DOI: 10.2478/rjr-2025-0003

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

LITERATURE REVIEW

The Blue Light LASER technology: a new progress in ENT surgery

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ABSTRACT

The advent of Blue LASER technology in otorhinolaryngology has transformed the management of various ear, nose and throat (ENT) disorders. Its distinct wavelength (445 nm) offers superior tissue selectivity, minimizing collateral damage and optimizing surgical outcomes compared to traditional LASERs. Blue Light LASER's ability to target haemoglobin and melanin reduces intraoperative bleeding, scarring, and thermal damage. Its precision and versatility make it a valuable tool in addressing complex ENT pathologies. However, limitations, such as shallow penetration and potential risks of thermal damage, necessitate careful application. While it requires specialized training and consideration of its limitations, its benefits in reducing complications and improving recovery times highlight its potential in modern surgical practices. The article aims to analyse the key characteristics of Blue LASER in ENT pathology, presenting also a case of a 57-year-old male with lingual tonsil hypertrophy and obstructive sleep apnea who underwent Blue LASER surgery for tongue base reduction.

CONCLUSION. Blue LASER technology ushers in a new era in ENT surgery. However, a thorough evaluation of its benefits and limitations is crucial to fully harness its potential in clinical applications.

KEYWORDS: Blue LASER, otorhinolaryngology, surgery, LASER, larynx, photocoagulation.

INTRODUCTION

The surgical approach of patients with a variety of ear, nose and throat disorders has been revolutionized by the introduction of LASER (Light Amplification by Stimulated Emission of Radiation) surgeries. The evolution of LASER technology has had a significant impact on multiple medical fields, including ENT surgery. Due to its precision, safety, and ability to minimize damage to adjacent tissues, LASER has become an indispensable tool in managing complex conditions in this domain. Clinical applications of LASERs range from surgical treatments for benign or malignant conditions of the upper airway to aesthetic or functional corrections[1].

Several types of LASERs are used in ENT surgery, each with specific characteristics and applications. These include CO2 LASER, KTP (Potassium Titanyl Phosphate), PDL (Pulse Dye Laser) and last but not least, Blue Light LASER. Comparing these types of LASERs is essential to understanding their benefits and limitations and selecting the most suitable technology for the patient's specific needs[2].

Commencing with the utilization of the CO2 LASER, which possesses a wavelength of 10,600 nm and is well known for its cutting and excisions properties, continuing with the photoangiolytic LASERs such as the potassium titanyl phosphate (KTP) LASER, with a wavelength of 532 nm, and the pulsed dye LASER (PDL), with a wavelength of 582 nm, used in particular for vascular lesions, the evolving technology has taken a further step to a new generation of photoangiolytic LASERs: the Blue LASER, with a wavelength of 445 nm[3].

The differences regarding tissue absorptions are characterized based on wavelengths of the above-

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Received for publication: November 9, 2024 / **Accepted:** December 18, 2024

mentioned LASERs. Therefore, the CO2 LASER (10,600 nm) is known for its highest water affinity, leading to an undifferentiated deterioration of tissues, while the Blue LASER (445 nm) possesses a higher tissue selectivity, being especially utilized in pigmentation and vascular lesions, protecting the prompt tissues and reducing the appearance of scars[4]. KTP (532 nm) and PDL (582 nm) LASERs have a similar relapse rate as the Blue LASER; however, the postoperative bleeding risk is higher after using the first two mentioned[5,6].

The utility of the Blue LASER in the treatment of various pathologies must be addressed. Beginning with hypertrophy of lingual tonsil, vocal fold varicosities and ectasias[3,7], vocal fold polyps[7,8], cysts, Reinke's edema[9] and other exudative lesions of the vocal folds, continuing with lesions with high recurrence rates, such as laryngeal granuloma, recurrent respiratory papilloma or more complex diseases, for example, laryngotracheal stenosis, the LASER therapy has demonstrated its vast addressability[3]. Although its primary use worldwide is in the field of laryngology, the Blue LASER is also employed in rhinology, addressing inflammatory pathology of the inferior nasal turbinates and recurrent epistaxis[10,11]. In otology, procedures like stapedotomy or myringotomy are performed using CO2 and diode LASERs for their high precision[12]. For the oral cavity and oropharynx, CO2 and diode LASERs are preferred for benign and malignant tumors, providing improved haemostasis and faster recovery[1].

