Laser nasal surgery (Review)

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Abstract. Laser nasal surgery has been an elusive subject in the last 10 to 15 years It was considered as a potential surgical staple for nasal surgery in the 1980s; however, it did not become one due to technical difficulties. Laser therapy has reemerged as an alternative to classical endoscopic surgery, and otorhinolaryngology surgeons are considering the benefits that it can offer. The advantages of this procedure are shorter hospitalization time, lack of nasal packing, high procedural precision with tissue sparing, and the unique capability of reducing both bacterial and fungal colonization at the level of the paranasal sinus. Therefore, laser therapy appears to be an invaluable tool for clinical practice. Due to the absence of a guaranteed cure for reoccurring nasal polyposis, laser therapy is worth investigating. For this therapy to evolve, an improved understanding of laser types and the effects that they produce is required. By investing in further developments of the equipment, the technique may become more widely used. With the current accelerated rate of technological evolution and robotic capabilities, laser nasal surgery may become a gold standard in future years. The aim of the present review is to evaluate whether it is worth investing in nasal laser surgery as a future alternative to current treatment standards.

Contents

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Abbreviations: ESS, endoscopic sinus surgery; CRS, chronic rhinosinusitis; CRSwNP, chronic rhinosinusitis with nasal polyps; YAG, yttrium aluminum garnet; Nd:YAG, neodymium-doped YAG; Er:YAG, erbium-doped YAG

Key words: laser, CRS, nasal polyps, quality of life, surgery

1. Introduction

Despite the improved outcomes of endoscopic sinus surgery (ESS) and biological therapy, numerous shortcomings remain (1). Nasal laser surgery was first proposed in 1982 with promising results (2). In the early 2000s, it continued to improve, consolidating into a modern technique (3). However, due to the lack of proper directional aiming of the laser beam, it entered a period of decline. At present, nasal laser use is reappearing as a treatment option along with improvements in technology (4).

Laser is an acronym for light amplification by stimulated emission of radiation, which originally described the process; however, it is currently used to describe both the light fascicle and the apparatus (5).

Chronic rhinosinusitis (CRS) with nasal polyps (CRSwNP) is presented in ancient texts dating back almost 4,000 years; however, it is still a pathology that is not fully understood and does not have a definitive therapeutic option (5). Currently, the most used treatment options are intranasal corticosteroids and ESS, with a high recurrence rate due to the preponderance of atopic origin in the majority of nasal polyp cases (1). With the advances in understanding CRS endotypes, type 2 (which is based on eosinophil activity) has been demonstrated to be the most common cause of nasal polyposis (6). Almost 80% of these cases present a high degree of recurrence due to ongoing immunological processes (6).

Nasal laser surgery may be useful in certain cases due to the added benefit of cauterizing and cutting at the same time, aiding in hemostasis. Due to these properties, day surgery may be achieved for patients who would normally undergo continuous hospitalization, thus reducing the hospital stay considerably, and also providing a financial gain for both the patient and the healthcare system (7).

A unique aspect of laser surgery is the ability to sterilize the exposed area. This quality is useful in a confined space such as the nasal sinus pathway, which is covered with a mucosa colonized with bacteria and fungi (8). These microorganisms can inhibit healing and maintain a blockage of the nasal drainage system by sustaining inflammation and affecting cilia movement (8).

The aim of the present review is to evaluate if laser technology is a viable option for nasal surgery and whether it is associated with improved patient outcomes in order to determine if future investments in equipment are worth the financial and research effort. Although laser treatment options for nasal pathologies have not seen major advancements in the last two decades, with the aid of certain technical improvements, they may still emerge as superior to the currently used techniques in treating various nasal pathologies.

2. Methods

A non-systematic search was performed using the PubMed (MEDLINE) (https://pubmed.ncbi.nlm.nih.gov/) and Embase (https://www.embase.com/) databases with the following medical subject headings terms: 'Nasal polyp', 'polyposis', 'laser', 'surgery' and 'endoscopic'.

The search results yielded 130 original and review articles in the PubMed database, and 77 in the Embase database. Duplicates were removed, resulting in 131 original and review articles.

