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DOI: 10.2478/rjr-2025-0002

Romanian Journal of Rhinology, Volume 15, No. 57, January - March 2025

LITERATURE REVIEW

Laser use in head and neck surgical procedures

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ABSTRACT

OBJECTIVE. The aim of this paper is to review laser use in head and neck surgical procedures.

MATERIAL AND METHODS. A search of the literature was conducted using PubMed, Medline, Google and Google Scholar search engines for the period between 1970 and 2024. Search terms related to "laser" or "head" or "neck" or "larynx" or "cancer" or "surgery" or "otology" or "Eustachian tuboplasty" or "acoustic neuroma" or "rhinophyma" or "skin rejuvenation" were identified and queried to select recent and relevant articles.

RESULTS. Laser types fall into two broad categories: photoangiolytic lasers and cutting/ablating lasers. CO2 lasers have been the preferred choice for treating various conditions, including vocal cord keratosis, polyps, nodules, papillomas, carcinoma in situ, and T1 cancer, owing to their capacity to cause minimal damage to surrounding tissue. PDL and KTP demonstrate superior hemostatic effects compared to CO2 laser. The accessibility of PDL, KTP, and other office-based photoangiolytic lasers, significantly boosts their popularity due to the cost and time reductions associated with office-based procedures. Laser applications in otology encompass a diverse array of treatments, such as vascular lesions and exostoses in the external auditory canal, debulking inoperable tumors, managing the Eustachian tube dysfunction, performing myringotomy/tympanostomy for otitis media, and conducting stapedectomy/stapedotomy for otosclerosis, and cholesteatoma removal. Laser treatment can also be used for skin rejuvenation.

CONCLUSION. Carbon dioxide lasers, Er:YAG lasers, photoangiolytic lasers like KTP and PDL may be used in head and neck surgical procedures and facial rejuvenation in appropriate cases.

KEYWORDS: laser, surgery, cancer, larynx, skin rejuvenation.

INTRODUCTION

Otolaryngologists, specialists in head and neck surgery, frequently operate in challenging anatomical regions like the larynx and skull base. They perform complex procedures, such as microsurgery on the vocal folds or stapes, where laser technology plays a crucial role. In microsurgery, precise control of the laser beam is achieved using a micromanipulator or a microscope-mounted scanner, even when dealing with beams as small as 100 mm. Surgeries involving the subglottis and trachea use flexible optical fibers or waveguides to transmit laser light to these hard-to-reach locations. High-power carbon dioxide (CO2) lasers, with a wavelength of 10.6 µm, are essential for minimally invasive laryngeal cancer operations, ensuring tissue cutting while maintaining hemostasis[1].

MATERIAL AND METHODS

A search of the literature was conducted using PubMed, Medline, Google and Google Scholar search engines for the period between 1970 and 2024. Search terms related to "laser" or "head" or "neck" or "larynx" or "cancer" or "surgery" or "otology" or "Eustachian tuboplasty" or "acoustic neuroma" or "rhinophyma" or "skin rejuvenation" were identified and queried to select recent and relevant articles.

LASER PHYSICS

Understanding the fundamental physics governing laser operations is essential for selecting the appropriate

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Received for publication: September 21, 2024 / **Accepted:** October 29, 2024

laser in clinical scenarios. The intensity required for surgical procedures is achieved through light amplification within the laser's optical cavity, which consists of two mirrors and the space between them. Energizing a group of atoms in this cavity releases energy, stimulating excited-state atoms and amplifying photons[2]. Monochromaticity, coherence, and directionality are three key properties of laser light that collectively influence the controllable parameters of a surgical laser[3].

The power of the laser beam, measured in watts (W), determines the energy transmission rate, while adjusting the beam's focus involves altering the spot size[4]. Dosage, measured in joules (J) over time (seconds, s), governs beam energy. Power density, expressed in watts per square centimetre (W/cm^2), affects tissue removal speed at the surgical site[2]. Fluence, a critical parameter for minimizing adjacent tissue damage, integrates power density and dosage. Higher power for shorter durations allows increased precision and reduced damage to nearby tissue[3].

