Lasers in Dermatology and Medicine

Dental and Medical Applications

Keyvan Nouri
Editor

Second Edition

Springer

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ISBN 978-3-319-76218-0 ISBN 978-3-319-76220-3 (eBook)
https://doi.org/10.1007/978-3-319-76220-3

Library of Congress Control Number: 2018955703

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Preface

Laser technology is quickly evolving with the presence of newer lasers, along with new indications, that are constantly being introduced. The use of lasers has become a major discipline and is currently practiced in a variety of fields of medicine today. This book offers comprehensive literature covering all the major disciplines in medicine in which lasers are being used such as ophthalmology, cardiology, gynecology, otolaryngology, neurology/neurosurgery, and dentistry. The authors of *Lasers in Dermatology and Medicine* are well known in their respective fields and have attempted to cover each topic in the most comprehensive, readable, and understandable format. Each chapter consists of an introduction and summary boxes in bulleted formats with up-to-date information highlighting the importance of each respective section, enabling the reader to have an easy approach toward reading and understanding the various topics on lasers. This book has been written with the sincere hope of the editors and the authors to serve as a cornerstone of laser usage in medicine, ultimately leading to better patient care and treatments. Lasers in medicine have significantly evolved and expanded significantly. For instance, in ophthalmology, there are chapters for treatment of anterior segment (i.e., laser vision correction), posterior segments of the eye, and control of intraocular pressure.

Furthermore, this book incorporates chapters on the use of lasers in the fields of cardiology, gynecology, general surgery, anesthesiology, urology, neurology, dentistry, and many other specialized branches of medicine making it a unique laser textbook. The expanding knowledge and growing expertise in lasers and light devices makes it necessary for physicians to be up to date about the advancements in this field.

We anticipate that this book will be of interest to all the physicians who use or are interested in using lasers in their practice. We are extremely grateful to our contributing authors. This book will serve as a potential study source for physicians in different specialties of medicine and surgery.

Miami, FL, USA — Keyvan Nouri, M.D.

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1 Laser/Light Applications in Ophthalmology: Visual Refraction

Amit Todani, Mahnaz Nouri, and Roberto Pineda

Abstract

- Refractive laser technology is used for correction of myopia, hyperopia and astigmatism.
- Laser vision correction can be performed on the surface the cornea after removing the epithelium or deeper into stroma under a hinged corneal flap.
- Proper candidate selection is essential to minimize the risk of complications.
- Corneal collagen cross-linking with ultraviolet light and riboflavin (a photo sensitizer) is a relatively new treatment modality for a variety of corneal keratectatic disorders.
- Femtosecond laser technology has recently evolved into a tool for cataract surgery.

Keywords

LASER · LASIK · LASEK · epi-LASIK · PRK · PTK · Ophthalmology · Visual science · Refraction · Refractive surgery · Femtosecond laser · Excimer laser

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History

Laser technology is only around half a century old. The first experimental laser, demonstrated by Maiman in 1960, was produced by a ruby crystal powered by a flashlamp [1]. However the first use of laser in the field of refractive surgery was demonstrated in 1983 by Trokel and Srinivasan who showed that argon-fluoride excimer laser of 193 nm could cleanly remove corneal stromal tissue with minimal damage to adjacent stroma [2]. This technology was developed for ophthalmic use after being applied to etch computer chips for IBM in the late 1970s. Initially, the laser was used to create radial keratotomy incisions [3, 4]; later it was used to ablate the corneal tissue in the central visual axis. This later procedure was termed photorefractive keratectomy (PRK) by Trokel and Marshall. The first PRK in a seeing human eye was performed by Mc Donald and coworkers in 1988 [5]. Since its inception, refractive laser technology has grown exponentially. In the US, The Food and Drug Administration (FDA) first approved the excimer laser for the treatment of mild to moderate myopia in October 1995. Later, it was approved for correction of hyperopia and astigmatism.

LASEK (laser-assisted subepithelial keratectomy) and epi-LASIK are modifications of the PRK procedure in which the corneal epithelium is preserved. The epithelium in such cases is displaced prior to the surface ablation, then replaced after laser application.

© Springer International Publishing AG, part of Springer Nature 2018
K. Nouri (ed.), *Lasers in Dermatology and Medicine*, https://doi.org/10.1007/978-3-319-76220-3_1

The term Laser (-assisted) in-situ keratomileusis (LASIK) was introduced by Ioannis Pallikaris and colleagues in 1988 [6]. LASIK involves the creation of a hinged corneal flap followed by ablation and reshaping of the underlying stromal tissue with an excimer laser beam. The hinged corneal flap can be created by an automated keratome or by a femtosecond laser platform. The keratome-laser combination was reported in 1990 separately by two investigators, viz. Burrato, who performed photokeratomileusis (PKM), and by Pallikaris, who performed LASIK [7]. Burrato's technique involved fashioning of a free keratomileusis cap and performing PKM on the posterior (stromal) aspect of the cap and replacing it. Pallikaris' technique involved raising a hinged cap and treating the underlying stromal bed with an excimer laser [7]. While the results of PKM were not as promising as LASIK, the LASIK hinged corneal flaps were safer and resulted in more accurate flap realignment.

Surface Ablation: PRK (Photorefractive Keratectomy)/ LASEK (Laser Subepithelial Keratomileusis)/Epi-LASIK

Surface ablation has traditionally referred to PRK and requires removal of the corneal epithelium. This can be performed mechanically (scapping), chemically with alcohol (15–20%), or with the excimer laser (transepithelial ablation). However, it is most commonly performed by using dilute alcohol (commonly 15–20% ethanol is used) to loosen up epithelial cells, removing the epithelium (sometimes as a sheet), followed by laser ablation of the subepithelial stroma. After the laser procedure is completed, the epithelial sheet is either replaced (LASEK) or discarded (PRK). The theoretical advantages of LASEK over PRK include decreased post-operative discomfort, reduced risk of scarring and faster visual recovery. A study by Wissing et al. demonstrated reduced keratocyte loss with LASEK when compared to PRK in an animal study [8]. However, more clinical data is needed to conclusively demonstrate that LASEK has significant advantages over PRK. On the other hand PRK may be more advantageous than LASEK in situations like anterior basement membrane (Cogan's) dystrophy [9], epithelial erosions or epithelial scarring, where it may be preferable to discard the diseased epithelium. In most cases, the choice of one procedure versus the other is largely dependant on surgeon preferences.

The principal advantage of surface ablation is the avoidance of flap-related LASIK complications, for e.g. flap dislocation, flap folds, buttonhole formation, etc. (discussed in details in section "Complications of Laser Refractive Surgery"). Moreover, surface ablation may be the preferred approach in certain situations. These include certain occupations in which the risk of flap trauma is persistently elevated, for e.g. in contact sports like basketball and rugby, military personnel, etc. Patients with a history of systemic herpetic infections (a relative contraindication) may be better suited for surface ablation, which theoretically severs less number of corneal nerves as compared to LASIK and may therefore have lesser propensity to reactivate the virus. For similar reasons, it is generally speculated that surface ablation has less of a tendency to induce dry eyes when compared to LASIK. Moreover, in patients with a prior history of flap abnormalities with attempted LASIK, it may be safer to perform surface ablation rather than run the risks of recutting the flap such as flap maceration and flap loss [10]. Several factors, such as lack of reproducibility of corneal flap thickness even when the same microkeratome is used [11] and variations in intensity and duration of microkeratome suction [12], predispose to serious flap complications during recutting the flap.

The major advantages of LASIK over surface ablation are earlier post-operative visual recovery, less post-operative discomfort, less risk of haze esp. when associated with higher level of refractive error correction and shorter duration of post-operative steroid treatment [9]. Moreover, LASIK may be associated with less regression when compared to surface ablation for higher levels of correction [9].

A variation of LASEK, termed epi-LASIK was applied by Pallikaris et al. who used an automated separator to remove the corneal epithelium mechanically, without the use of alcohol [13]. They suggested that this technique would provide increased post-operative comfort and decreased haze formation as compared to PRK. Histological studies seem to show better preservation of the epithelial sheet when compared to LASEK [14].

LASIK

Laser in-situ keratomileusis (LASIK) is a two-step procedure that involves creation of a hinged corneal flap followed by ablation and reshaping of the underlying stromal tissue with an excimer laser ('excited dimer') beam. This is an argon fluoride (AFl) laser that operates at 193 nm in the ultraviolet spectrum and was first used for etching computer chips [2]. This laser wavelength allows ophthalmologists to surgically reshape the cornea through a series of mirrors and lenses in an attempt to circumvent the need for corrective lenses There are three general types of delivery systems for the excimer lasers, depending on the size of the beam: broad beam, scanning slit, and small beam. The broad beam laser is the one more commonly used for corneal reshaping through an iris diaphragm. Due to the high energy per photon of the excimer laser beam, the ablation of the carbon-carbon bonds at the corneal surface allows for an accurate tissue removal of each layer with minimal penetration and therefore damage to adjacent tissues.

The first step in LASIK is creation of a hinged corneal disc (i.e. the 'flap'). This can be created by an automated microkeratome or more recently and with increased precision utilizing a femtosecond laser platform such as the Intralase® femtosecond laser (Intralase Corp., Irvine, CA), an infrared YLF:glass (Nd:glass) laser which operates at 1053 nm [15] (Fig. 1.1).

Microkeratomes have greatly evolved in terms of ease of use, reliability and safety profile since the earlier original versions. Jose Ignacio Barraquer in 1958 unveiled his first manual microkeratome, which was designed for keratophakia and freeze

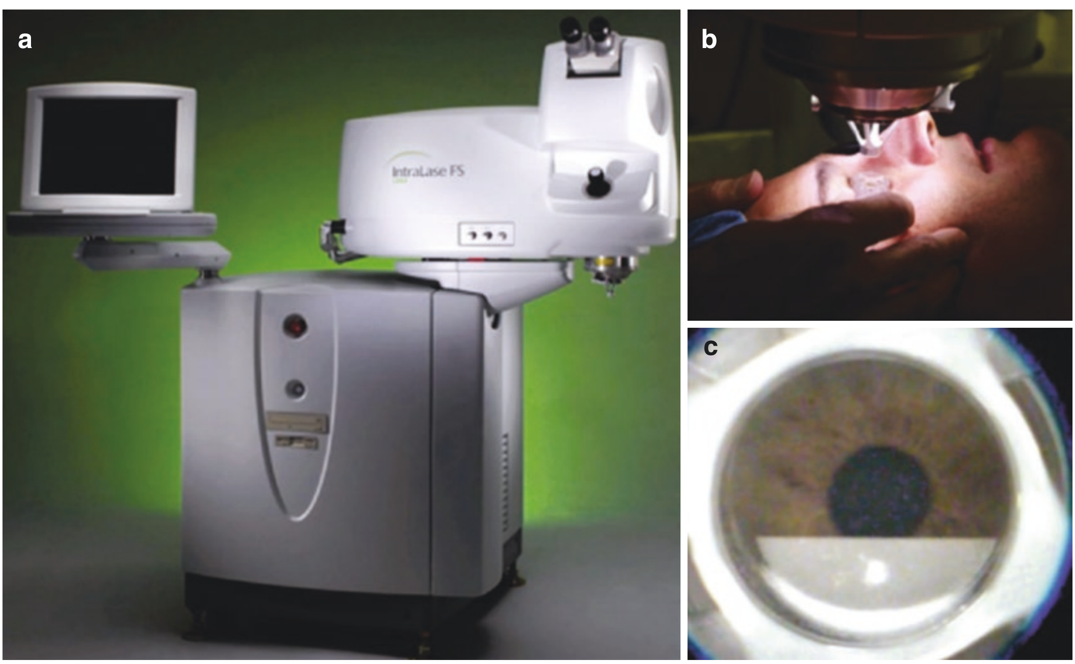

Fig. 1.1 (**a**) Intralase™ Femtosecond laser unit. (**b**) Placement of suction ring for stabilization and alignment of the globe with applanation cone. (**c**) LASIK Flap creation with Intralase™ raster scan pattern

keratomileusis [16]. Over time, this technique was evolved for obtaining a smoother technique to cut through the corneal stroma. Microkeratomes come in manual, semiautomated, and automated models. Some are even disposable. Typical components of a standard microkeratome include the motor for translational movement, head of the microkeratome bearing the blade, applanator lens to measure the diameter of the exposed cornea, vacuum fixation ring to secure the eye, flat stop ring to limit the movement of the microkeratome head through the fixation ring and a foot switch to operate the microkeratome movement. Although much improvement has been made since the earlier days in mirokeratome design, modern day microkeratomes are not devoid of complications. Most of the flap related complications during LASIK (discussed in section “Complications of Laser Refractive Surgery”) are related to the use of microkeratomes. These complications depend on many factors, including surgeon experience and microkeratome safety features. Although there is a steep learning curve, complications decrease over time with increasing surgeon experience. Most modern microkeratomes have inbuilt safety features such as alarms, automatic shut down buttons and suction indicators.

With the advent of the femtosecond laser, creation of the LASIK flap has become much safer and simpler (Fig. 1.1). The flap can now be created optically with the near infrared laser, focused at a set depth within the corneal stroma. The laser fires at a rapid rate with pulse duration in the range of femtoseconds. This results in vaporization of corneal tissue by the process of photodisruption, leading to formation of plasma and shockwave. The expansion of plasma results in a resection plane which ultimately leads to creation of a lamellar flap. This flap still requires dissection of the lamellar plane prior to lifting the flap for treatment with the excimer laser. Thus, more uniform flaps with consistent thickness can be created. Also this laser system allows the refractive surgeon to fashion thinner flaps that have the advantage of preserving greater amounts of residual stromal bed. LASIK flap creation with femtosecond laser is growing in the U.S. and principally hindered by the cost of the laser.

Before the corneal lamellar flap is created, gentian violet surgical landmarks spanning the hinged flap and the peripheral cornea are placed and the flap is folded over to expose the stromal bed. The excimer laser (Fig. 1.2) is then used to reshape the corneal stroma to achieve the desired

Fig. 1.2 Visx Star S4™ Excimer laser unit

correction of refractive error. Both the size of the optical zone as well as the depth and profile of the laser ablation are important determinants of the correction achieved. Small or decentered ablation zones can result in problems of glare and haloes at night when the pupils may dilate beyond the functional optical zone. Deeper ablations can distort the corneal surface and can predispose to corneal flap striae or 'mudcracks.' In order to ensure adequate stromal hydration during LASIK, the laser treatment should be performed in a timely manner. Dehydration of the stroma can lead to overcorrection while over-hydration with BSS can dampen the effect of the laser. Most modern excimer lasers have a tracking mechanism (usually infrared cameras) based on the position of the pupil or the iris pattern in order to nullify the effect of torsion or slight movements of the eye during the time of laser treatment.