The selection process was performed by two independent authors based on the inclusion and exclusion criteria. For the inclusion criteria to be met, articles needed to define and mention at least one of the following surgical procedures: Sinus surgery, nasal septum surgery, turbinate procedures or lacrimal sac procedures. In addition, articles needed to define how the procedural benefits were evaluated, if the impact of the surgical procedure on the quality of life had been surveyed and for the results of the surveys to be clearly explained. Articles referring to other pathologies or those presenting irrelevant techniques for the subject were eliminated throughout the selection process. As a first step, article and review titles and abstracts were screened. If no information on the topic was mentioned, the article was discarded. Full-text analysis was performed for the remaining articles. Finally, 49 articles were included in the present review.

Articles selected for the present review described the effect of surgical laser, implementation in otorhinolaryngology, quality of life assessment, endoscopic and robotic surgery, and CRSwNP. The surgical and scholarly expertise of the authors was used to compile and create a comprehensive review.

3. Laser types used in surgery

Laser technologies are used in a wide spectrum of pathologies. Continuous wave argon, CO_2 and yttrium aluminum garnet (YAG) lasers are paving the way for improved surgical outcomes. Their main usage in surgery is due to their unique properties of being able to cut and coagulate at the same time (9). Further advancements are now aiding the technology to become more selective in differentiating tissue absorption and minimizing thermal damage while targeting only the desired structures (9). The lasers used in the medical field have a wavelength between the ultraviolet and infrared spectra, with the YAG laser having a wavelength between 1,000 and 3,000 nm, and the CO_2 laser having a wavelength of 10,600 nm. The most important properties of a laser are that the emitted light is monochromatic, coherent and collimated. These characteristics help lasers perform with a high grade of precision and high energy delivery (10). Currently, laser technologies with shorter wavelengths are less used in clinical practice due to the lesser penetration power and dispersed energy delivery (10).

When the laser interacts with the tissue, there are four scenarios that can occur: i) Through reflection, the incident laser light returns to the same medium; ii) by transmission, the incident light passes through the tissue; iii) by scattering, the laser penetrates the surface of the tissue following different paths in a nonlinear manner; or iv) absorption, where the laser transfers the energy that it carries to the tissue, which becomes hot (11). The interaction of a tissue with the laser light during absorption produces three distinct effects: i) Photothermal effect, in which the energy is converted to heat (as aforementioned); ii) photomechanical effect, which produces expansion of the targeted tissue due to high temperature; and iii) photochemical effect, where different chemicals and molecules subjected to the energy of the laser react (10).

To achieve the best results, the apparatus settings should be specifically adjusted for the purpose and use. In a clinical setting, the wavelength should be selected according to the target tissue. The pulse duration should be equal to or shorter than the thermal relaxation time, which is the time needed for the target to dissipate 63% of the heat of the peak temperature. The energy density should be measured in J/cm^2. During surgical use, setting the correct pulse duration influences the outcomes, as the energy also interacts with blood vessels (12). Small blood vessels, with a diameter $\leq 50\ \mu m$, have a thermal relaxation time of <1 msec, while large blood vessels, with a diameter $>50\ \mu m$, have a thermal relaxation time of 20 msec (12).

A solid-state laser uses a solid component as the laser medium. The solid component is usually made from glass and crystalline materials, which can be doped with diverse impurities. Through this process, the power of the laser can be controlled either by amplifying or lowering the wavelength. Some of these impurities are rare earth elements such as terbium, cerium, erbium and neodymium. The most used and researched is the neodymium-doped YAG (Nd:YAG); however, alternatives such as erbium-doped YAG (Er:YAG), holmium-doped YAG, thulium-doped YAG and ytterbium-doped YAG are also utilized in various industries such as research or automotive. All the aforementioned lasers operate at wavelengths between 1.00 and 2.94 μm and have the potential to create diverse effects depending on the settings and the targeted tissue (13). In the future, these variations may be associated with different uses in rhinology and nasal surgery.