Laser types are characterized by the laser medium and the target chromophore. The laser medium, whether solid, liquid, or gas, determines the laser's wavelength. Solid and liquid mediums are optically stimulated, while gas lasers rely on electrical energization[2]. The target chromophore identifies the substance that absorbs the laser beam, typically haemoglobin or water[3].

LASER TYPES AND DEVICES

Laser types fall into two broad categories: photoangiolytic lasers and cutting/ablating lasers, each with their selectivity. Photoangiolytic lasers, like long-pulse potassium-titanyl-phosphate (KTP) laser and pulsed dye laser (PDL), specifically target hemoglobin, while cutting/ablating lasers like CO2 and Thulium are primarily absorbed by water[3].

Since 1972, CO2 lasers have been the preferred choice for treating various conditions, including vocal cord keratosis, polyps, nodules, papillomas, carcinoma in situ, and T1 cancer, owing to their capacity to cause minimal damage to surrounding tissue[5]. Polanyi et al. initially tested the CO2 laser on human cadaver larynges, noting precise wounds[6]. Subsequent advancements, including endoscopic delivery systems, facilitated Jako's utilization of the tool in canine larynges[7]. When delivered to the larynx via a microscope, CO2 lasers ensure the precise and efficient removal of small tumors[8]. While CO2 lasers offer better focus compared to PDL, KTP, or thulium lasers, the latter options enable fiber optic transmission, making them suitable for both office and operating room settings[9-11]. Fiber optic transmission allows surgeons to choose between contact or non-contact modes when delivering laser energy to tissue. However, traditional CO2 lasers lack this capability, limiting their use to areas with direct alignment, primarily in the operating room[12].

An essential differentiation emerges: lasers utilizing fiber optic transmission (such as PDL and KTP) enable office-based procedures without the need for general anesthesia, whereas procedures involving CO2 and other non-fiber optic transmission lasers typically require general anesthesia. PDL and KTP demonstrate superior hemostatic effects compared to CO2[13]. The accessibility of PDL, KTP, and other office-based photoangiolytic lasers significantly boosts their popularity due to the cost and time reductions associated with office-based procedures[3].

Since Jako[7] initially combined the carbon dioxide (CO2) laser with the operating microscope in 1972 for laryngeal surgery, the CO2 laser has consistently maintained its position as the preferred wavelength. Its widespread utilization in various procedures is attributed to its availability in most medical centres and its effectiveness in both cutting tissue and ensuring hemostasis. Other frequently employed lasers in otolaryngology encompass the KTP laser (Nd:YAG [neodymium-doped yttrium aluminum garnet]) and the Argon laser. In the realm of laryngeal surgery, the integration of the CO2 laser with a micromanipulator connected to the microscope enables the simultaneous use of microsurgical instruments and the laser. This configuration ensures optimal visualization of the surgical field with high magnification and an unobstructed view of the lesion. The CO2 laser presents "advantages over conventional surgical instruments" that cut or cauterize, as traditional devices may obstruct the field of view or amplify the surgeon's intention tremor through "a lever arm extending up to 20 cm"[1].

LASER SURGERY IN THE LARYNX

The CO2 laser is frequently used in the treatment of early glottic cancer due to its dual capability for cutting and coagulation, depending on the degree of focus. Ledda et al.[14] illustrated the effective application of the CO2 laser in early glottic cancer, emphasizing positive oncological outcomes, reduced surgical trauma, faster recovery, and preservation of voice quality. However, the optimal approach for early glottic carcinoma remains a matter of debate[15]. In cases involving the anterior commissure, Steiner et al.[15] recommend laser microsurgery as the preferred option. Alternative treatments, such as radiotherapy, exhibit inferior local control rates, longer procedure and healing times, and increased complication risks. Nevertheless, for transglottic tumors with lateral submucosal extension, endoscopic resection using a CO2 laser may prove insufficient, and alternative approaches like open neck surgery and radiotherapy should be considered[16].