Once the ablation is complete, the undersurface of the flap along with the stromal bed is irrigated with balanced salt solution to remove any debris, and the flap repositioned onto the stromal bed. The interface is then allowed to dry for a few minutes. Proper adhesion of the flap is then confirmed. It is equally important to confirm adequate alignment of the flap with respect to the peripheral cornea using the pre-placed surgical landmarks as a guideline along with the configuration of the gutter between the flap and the peripheral cornea. At the end of the procedure, the patient should be re-examined under a slit lamp before being discharged and again the following day. One of the important reasons for such a close monitoring is that flap related complications such as flap folds or dislocation are easier to fix if detected early rather than later during the post-operative course. Post-operative regimen typically consists of topical antibiotics and topical steroids for a short duration along with non-preserved artificial tears as needed.

Custom Wavefront LASIK

Standard laser vision correction treats lower order aberrations only such as myopia, hyperopia, and astigmatism. However, higher order aberrations exist, such as coma, trefoil and spherical aberrations, that are not treated or even worsened by conventional excimer laser treatment (Fig. 1.3b). Induction or lack of treatment of these factors limit patient satisfaction after LASIK and include reduced contrast sensitivity that is largely accounted for by an increase in optical aberrations. Along with this, many patients experience night vision problems such as glare, haloes and starbursts postoperatively. Wave-front guided (Fig. 1.3a, b) LASIK is a relatively new

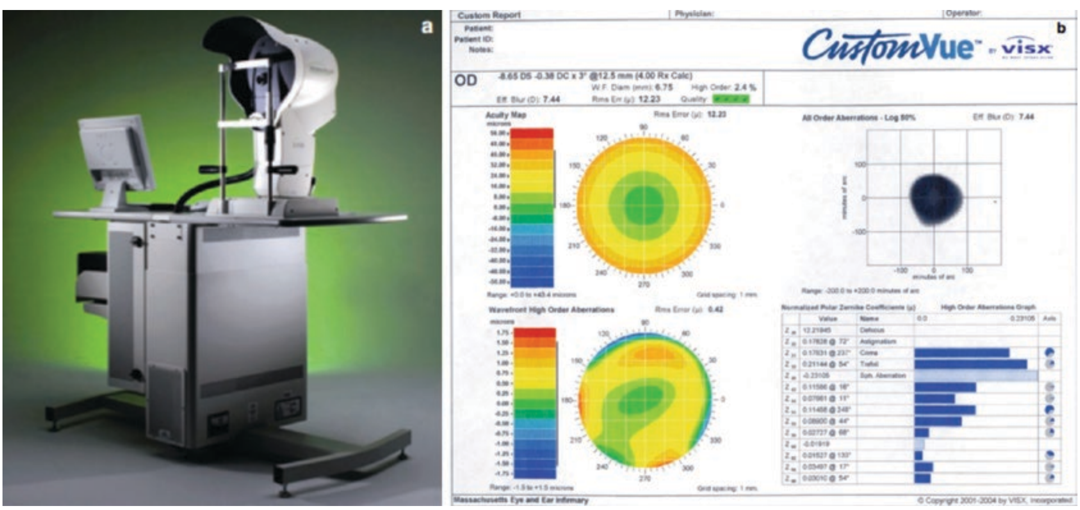

Fig. 1.3 (**a**) WaveScan® Wavefront Unit. (**b**) Scan generated by WaveScan® Wavefront Unit showing total and higher order aberrations. Copyright Amit Todani

development in the field of refractive surgery that aims to achieve better visual outcomes by correcting existing ocular aberrations [17].

Wave-front guided LASIK aims to treat total ocular aberrations. This is in contrast to topography-guided ablation, which can treat ocular aberrations which arise from the corneal surface only and the conventional LASIK which cannot treat higher order aberrations. The wavefront guided ablation technology uses sophisticated computer software to display both low and higher aberrations to the surgeon. By canceling the phase differences within the wavefront, wavefront customized ablation aims to equalize the optical path of all rays entering the pupil from the object of focus to the fovea. Various factors, such as refractive index of the cornea, corneal curvature and optical zone blending are taken into account to optimize the ablation profile [18]. In simple terms, conventional LASIK aims to treat a patient's refractive error without taking into account other optical aberrations; therefore any two individuals with same eye-glasses prescription would have similar pattern of laser ablation, provided the other treatment parameters (for e.g. the size of the optical zone) are the same. Wavefront guided LASIK, on the other hand is much more customized to an individual's hill of vision. It takes into account not just the patient's eyeglasses' prescription but also other optical aberrations which influence the quality of vision; therefore the pattern of ablation would be different amongst any two individuals with the same eye-glasses' prescription.

Several studies show better contrast sensitivity and less night vision problems after wavefront guided LASIK [19]. Some other studies, however, seem to suggest that wave-front guided LASIK cannot remove high-order aberrations but can reduce the increase in high-order aberrations after laser treatment when compared to conventional ablation [20]. Despite its many advantages, every patient may not be a suitable candidate for wave-front guided laser treatment. This is because correction of large amounts of higher-order aberrations necessitates ablation of increased amounts of corneal tissues. Careful consideration of the benefits of customized ablation versus the risks of keratectasia due to inadequate residual corneal stromal bed thickness should be made, especially in patients with higher levels of refractive error and border-line thin corneas [21].

Complications of Laser Refractive Surgery

Laser vision correction is not free of complications. Proper candidate selection is one of the most critical steps to minimize the risk of such complications. Nonetheless, despite adequate candidate selection, complications still occur in the best of the hands, and patients should be warned about the potential risks of this elective procedure. In addition to explaining the general risks, individual patients should be warned about the specific risks of particular complications based on their prescription and the configuration of the cornea and the pupils. Any co-existing pathology such as glaucoma, lens opacities, corneal dystrophies, dry eyes and diabetes should be clearly documented and explained to the patient. Table 1.1 lists the important pre-operative tests that are considered to be essential in order to adequately determine candidacy for refractive surgery in addition to a thorough history and meticulous clinical examination of the eye.

Table 1.1 Patient evaluation prior to refractive surgery

(a) Contact lens users should discontinue the use of contact lenses for at least 10–14 days prior to evaluation. Hard and toric contact lens wearer longer
(b) The following tests should be done on a day other than the day of surgery
• Full ocular examination including fundus examination and motility assessment
• Refraction: both dry manifest and cycloplegic
• Keratometry
• Corneal topography
• Pupillometry
• Pachymetry
• Dry eye testing
• Wavefront aberrometry

A full discussion of the associated complications and their management options is beyond the scope of this book. Herein, we discuss some the key complications which can be broadly divided into the following categories:-

I. Anatomic Complications
II. Refractive Complications
III. Complications of healing/infection/inflammation

Anatomic Complications

These generally occur at the time of surgery or in the immediate post-operative period and are mostly flap-related and therefore more likely with LASIK than with surface ablation treatments (PRK/LASEK). Common anatomic complications are:-

1. *Thin or Button-holed flap*: An standard flap is one that cuts below Bowman's layer. A "thin flap" is one which is cut within or above the 12 μm thick Bowman's layer. Its recognition may be aided by performing pachymetry (corneal thickness measurement test) before and after lifting the flap. As the corneal epithelial layer is approximately 50 μm thick and the Bowman's layer is another 12 μm, a flap measurement of below 60 μm is suspicious.

   A LASIK flap button-hole occurs when the microkeratome travels more superficially than intended and enters the epithelium/Bowman's complex. Button-holes may serve as a conduit for epithelial ingrowth and predispose to flap-melt and scarring. The reported incidence of button-hole varies from 0.2% to 0.56% [22–24].
2. *Incomplete flap*: Incomplete flaps can result if the microkeratome blade fails to complete the translational movement and comes to a halt before reaching the intended hinge location. Its reported incidence is between 0.23% and 0.30% [23, 25].
3. *Dislodged flap*: Flaps are particularly vulnerable to dislodgement in the immediate post-operative period due to eye-rubbing or trauma although it can also occur several months after the procedure. A dislodged flap is a true emergency and should be repositioned immediately to minimize the risk of infections, fixed folds and epithelial ingrowth. Up to 2% incidence of dislodged flaps have been reported in various studies [22, 23].
4. *Free Cap*: This results from unintended complete dissection or avulsion of the corneal lamellar flap. Preplaced fiducial marks can be used to realign the flap followed by placement of a bandage contact lens. Suturing the flap may be necessary. The management is more complex if the corneal cap cannot be retrieved. Free caps have generally been reported to occur in 0.08–1.0% of cases [22, 23, 25, 26]. They are particularly prone to occur in very flat corneas (42D or less) [22].
5. *Flap folds*: Some flap folds can induce significant astigmatism and loss of best corrected visual acuity while others may be visually insignificant. Management can vary from simple observation to refloating and repositioning of the flap with or without placement of nylon sutures. The incidence of flap folds requiring repositioning has been reported to be 1.1–1.8% [22, 23].
6. *Epithelial ingrowth*: Sometimes implantation of corneal epithelial cells at the interface can occur due to seeding during surgery or migration under the flap. This can progress to involve the visual axis with resultant irregular astigmatism and/or overlying flap melt due to proteolytic enzymes produced by such cells. In such cases, the flap should be lifted, followed by thorough irrigation and scraping of the stromal bed and the undersurface of the flap. Epithelial ingrowth generally has a higher incidence after LASIK enhancement as compared to primary procedure [27]. There is a wide variation in its reported incidence in the literature (0.01–32%) [27–29].
7. *Interface Debris*: This can often masquerade as inflammatory or infectious reactions and therefore its recognition is mandatory.

Generally these comprise meibomian gland secretions and are inert. They may merely be observed unless present in large quantities involving the visual axis.

8. *Epithelial defect*: These are often found at the flap edges (demonstrating mild staining with fluorescein solution) on the first post-operative day. Larger defects may cause pain and inflammation and should be immediately treated.
9. *Corneal Ectasia*: This is a serious complication which generally results from a thin residual corneal stromal bed. Initially the patients may be managed by a hard contact lens wear but some patients may eventually require a corneal graft. Other treatment modalities are collagen cross-linking (discussed in details in section "Corneal Collagen Cross-Linking") and intrastromal corneal rings (Intacs, KeraVision), which aim to reduce corneal steepening and improve the refractive error The general consensus in order to minimize the risk of this complication is to target a minimum stromal bed thickness of 250–300 µm. Pre-existing keatoconus is another pre-disposing condition that must be ruled out by thorough preoperative evaluation, esp. corneal elevation topography and pachymetry. The incidence of corneal ectasia after LASIK has been reported to be 0.2% [30].
10. *Corneal Haze*: This complication is more likely with surface ablation than with LASIK. Corneal haze is related to the corneal wound healing response after excimer laser treatment induced by activation and migration of keratocytes and newly synthesized collagen. Corneal haze is chiefly related to the depth of ablation and presence of an epithelial flap. It is therefore conceivable that LASEK is reported to produce less corneal haze than PRK. Dilute Mitomycin C (0.02%) as a single application intraoperatively for a short duration has been shown to be safe and effective in reducing the incidence of haze after photorefractive surgery [31, 32].

Refractive Complications

1. *Central Islands and Decentration*: Various factors, such as improperly registered laser ablation pattern and surgical technique can lead to topographical irregularities in the treatment zone leading to central islands. These can result in multifocal corneas with diplopia, ghost images, visual fluctuations and poor quality of vision [33].

   Decentration can occur if the laser treatment is not centered adequately over the pupil. This can result in difficult to treat astigmatism, diplopia, glare and haloes [33].
2. *Over/under-correction and Regression*: A variety of factors, including variations in corneal healing, ambient temperature and atmospheric pressure, erroneous nomogram adjustments by the physician, faulty calibration of the laser, can lead to over and under-correction or induced/residual astigmatism.

   Regression towards the pre-treatment refractive error has frequently been reported to dampen or nullify the effect of Lasik treatment in both myopia and hyperopia. Regression tends to occur with higher frequency after high myopic correction and after hyperopic LASIK [34].
3. *Haloes and Glare*: Visual aberrations after refractive surgery can lead to disabling haloes and glare, which may have far-fetching consequences in the patient's life from inability to drive at night to loss of occupational abilities. Although it is not clear to what extent, each of the individual factors play a role in the causation of these disabling symptoms, individual patients must be warned of the additional risks in case of increased scotopic pupil size, high refractive correction and increased cylindrical treatment. Other contributing factors include decentration of the treatment zone, flap folds, irregular epithelial surface, and dry eyes. In a large retrospective survey looking at patient satisfaction and visual symptoms after LASIK, halos were reported by as many as 30%, glare by 27%, and starbursts by 25% of all the study participants [35].

4. *Loss of Best Corrected Visual Acuity (BCVA) and Contrast sensitivity*: This can particularly occur after high treatment and correction of compound astigmatism. It can also result from complications such as button-hole and corneal scarring. Individual surgeons have their own threshold on treatment levels in order to minimize this complication. In large studies ($n \geq 1000$), the incidence of loss of ≥2 lines of BCVA after LASIK has been reported to be 0–4.8% [22, 24].

Complications of Healing/Infection/Inflammation

1. *Dry Eyes*: This is one of the most common complications and may occur as a result of decreased corneal sensation resulting from ablation of corneal nerves with subsequent decreased blinking rate. In a large survey of patients who underwent primary myopic LASIK or PRK, symptoms of dryness were reported in 48% of LASIK and 43% of PRK patients in the first 6 months after surgery [36].
2. *Diffuse Lamellar Keratitis*: Also known as 'Sands of Sahara' or DLK, is characterized by proliferation of inflammatory cells within the LASIK flap interface. This condition can lead to stromal corneal melting, induced hyperopia, irregular astigmatism and loss of BCVA. It is more prevalent in cases with epithelial defects in the peri-operative period. DLK has been reported to occur with higher frequency when the LASIK flap is created with the femtosecond laser as compared when it is created with a microkeratome [37].
3. *Infectious Keratitis*: Large studies suggest an incidence of 1:3000. Both fungal and bacterial keratitis have been reported in the literature after LASIK. Sometimes, sterile infiltrates may be seen at the flap edge, although it cannot be reliably differentiated from infectious keratitis solely by its appearance.
4. *Other complications*: In addition to the complications mentioned above, other rarer complications have been reported, including ischemic optic neuropathy, corticosteroid-induced glaucoma, decreased endothelial cell count and macular hemorrhage. Additionally, intraocular lens (IOL) power calculations become more of a challenge in patients undergoing cataract surgery after a refractive procedure.