This article aims to analyze the key characteristics of some types of LASERs. This comparative approach will provide a clear perspective on LASER technology's role in optimizing ENT surgical treatments.

FUNCTIONAL CHARACTERISTICS OF THE BLUE LASER

The main characteristic of the Blue Light LASER is its capacity to be absorbed in haemoglobin, pigment and melanin, which leads to lower power density needed for obtaining similar or superior results, compared to the other photoangiolytic LASERs and the Diode LASER[3]. Due to its small tissue penetration (attributable to the Blue LASER's shorter wavelength) and the minimization of thermal stress and necrosis in adjacent tissues, its efficacy has been proven in the treatment of various pathologies, while also preserving the integrity of the underlying and adjacent tissue[13]. The precision and minimal thermal spread of the Blue LASER can result in fewer postoperative complications, such as scarring or impaired function, which may be particularly beneficial when used on sensitive structures like the vocal cords[14].

In addition, the Blue LASER allows the surgeon to adjust the power based on the intended use: a higher power is necessary for cutting, while a lower one can be used on vessels[1]. This dual functionality reduces intraoperative bleeding and shortens procedure times[8].

Moreover, the Blue LASER can be used in both contact and non-contact modes. While used in contact mode, a more precise incision and dissection of soft tissue is ensured, which is particularly helpful in laryngeal and pharyngeal surgeries[15]. Surgeons have greater control over tissue manipulation due to tactile feedback during procedures. The non-contact or near-contact mode is crucial to prevent excessive thermal damage while still achieving the desired outcome[3].

However, despite their advantages, they come with certain disadvantages that should be considered when choosing the surgical tools. Blue LASERs have a shallow penetration depth due to their shorter wavelength. While this is advantageous for precision, it may limit their effectiveness in cases requiring deeper tissue dissection or ablation[15]. The strong absorption of blue light by haemoglobin and other chromophores can increase the risk of thermal damage to surrounding tissues if not carefully controlled, during prolonged use in contact mode, even though it has the least thermal impact compared to the other LASERs[16]. The high-intensity blue light poses a risk to the surgeon's and staff's eyes if appropriate protective measures are not taken. Moreover, the scattering of blue light can create a glare, complicating visualization during surgery[17].

BLUE LASER SURGERY IN LARYNGOLOGY

In laryngology, LASERs such as CO2, KTP and, more recently, the Blue LASER, are used for the treatment of benign and malignant lesions (Tis, T1, T2). The Blue LASER combines photoangiolytic and cutting properties, making it a viable alternative to KTP[15].

The Blue LASER, the latest technological innovation, is characterized by its ability to selectively target and damage pigmented/vascular lesions, resulting in fewer postoperative scars compared to other types of LASERs[4]. It is highly effective in targeting vascular structures while protecting healthy tissues. The CO2 LASER has a high affinity for water and indiscriminately damages tissues. KTP and PDL LASERs have a higher postoperative bleeding risk and similar recurrence rates. The CO2 LASER is the most appropriate for deep and precise incisions; however, the KTP and Blue LASERs provide superior results for the superficial evaporation of lesions[18].

