kinds of advantages compared to cold-cutting surgery. TLS offers minimal damages to the surrounding tissue and allows an intraoperative hemostasis (Yan et al., 2009). The need of only burning the tissue away also decreases the amount of tissue manipulations, which need to be done with cold cuttings techniques (Yan et al., 2009). Surveys confirm that TLS have less short and long term side effects than cold-cutting techniques and there is a high chance that the swallowing and voice function can be preserved (Rich, Liu, & Haughey, 2011; Roh, Kim, & Park, 2008). Patients treated with TLS experience shorter hospital stays and the wounds recover faster (Yan et al., 2009). The shorter hospitals stays of the patients lead to the fact that TLS is more cost-effective than cold cutting techniques (Yan et al., 2009).

The main advantage of hyperthermal approaches is the possibility of closing blood vessels by hemostasis.

Using laser in surgery requires some precautions. Reflections of the laser can injure the retina which makes eye protection for staff and patient necessary (Adelstein, 2005). Another aspect which should be considered when using an endotracheal ventilation system, that this system could take fire or ignite when it is touched by the laser beam (Bernier, 2011, p. 339). An expensive tube which is specific designed for laser protection must be used (Bernier, 2011). Also could a jet ventilation system used, by this oxygen are blown under high pressure into the lungs (Eastern Virginia Medical School, 2015). This would obviate the tube (Eastern Virginia Medical School, 2015).

The laser beam creates high temperatures. So the surgeon should operate with caution, otherwise he could increase scarring and damage healthy tissue (Yan et al., 2009).

3.2.2. Radiofrequency ablation

Radiofrequency ablation (RFA) is a hyperthermal approach for destroying tumor cells inside the body, whereby the surgeon places electrodes directly into the tumor. The electrode is connected to a radio frequency generator, which offers an alternating current (AC). The heat is developed by means of Joule heating and dielectric losses. In general RFA incorporates the advantages of CO_2 laser surgery like bleeding-control. But a non-necessity of expensive laser intubation tubes, makes RFA approaches more cost effective than laser surgery (Somogyvári et al., 2015).

One problem of most hyperthermal dissections is that the temperatures acquired are often too high and an unwanted heating of healthy tissue can appear. Coblation (acronym for controlled ablation) is a special RFA approach which uses a plasma for energy transport (Smith & Nephew, n.d). The plasma is created in a high density energy field within an electric conductive fluid by a special delivery system (Smith & Nephew, n.d).

Lower temperature developments during the coblation leads to a lower thermal penetration and so damages to the healthy tissue can be avoided (Smith & Nephew, n.d). Optical fiber for flexible laser surgery can have a diameter of 0.6 mm (Kraaij et al., 2011). In contrast to that the rigid coblation electrode has a diameter of 3.5 mm (Kraaij et al., 2011). So there must be a higher effort made to navigate coblation electrodes in the narrow operational environment (Kraaij et al., 2011).

Table 2. Comparison of surgery tools for throat surgery

	Pro	Con	Access to the larynx
Microlaryngeal tools	• Tools are adapted to the Throat	• No bleeding control	• Transoral
Microdebrider	• Sucks and cut tissue • No danger of airway fires	• Large geometry	• Transoral
Laser surgery	• Hemostasis • Very precise	• Laser reflection • Overheating	• Transoral • Transnasal
RFA	• Less temperatures than TLS	• Large geometry	• Transoral
TORS	• Very precise movement • 3D imaging	• Not designed for the throat • Expensive	• Transoral

3.3. Transoral robotic surgery

Endoscopic surgery minimizes damages to the healthy tissue compared to open surgery. But also endoscopic surgery has disadvantages like a lack of steerable instruments and a missing three dimensional view. TORS allow to improve surgery in the region of the throat. The most common TORS system used is the da Vinci R system (White et al., 2010). This system consists of a 3D imaging modality and independently steerable robot arms, which are controlled by the surgeon. The greatest advantage of TORS is the increased degrees of freedom (DoF).

These increased DoF of the da Vinci system simulate the movements which could be also done during an open surgery by the surgeons arm. The narrow spaces in the throat limit the use of da Vinci system (Hillel, Kapoor, Simaan, Taylor, & Flint, 2008).