Corneal Collagen Cross-Linking

Corneal collagen cross-linking (CXL) using ultraviolet-A light (UVA) combined with a photosensitizer like riboflavin has been developed as a relatively new treatment modality for a variety of keratectatic disorders like keratoconus [38], post LASIK corneal ectasia [39], corneal melts associated with infectious [40], and non-infectious keratitis [41]. Several studies have shown CXL to be an effective modality for delaying or avoiding the need for penetrating keratoplasty (PKP) [38] in patients with keratectatic disorders.

Keratoconus is a non-inflammatory disease that causes thinning of the corneal stroma which can lead to conical protrusion, visual reduction and discomfort. The pathological basis of this disease is thought to be related to reduction of collagen crosslinks and a reduction of molecular bonds between neighboring stromal proteoglycans. Although several treatment modalities for this progressive condition have been attempted, most of these treatments aim for visual rehabilitation of the patient and do not address the underlying pathology in an attempt to halt or reverse its progression. Some of the traditional treatment options include use of rigid gaspermeable contact lens, intracorneal ring segment implantation or lamellar keratoplasty. Ultimately, PKP is the only available treatment option in advanced cases. CXL is a photodynamic treatment modality which aims to address some of the underlying pathophysiological mechanisms of keratoconus by increasing the rigidity of the cornea, thereby improving corneal shape and producing better quality of vision. Several studies have shown that the biomechanical, thermo-mechanical and biochemical properties of the cornea can be modified by CXL. CXL enables additional covalent binding between collagen molecules. Studies on animal eyes show significant increase in corneal rigidity by approximately 70% over untreated corneas.

Moreover, corneal and lens transparency as well as endothelial cell density seem to be unaffected after the treatment. In order to prevent endothelial damage, however, cross-linking treatment should be avoided if cornea is thinner than 400 μm. Spoerl et al. reported that cross-linked corneas had increased resistance against enzymatic digestion with pepsin and collagenase [42]. Although keratoconus is not curable at present, CXL can prevent its progression.

The use of CXL for stabilizing progression of iatrogenic keratectasia after LASIK was reported by Kohlhaas et al. [43] and later by Kymionis et al. [39]. The latter authors reported DLK after CXL, which they postulated could be due to several cross-linking factors such as epithelial removal and UVA light. The inflammation was reported to respond with a regimen composed of intense dose of topical corticosteroids combined with an oral steroid. Schnitzler et al. reported successful treatment of four cases of non-infectious corneal ulcers with CXL. Later, Iseli et al. [40] reported the use of CXL for treating corneal melt due to infectious keratitis in five patients and suggested its use in therapy-refractory infectious keratitis to avoid emergency keratoplasty.

Complications of CXL

Appropriate patient counseling and postoperative care are essential for ensuring optimal visual rehabilitation and minimizing postoperative complications after CXL. It is imperative to ensure complete epithelialization of the cornea after the procedure in order to achieve a healthy ocular surface.

The epithelial layer of the cornea servers as a barrier to infections and standard Dresden protocol CXL involves de-epithelialization of the cornea before administration of riboflavin to allow for its stromal penetration. There have been several reported instances of severe microbial keratitis with corneal melt and visually debilitating scars after CXL [44, 45]. Typically, patients receive a bandage soft contact lens for a few days after the procedure to promote epithelialization and minimize pain, along with topical antibiotics to reduce risk of infection. Preservative-free artificial tears are also typically recommended to aid in epithelialization and improve patient comfort. In addition, oral pain medications may be needed especially early on during the recovery period. It is not uncommon to experience photophobia following the procedure, for which dark glasses are recommended.

Development of corneal haze is another potential complication. It can take the form of a minor haze to a visually significant scar. Patients with advanced keratoconus have an inherently higher risk of scar development after CXL due to low corneal thickness and high corneal curvature [46]. The haze after keratoconus is different from that after PRK. While haze after PRK is subepithelial, haze after CXL extends to the anterior stroma. Also, unlike haze after PRK, which has a fine granular or dust-like appearance, haze after CXL is more reticulated or honeycomb-like. This difference in character and depth of haze after CXL is probably related to more keratocyte loss after CXL compared to PRK [47, 48]. Several other factors may also play a role in development of corneal haze after CXL, such as stromal swelling pressure changes, proteoglycan-collagen interactions and glycosaminoglycan hydration [49]. Topical steroids are prescribed to minimize the incidence of corneal haze after CXL.

Sterile corneal infiltrates can also develop after CXL in some patients. They probably occur as a result of enhanced cell-mediated immunity to staphylococcal antigens which are found in high concentrations in areas of static tear pooling beneath the bandage contact lens [50]. These infiltrates are typically seen subepithelially in corneal periphery, separated from limbus by a clear zone. These infiltrates generally resolve after treatment with topical steroids.

Femtosecond Laser Assisted Cataract Surgery (FLACS)

Femtosecond laser technology, which has traditionally been employed for creating lamellar corneal flaps in LASIK since 2001, has recently evolved into a tool for cataract surgery [51, 52].

This technology has the potential to improve safety, accuracy and visual outcomes in cataract surgery, which is the most commonly performed surgical procedure worldwide. At the time of writing, there are five commercially available platforms in the US for femtosecond laser assisted cataract surgery (FLACS): LenSx (Alcon Laboratories, Inc.) (Fig. 1.4), Catalys (Optimedica), Lensar (Lensar, Inc.), Victus (Technolas) and Femto LDV (Ziemer).

The FLACS system uses neodymium:glass 1053 nm (near-infrared) wavelength light. This light can be focused at a 3 μm spot size, accurate to within 5 μm in the anterior segment [53]. The quintessential aspect of this laser technology is the speed at which the light is fired: the system generates ultrashort pulses in the range of a femtosecond (10^{-15} s). While heat requires a picosecond (10^{-12} s) to begin diffusing across a surface, with a femtosecond laser, the pulse is absorbed by the target tissue before the heat begins to dissipate. This eliminates the collateral damage of the surrounding tissues and almost 100% of the energy is utilized for photodisruption. These properties enable precise tissue dissection along microscopic planes.

There are three main components of the FLACS system: (i) patient-interface (PI), (ii) imaging system, and (iii) laser delivery system. The procedure begins with docking the PI to the operative eye. This requires the patient to lie supine and remain still for several minutes until the imaging and laser treatment are completed. Following docking, the laser platform uses either spectral domain OCT (with LenSx, Catalys and Victus platforms) or three-dimensional confocal structural illumination (with Lensar platform) to image and map the treatment plan. During this step, the surgeon ensures that the anterior segment structures are correctly identified by the

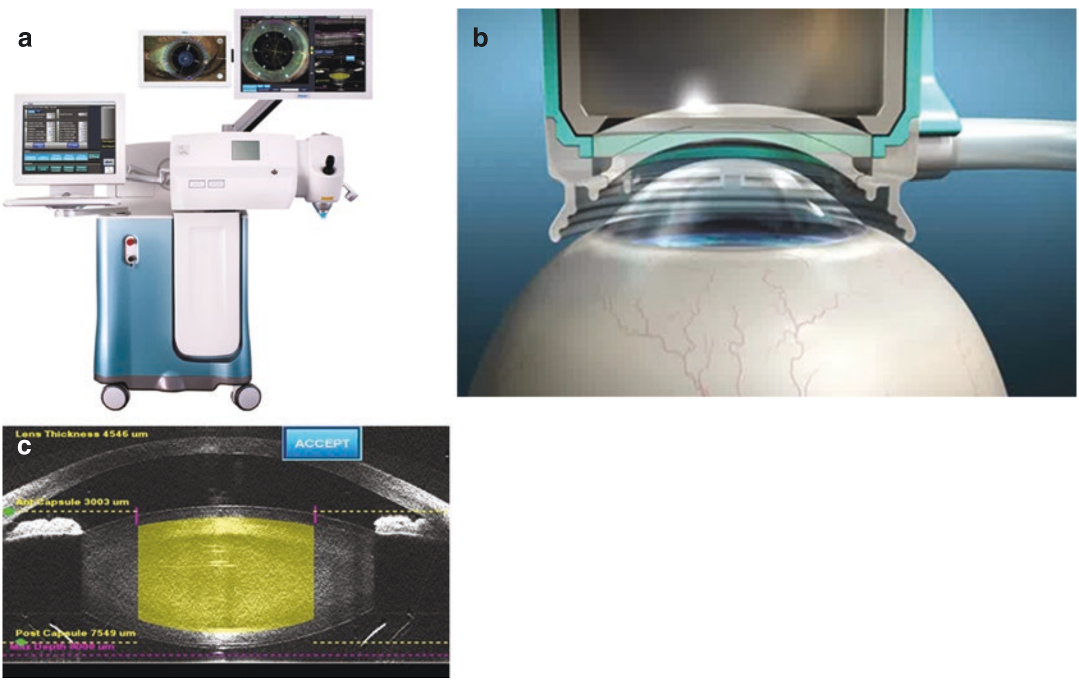

Fig. 1.4 (**a**) LenSx® Laser System for FLACS (Femtosecond laser assisted cataract surgery). (**b**) 'Softfit' PI (Patient Interface) for docking the LenSx® Laser System to the operative eye. (**c**) Imaging system that employs high definition OCT (Optical Coherence Tomography) to capture the anterior segment of the eye and provides real-time video feed allowing the surgeon to precisely set the size and location of capsulotomy, lens fragmentation pattern, corneal wound architecture and configuration of any astigmatic keratotomies. Reproduced with permission of Alcon Laboratories Inc.

imaging system and selects the treatment parameters. Typically, the laser is set to create primary and secondary (paracentesis) corneal wounds, capsulotomy, and lens fragmentation. Most laser platforms can also be set to create astigmatic keratotomy incisions to reduce corneal astigmatism. Following the completion of laser treatment, the PI is removed and patient prepared for phacoemulsification procedure.

There are several theoretical advantages of employing the FLACS platform for cataract surgery and lens-based refractive surgery [54]. These advantages can be grouped under two unique headings:

1. *Safety*: FLACS produces incisions with consistency in size, depth and architecture which promotes better wound closure and may reduce the risk of infections.
   The risk of capsular tears, which can predispose to vitreous loss and retinal detachment, is significantly reduced with FLACS when compared to manual capsulorrhexis [55].
   Lens fragmentation and softening during FLACS can also reduce the requirement for subsequent phacoemulsification energy, thus reducing the risks of corneal decompensation and zonular dehiscence [56].
2. *Refractive predictability*: The precision with which the corneal wounds can be made, the consistency in size and location of the capsulotomy which influences effective lens position, and the ability to produce precise astigmatic keratotomies with predictable incision depths, arc lengths and optical zones can all contribute to superior refractive outcomes [57].

FLACS also has a unique set of disadvantages as outlined below:

1. *Cost and workflow*: The average laser systems costs anywhere from $400,000 to $550,000 to acquire and typically requires additional annual maintenance expenses. Disposable PI cost ranges from $300 to $450 per eye. Additional staff members or technicians may be needed to upload patient information and surgical parameters, calibrate the laser and assist in the procedure and workflow. The introduction of a separate laser procedure prior to phacoemulsification also affects patient flow and volumes, and may add to increased total surgical time, especially during the initial learning phase [51].
2. *Challenging cases*: Patients with stiff neck and back, and those with inability to lie still for the duration of the procedure are not suitable candidates for FLACS. Hypotony, poor optical quality of cornea and very steep corneas may make docking very difficult as well as result in incomplete application of laser energy. Small pupils can also present a challenge for surgeons. The pupil must be able to dilate sufficiently to make an adequately sized capsulotomy. In addition, application of laser energy can induce pupillary miosis before initiation of phacoemulsification [58].
3. *Suction loss*: Similar to femtosecond LASIK procedure, suction loss can occur during FLACS [59]. However, it seems to be less of a concern with FLACS due to lower level of applanation required to maintain suction with FLACS compared to femtosecond LASIK. The patient should, nonetheless, be able to hold still during the procedure to avoid suction loss.
4. *Incomplete capsulotomy*: Although the incidence of incomplete capsulotomies were higher with the first generation devices [59], this complication has decreased with the latest software and hardware improvements. Nonetheless, surgeons should still check for presence of complete capsulotomy prior to proceeding with phacoemulsification.
5. *Capsular blockage syndrome*: FLACS causes generation of intralenticular gas, which can be trapped behind the nucleus. When combined with aggressive hydrodissection, the resultant increase in pressure within the lens can rupture the posterior capsule [60]. This is extremely uncommon.

In conclusion, while this technology has the potential to enhance patient safety and improve refractive results, it comes with a host of new financial and clinical challenges. While improvements in platform software and hardware designs as well as the patients' desire for "premium bladeless cataract surgery" have undoubtedly added to its appeal, cost remains the most significant deterrent to its universal adaptation.

Acknowledgment The authors would like to thank Advanced Medical Optics, Inc. (AMO, USA) and Alcon Laboratories, Inc. (Alcon, USA) for providing the color photographs used in this chapter.

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2 Laser/Light Applications in Ophthalmology: Posterior Segment Applications

Victor M. Villegas, Timothy G. Murray, Amy C. Schefler, and Charles C. Wykoff

Abstract

Among medical fields, ophthalmology has perhaps the richest history with regard to the widespread application of laser technologies. The first experimental use of laser in ophthalmology was that of the German ophthalmologist Gerd Meyer-Schwickerath, who began using the Beck arc in 1949 (Abramson. Acta Ophthalmol Suppl, 194:3–63, 1989; Neubauer and Ulbig. Ophthalmologica 221(2):95–102, 2007). By 1954, Meyer-Schwickerath had treated 41 patients with the xenon arc photocoagulator and by 1957, he reported that he was able to close 82 macular holes with this technology (Abramson. Acta Ophthalmol Suppl, 194:3–63, 1989). Working together with Littmann from the Carl Zeiss Company, he created a similar xenon arc photocoagulator which became available for widespread ophthalmic applications in the late 1960s and was used more frequently in the 1970s. Since then, lasers have been used with notable success for a wide variety of ophthalmic conditions including refractive error, glaucoma, lens-related conditions such as posterior capsular opacification, and retinal conditions including diabetic retinopathy and age-related macular degeneration.