One study conducted by R. Jun Lin et al.[4] shows that the treatment with the Blue Light LASER causes less scarring of the vocal folds compared to the KTP LASER, making it a promising alternative for laryngeal treatments. The study group consisted of 24 Sprague-Dawley rats with normal vocal folds (randomly assigned to the KTP group or Blue LASER group) and 3 served as negative controls. The harvested tissues were histopathologically analysed from the point of view of submucosal inflammation and subepithelial protein deposition/ fibrosis (scarring). Both LASERs produced significant scarring compared to the control group (KTP: 2.67±0.29; BL: 2±0; control: 1.17±0.29; $p < .05$). Still, the KTP LASER (set at 10W, 15 ms pulse width, 2 pulses/second) led to a higher degree of fibrosis, observed as early as day 30 postoperatively ($p = .016$), while for the Blue LASER (set at 2W, 10 ms pulse width, 300 ms pulse-pause duration), these signs appeared only at 90 days. The Blue LASER has a shorter wavelength, allowing greater absorption of haemoglobin, melanin, and collagen, but lower absorption of water, thereby reducing the risk of thermal damage to normal tissues. It can produce effects similar to KTP at lower power settings, which reduces the risk of thermal injury. Inflammation associated with Blue LASER treatment was more intense immediately after treatment (day 1) (compared to KTP group: $p = .023$; compared to control: $p = .008$), but resolved more quickly than with KTP. The Blue LASER may have antibacterial properties, offering additional clinical benefits[4].

Another scientific article by González-Herranz et al.[19] analyzes the use of the Blue LASER (445nm) for treating laryngeal pathologies through flexible transoral surgery. The study included 47 patients, and its objective was to investigate the safety, efficacy, and clinical applications of this type of LASER in laryngeal treatments, both in-office and in the operating room. The results showed that most lesions were successfully treated (95.75% of patients with resolution of the laryngeal pathology, 4.25% with an evident decrease in the lesion), and 54% of cases were managed exclusively in the office. Thus, it can be concluded that the efficacy is high. The LASER was used for both complex lesions (subglottic stenosis) and simpler lesions (polyps, Reinke's edema), making it extremely versatile. No significant complications directly associated with its use were observed, which highlights its safety. The transition of interventions from the operating room to the office shortened procedural times and reduced hospitalization duration, simplifying patient management. Patients with complex pathologies (e.g., subglottic stenosis, laryngeal papillomatosis, granulomas) required multiple sessions (an average of three), but the outcomes were satisfactory and durable. The authors report an average number of LASER sessions of 2.1 (range of 1-4).

These findings are further validated by Campos et al.[20], who evaluated the applicability and efficacy of the Blue LASER in treating upper aerodigestive tract pathologies using flexible transoral surgical techniques, focusing on functional outcomes and safety. Regarding laryngotracheal stenosis (12 patients), significant improvements in respiratory space were reported in all cases, both from the stenosis area (ranging between 39% and 1200%) and length (60% in one patient, 100% in 4 patients) point of view. In papillomatosis (7 patients), the average intervention rate per patient was 2.7 (range 1-6), with complete recovery of vibratory epithelial function observed by stroboscopy, without scars. For dysplasia and carcinoma (5 patients), lesion control was achieved by selective vaporization, but with recurrences in 2 cases. In the area of phonosurgery (11 patients), the authors reported excellent results, with recovery of the vibratory activity of the vocal cords during stroboscopy. Moreover, with the help of this type of LASER, pre-epiglottic cysts (1 patient) can be excised and arytenoidectomy (2 patients) can be performed with satisfactory anatomical and functional results.

The impact of the blue LASER on the chorioallantoic membrane vasculature of chicken embryos and its implications for microlaryngeal surgery have been studied by Nguyen et al.[21]. The inquiry analyzes the optimal laser settings for vascular ablation. The most effective working distance, with the lowest risk of vascular rupture, was found to be 3 mm. It was also noted that working distance and pulse duration have a significant impact on the results. Due to the greater exposure area and longer interaction time at 3 mm, visible thermal impacts on tissues are more noticeable. These effects are lessened at 1 mm, making it more suitable for sensitive procedures.