4. Comparing laser types

Lasers produce different effects depending on the type of laser. The most common types currently used are diode, Nd:YAG, CO_2 and Er:YAG. All of them are used with two main functions, namely to cut and/or to coagulate (14). This duality may offer an advantage in nasal polyposis surgery due to the confined space and the limited surgical instruments that are in use at present. Cold instruments primarily grasp and pull the tissue but do not cauterize or cut; thus, a more versatile instrument is required. Monteiro *et al* (15) compared the effect of different laser technologies on nasal mucosa and revealed that the least destructive laser was the Er:YAG laser, followed by the Nd:YAG laser. The results of the CO_2 laser were similar to the thermal damage caused by electrosurgical scalpels, yielding the worst overall results.

Another factor to consider for preferential use is the speed at which the laser performs, with the CO_2 laser being the best option (16). Keane and Atkins (17) suggested that the CO_2 laser could be considered for endonasal application, with the generated energy being absorbed by water, producing the thermal cutting and coagulating effects that are required in surgery. It also had a shallow penetration; thus, it could be used efficiently in nasal surgery without producing deep tissue trauma. Its biggest disadvantage was the inability to curve the beam. Mirrors had to be used for execution, thus complicating the technical implementation and raising the end cost.

The YAG laser has been demonstrated to be a superior option for endonasal surgeries, providing good postprocedural healing and superior cauterization compared with the CO_2 laser. With these advantages, applications range from nasal turbinate reduction to dacryocystorhinostomy. Due to these properties, the YAG laser is widely used in endoral tumor resections, where faster healing and good cauterization are paramount. However, the disadvantage of the YAG laser type is the time needed for efficient tissue obliteration (18).

Laser equipment involves a great financial cost, not only for acquisition but also for maintenance. Due to the hard-to-reach spaces in the paranasal sinuses, different adaptors must be used to guide the laser beam, which generates further expenses (19). With time and advancements in technology, improved, smaller and more precise laser devices should be used, helping these techniques to spread faster and to be implemented into clinical practice (20).

5. Novel techniques for nasal polyposis treatment

In the European Position Paper on Rhinosinusitis and Nasal Polyps 2020, CRS was classified as type 2 or non-type 2 polyposis. Type 2 is the most common variant and also the most difficult to treat due to its high recurrence rate and high morbidity (21).

Emerging techniques in the field of biomodulation therapy are achieving full remission of the pathology in certain recurring nasal polyps cases (22). By regularly administrating biological therapies, usually months apart, the underlying immunological disease can be temporarily controlled (23). Some of the approved treatment options are dupilumab, omalizumab and benralizumab, which have been demonstrated to be effective and have been approved by the USA Food and Drug Administration (23).

In a study by Levine (7), 128 patients underwent laser surgery for various endonasal pathologies, varying from turbinate hypertrophy to inverted papillomas. No postoperative hemorrhage or synechia were found after using a potassium titanyl phosphate/Nd:YAG laser. Selkin (24) also reported good results in a study including 250 surgical procedures, with only 1 case having the undesired effect of postoperative bleeding, a few having small incidents, and the majority of patients having no postoperative bleeding or synechia.

Two main problems that arise from this form of treatment are the necessity of a lifelong administration and the high cost of treatment. Cases for biological treatment should be carefully selected considering that the results were only obtained for a type 2 endotype. Until lower treatment costs and a more permanent medical solution are found, the need for improved surgical options remains (25).

A novel technique used in recurring nasal polyposis is reboot surgery. The principle is focused on the removal of the whole mucosal lining from the sinuses during classical ESS. This procedure permits the normal mucosa from the turbinate processes to form and grow the new epithelial lining in the sinuses, thus preventing the recurrence of polypoid structures.

The principles of laser surgeries have the advantage of generating both a focused and a dispersed beam that can quickly cauterize and remove the mucosa, and let it redevelop without the need of physically scraping and detaching the old mucosa using blunt instruments. This technique is not currently in use; however, with further research, it has the potential of becoming a viable surgical option (26).

6. Lasers and biofilms

One of the advantages when using laser technology as an alternative to cold instruments in performing endonasal surgery is the non-requirement of nasal packing after surgery (27).

Zernotti *et al* (27) suggested that the presence of biofilms may contribute to mucosal damage, increase inflammation and initiate hyperplasic processes.