Keywords

Ophthalmology · Laser therapy · Refractive error · Glaucoma · Posterior capsular opacification · Diabetic retinopathy · Age-related macular degeneration · Uveal melanoma · Retinoblastoma

- Lasers have a rich history in ophthalmology
- Lasers have been used to treat common diseases such as diabetic retinopathy and macular degeneration as well as rare conditions such as intraocular tumors

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© Springer International Publishing AG, part of Springer Nature 2018
K. Nouri (ed.), *Lasers in Dermatology and Medicine*, https://doi.org/10.1007/978-3-319-76220-3_2

- Several types of lasers are used in the posterior segment including argon, diode, and photodynamic therapy
- Lasers are commonly used in the clinic setting and operating room

Introduction and History

Among medical fields, ophthalmology has perhaps the richest history with regard to the widespread application of laser technologies. The first experimental use of laser in ophthalmology was that of the German ophthalmologist Gerd Meyer-Schwickerath, who began using the Beck arc in 1949 [1, 2]. By 1954, Meyer-Schwickerath had treated 41 patients with the xenon arc photocoagulator and by 1957, he reported that he was able to close 82 macular holes with this technology [1]. Working together with Littmann from the Carl Zeiss Company, he created a similar xenon arc photocoagulator which became available for widespread ophthalmic applications in the late 1960s and was used more frequently in the 1970s. Since then, lasers have been used with notable success for a wide variety of ophthalmic conditions including refractive error, glaucoma, lens-related conditions such as posterior capsular opacification, and retinal conditions including diabetic retinopathy and age-related macular degeneration.

This chapter will outline the past and current uses for laser in the posterior segment of the eye [1–58]. Anatomically speaking, the term posterior segment generally refers to the vitreous, retina, choroid, and posterior sclera. As such, the laser procedures discussed herein are most commonly performed by retina specialists in subspecialized medical settings. Table 2.1 summarizes current posterior segment laser applications. In many cases, similar procedures have been adapted for varying ophthalmic conditions.

Table 2.1 Major current posterior segment applications for laser in ophthalmology

Laser type	Procedure name	Wavelength (nm)	Disease/indication
Argon/krypton/dye	Pan retinal photocoagulation	488–647	• Proliferative diabetic retinopathy
Argon/krypton/dye	Focal laser photocoagulation	488–647	• Diabetic macular edema
Argon/krypton/dye	Photocoagulation of subretinal neovascular membrane/complex	488–647	• Age-related macular degeneration • Many other causes including: infections, inflammatory conditions, idiopathic central serous chorioretinopathy, retinal or choroidal tumors
Argon/krypton/dye	Retinopexy for retinal tear	488–647	Retinal tear demarcation to prevent retinal detachment
Photodynamic therapy (PDT)	PDT	689	• Age-related macular degeneration • Subretinal neovascular membranes due to infections or inflammatory conditions • Idiopathic central serous chorioretinopathy • Retinal or choroidal tumors
Diode	Transpupillary thermotherapy (TTT) or diode therapy	810	• Ocular tumors such as retinoblastoma or melanoma
Endolaser for vitreoretinal surgery (argon green or diode)	Pan-retinal photocoagulation	Varied	• Proliferative diabetic retinopathy • Intraocular tumors • In • In • Intraocular tumors

Argon Laser

- The three current common procedures for which argon laser is used are: pan-retinal photocoagulation (PRP), focal macular coagulation, and photocoagulation of choroidal or subretinal neovascular membranes or complex, and lasering of retinal holes or tears.
- The current treatment recommendations which incorporate the DRS findings and those of later large scale trials include: high risk proliferative diabetic retinopathy.
- The complications of PRP in the DRS were generally mild and included a decrease in visual acuity of 1 or more lines in 11% and peripheral visual field loss in 5%.

The three current procedures for which argon laser is used are: pan-retinal photocoagulation (PRP), focal macular coagulation, and photocoagulation of choroidal or subretinal neovascular membranes or complexes.

Indications

Pan-Retinal Photocoagulation

Full scatter PRP is a treatment approach which was first established on a widespread basis in the 1970s in the Diabetic Retinopathy Study (DRS) [3] and then further explored in the 1980s and early 1990s in the Early Treatment Diabetic Retinopathy Study (ETDRS) [4]. The theory behind PRP for proliferative diabetic retinopathy (PDR) is that by destroying the peripheral retina, it decreases the stimulus for the growth of new abnormal blood vessels. The DRS enrolled 1742 patients, 876 of whom were randomized to the argon group and 875 to the xenon group [5]. In the end, the harmful effects of xenon coagulation were more significant than for argon, thus argon laser became the standard of care.

The current treatment recommendations which incorporate the DRS and DRCR findings and those of later large scale trials include: high risk proliferative diabetic retinopathy which is defined as: mild neovascularization of the optic disc (NVD) with vitreous hemorrhage, moderate to severe NVD with or without vitreous hemorrhage, or moderate neovascularization elsewhere in the retina (NVE) with vitreous hemorrhage (Figs. 2.1a, b and 2.2). High risk proliferative diabetic retinopathy is also defined in any case with three of the following four risk factors: vitreous or preretinal hemorrhage, presence of new vessels, location of new vessels on or near the optic disc, and moderate to severe extent of new vessels. In the DRS, the risk of severe visual loss

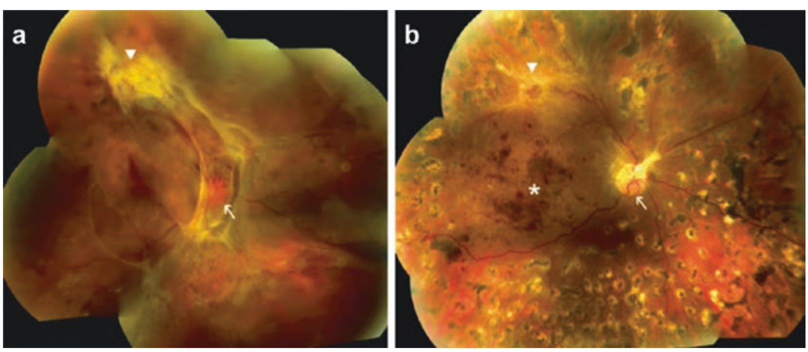

Fig. 2.1 59-year-old female with proliferative diabetic retinopathy, fundus photographs. (**a**) Extensive neovascularization of the optic nerve head (*arrow*) and along the superior macular vascular arcade (*triangle*) with associated fibrosis and retinal traction. (**b**) Five months after panretinal argon laser photocoagulation. Neovascular complexes involving the optic nerve head (*arrow*) and along the superior macular arcade (*triangle*) have regressed, with residual fibrosis. Foci of atrophic retina with pigment clumping are seen throughout the periphery at sites of laser treatment. Multiple, confluent dot blot hemorrhages are seen in the macula (*star*)

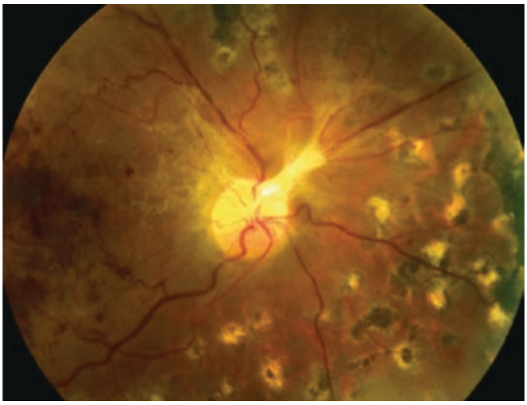

Fig. 2.2 59-year-old female with proliferative diabetic retinopathy, fundus photograph 5 months after pan-retinal argon laser photocoagulation. Fibrotic scar involving the optic nerve head is seen following regression of the neovascular complex. Foci of atrophic retina with pigment clumping are seen at sites of laser treatment. These foci are noted approximately 1 disc diameter from the optic disc and extend into the periphery

(defined as a visual acuity of <5/200) was 26% for patients with high risk proliferative diabetic retinopathy versus 7% in patients without the aforementioned high risk characteristics after 2 years [6]. PRP reduced this risk of severe visual loss by 50%. In addition to these criteria, many studies including ETDRS have suggested that PRP may be indicated for patients with severe nonproliferative diabetic retinopathy in special high risk situations such as poor compliance history, impending pregnancy, or impending cataract surgery [4].

Focal Argon Laser Photocoagulation

Macular edema is responsible for a major part of visual loss in diabetic retinopathy. Many of the current treatment paradigms are based on the results of the ETDRS [4]. The study enrolled 3711 patients between 1980 and 1985 who had either (a) no macular edema with visual acuity better than 20/40 or (b) macular edema with visual acuity better than 20/200. Clinically significant macular edema (CSME) was defined in the study as one of the following: thickening of the retina at or within 500 μm of the center of the macula, hard exudates at or within 500 μm of the center of the macula if associated with thickening of the adjacent retina, or a zone of retinal thickening of ≥1 disc area within 1 disc diameter of the center of the macula (Figs. 2.3a–c and 2.4a, b). The ETDRS results demonstrated that eyes with CSME benefited from focal laser photocoagulation by reducing the risk of moderate visual loss by at least 50% and increasing the chance of visual improvement [7]. This effect was maintained over time with moderate visual loss at 3 years of follow-up in 24% of treated patients treated versus 12% of untreated patients. The study concluded that patients with CSME and good vision should be considered for treatment based on other factors such as status of the fellow eye, anticipated cataract surgery, proximity of exudates to the fovea, or the presence of high-risk PDR [8].

Laser for Choroidal Neovascular Membranes in Neovascular ARMD and Other Conditions

For many years, laser photocoagulation was the only proven treatment for choroidal neovascularization associated with neovascular macular degeneration and other retinal conditions. In the late 1980s and early 1990s, the Macular Photocoagulation Study (MPS), a series of eight multicenter, randomized, prospective trials examining the use of argon and krypton laser for choroidal neovascular membranes was published [9]. This study evaluated the use of laser for extrafoveal and juxtafoveal lesions in three conditions: neovascular ARMD, presumed ocular histoplasmosis (POHS), and idiopathic choroidal neovascularization. One major drawback of these trials was the narrow eligibility criteria: no more than 15–20% of neovascular ARMD cases present with well-defined choroidal neovacularization as required by the trial.

In general, in all of the MPS trials, treatment did not decrease the patient's chance of maintaining stable visual acuity, but the proportion of eyes, treated or untreated, that maintained good or stable visual acuity was very small. The reason for this inadequate treatment effect is that despite treatment, many eyes continued to lose vision because of persistent or recurrent neovascularization that extended into the foveal center.

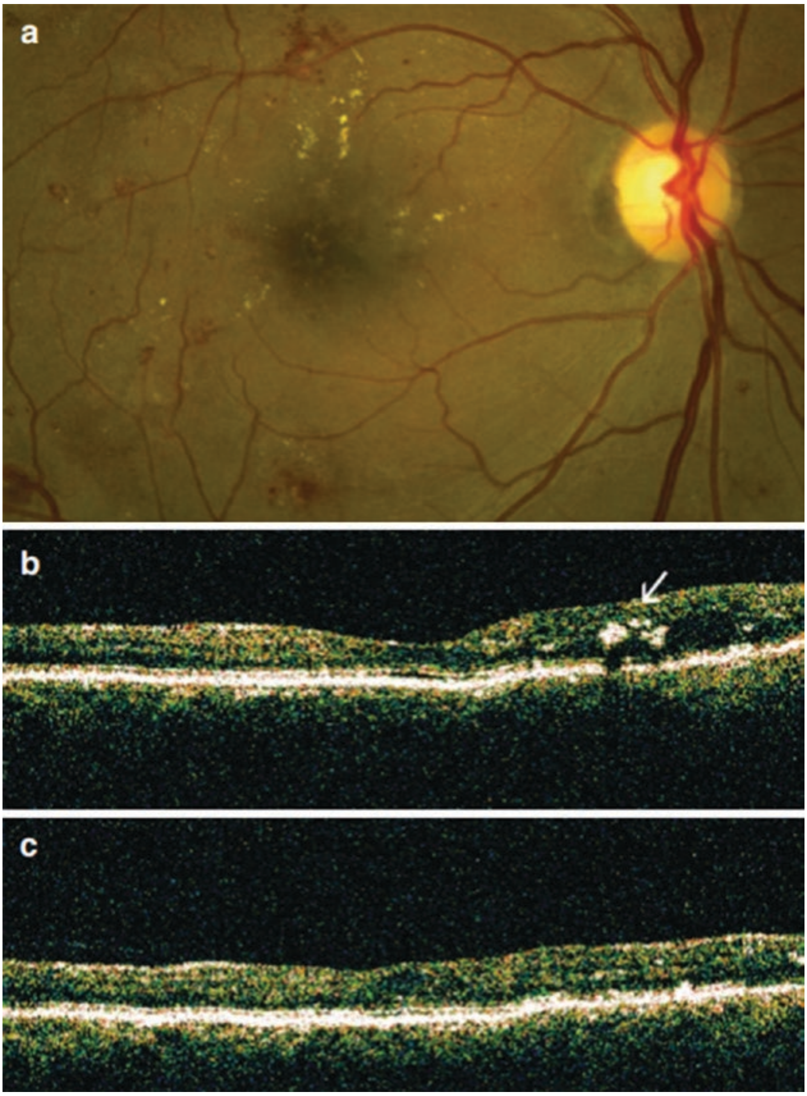

Fig. 2.3 54-year-old man with diabetic macular edema treated with focal argon laser. (**a**) Fundus photograph: clinically significant macular edema in the right eye. Yellow, refractile, hard exudates superiorly indicate an area of retinal thickening. (**b**) Optical coherence tomography (*OCT*): vertically oriented scan with the retinal area located inferior to the fovea represented on the left and the retinal area located superior to the fovea represented on the right. The superior retina is thick compared to the inferior retina because of diabetic macular edema. Intraretinal hard exudates (*arrow*) are seen in the superior retina as manifested by shadowing, with diminished detection of the more posterior retinal layers. (**c**) OCT of the same retinal area as shown in (**b**): 3 months after focal argon laser treatment. The superior retina is no longer thick and there has been resolution of the intraretinal hard exudates

Subfoveal recurrences were not treated with laser in these trials due to concerns about permanent central visual loss. Due to its deleterious effect on normal surrounding neural retina, the use of argon laser for choroidal neovascularization near the fovea sharply decreased with the advent of photodynamic therapy (see below) and antivascular endothelial growth factor therapies. However, argon laser does continue to have a rarely used but important role in that it is highly effective for extrafoveal isolated choroidal neovascular lesions. Patients should always be informed that this treatment induces a permanent scotoma.