Balouch et al.[5] conducted a study on 31 subjects diagnosed with vascular lesions of the vocal folds, in which the Blue LASER was used in pulsed mode at low power densities (3-4 W). They found that it was less effective in preventing recurrence of vascular lesions on the vocal folds compared to the KTP LASER. However, postoperative edema and haemorrhage were less severe in patients treated with the Blue LASER, indicating reduced thermal trauma. In patients operated on with the KTP LASER, at postoperative follow-up visits one and two, there was a significantly higher generalized edema, while after the Blue LASER, a localized edema was observed at the same follow-up periods. Postoperative haemorrhage was less significant after the Blue LASER compared with the KTP LASER (first visit: 1.79±0.54 versus 2.26±0.83; second visit: 1.59±0.48 versus 1.98±0.72). The recurrence of lesion vascularization was significantly more frequent with the Blue LASER (24.07% compared to 6% with the KTP LASER), suggesting a limitation in achieving complete vessel coagulation at the low power densities used. This may restrict its use for recurrent or complex vascular lesions.

The blue LASER also provides a viable solution for oncological conditions, such as early glottic carcinoma (Tis, T1, T2), replacing KTP while maintaining high standards of oncological and functional efficiency[14,20]. In the study of Rosow et al.[14] published in 2024, the survival rates, local control and laryngeal preservation were similar between the group treated with the Blue LASER (BL) and the group treated with the KTP LASER (95.9% for BL and 100% for KTP; 93.9% for BL and 92.1% for KTP); 98% for BL and 95.6% for KTP), indicating that the first one can be successfully used in the treatment of early glottic carcinoma. Both LASERs led to significant improvements in subjective voice parameters (Consensus Auditory-Perceptual Evaluation of Voice score – $p = 0.04$ for BL, $p = 0.006$ for KTP; Voice Handicap Index-10 score – $p = 0.003$ for BL, $p < 0.00001$ for KTP), suggesting that the use of the Blue LASER is beneficial for preserving the vocal function. No significant differences were observed in objective voice parameters (Cepstral Spectral Index of Dysphonia)[14].

Several studies[7,22-24] indicate that the Blue LASER is easy and safe to use, even in an ENT office setting, without requiring hospitalization. It is a safe and effective technique for treating benign and premalignant vocal fold lesions.

Blue LASER therapy provides excellent outcomes for vocal polyps and Reinke's edema, with high rates of complete or partial disease regression reported by Hamdan et al.[22] in 2024 (vocal polyps: 76.5% complete regression, 23.5% partial regression; Reinke's edema: 33% complete regression, 67% partial regression; the best results were achieved for less severe lesions). Patients also reported a significant reduction in the impact of the disease on their quality of life, as reflected by decreased VHI-10 scores (from 21.24±7.56 to 3.88±4.13 for polyps, $p < 0.001$, and from 20±10.04 to 2.5±3.81 for Reinke's edema, $p < 0.001$). In terms of acoustic analysis and aerodynamics measures, in the polyps' group, there was a significant decrease in shimmer ($p = 0.028$) and a significant increase in maximum phonation time ($p = 0.12$) after Blue LASER therapy, while in the Reinke's edema group, a significant decrease in both shimmer ($p = 0.035$) and noise-to-harmonic ratio ($p = 0.020$) were reported after surgery. The procedure was well-tolerated, with no major complications reported. Performing the procedure in an office setting eliminates the risks associated with general anaesthesia and shortens recovery time[22].

Another study[23] highlights the effectiveness of Blue LASER therapy in reducing dyspnea and the risk of obstructive sleep apnea in patients with type 3 Reinke's edema. Ten patients, all smokers, were examined and underwent surgical intervention. The blue LASER was used transnasally, under endoscopic guidance. Blue LASER therapy significantly reduced the severity of dyspnea (DSI score decreased from 16.1±10.2 to 2.3±2.3 after therapy, $p < 0.001$) and lowered the risk of apnea (STOP-BANG score dropped from 4.8±1.47 to 3.1±1.28, $p = 0.001$). Significant respiratory improvements were also reported, indicating that type 3 Reinke's edema considerably contributes to upper airway obstruction. Furthermore, marked improvements in dysphonia were noted (VHI-10 score significantly decreased from 22.7±7.0 to 4.4±5.6, $p < 0.001$). The procedure was well-tolerated, with no reported complications.