Despite its limitations, the CO2 laser continues to be the most commonly employed laser for vocal pathologies[8,12]. Due to its widespread availability, healthcare professionals possess comprehensive knowledge of its use, capabilities, and limitations. More recently, the thulium

laser has demonstrated efficacy in cancer treatment. Functioning as an office-based laser that emulates CO2 laser properties[8], it offers improved coagulation and versatile delivery through its flexible fiber and the option for contact mode.

The pulsed KTP laser represents a relatively recent addition to vocal fold surgery when compared to the PDL, and several advantages have been reported[11,17-19]. Initially employed in continuous mode, it demonstrated significant utility in the treatment of subglottic hemangiomas, vocal fold ectasias, and varices[12]. With a wavelength of 532 nm, the KTP laser exhibits stronger hemoglobin absorption compared to the PDL's 585 nm wavelength[17,18]. The KTP laser holds a notable advantage due to its wider pulse width, enabling laser energy to spread over an extended period, resulting in slower heating and more uniform coagulation[17-19]. In contrast, the PDL is commonly used for treating conditions such as RRP, keratosis, leukoplakia[17], and other lesions. However, its short pulse width can sometimes lead to vessel wall rupture before complete coagulation[17-19]. Additional benefits of the pulsed KTP laser include adjustable fiber size and a durable solid-state design, reducing the likelihood of costly repairs often required for the PDL[11].

Glottic carcinoma

The standard approach for T1 and T2a carcinomas of the glottis is "en bloc" resection, typically achieving clear margins within the range of 1-3 mm. However, laser surgery introduces the possibility of maintaining narrower margins, facilitating the preservation of vocal function and minimizing post-operative edema. Since the 1990s, Transoral Laser Microsurgery (TLM) has consistently demonstrated favourable functional outcomes and low recurrence rates in various studies. The current research suggests that the preservation of the larynx can be achieved in over 92% of cases, with a 5-year local control rate ranging from 80% to 94%[20,21]. TLM stands out as an advantage in treating early glottic cancer compared to alternative procedures, providing a range of treatment options for patients facing local or secondary tumor recurrence. These options include laser reexcision, radiation therapy, or open partial laryngectomy[21,22].

For glottis T2b and T3 carcinomas, which typically involve the vocal cords with "supraglottic or subglottic extension", laser operative techniques may require subdividing the tumor into multiple pieces for removal. Resection may encompass the cricoid and thyroid cartilage, cricothyroid ligament, arytenoids, and any involved laryngeal soft tissue[1].

Supraglottic carcinoma

T1 and T2 carcinomas of the supraglottis pertain to tumors that have not infiltrated the preepiglottic fat, immobilized a vocal cord, or metastasized to a local lymph node. The application of CO2 laser resection for supraglottic carcinoma was initially detailed by Vaughan. Subsequently, Steiner, Davis et al., and Zeitels et al. have employed Transoral Laser Microsurgery (TLM) for supraglottic resections[23-26]. In this region, laser excision of tumors typically involves extensive dissection, requiring the removal of affected muscle, cartilage, and, in advanced cancer cases, portions of the base of the tongue and piriform sinuses. Remarkably, tracheostomy is often unnecessary, even after extensive laser dissection, due to limited postoperative edema. However, it should be considered in procedures with "high blood loss" or "for elderly patients with decreased pulmonary function".

While literature on laser resection of T1 and T2 cancers in the supraglottis is limited, Ambrosch et al.[27] reported a series of 48 patients with supraglottic T1 and T2 carcinomas. Their outcomes included a 100% local control rate for pT1 tumors and an 89% local control rate for pT2 tumors at 5 years. The recurrence-free survival rate over 5 years was 83%, and the overall 5-year survival rate was 76%. Notably, none of the patients experiencing recurrence required laryngectomy as a secondary treatment[27].

Laser excision for T3 carcinoma of the supraglottis is not commonly practiced. Hinni et al. described a series of 117 patients with T2 to T4 lesions treated with TLM[28].