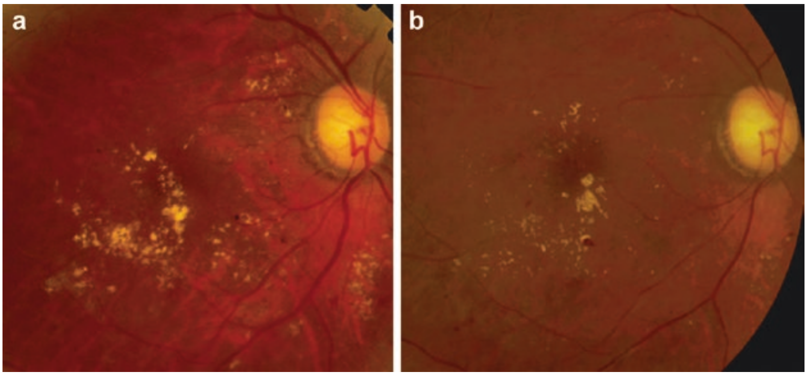

Fig. 2.4 60-year-old female with diabetic macular edema treated with focal argon laser. (**a**) Fundus photograph: clinically significant macular edema in the right eye. Yellow, hard exudates indicate areas of retinal thickening. (**b**) Fundus photograph: marked resolution of hard exudates 5 months after focal argon laser treatment

Fig. 2.5 Slit-lamp based delivery of argon laser photocoagulation. The patient is seen seated to the left with her face firmly placed in an ophthalmic microscope modified for laser delivery. The ophthalmologist views the retina and applies argon laser burns through a corneal contact lens seen in the physician's right hand

Fig. 2.6 Commonly employed ophthalmic lenses. A multitude of lenses can be used for argon laser treatment application depending on the desired magnification and field of view. Such lenses can be broadly categorized as either corneal contact lenses (five lenses located on the left: ocular Mainster 165, ocular three mirror, ocular Yannuzzi fundus, ocular Reichel-Mainster and ocular Mainster wide field) or indirect lenses (two lenses located on the right: 20-diopter and 28-diopter)

Technique

Pan-Retinal Photocoagulation

Argon laser can be applied for PRP from a slit-lamp based or indirect ophthalmoscopic system (Fig. 2.5). The slit lamp-based system is used for a seated patient and consists of a modified slit-lamp (specialized microscope for ophthalmoscopic exam) mounted on a table. The retina is visualized by using a wide-field contact lens (Fig. 2.6). The indirect system is composed of a headset worn by the ophthalmologist which emits the laser directly. For this system, the patient is typically reclined in an examining chair and the retina is visualized by using a 20-Diopter or 28-Diopter lens (Fig. 2.7).

The standard technique for PRP currently involves the placement of 800–1600 laser burns with a 500 ∝ m spot size, spaced 0.5 burn widths apart from each other with 0.1–0.2 s of duration [10]. Intensity is regulated so that mild white bleaching is obtained (Fig. 2.8). The treatment reaches from the temporal arcade to the equator, and up to 2 disc diameters temporal to the macular center. Typically 1 disc diameter or space is spared around the optic nerve to avoid central visual field defects.

Fig. 2.7 Indirect-ophthalmoscopic based delivery of argon laser photocoagulation. The patient is seen reclined in an examining chair. The ophthalmologist applies argon laser spots using a headset-based laser and visualizes the retina using either a 20-diopter or a 28-diopter lens seen in the physician's right hand

Focal Argon Laser Photocoagulation

Focal laser is typically applied using a slit-lamp based system for a seated patient (Fig. 2.5). A magnifying contact lens is held by the ophthalmologist for detailed viewing of small retinal features (Fig. 2.6). Focal laser treatment typically consists of 50–100 μm laser burns of 0.05–0.1 s duration applied to microaneurysms between 500 and 3000 μm from the center of the macula with the clinical endpoint defined as a color change to a mild whitening. For more diffuse macular edema, a grid pattern is typically applied in the following manner: 100–200 burns of a 50–200 μm spot size spaced 1 burn width apart within 2 disc areas of the fovea. In the ETDRS, an average of 3–4 treatment sessions 2–4 months apart were required [7]. The grid technique has been demonstrated in several more recent studies to be more effective than milder focal techniques in reducing retinal thickening based on detailed measurements taken with the optical coherence tomography (OCT) and thus continues to be the standard of care [11].

Fig. 2.8 42-year-old female with proliferative diabetic retinopathy underwent pan-retinal argon laser photocoagulation. Fundus photograph of retinal burns 3 h after application. Discrete, cream-colored round lesions are seen deep to the retinal vasculature. Over the ensuing weeks to months, these subtle lesions will evolve into more noticeable areas of retinal atrophy, often with associated pigment clumping, as seen in Figs. 2.1b and 2.2

Laser for Choroidal Neovascular Membranes in Neovascular ARMD and Other Conditions

Laser for choroidal neovascular membranes is typically applied using a slit-lamp based system for a seated patient. A magnifying contact lens is held by the ophthalmologist for detailed viewing of small retinal features. In the MPS studies, argon laser was applied to cover the choroidal neovascular membrane (location judged on fluorescein angiogram) and 100 μm beyond the edge of the lesion, but was never applied closer than 200 μm from the center of the fovea. The laser was set initially at a 200 μm spot size, 0.2–0.5 s duration, and 100–200 mW power. The power was adjusted to achieve an intensity sufficient enough to produce a uniform whitening of the overlying retina.

Adverse Events

Pan-Retinal Photocoagulation

The complications of PRP in the DRS were generally mild and included a decrease in visual acuity of 1 or more lines in 11% and peripheral visual field loss in 5% [12]. The DRS and ETDRS also indicated that macular edema can be worsened by PRP leading to moderate visual loss [4].

Focal Argon Laser Photocoagulation

The side effects and complications of focal laser in the ETDRS included: paracentral scotoma, transient increased edema/decreased vision, choroidal neovascularization, subretinal fibrosis, photocoagulation scar expansion over time, and inadvertent foveal burns [4, 7].

Laser for Choroidal Neovascular Membranes in Neovascular ARMD and Other Conditions

Complications from argon laser for choroidal neovascularization include: hemorrhage, perforation of Bruch's membrane, retinal pigment epithelial tear, and arteriolar narrowing [9, 13]. Persistent or recurrent neovascularization is common: in the MPS, 34% of patients treated for new subfoveal neovascularization had persistent or new neovascularization over 3 years of follow-up [14]; 53% of eyes treated for extrafoveal neovascularization in the MPS had recurrent neovascularization [15]; 32% of eyes treated for juxtafoveal neovascularization had persistent neovascularization, and an additional 42% had recurrent neovascularization at 5 years of follow-up [9, 13].

Future Directions

Pan-Retinal Photocoagulation and Focal Argon Laser Photocoagulation

The uses of PRP for proliferative diabetic retinopathy and focal laser for diabetic macular edema have been reliable mainstays of treatment for diabetic patients for decades. Pars plana vitrectomy (PPV) has also been used successfully for a decade for refractory diffuse macular edema which demonstrates a tractional component [16]. In the last decade, there has been a shift in the use of antivascular endothelial growth factors (anti-VEGF) formulated as intravitreal injections to serve as alternatives or supplements to laser treatments [45]. Many early studies have found these agents to be beneficial for these conditions, especially in the short term [17–19]. Recent trials have found monotherapy with anti-VEGF agents non-inferior to PRP over the course of 2 years with fewer vitrectomies and better central visual acuity [46–48]. However, there is still significant concern regarding the chronic dependence for anti-VEGF agents in diabetic retinopathy and the possible masking of ischemic changes with intravitreal treatments.

Laser for Choroidal Neovascular Membranes in Neovascular ARMD and Other Conditions

Argon laser photocoagulation is limited in its use for choroidal neovascularization due to narrow eligibility criteria, immediate visual loss due to scotoma, and high recurrence rates [21]. These shortcomings prompted research into other treatment modalities which have since proven to be safer and more effective in preserving and improving vision, such as intravitreal anti-VEGF agents.

Photodynamic Therapy (PDT)

Indications

Ocular PDT was first introduced as a novel treatment for neovascular (wet) age-related macular degeneration (ARMD) and choroidal neovascularization in the mid to late 1990s. At the time, it was hoped that the narrow eligibility requirements and high recurrence rates of the MPS would be improved with PDT. Two large prospective multicenter randomized trials were completed with long-term follow-up examining its use for these conditions with extended follow-up, the Treatment of Age-Related Macular Degeneration with Photodynamic Therapy (TAP) study [22], and the Verteporfi in Photodynamic Therapy Study Group (VIP) study [23]. The TAP study examined the use of PDT for certain subtypes of wet ARMD (those with some classic component on fluorescein angiography) and demonstrated benefit over placebo for patients with predominantly classic lesions. Vision in these patients remained stable with extended follow-up. In the VIP study, there were two arms: patients with choroidal neovascularization secondary to pathologic myopia and patients with wet ARMD with occult neovascularization. Patients in both arms had a visual benefit over placebo at 24 months, although subset analyses revealed a decrease in vision in treated patients over controls when the treated lesion size was large and baseline vision was better than 20/50.

Since the completion of the TAP and VIP trials, the off-label use of PDT has been reported in many small series for the treatment of many inflammatory, infections, trauma-related and idiopathic conditions associated with choroidal neovascularization including: idiopathic polypoidal choroidal vasculopathy (IPCV); chorioretinitis including presumed ocular histoplasmosis syndrome (POHS), punctate inner choroidopathy (PIC), multifocal choroiditis; angioid streaks; chronic idiopathic central serous chorioretinopathy (ICSC); macular dystrophies; and choroidal rupture [24]. For many of these conditions, the advent of anti-VEGF pharmacotherapies has largely replaced the use of PDT over the past several years. PDT has also been reported in small case series for the treatment of intraocular tumors including: in tuberous sclerosis; choroidal hemangioma; capillary hemangioma; retinoblastoma; uveal melanoma; angiomas in Von Hippel Lindau disease; and squamous cell carcinoma of the conjunctiva [25, 57]. Among these tumors, the largest body of evidence exists for the use of PDT for subretinal exudation and serous retinal detachment associated with choroidal hemangioma (Fig. 2.9). First reported by Barbazetto et al. in 2000 [26], there are now more than ten small case series reporting its successful use including the largest series which had 19 patients [27]. Given its success with minimal complications, PDT has emerged as the new standard of care for this disease entity.

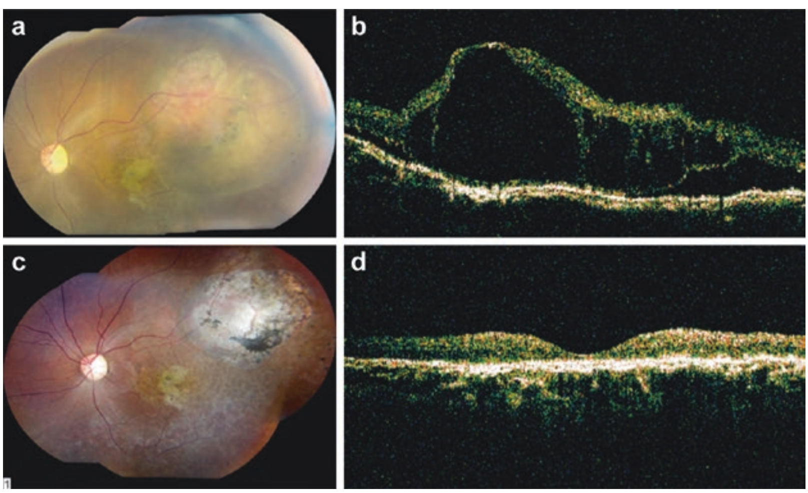

Fig. 2.9 45 year-old male with a large choroidal hemangioma, left eye. (**a**) Fundus photograph demonstrating the orange-red tumor at presentation. (**b**) Optical coherence tomography (*OCT*): vertically oriented scan with the retinal area located inferior to the fovea represented on the left and the retinal area located superior to the fovea represented on the right. There is a large amount of subretinal fluid (black cystic-appearing space under the retina) associated with the tumor. (**c**) Fundus photograph 9 months after photodynamic therapy (*PDT*). The tumor has regressed with associated chorioretinal scarring and atrophic changes in the retinal pigment epithelium. (**d**) OCT demonstrating resolution of the subretinal fluid

Technique

The protocol for the application of PDT was established in the TAP and VIP trials [22, 23], and generally a similar or identical protocol is used for off-label uses other than wet ARMD or pathologic myopia. PDT is performed by using the photosensitizer verteporfin (Visudyne, Novartis Ophthalmics, Switzerland) which selectively targets vascular endothelial cells [22]. The procedure has two steps: first, the verteporfin is injected intravenously for 10 min (at a dose of 6 mg/m^2 body surface area). Five minutes later, selective activation of the dye in the target tissue is achieved by applying a diode laser emitting light at 689 nm to an area 1000 ∝ m larger than the greatest dimensions of the lesion of interest. The dose of light delivered is 50 J/cm^2 at an irradiance of 600 mW/cm^2 over 83 s. PDT's presumed mechanism of action is the selective vascular occlusion of the intraluminal portion of exposed vessels without damaging adjacent neural structures [24].

Adverse Events

Minor adverse events reported in the TAP and TAP extension trials included: injection site inflammation, infusion-related back pain, allergic reactions, and photosensitivity reaction [22]. Rare ocular adverse events included vitreous hemorrhage and retinal capillary nonperfusion. Visual disturbance, defined as any visual complaint including visual field defect irrespective of its relationship to the treatment, occurred in 22% of treated patients versus 15% of controls at 24 months of follow-up [28]. Acute severe acuity visual decrease was extremely rare (<1%).

Future Directions

With the successful introduction of anti-VEGF, the use of PDT for wet ARMD has diminished dramatically. It will likely continue to be used as a secondary treatment option in patients who do not respond to anti-VEGF therapy and seek an alternative. Recent studies have shown that in some cases it may be used in combination with anti-VEGF agents to decrease the intravitreal injection burden [49, 50]. PDT may continue to play in important role in the treatment on intraocular tumors [57, 58].