An additional research article[24] compares Blue LASER therapy (10 patients, 17 lesions) with Thulium LASER therapy (12 patients, 22 lesions) for treating Reinke's edema in an office setting, focusing on voice quality and disease regression. The study found that both provide equivalent results, indicating that they can be used interchangeably. There were no significant differences between the two types of lasers in terms of VHI-10 score reduction ($p = 0.657$) or illness regression ($p = 0.455$).

The Blue LASER is a versatile, safe, and effective tool in laryngeal surgery, integrating both photoangiolytic and cutting capabilities into a single device. It delivers performance comparable to or even superior to other LASERs, such as KTP, in terms of precision and efficiency[15].

BLUE LASER SURGERY IN RHINOLOGY

Most studies have been conducted in laryngology, focusing on the indications, advantages, disadvantages, complications, and efficiency of the Blue LASER compared to other types of LASERs. However, there are a few studies[2,10-12] that have also explored its properties in rhinology, otology, and even in rheumatological conditions with implications in the ENT sphere.

In 2024, Hamdan et al.[10] conducted a retrospective study on a cohort of 14 patients who underwent turbinate reduction using the Blue LASER. The degree of nasal obstruction improvement was assessed subjectively using the Nasal Obstruction Symptom Evaluation (NOSE) score and the Visual Analog Scale (VAS). The procedure was performed under local anaesthesia, employing the laser in non-contact, close-contact, and full-contact modes to address different tissue layers. The study results demonstrated significant improvement in nasal obstruction symptoms, as confirmed by decreased NOSE scores (13.07±3.89 preoperatively to 2.64±2.43 postoperatively, $p = 0.002$) and VAS scores (7.43±0.85 preoperatively to 2.0±1.57 postoperatively, $p = 0.002$). During the procedure, the LASER minimized damage to surrounding tissues and epithelium, thereby reducing the risk of necrosis or severe inflammation. The procedure was well-tolerated by patients (an average VAS level of comfort during surgery of 7.59±1.34, range from 6 to 9), with no complications reported. The high comfort level suggests that the intervention is suitable for use in outpatient clinics without requiring general anaesthesia. However, there are some technical limitations. The LASER's limited penetration depth (1 mm at low power and 3-4 mm at high power) can be a disadvantage for treating deeper tissues in the inferior turbinates. Additionally, energy scattering, which varies based on divergence angle and tissue distance, may affect the uniformity of treatment. The outcomes were comparable to other turbinate reduction methods (KTP, diode, and CO_2 LASERs), but the Blue LASER offers the advantage of precision combined with minimal tissue trauma. However, it is important to note that the evaluation was based solely on subjective measures. The absence of objective assessments, such as rhinomanometry, limits the ability to evaluate anatomical improvements.

The use of LASERs in the treatment of epistaxis caused by hereditary haemorrhagic telangiectasia (Osler-Weber-Rendu syndrome) is a safe and effective method, especially when the appropriate LASER type is selected based on the severity of the lesion[2,11,25]. Argon and Nd:YAG LASERs have proven to be more effective than Diode LASERs in reducing the frequency and intensity of epistaxis[2]. The Nd:YAG LASER, with its deeper penetration (1064 nm), is suitable for severe and extensive lesions. The Argon LASER is highly effective in mild-to-moderate cases due to its selective absorption in haemoglobin and precise thermal control. The Diode LASER can be used when other options are unavailable or in cases with low severity[2]. Laser photocoagulation as a treatment of HHT-related epistaxis proved to be safe regarding the postoperative possible complications. Multiple studies report no postoperative complications in all three types of LASERs[26-28].