With the use of nasal packing, the avoidance of the formation of *Staphylococcus aureus* biofilms is a difficult task. Biofilms have been identified at 3, 7 and 15 days post-surgery in patients with nasal packing (28). In addition, the discomfort that arises from a packed nose and the minimal risk of packing dislodgement towards the nasopharynx must be taken into consideration (29). By using a laser, both inconveniences can be avoided, with less need for packing after surgery and a higher degree of sterilization of the nose (30,31).

Staphylococcus aureus is present in the nasal and paranasal cavities as a commensal bacterium. Its presence and quantity can amplify the immune-mediated response in pathologies such as CRS. By sterilizing and eradicating biofilms containing *Staphylococcus aureus* from the paranasal spaces, patients suffering from CRS had improved outcomes (32). In CRSwNP, bacterial biofilms have been demonstrated to be internalized by mast cells through the process of phagocytosis. After multiplication within the mast cells, the rupture of the cell wall occurred, and viable bacteria spread back into the extracellular space, leading to biofilm growth (33). Localization of bacteria is determined in both levels of the epidermis, in which the laser fascicle can penetrate, thus achieving its desired effect (34).

Sun *et al* (35) has demonstrated that *Staphylococcus aureus* is not the only pathogen that can cause disease activity, and the presence of coagulase-negative *Staphylococci*, *Streptococcus* *pneumoniae*, *Moraxella catarrhalis*, *Hemophilus influenzae*, *Pseudomonas aeruginosa, Escherichia coli* or *Klebsiella pneumoniae* as commensal and pathogenic bacteria has been proposed as a possible cause of treatment-resistant disease. Laser surgery may become a compelling treatment option, improving results by sterilizing colonies, and clearing the nasal and paranasal mucosa (35).

A study performed by Krespi and Kizhner (36) on 25 patients compared laser alone and laser combined with antibiotics (erythromycin). The laser used was a low-powered, dual-wavelength 870/930 nm, and it had the potential to eradicate MRSA or even reverse the resistance level and re-sensitize the bacterium to erythromycin.

Biener *et al* (37) discussed that laser therapy has shown great potential for inactivating MRSA by altering the transmembrane potential by using 121 J/cm^2, which is a relatively low dose of energy that can be targeted at the human body without creating other undesired negative effects.

A study on conjunctival and lacrimal sac specimens before and after dacryocystorhinostomy, with *Staphylococcus aureus* being the primarily isolated bacterium, revealed a decreased growth rate and a change in antibiotic sensitivity following external, endoscopic and trans-canalicular multidiode laser surgery. These findings may be extrapolated to show the benefits of laser surgery in other nasal and paranasal cavity disorders (38).

7. Laser surgery technique and precautions

Due to the specific nature of the laser as having an open-ended energy source, special care must be taken when using it in an enclosed environment. Specifically, protection of the alar rims and septum should always be considered regarding the patient. Facial and ocular protection is mandatory, and wet towels can be used for this purpose. Wet cotton should also be placed in the nasopharynx, and the intubation tube should be draped with wet towels, so it can be protected from accidental misuse (39). During procedures that use any form of laser in a cavity, suction should always be used to clear the smoke generated and to cool the tissues to prevent further thermal trauma (39).

As a preferred position for endonasal laser surgery, the surgeon should sit at the head of the patient, with the patient in the Trendelenburg position (33). The energy emitted by the laser can cause deeper lesions, thus causing thermal damage to bony structures and leading to osteonecrosis or sequestration of bone fragments (24). When dealing with a potentially malignant tumor, pulse mode should be used rather than the continuous one, so that the specimen is not carbonized (24).

8. Advantages and disadvantages of laser treatment

The benefits of laser surgery in conditions such as CRSwNP remain to be demonstrated along with future advances in technology. In certain situations, the use of laser on the nasal mucosa may be able to eradicate bacterial biofilms, thus ending a vicious cycle of recurring nasal afflictions (40).

Shorter hospitalization time, and possibly enhancing the quality of life of patients, can be considered as key improvements. The quality of care offered by the health system and the advantage of ending the surgery without nasal packing (41), thus reducing the psychological trauma of the patient, offering instant results and preventing bacterial growth should become a future target (42).