Diode Laser

Indications

The current primary application of diode laser in the posterior segment is the treatment of ocular tumors such as retinoblastoma, the most common primary intraocular malignant tumor in children, and uveal melanoma, the most common primary malignant intraocular tumor in adults. Diode laser has also been used effectively in other rare pediatric retinal conditions [51, 52]. Guidelines and indications for the use of diode laser for these tumors are highly variable by center, and no clear standard has been established.

For retinoblastoma, laser treatment is most commonly used as an adjunctive therapy along with systemic chemotherapy. In the largest published study, 188 tumors in 80 eyes of 50 patients were treated with chemotherapy and laser, and 86% demonstrated regression [29]. In another study of 91 small tumors in 22 eyes of 24 patients treated with laser alone, 95% of tumors 1.5 disc diameters or smaller underwent long-term regression without any other treatment [30].

For uveal melanoma, several groups of authors have reported the use of argon or diode laser in combination with plaque radiotherapy with the goal of ensuring better local tumor control, especially for tumors located near the optic nerve and fovea [31–35]. The largest of these studies examined the local tumor control rates in 270 patients treated with Iodine-125 plaque therapy followed by three sessions of transpupillary thermotherapy administered at plaque removal and at 4-month intervals [33]. Kaplan Meier estimates of tumor recurrence were 2% at 2 years and 3% at 5 years. These local control rates appear to be higher than those observed in the Collaborative Ocular Melanoma Study (10.3% failure at 5 years), but cannot be compared easily due to short follow-up time in the study. When compared with patients treated with radioactive plaque therapy alone, tumors treated with radioactive plaques and argon laser appear to regress faster but result in more short-term visual acuity loss [35]. Larger randomized prospective trials are needed comparing radioactive plaque therapy alone to plaque therapy with adjunctive laser and/or transpupillary thermotherapy.

Technique

For retinoblastoma, thermal energy is delivered from the 810 nm infrared lased by one of three techniques: (1) using an adaptor on the indirect ophthalmoscope and a 20-Diopter or 28-Diopter lens which delivers a large 1.6 mm spot size; (2) using a pediatric laser gonioscopy lens and an adaptor on the operating room microscope which delivers a 3 mm spot size; or (3) using a transconjunctival diopexy probe which delivers a 1 mm spot size [36]. The laser is generally set on 350 mW to start the procedure and adjusted until a gray-white color change is noted in the tumor. Some centers utilize a method called transpupillary thermotherapy (TTT) which consists of modifi to the diode laser's hardware and software. Typically, the laser beam is aimed directly at the tumor, and the tumor surface is completely covered with overlapping laser spots to ensure that no areas are missed. The mechanism by which diode laser causes tumor cell death is thought to be different from the mechanism by which classic laser photocoagulation destroys tumors. The temperature of the diode laser is thought to be lower (45–60 °C) and the thermal effect leads to direct apoptosis of the tumor cells. For this reason, the laser is directed at the tumor rather than at its feeder vessels [36].

One controversy regarding the use of laser for retinoblastoma is whether to apply the laser directly to the macula. Some centers advocate the use of laser with avoidance of application directly to the fovea to decrease the risk of severe treatment-related central visual loss [37]. Other centers have reported results when using chemotherapy alone without and laser [38]. Our group recently published an analysis of our series of retinoblastoma patients treated with 4–9 cycles of three-drug chemotherapy and diode laser ablation [39]. All of the patients in this cohort had retinoblastoma presenting in the macula and each patient was treated aggressively with diode laser at every examination under anesthesia until the patient's tumor was noted to be inactive for at least 6 months (Fig. 2.10a–d). Hundred percent of the patients with early stage disease and 83% of patients with advanced disease avoided external beam radiation and enucleation at 3 years. These tumor control rates far exceed those published at other centers. Furthermore, 57% of patients maintained 20/80 or better vision.

Adverse Events

Reported complications from diode laser include: focal iris atrophy, focal lens opacities, sector optic disc atrophy, retinal traction, optic disc edema, retinal vascular occlusion, serous retinal detachment, choroidal neovascular membrane, peripheral anterior synechiae, and corneal edema [29, 39]. The most common side effect is focal iris atrophy which is associated with an increasing number of treatment sessions and an increasing tumor base diameter [29].

Future Directions

No standardized protocols have been established for the application of diode laser therapy for intraocular tumors and other rare retinal entities. Optimal technique-related approaches, such as when and how often to treat, how much power to use, which areas of the tumor to treat, and whether to treat the fovea remain uncertain. Prospective standardized studies are essential in the future in order to establish the ideal treatment method and clinical standardization, especially for retinoblastoma given the current disparate tumor control rates at different institutions.

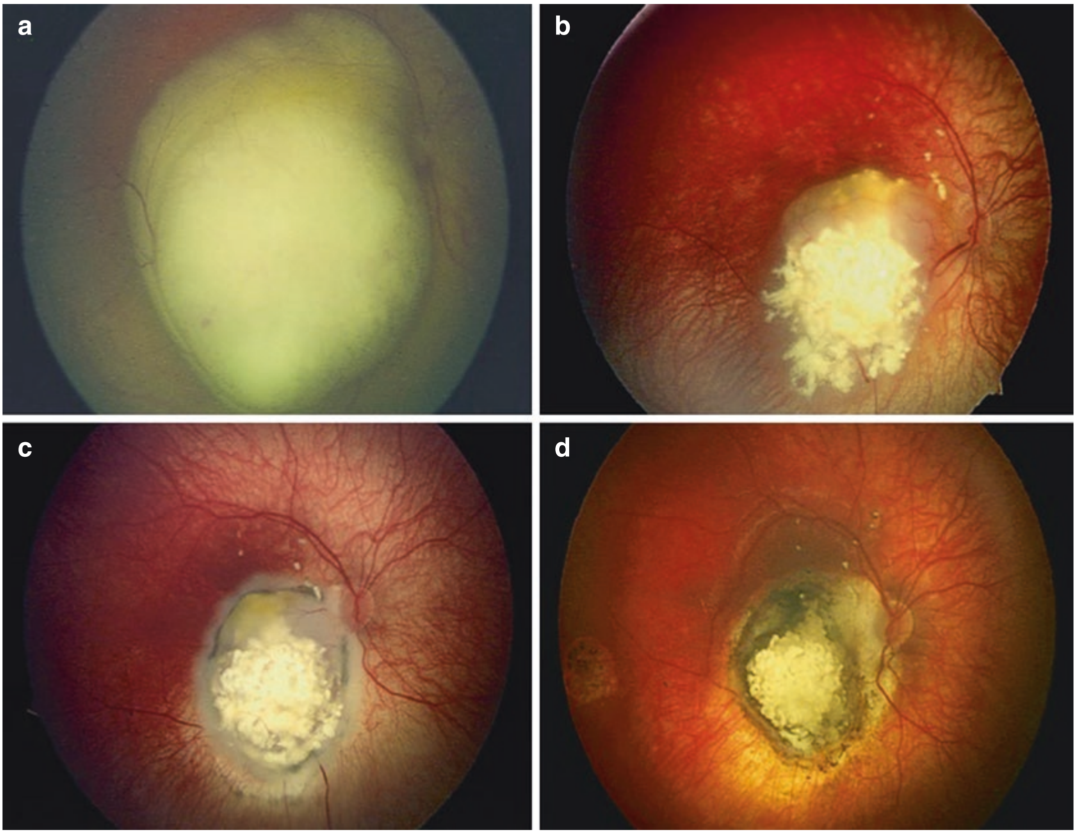

Fig. 2.10 Right eye of an 11 month-old male with advanced retinoblastoma, fundus photographs. (**a**) At presentation, the large tumor obscures the macula and optic nerve. (**b**) Dramatic shrinkage of the tumor is observed after two cycles of intravenous chemotherapy and two diode laser treatments. (**c**) Additional reduction in the size of the tumor is noted after four cycles of intravenous chemotherapy and nine diode laser treatments. (**d**) Chorioretinal scarring and complete tumor regression with typical calcified appearance. The patient underwent a total of six cycles of intravenous chemotherapy and nine diode laser application sessions. The patient developed an additional tumor focus temporal to the macula (left margin of photograph) that was treated with laser. The final visual acuity in this eye was 20/60 (Figures reproduced from Schefler et al. [39] with permission)

Endolaser During Vitreoretinal Surgery

Indications

First developed in 1979 by Charles, the introduction of endophotocoagulation was a significant advance in vitreoretinal surgery [40]. In his original system, he used a fiber optic probe attached to a portable xenon arc photocoagulator. The xenon arc was not ideal for surgery, however, and several years later, Peyman developed an argon laser probe that enabled more rapid firing, had a more comfortable and safe working distance, and didn't generate as much heat [41]. The argon green and diode lasers are currently used most frequently.

During vitrectomy procedures, the endolaser is used most commonly to create a laser barricade around retinal hole, surround retinectomy edges or giant retinal tear margins, and deliver scatter pan-retinal photocoagulation. It can also be used for primary treatment of some intraocular tumors such as secondary angiomas, choroidal hemangiomas, capillary hemangioblastomas, and small choroidal melanomas.

For retinal holes, the goal is to achieve 360° of laser encircling the tear. In order to achieve an effective laser burn, subretinal fluid under the hole must be fully aspirated or the retinal pigment epithelium will not absorb the laser energy effectively. For retinectomies and giant retinal tears, laser spots are generally placed around large areas of detached retina or to wall off the area of prior detachment such as in cases or proliferative vitreoretinopathy or viral retinitis. Reattached retina is typically lasered overlying a scleral buckle which is typically a silicone band placed around the outside of the eye to maintain the reattached position of the retina. Endolaser can be placed through perfluorocarbon liquids which are often used to hold the retina in position. Afterword, perfluorocarbons are exchanged with air, reducing visibility and making lasering more difficult.

For panretinal laser photocoagulation, the goal is similar to pan-retinal photocoagulation performed using slit-lamp or indirect ophthalmoscopic systems. The endolaser typically enables easier access to more peripheral retina than the nonoperative systems, particularly if wide-angle intraoperative viewing systems are used.

Endophotocoagulation can also be applied to neovascular tissues prior to removing them or to healthy retina prior to a retinectomy to minimize bleeding. The argon green laser is generally used for this purpose because it is best absorbed by blood. Diathermy can also be used.

For intraocular tumors, the goal is varied. In choroidal hemangiomas, the goal is to create a chorioretinal scar that blocks fluid from reaching the fovea. In secondary angiomas and capillary hemangioblastomas, it can be used as the primary treatment at the time of vitrectomy. In small choroidal melanomas, the goal is to increase the intratumoral temperature and denature proteins associated to the tumor.

Techniques

The endolaser probe is an instrument that is available in several forms including: different gauges, straight or curved, blunt or tapered, simple or aspirating [42], or illuminating (Fig. 2.11) [43]. The straight probe with a blunt or tapered tip is used most commonly. The curved tip is useful for applying laser to the difficult-to-reach anterior superior retina or peripheral retina near the surgeon's dominant hand. The aspirating tip can be used to drain subretinal fluid or blood from the edge of retinal holes while lasering. The illuminating probe frees the opposite hand for use of another instrument [44]. More recently, thinner probes have been developed including 23-gauge, 25-gauge and 27-gauge systems. These probes can be used in smaller sclerotomy incisions enabling a sutureless closure at the end of the surgery and enhanced post-operative comfort for the patient.

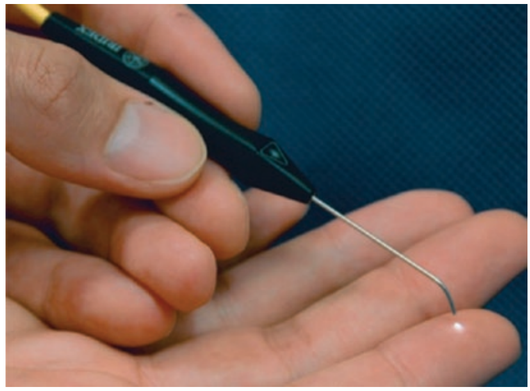

Fig. 2.11 Endocoagulation is performed using an argon laser probe. The fiber optic probe shown is a self-illuminating instrument with a curved tip. During vitrectomy, the probe is inserted through a sclerotomy. Common clinical indications for endolaser use include creating a laser barricade around a retinal hole, surrounding retinectomy edges or giant retinal tear margins, and delivering scatter pan-retinal photocoagulation

The initial settings of the argon laser are typically for 0.1–0.2 s with a power of 200 mW. For the diode laser, the settings are generally 0.2–0.3 s, and 200–300 mW. The power is typically adjusted gradually in 50 mW steps until a gray-white color change is noted. A continuous setting is helpful for treating active hemorrhage or around retinotomies.

When treating intraocular tumors, it is important to apply treatment continuously to the tumor surface and avoid any skip areas. Overtreatment should be avoided to minimize postsurgical complications.

Adverse Events

Complications from endolaser are rare but can include: retinal tears, choroidal neovascularization, and retinal necrosis from overly intense treatment. Inadvertent overtreatment can occur by placing the probe too close to the retina or by not titrating the laser energy slowly upward based on a retinal color change.

Future Directions

Recent studies have shown that tumoral genetic expression profile (GEP) is the most important prognostic measurement associated to choridal melanoma [53, 54]. Endophotocoagulation may be used at the time of transvitreal GEP biopsy to primarily treat small choroidal melanomas. Endophotocoagulation at the time of transvitreal biopsy may also decrease vitreous hemorrhage and vitreous seeding postoperatively. Recent reports have shown that endophotocoagulation can be used prior to transvitreal biopsies for small, medium, and large choroidal melanomas [55, 56]. The ongoing trend towards GEP characterization in choroidal melanoma may lead to increased use of the endolaser in the management of malignant uveal tumors. This treatment approach may decrease the use of brachytherapy and improve the historically poor visual outcomes.

The endolaser is a highly critical component of vitreoretinal surgery. When placed on proper settings and applied carefully, it can be performed safely with minimal risks. As smaller gauge systems have recently been developed, the number of available probes and configurations has increased, enabling greater choice and versatility for the surgeon. Endophotocoagulation will no doubt continue to be an integral aspect of vitreoretinal surgery for a long time.