Currently, there are not enough studies comparing the Blue LASER with other types of LASERs in terms of effectiveness in controlling epistaxis associated with this condition. Several articles found in the literature demonstrate that the Blue LASER therapy is also a safe and effective method for managing epistaxis associated with hereditary haemorrhagic telangiectasia (HHT) due to its high specificity for haemoglobin, which minimizes damage to surrounding tissues and reduces the side effects associated with other types of LASERs[11,25]. In a study published in 2021, Bertlich et al.[11] evaluated the safety and efficacy of Blue LASER therapy in HHT by analysing the charts of patients who received LASER treatment over a 1-year period and compared the results of bipolar to Blue LASER coagulation of vessels in the thyroid gland lobes of guinea pigs. The patients' quality of life increased significantly after Blue LASER therapy, with an initial VAS score of 5.6±0.5 and a VAS score of 7.5±0.9 after the third session. No side effects were noted, such as infections, septal perforation, bleeding or crusting. The animal experiment revealed a significant difference in both depth and area of coagulation damage between Blue LASER and bipolar coagulation ($p < 0.001$). In a four-year retrospective chart analysis, Kashani et al.[25] showed the efficacy of Blue LASER therapy in the stabilization of haemoglobin levels in patients with HHT-related epistaxis, in the improvement of patients' quality of life and epistaxis severity score. However, this cauterization method has certain limitations: although the Blue LASER reduces epistaxis in the short term, the effects are temporary, requiring repeated treatment sessions to maintain results.

BLUE LASER SURGERY IN OTOLOGY

The medical literature describes a clinical case[12] of a left tympanic paraganglioma classified as Fisch A2, which was completely excised by combining the Blue LASER with traditional otologic surgical techniques. The article highlights the safety and efficacy of this technology in minimally invasive surgery for vascular lesions of the middle ear, emphasizing its advantages in reducing intraoperative bleeding and protecting adjacent tissues. The tumor was completely excised without affecting the surrounding tissues. The compact size of the laser fiber (300 μm) facilitated access to narrow anatomical areas (the middle ear), and the portability of the equipment contributed to a simpler and

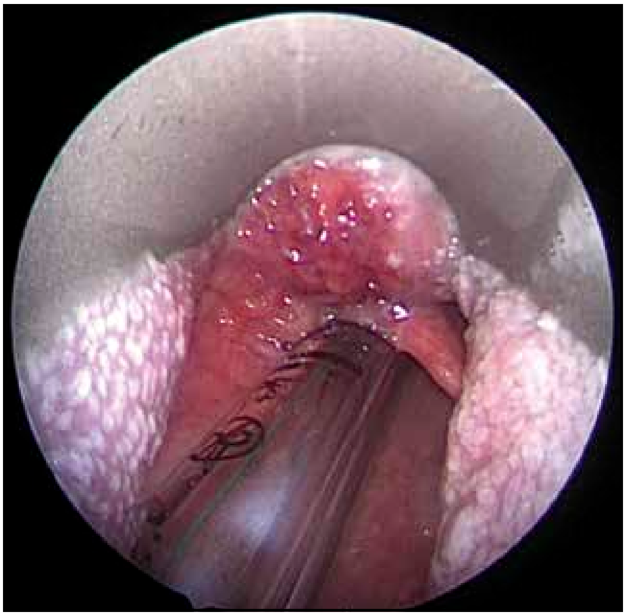

Figure 1. Endoscopic intraoperative view of the hypertrophy of the lingual tonsil.

Figure 2. Intraoperative view of the process of lingual tonsil reduction surgery performed with the Blue LASER.

shorter procedure (42 minutes). No intraoperative or postoperative complications were reported, and the functional outcome was excellent, with improved hearing.

OUR EXPERIENCE

We are the first ENT Department in Romania to integrate the innovative Blue LASER technology into medical practice, opening new perspectives for effective and minimally invasive treatments.