The major shortcomings of laser surgery in rhinology are primarily associated with high costs and technical ineffectiveness due to poor guiding technology (43). Due to past failures, doctors can be reserved in re-adapting technologies that did not pass the Gartner hype cycle (43). The costs of purchase can be relatively high, which can be a challenge for numerous hospitals. Besides the laser itself, the specialized equipment and protective gear needed, and the maintenance fees are costly (44).

Due to the tight spaces in which the surgeon needs to manipulate the laser, guiding technologies need to evolve to achieve the level of precision needed to avoid injuries (45).

The CO_2 laser tends to be ~5-fold cheaper than a YAG laser, helping the odds of implementation and experimentation in diverse surgical fields, with proven advantages and disadvantages for different tissues. In the case of nasal surgery, experience from dacryocystorhinostomies and partial resections of the inferior turbinate processes may be a useful starting point for nasal polyp surgeries. However, the need to use different surgical approaches and angles can challenge the surgical team, thus lowering the rate of implementation of this technology (46).

9. Current use of lasers

The usage of a laser with a power between 3 and 7 W has been demonstrated to be a great option for sterilizing intranasal mucosa, resecting tumors and cutting diverse lesions. Due to these advantages, lasers are now used more frequently without traumatizing the underlying tissues, and with improved results in healing and surgical scar forming. Due to the capability of adapting the power of the laser, necrosis of the periosteum and bone can be prevented. Another added benefit of laser surgery is that it only targets the connective tissue, while sparing the epithelial glands (47).

Olszewska *et al* (48) evaluated the effect of the CO_2 laser as a means of producing mucotomy. The evaluation was performed using rhinomanometry and olfactory measurements, and by comparing cytological exams before and 3 months after the procedure. At 3 months following the procedure, histologically, there was a reduction of goblet cells, which were predominant in the cytograms of the patient before the surgery. There was also a reduction in nasal airway resistance and a slight increase in olfactory function after the procedure.

Allergies are the predominant cause of CRSwNP and have become a target for surgical and medical treatments (49). Diode laser surgery has been demonstrated to improve subjective symptoms such as nasal obstruction, rhinorrhea, sneezing, itching and overall satisfaction. Notably, improvements were higher in cases of perennial allergic rhinitis at the beginning of the treatment, but they were more sustained in seasonal allergic cases (43).

In cases of aggressive recurring nasal polyposis, surgical treatment is repeated multiple times during the lifetime of the patient, and the underlying problem is that even in the best conditions, accidental removal of healthy tissue or even whole structures such as the middle and inferior turbinate processes can occur. The most dreaded morbidity that can occur is empty nose syndrome, which does not only alter the flow of air through the nose but is also associated with mental health disorders. Laser surgery can aid in this matter by reducing the number of surgeries due to its longer-lasting effects, and by promoting a more targeted approach with a lower risk of harming normal tissue (50).

10. Conclusion

Laser surgery may be adapted for nasal surgery, including turbinate resections, dacryocystorhinostomies and nasal polyp surgeries, and can improve sinus surgery outcomes. Laser surgery can reduce hospitalization, limit postoperative bleeding and provide an improved quality of life for patients. If further researched, laser surgery may be demonstrated to be beneficial in modulating nasal biofilms, thus potentially benefiting patients with nasal polyposis. The costs of acquisition and maintenance can be a burden for certain medical providers. Therefore, more detailed guidance of the laser beam is necessary to use lasers efficiently and safely in nasal surgery as an alternative to the currently existing technology.

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Authors' contributions

MIT, RGD and MC contributed to the analysis and interpretation of data and made substantial contributions to the design of the study. MIT, AAM, RGD and SSP performed the literature review. MB, CS, AAM and SSP made substantial contributions to the conception and design of the study. AAM, RGD, MC and SSP supervised the present study and revised the manuscript for important intellectual content. Data authentication is not applicable. All authors have read and approved the final manuscript.

Ethics approval and consent to participate

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Competing interests

The authors declare that they have no competing interests.

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