Conclusions

Laser technology has been used for many years in ophthalmology with great success. Some previously common indications for the use of laser have become largely obsolete in recent years such as the use of argon laser for the treatment of juxtafoveal choroidal neovascular membranes. This shift in treatment approach has occurred due to the introduction of newer, more effective treatments. Nonetheless, the use of laser will no doubt continue to have an important role in ophthalmology. Given its accessibility and transparent media such as the cornea, aqueous, and vitreous, the eye remains an organ that is particularly amenable to this form of treatment. Direct inspection both during and after laser procedures enables easy assessment of the efficacy of laser use. Furthermore, the uveal tract, made up of the iris, ciliary body, and choroid, contains melanin pigment, allowing effective absorption of photothermal laser energy. As more clearly defined indications for the use of new pharmacotherapies such as anti-VEGF drugs are developed, laser procedures will likely develop an important combination therapy/adjunctive role for rare conditions such as intraocular tumors as well as for more common diseases such as proliferative diabetic retinopathy, diabetic macular edema, and choroidal neovascularization.

Disclaimer No conflict of interest or financial interest exists for any author.

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3 Laser/Light Application in Ophthalmology: Control of Intraocular Pressure

Krishna B. Patel, Michael C. Giovingo, Ramez I. Haddadin, and Douglas J. Rhee

Abstract

The term "glaucoma" refers to a group of disorders that share common phenotypes. There are over 20 different subtypes of glaucoma. The glaucomas are defined by a characteristic loss of retinal ganglion cell axons leading to a progressive optic neuropathy that is related to intraocular pressure (IOP). If untreated, glaucoma can cause visual disability and even blindness. Although elevated intraocular pressure (IOP) is no longer formally part of the definition, it is recognized as the major risk factor for progression of the disease.

Keywords

Glaucoma · Intraocular pressure · Laser applications · Laser iridotomy · Laser iridoplasty · Laser trabeculoplasty · Cyclophotocoagulation

- Glaucoma is a multifactorial optic neuropathy that results in progressive vision loss.
- The only treatable risk factor for glaucoma is intraocular pressure (IOP).
- Diagnosis of glaucoma requires measurement of IOP, assessment of vision loss by visual field testing, determination of corneal thickness, examination of the ocular fundus for signs of optic neuropathy such as cupping, and differentiation of open- and closed-angle glaucoma by gonioscopy.
- Treatment differs for closed-angle glaucoma (CAG) and open-angle glaucoma (OAG).
- Medications, laser procedures, minimally invasive glaucoma surgeries (MIGS) and incisional surgery are all critical to the management of glaucoma. The method of treating a particular patient depends on the severity as well as the type of glaucoma
- Laser iridotomy is the creation of a microscopic hole through the iris that serves as an alternate route of aqueous flow that bypasses the blockage at the pupil between the iris and the lens.
- Laser peripheral iridoplasty is a procedure that causes circumferential contraction of the iris away from the trabecular meshwork. Its main indication is CAG, specifically plateau iris syndrome, and is often attempted when

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K. Nouri (ed.), *Lasers in Dermatology and Medicine*, https://doi.org/10.1007/978-3-319-76220-3_3

laser iridotomy fails or is not indicated because the pathophysiology does not involve pupillary block.

- Laser trabeculoplasty is the application of laser to the trabecular meshwork with the intention of increasing aqueous outflow. Selective laser trabeculoplasty (SLT) is a technique that seems to be equally effective to argon laser trabeculoplasty (ALT). Advantages of SLT include a potential benefit from treatment following ALT, and theoretically its use for multiple treatments.
- Both ALT and SLT are effective first-line agents for primary open-angle glaucoma.
- Cyclophotocoagulation is the use of laser to destroy ciliary body tissue in order to decrease aqueous humor production and reduce intraocular pressure. Because of its higher rate of side effects and complications, it is usually reserved for glaucoma refractory to all other treatment options. There are four approaches to cyclophotocoagulation: contact transscleral, including transscleral cyclophotocoagulation and micropulse transscleral cyclophotocoagulation, noncontact transsceral, transpupillary, and endoscopic.
- There are a number of other applications for laser in glaucoma that are either adjuncts to or very similar to surgical procedures for glaucoma. These include laser sclerostomy, laser suture lysis, closure of cyclodialysis clefts, and goniophotocoagulation.

Introduction

- Glaucoma is a multifactorial optic neuropathy that is initially asymptomatic but can result in progressive visual field deficits.
- The prevalence of glaucoma increases with age, but can be seen at birth (i.e. congenital). Intraocular pressure (IOP) elevation is a major primary risk factor.
- The many types of glaucoma can be generally categorized into open-angle glaucoma (OAG) and closed-angle glaucoma (CAG).
- Diagnosis of glaucoma requires measurement of IOP and corneal thickness, optical coherence tomography of the retinal nerve fiber layer, ganglion cell analysis, assessment of vision loss by visual field testing, and examination of the ocular fundus for signs of optic neuropathy such as cupping, and differentiation of OAG and CAG by gonioscopy.
- The only clinically proven treatment for glaucoma is lowering the IOP. This can be accomplished with medications, laser surgery, and/or incisional surgery.
- Laser surgery has become increasingly popular as a treatment modality for glaucoma because the risks are favorable in comparison to incisional surgery. A number of lasers are used, the most common being argon, neodymium:yttrium-aluminum-garnet (Nd:YAG), and diode lasers. The specific laser used

Definition, Classification, and Epidemiology

The term "glaucoma" refers to a group of disorders that share common phenotypes. There are over 20 different subtypes of glaucoma. The glaucomas are defined by a characteristic loss of retinal ganglion cell axons leading to a progressive optic neuropathy that is related to intraocular pressure (IOP). If untreated, glaucoma can cause visual disability and even blindness. Although elevated intraocular pressure (IOP) is no longer formally part of the definition, it is recognized as the major risk factor, and only modifiable risk factor, for progression of the disease.

The subtypes of glaucoma are categorized into open-angle glaucoma (OAG) or closed-angle glaucoma (CAG). The "angle" refers to the iridocorneal (iris-cornea) junction at the periphery of the anterior chamber (Fig. 3.1). The angle is the site of drainage for aqueous humor. OAGs and CAGs are further subclassified into 'primary,' when the cause of the dysfunctional IOP is unknown, or 'secondary,' when the cause of the elevated IOP is the result of a known disease process. Furthermore, glaucomas are classified by their onset—acute or chronic. The most common

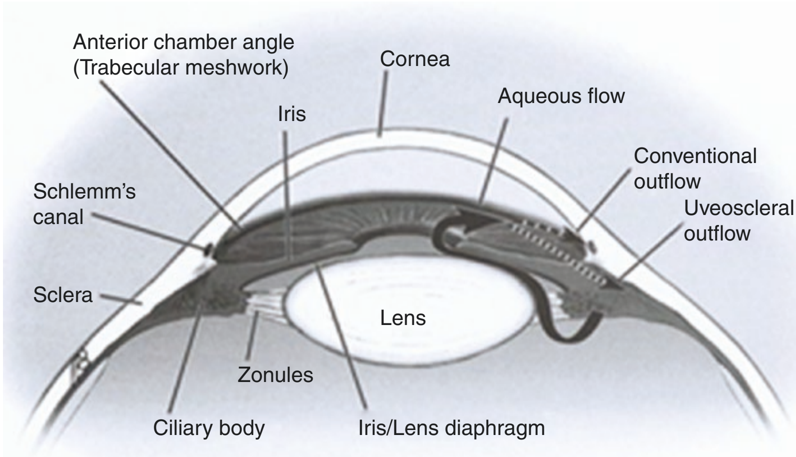

Fig. 3.1 Anterior segment anatomy and physiology

form of glaucoma in the United States is primary open-angle glaucoma (POAG).

With approximately three million Americans affected by glaucoma it is the second leading cause of blindness in the United States. Although it affects people of all ages, it is six times more common in those over 60 years of age than those 40 years of age. Annual medical costs for glaucoma services to glaucomatous patients and glaucoma suspects totals over 2.86 billion dollars.

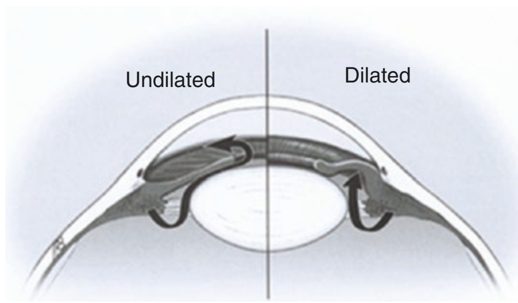

Fig. 3.2 Close-angle glaucoma due to pupillary block

Aqueous Physiology and Pathophysiology

Aqueous humor is a clear fluid that circulates in the anterior chamber of the eye to provide nutrients and remove metabolic waste from the avascular structures of the eye—namely the lens, cornea, and trabecular meshwork. The balance of aqueous secretion and drainage determines the IOP. Aqueous humor is produced by the ciliary processes, which are located behind the iris, through active secretion, ultrafiltration, and diffusion. Aqueous circulates within the posterior chamber, travels through the pupil, and exits the eye through the angle via one of two pathways (Fig. 3.1): (1) the conventional pathway through the trabecular meshwork, canal of Schlemm, intrascleral channels, and then episcleral and conjunctival veins; or (2) the uveoscleral pathway, through the ciliary body face, choroidal vasculature, and vortex or scleral veins. The conventional pathway is responsible for the majority of outflow, especially in older adults. CAG results from physical obstruction of these drainage tissues by approximation of the iris and cornea (Fig. 3.2). OAG occurs when aqueous drainage is impaired by increased resistance to aqueous drainage that is intrinsic to the outflow pathways (Fig. 3.3). Although it is possible that overproduction of aqueous humor could lead to an elevated IOP, all studies have shown that the pathophysiology is poor aqueous drainage. The average IOP is approximately 16 mmHg (2 mmHg standard deviation). An elevated IOP is defined as a value that is 2SD above the average (i.e., >20 mmHg). There is a form of OAG, named "low-" or "normal-tension glaucoma," in which damage occurs within the average range (11–21 mmHg). Although IOP reduction is often effective treatment for this type of glaucoma, other etiologic factors such as vasospasm or

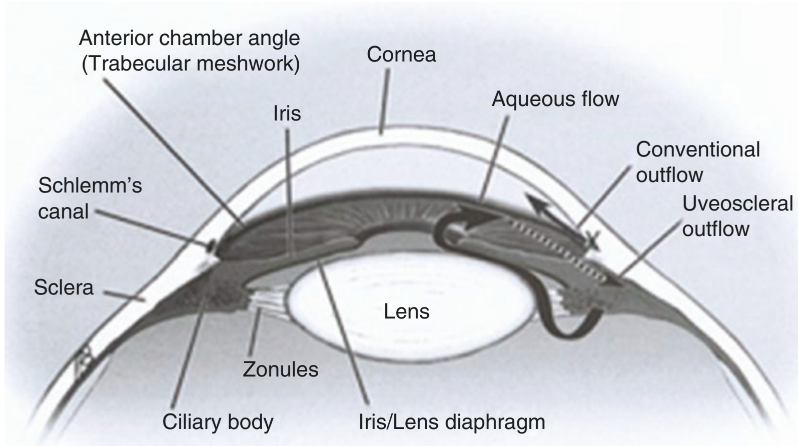

Fig. 3.3 Open-angle glaucoma

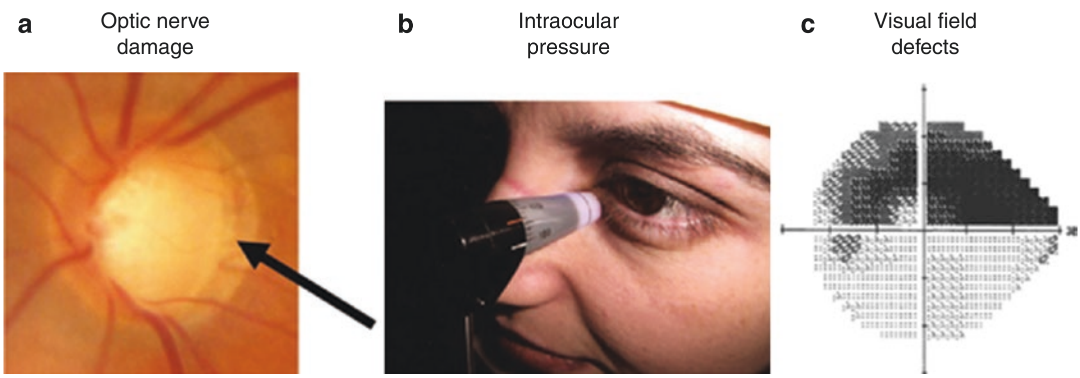

Fig. 3.4 Clinical triad of glaucoma, (**a**) optic nerve damage, (**b**) intraocular pressure, (**c**) visual field defects

ischemia are thought to have a larger role in the pathophysiology.

Symptoms

Vision loss from chronic glaucoma is usually painless and slowly progressive. Peripheral vision is usually affected first, and the deficits may be asymmetric. This results in delays in realization of vision loss.

Acute angle closure and a few secondary glaucomas present with symptoms, most commonly a painful red eye, blurred central vision, and rapid progression of visual loss. The presence of non-visually related symptoms are due to the rapid change in IOP causing immediate ischemic compromise of several ocular tissues—principally, the cornea and optic nerve.

Diagnosis

Diagnosis of glaucoma requires a complete history and ocular examination including measurement of IOP, determination of corneal thickness, assessment of the anterior chamber angle by gonioscopy, quantification of vision loss by visual field testing, and examination of the ocular fundus for signs of optic neuropathy such as cupping (Fig. 3.4). Gonioscopy is examination of the iridocorneal angle with a slit-lamp and contact lens containing mirrors to visualize the angle. Measurement of an elevated IOP identifies a significant risk-factor but is neither necessary nor sufficient for the diagnosis of glaucoma. Visual field defects and optic nerve defects characteristic of glaucoma are strong support for the diagnosis but other causes of optic neuropathy such as optic neuritis need to be excluded.