A 57-year-old male patient was referred to our ENT Department at "Sfanta Maria" Hospital for obstructive sleep apnea syndrome. The patient was previously evaluated by nocturnal respiratory polygraphy, which revealed a severe obstructive sleep apnea (AHI = 56.7/h), and has been using a continuous positive airway pressure (CPAP) machine for two months. Clinical examination showed a body mass index of 30.56. Lung and cardiac radiographic evaluations did not show any pulmonary disorders, and his laboratory tests were within normal limits. ENT clinical examination and flexible nasopharyngolaryngoendoscopy revealed hypertrophy of the lingual tonsils, along with an atonic soft palate, hypertrophic uvula and macroglossia.

Based on these findings, it was decided to proceed with the reduction of the lingual tonsil hypertrophy using Blue LASER through suspension microlaryngoscopy. The procedure was performed under general anaesthesia. A blue LASER fiber (400 μm, pulsed mode, 0.62 W, 0 mJ) was introduced into the operative channel alongside a rigid endoscope and, after obtaining good visualization of the operatory field (Figure 1), volume reduction of the lingual tonsil was performed (Figure 2). At the end of the procedure, the endoscopic image revealed a reduction in the size of the lingual tonsil, with no signs of active bleeding (Figure 3).

The patient was discharged 24 hours after clinical observation. During hospitalization, the patient did not report any pain, nor were there any signs

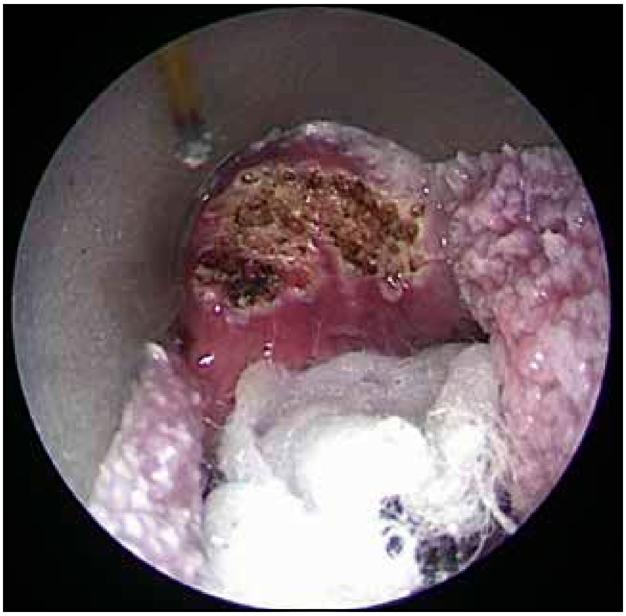

Figure 3. Intraoperative view of the lingual tonsil area immediately after reduction surgery with Blue LASER.

of laryngeal edema, bleeding or difficulty in swallowing. Postoperative recovery was rapid, with no pain or edema observed.

At the 1-month postoperative follow-up, the lingual tonsil was observed to be significantly reduced in size compared to the previous examination. The patient will undergo nocturnal ventilatory polygraphy to establish a new AHI.

CONCLUSIONS

The introduction of Blue LASER technology represents a significant advancement in the field of ENT surgery, offering both precision and selectivity for the treatment of various disorders. Its ability to target specific tissue types with minimal collateral damage, especially in vascular and pigmentation-based lesions, has broadened its application in complex procedures. As demonstrated in the case of lingual tonsil hypertrophy, the Blue LASER facilitates effective tissue reduction while minimizing postoperative complications, such as bleeding and scarring.

However, the use of Blue LASER also comes with certain limitations. Its shallow tissue penetration, while advantageous for precision, may reduce its effectiveness in deeper tissue ablation. The risk of thermal damage to adjacent structures, specialized training requirements, and high equipment costs are additional factors that surgeons must consider.

Despite these challenges, when utilized by well-trained professionals, Blue LASER can greatly enhance surgical outcomes.

In conclusion, Blue LASER technology marks a new era in ENT surgery, but carefully considering its advantages and limitations is essential to maximize its potential in clinical practice.

Funding: None.

Financial disclosure: There are no financial disclosures.

Conflict of interest: The authors have no conflicts of interest.

Contribution of authors: The authors have equal contributions to the article documentation and writing.

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