Normally the da Vinci system was designed for abdominal and thoracic interventions, where the robot arms have much place. Surgeons claims it is only possible to insert one robotic arm within the laryngoscope (Hillel et al., 2008). Hockstein reported a feasibility for inserting three robotic arms using additionally a mouth gag (Hillel et al., 2008). But the requirement of movement space of the instruments can lead to overcrowding and inhibit the procedure. While the technology of the da Vinci system enables promising opportunities to improve the surgery, many scientists doubt a widespread use of these systems.

Because the high cost factor dominates the small benefit factor (Hillel et al., 2008). In Table 2 are the surgical tools summarized for minimal invasive laryngeal interventions that have been mentioned.

4. Summary

The variety of different surgical interventions in combination with intraoperative imaging modalities allows the surgeon to establish for different requirements of the procedure an optimal solution. Direct laryngoscopy is very uncomfortable for the patient and requires general anesthesia. Alternatives for this are rigid and flexible endoscopy.

A transnasal endoscopic approach is better tolerated by the patient and allows ambulant procedures.

The use of microlaryngeal cutting tools especially designed for the throat, facilitate a cheap and precise removing of tissue. Bleeding during surgery prevent the vision and require suction systems by which the blood could be removed. A microdebrider (MD) combines cutter and suction system in one gadget. This allows that the intervention can run more fluently and a repetitive change between cutter and suction system does not interrupt the intervention. However, a limited mobility reduces possible applications in the throat.

Laser surgery is the most widely-used method for the removal of cancer in the throat area. The difficulty of transport CO_2 laser through fiber optical classical approaches, needs a direct laryngoscopy and thus a ventilation system. This requires strict and costly security measures to avoid collateral damage. The use of robotic systems is currently limited by the low mobility in the throat area.

5. Future outlook

Complete removal of the cancer cells is a prerequisite to prevent regrowing of the tumor. However, for the surgeon, it is often difficult to distinguish between healthy and cancerous tissue. A computer generated segmentation can allow better distinction. Segmentation can be carried out by spectroscopy or by use of medical imaging, such as preoperative PET/MRI (Leibfarth et al., 2015; Regeling et al., 2015). The transfer of these segmented data in an augmented reality application could show the surgeon the boundaries between healthy and diseased tissue, thus improving a selective incision.

Another possibility to highlight cancerous tissue is based on narrow band imaging (NBI) (Kraft et al., 2015). NBI is based on optical filtering and enhance the contrast of cancerous tissue in an image. This technique allows a very rapid detection of laryngeal cancer.

The patient discomfort during direct laryngoscopy, with the potential risks and problems of general anesthesia should be avoided when possible. One focus should be on the transnasal fiber optical approach, which has no need for general anesthesia. A transnasal approach allows only working channels of small diameter. Transoral approaches would allow larger diameters of the working channel. Wherein a triggering of the gag reflex must be avoided.

The intervention should be designed as comfortable and uncomplicated as possible for the surgeon. Video endoscopy could bring significantly improvements. The surgeon can achieve a better operational environment over large external monitors and he can work in a more comfortable position.

The requisite of having to use different tools at the same time as cutting tools, endoscope and suction tools, may disturb the course of the intervention. Innovative ideas such as the implementation of a cutting system and a suction system in one tool, or by creating steerable endoscopes, or by developing special holdering systems can guarantee a much smoother intervention (Boese, Detert, Stibbe, Thiele, & Arens, 2015; Kristin, Geiger, Kraus, & Klenzner, 2015).

When precision cutting or handling multiple instruments is necessary, robotic systems can assist the surgeon. The challenge, however, is that these systems must be designed to the environmental conditions of the throat in order to ensure mobility. Highly flexible robots could overcome the impaired mobility of the da Vinci system (Rivera-Serrano et al., 2012).

Laser surgery is and remains an important component of the treatment of cancer in the throat area. Although lasers as PDL and KTP are already suitable for fiberoptical transmission, efforts are made to transmit CO_2 laser via fiberoptic approaches due to the better surgical specification of the CO_2 laser. Concerning patient safety, coblation could be an alternative to laser surgery. This has the bleeding control advantages of CO_2 laser surgery, but the hazards of burns in this method are much lower.

Another possibility for minimal invasive surgery inside the larynx is based on intraoperative radiation therapy (IORT) with miniaturized X-ray tubes. This procedure could emit high dose radiation to the clinical target, but healthy tissue would experience only low dose radiation. IORT could offer a better preservation of the sensitive organs in the throat, and it is more cost and time effective compared to external beam radiation (Johnson, Boese, & Friebe, 2016).

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