Laryngomalacia

From an anatomical perspective, laryngomalacia manifests as the inward collapse of the supraglottic mucosa during inspiration. When conservative approaches prove ineffective, the surgical solution is supraglottoplasty. In cases where stridor results from shortened aryepiglottic folds, the preferred treatment involves bilateral laser incision of the aryepiglottic folds and the arytenoid cartilage region. Conversely, if the stridor arises due to the inward collapse of the epiglottis during inspiration, the recommended surgery is an epiglottopexy. Further details on laser use in the pediatric population will be discussed in a subsequent section[1].

Papillomas

Transoral laser microsurgery (TLM) represents a minimally invasive procedure conducted with low-power lasers. This method uses CO2, KTP, and pulse dye lasers in various settings, including both the operating room and in-office environments. Through precise targeting of the affected tissue, TLM enables surgeons to eliminate disease while minimizing disturbance to the normal surrounding tissue. More specifically, it selectively removes only the mucosa affected by papillomas, leaving small islands of healthy mucosa intact. This approach promotes faster re-epithelialization[29].

LASER USE IN OTOLOGY

Laser applications in otology encompass a diverse array of treatments, addressing conditions such as vascular lesions and exostoses in the external auditory canal (EAC), debulking inoperable tumors, managing Eustachian tube dysfunction, performing tympanostomy/myr-

ingotomy for otitis media, fixing grafts in tympanoplasty, and conducting stapedectomy or stapedotomy for otosclerosis, tympanosclerosis, and cholesteatoma removal. Additionally, lasers play a role in procedures such as cochleostomy, labyrinthectomy for benign paroxysmal positional vertigo (BPPV), facial nerve decompression and endolymphatic hydrops[30].

The utilization of lasers in middle ear surgery exemplifies the sophisticated application of laser technology. In the late 1970s, Perkins pioneered the introduction of the Argon laser to middle ear surgery and conducted the inaugural laser stapedotomy for otosclerosis. Surgical correction can address the mechanical causes of hearing loss[31,32]. The Argon laser has proven beneficial for patients with otosclerosis by precisely vaporizing the stapedial tendon, mobilizing the posterior crus of the stapes, and fenestrating the stapes footplate. This procedure, known as stapedectomy or stapedotomy, aims to restore ossicular chain mobility and reduce conductive hearing loss. A comprehensive understanding of the middle ear anatomy is crucial for achieving post-operative success with minimal complications, emphasizing the standard of care to avoid injury to the facial nerve and the chorda tympani nerve[30,32-39].

Laser Eustachian tuboplasty

Eustachian tube dysfunction is a prevalent ear disorder that can result in chronic recurrent ear infections or difficulties in clearing a blocked sensation in the middle ear. One approach to address this issue is laser myringotomy, aiding in equalizing pressures between the middle and outer ear and facilitating fluid drainage[40-45]. However, it is important to note that this method is notably more expensive. Another technique, Laser Eustachian Tuboplasty (LETP), involves using a diode or Argon laser to vaporize specific areas of hypertrophic mucosa and submucosal tissue along the length of the Eustachian tube. Although there are limited studies with small patient numbers, combining medical management with LETP for a select group of patients has shown promise in successfully eliminating chronic middle ear effusions[46-48].

CO2 laser use in acoustic neuroma surgery

In acoustic neuroma surgery, the CO2 laser has demonstrated advantages owing to its precision in cutting and coagulating around the facial and vestibular nerves[49]. While KTP and Argon lasers have been mentioned for acoustic neuroma excisions, their usage is not widespread[50,51]. The application of lasers is influenced by several factors such as tumor size, the chosen approach to the lesion, and the surgeon's expertise. For smaller tumors (approximately 2–3 cm), stereotactic radiation is beneficial in preventing further mass growth while preserving facial nerve function and hearing[30].

Laser use in endolymphatic hydrops

Laser applications in endolymphatic hydrops[52] and labyrinthectomy for benign paroxysmal positional vertigo (BPPV) have been described, but their adoption remains limited due to the potential risk of hearing loss compared to traditional surgery[53-56]. On the other hand, successful laser use in facial nerve decompression has been reported[56].

LASER TREATMENT IN RHINOPHYMA

In the early stages, treatments often relied on the Argon laser, allowing selective coagulation of capillaries but presenting challenges in predicting tissue destruction depth[57].

CO2 laser treatment offers the capability to both cut and vaporize skin. Operating at a 10600 nm wavelength, primarily absorbed by water, it allows for more controlled penetration depth, reaching up to 0.5 mm beyond the visibly burned layer. The laser eliminates sebaceous glands, and expressed sebum serves as a surrogate depth marker during surgery. Notably, the use of the CO2 laser requires less thermal energy than electrocautery and electrosurgery, ensuring a bloodless surgical field, simple postoperative care, and a low risk of scarring. Surgeons can combine the CO2 laser with "bulk scalpel removal for precise contouring", and initial scalpel reduction provides tissue for histopathologic assessment. However, drawbacks include hypopigmentation, dilated pores, high equipment cost, and an extended procedure time, with complete re-epithelialization taking approximately three weeks[58,59].

The Er:YAG (erbium-doped yttrium aluminium garnet) laser, operating at the ideal wavelength of "2940 nm for water absorption", offers a smaller heat damage zone (less than 50 micrometres) and quicker re-epithelialization in 1 to 2 weeks. However, it provides minimal hemostasis[60].

Other lasers with successful track records include "the diode laser (808 nm), Nd:YAG laser (1064 nm), and KTP laser (532 micrometres)"[57].

LASER FOR SKIN REJUVENATION

Excessive heat transfer to the dermis may lead to unwanted outcomes like scarring and lasting hypopigmentation. To reduce this risk, the laser beam's contact time with the skin (pulse duration) should be kept shorter than the time required for the treated area to cool back to its normal temperature (tissue thermal relaxation time)[61-63]. Initially, CO2 laser resurfacing involved continuous-wave CO2 lasers, providing limited control over the duration of contact between the laser beam and the skin. However, the introduction of high-energy pulsed CO2 lasers (with a pulse duration less than 1 ms) and short-pulsed Er:YAG lasers (with a pulse duration of 250 to 350 microseconds) enabled the delivery of sufficient energy for ablation while ensuring precise control over the duration of light delivery, thereby reducing the risk of inadvertent damage. Rapidly scanning CO2 lasers employ a computerized scanning

mechanism to restrict the duration of contact between the laser beam and specific skin sites, offering an alternative to pulsed devices[63].

CHOICE OF LASER

Concerning the selection of lasers, the effectiveness comparison between traditional and fractional ablative lasers remains inconclusive. The standard CO2 laser seems to have a more noticeable impact on remodelling dermal collagen in comparison to traditional Er:YAG lasers, leading to observable skin tightening in cases of lax skin[64,65]. Nonetheless, the decreased use of the CO2 laser is attributed to its higher risk of adverse effects, including scarring, dyspigmentation, and prolonged erythema, as well as a lengthier recovery period compared to fractional lasers[66].

The widely acknowledged effectiveness of cutaneous rejuvenation through skin resurfacing with traditional ablative lasers is supported by existing literature. Nevertheless, the available data on efficacy predominantly stem from uncontrolled studies and a restricted number of small randomized comparison trials. Additionally, the evaluation methods employed to assess treatment responses have been inconsistent and frequently poorly defined[63].

CONCLUSIONS

Carbon dioxide lasers, Er:YAG lasers, photoangiolytic lasers like KTP and PDL may be used in head and neck surgical procedures and facial rejuvenation in appropriate cases.

Financial disclosure: There are no financial disclosures of the author.

Funding: None.

Ethical approval: There was no need to take Ethical approval, because this is a review paper.

Informed consent: There was no need to take informed consent, because this is a review paper

Conflicts of interest: The author Nuray Bayar Muluk declares that she has no conflicts of interest.

Contribution of authors: Nuray Bayar Muluk: Planning, designing, literature survey, evaluation of literature search, writing, submission

Availability of data and materials: All data for this study is presented in this paper.

Acknowledgments: None

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