Treatment

To date, lowering IOP is the only clinically proven treatment for the glaucomas. Glaucoma suspects may also be treated depending on the presence of high risk characteristics and the individual risk aversion of the patient. The treatment approach differs between CAG and OAG. CAG treatment requires laser or incisional surgery to bypass the mechanical blockage. OAG can be treated with topical medications, laser, and/or incisional surgery. Topical medication may decrease aqueous production or increase aqueous drainage. Laser trabeculoplasty attempts to enhance the drainage function of the trabecular meshwork. Laser peripheral iridotomy creates a secondary pathway to allow aqueous to bypass a potential blockage; in doing so, equalization of the pressure gradient between the spaces anterior and posterior to the iris often allows the angle to deepen. Laser iridoplasty directly alters the angle anatomy by moving the iris away from the drainage structures. Glaucoma refractory to the above treatments may require cyclodestructive procedures to destroy the ciliary body and decrease aqueous production. Incisional operations such as trabeculectomy and glaucoma drainage implant devices create a new pathway to drain aqueous from the anterior chamber to the subconjunctival space.

General Comments Regarding Lasers in Glaucoma

Many lasers are used in glaucoma management. Their use has increased because their less invasive nature and generally lower rates of complications appeal to surgeons. The most commonly used lasers are argon diode and neodymium:yttrium-aluminum-garnet (Nd:YAG). The argon laser (488–514 nm) has a thermal effect on tissues, which either results in coagulation or vaporization depending upon the power settings used. The diode laser (810 nm) also has a photocoagulative effect. The Nd:YAG laser (1064 nm) has a coagulative effect when used in a continuous-wave mode. The short-pulsed q-switched Nd:YAG has a photodisruptive effect on tissues, which has an explosive effect. Other lasers have a photoablative effect that results in excision of tissue without any damage to the adjacent tissue. Photoablation has more applications for the cornea, but is also used in glaucoma. Besides the type of effect observed on tissues, different lasers may be used because they specifically target a certain type of tissue or because they have a desirable depth of penetration.

Laser Iridotomy

Iridotomy is the creation of a microscopic hole through the iris that provides an alternate route for aqueous to enter the anterior chamber (Fig. 3.5). Laser iridotomy is preferred over surgical iridotomy because it is safer, equally effective, and preferred by patients; however, surgical iridectomy serves as second-line treatment if laser iridotomy is unable to be performed (e.g. a patient who is unable to maintain position in the laser). The popularity of this established technological advancement is evidenced by utilization statistics. Although the total number of laser iridotomies and surgical iridectomies has increased in proportion to the aging population, the ratio of laser iridotomies to surgical iridectomies performed has increased from 15:1 in 1995 to 52:1 in 2004. The procedure is treatment for all forms of CAG that involve pupillary block. Patients with easily occludable angles may also require the procedure.

Indications and Contraindications

Indications

- Closed-angle glaucoma with pupillary block
- Narrow angles with signs of glaucoma
- Narrow angles with positive provocative tests

Contraindications

- Opacified cornea
- Uncooperative patient who is unable to maintain position for the procedure

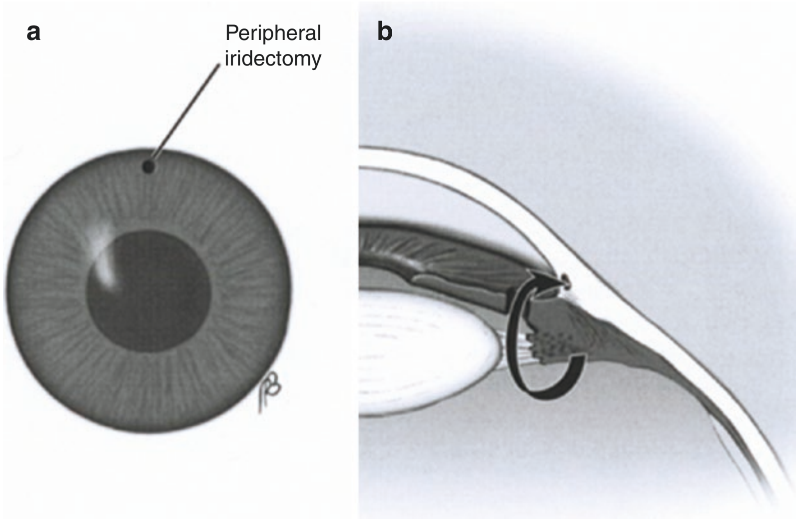

Fig. 3.5 Laser peripheral iridotomy, (**a**) shows clinical appearance of an iridotomy at the 12 o'clock position of the iris; (**b**) shows a secondary pathway to allow aqueous to bypass a potential blockage

The primary indication for laser iridotomy is to relieve pupillary block that may progress to acute angle closure glaucoma or CAG. Mechanistically, pupillary block is caused by an increased resistance to aqueous flow through the pupil because of anatomic obstruction of the pupil by the lens or another anterior or posterior structure. Increased resistance leads to a pressure differential between the anterior and posterior chambers, which results in anterior bowing of the peripheral iris over the trabecular meshwork. Laser iridotomy is indicated if pupillary block has caused angle-closure or is in imminent threat of causing angle-closure. Angle-closure glaucoma may be acute, intermittent, or chronic; and all are indications for laser iridotomy. If narrow angles are identified, then the risks and benefits of treatment should be considered. For example, treatment would be indicated if there are signs of previous attacks or if the fellow eye has CAG. Additionally, patients with narrow angles can undergo tests to provoke angle-closure such as administration of a mydriatic agent, exposure to dark, or placement in the prone position. These tests may cause IOP elevation, and therefore may serve as an indication for treatment. Finally, in eyes where the clinician feels the angle is potentially occludable, laser iridotomy is indicated.

Specific causes of pupillary block include phacomorphic glaucoma (glaucoma caused by an excessively large lens), a dislocated lens, anterior protrusion of the vitreous face, occlusion by an artificial (pseudophakic) lens in the anterior chamber, posterior synechiae (adhesions of the central iris to the lens usually as a result of inflammation), or extreme miosis. This is in contrast to CAG without pupillary block such as vascular or inflammatory diseases that may cause peripheral anterior synechiae (adhesions of the peripheral iris to the cornea). However, patients with CAG without pupillary block may also be treated with laser iridotomy because some degree of pupillary block may be secondarily involved. Nanophthalmic (small eye) eyes frequently develop CAG because they have very small eyes relative to the size of their natural crystalline lens. Pupillary block related to an enlarged lens may be a contributing factor in these cases. The same reasoning may extend to patients with primarily an OAG. If a pupillary block component is suspected, the benefits of eliminating such a factor may outweigh the risks.

Contraindications to laser iridotomy are few and primarily include findings that increase the risk of complications from the procedure. Corneal burns may result from either (1) use of laser through an opacified cornea, or (2) use of laser in an eye with an extremely narrow angle. There is also a risk of increased IOP following the laser procedure, and to avoid that, usually apraclonidine or brimonidine are instilled prior to the procedure, and the IOP is checked 30 min to 2 h following the procedure. Acute CAG with pupillary block is ultimately treated with laser iridotomy; however, the procedure should ideally be done following the acute phase after the eye's inflammation has had a chance to subside and the cornea has cleared. However, this is not always possible and laser iridotomy is still indicated if the cornea is clear enough to perform the procedure. Topical and systemic anti-glaucoma medications can acutely lower the pressure.

Techniques

- Topical anesthetic and miotic medications are applied preoperatively.
- The argon, diode, or Nd:YAG laser is used to apply laser to the peripheral iris through a focusing iridotomy lens.
- The photocoagulative effect of argon laser is dependent upon pigmentation; therefore, techniques vary for irises of different colors.
- The Nd:YAG laser is photodisruptive and therefore does not dependent upon tissue pigmentation.
- IOP-lowering medications are used perioperatively. Corticosteroids may be temporarily used postoperatively to control inflammation.

Pre-operative Management

Topical anesthetics are sufficient to provide anesthesia. A miotic agent is applied topically to thin the iris and pull it away from the angle. This allows for easier penetration and minimizes corneal endothelial injury. An Abraham iridotomy lens will help stabilize the eye, keep the eyelids open, provide a magnified view, and minimize corneal burns by acting as a heat sink and increasing the power density of the laser at the iris. The iridotomy site should be made in a relatively thin region of the iris, or in an iris crypt.

Description of the Technique

Q-switched Nd:YAG laser, the argon laser, and diode lasers can be effectively used for iridotomy. This review will focus on q-switched Nd:YAG and the argon laser because these two are most commonly used in practice. Each has unique properties that affect the selection of laser type and use of the laser for different colored irises. The q-switched Nd:YAG creates the iridotomy by photodisruption, an optical break-down of molecules into their component ions resulting in explosive disruption and essentially excision of tissue. One advantage of photodisruption is that it does not depend upon tissue absorptivity and therefore is equally effective for different colored irises. One disadvantage of photodisruption is its lack of coagulative effect. On the other hand, argon laser has a thermal effect and therefore results in photocoagulation or photovaporization, the specific effect depending upon the duration of exposure and energy density of the laser used. The thermal effect is beneficial in that it can provide coagulation. The disadvantage of argon laser is its dependence upon absorption by tissue pigments. Argon laser is ideal for medium brown irises, but may have a charring effect on dark brown irises and poor absorption in blue irises. As a result of the above differences, q-switched Nd:YAG laser is simpler to use, and argon laser iridotomy techniques vary for irises of different color. Specific descriptions of the techniques follow.

Q-switched Nd:YAG lasers have a wavelength of approximately 1064 nm and can be used at a range of power densities depending upon the number of bursts. Typically, there are 1–3 pulses per burst with each burst delivering 1–10 mJ. The focal point of the laser should be within the iris stroma to avoid corneal damage from the explosive effect. The iridotomy site should be at least 0.1 mm.

The effects of argon laser vary for tissues with different levels of pigmentation, therefore different techniques have been employed. The darker the iris color (i.e. greater amount of melanin in the stroma), the greater the absorption of the laser energy. Thus, the darker colored iris will require less energy to achieve the same results. Typical settings range between 600 and 1000 mW with a spot size of 50 µm with a duration of 0.02–0.05 s. The pit that is initially formed can be enlarged to a diameter of 0.2 mm with 30–70 pulses. Light blue irises have little pigment anteriorly (in the stroma) but the same iris pigment epithelium as brown irises posteriorly. As a result, the argon laser may penetrate the iris pigment epithelium but leave the stroma intact. A variety of creative techniques can be used to avoid this. One approach is to use longer exposures that generate heat that transmits to the stroma and creates a bubble. Laser entering through the apex of the bubble will repeatedly reflect within the bubble and more effectively ablate the stroma.

Although the first laser iridotomies were performed using the argon laser alone, in the modern era, either the Nd:YAG laser will be used alone or a combination an argon laser. Use of the two lasers minimizes the risk of hyphema and total energy delivered. Argon laser is used to for photocoagulation to increase tissue density and minimize the risk of bleeding. The Nd:YAG laser is then used for photodisruption.

Post-operative Management

Intraocular pressure is generally checked 30–120 min after the procedure. Apraclonidine or brimonidine are given perioperatively to mitigate elevations in pressure. Topical steroids may be given for several days post-operatively to control inflammation. If the angle remains narrow, laser peripheral iridoplasty may be considered, which will be described in the next section.

Adverse Events

Adverse events	Management
Iritis	Corticosteroids if more than mild
Increased intraocular pressure	Topical medications (α-adrenergic agonists, β-blockers, osmotic agents, or carbonic anhydrase inhibitors)
Cataract	No treatment
Hyphema	Pressure with contact lens for hemostasis
Corneal damage	No treatment
Failure to perforate	Retreatment after pigment cloud has dispersed
Late closure	Retreatment
Retinal burn	Avoid with standard precautions

Most side effects of laser iridotomy are often minimal and self-limited. *Iritis* occurs and is treated by post-operative corticosteroids or topical non-steroidal anti-inflammatory treatment. Persistent iritis may be related to a preexisting uveitis. *Intraocular pressure elevations* are common 1–2 h after the procedure but are usually self-limited and resolve within 24 h. Topical medications to lower IOP can be used to limit IOP elevation. Filtering surgery may be required if more severe and sustained elevations occur, more commonly in eyes with a component of OAG.

Most complications can be avoided with appropriate precautions and careful technique. *Cataract* may occur and is more easily formed by the q-switched Nd:YAG laser if it is applied to an open iridotomy site because the effect of the laser does not depend upon pigmentation. *Hyphema* is also much more common with q-switched Nd:YAG laser because it does not have a coagulative effect. Applying pressure with the contact lens usually provides sufficient homeostasis. *Corneal damage* may occur from either argon or Nd:YAG laser iridotomy. If the iridocorneal angle is closed or extremely narrow, the endothelium may be affected. No treatment is generally required, but if the iridotomy is incomplete, a new site may be selected. *Closure* of the iridotomy site may occur if the site is small or if there is an underlying uveitis.

Argon Laser Peripheral Iridoplasty

Argon laser peripheral iridoplasty is the delivery of thermal energy that causes circumferential contraction of the iris away from the trabecular meshwork. Laser iridoplasty is a treatment for certain closed-angle glaucomas, and is often attempted when laser iridotomy fails or is not indicated because the pathophysiology does not involve pupillary block.

Indications and Contraindications

Indications

- Closed-angle glaucoma without pupillary block (e.g. plateau iris syndrome)
- Preceding laser iridotomy for CAG with pupillary block and inflammation
- Preceding laser trabeculoplasty for focal areas of angle narrowing

Contraindications
- Severe corneal edema
- Peripheral anterior synechiae
- Corneal opacities—treatment through the opacity is not recommended

Closed-angle glaucoma without pupillary block is the major indication for laser peripheral iridoplasty. Plateau iris, an anatomic variant in which the posterior chamber structures are positioned more anteriorly resulting in an anteriorly displaced peripheral iris, is a configuration which can lead to closed-angle glaucoma without pupillary block (Fig. 3.6). Similarly, any posterior chamber or segment structure can cause the iris to be anteriorly displaced. This includes nanophthalmos, which results in a crowded anterior chamber, which predisposes patients to CAG.

Additionally, patients with closed or narrow angles that have laser iridotomy performed but continue to have narrow angles may be considered for laser iridoplasty. Laser peripheral iridoplasty may precede laser iridotomy in cases of acute CAG when the cornea is edematous and medications are not sufficient to control the attack. The effect of the iridoplasty lasts long enough for the corneal edema and anterior chamber inflammation to subside so that laser iridotomy can be performed under more optimal conditions.

Argon laser peripheral iridoplasty may also be used prior to laser trabeculoplasty in patients with open-angle glaucoma. It is indicated when patients have focal areas of angle narrowing, which can be opened to permit laser trabeculoplasty.

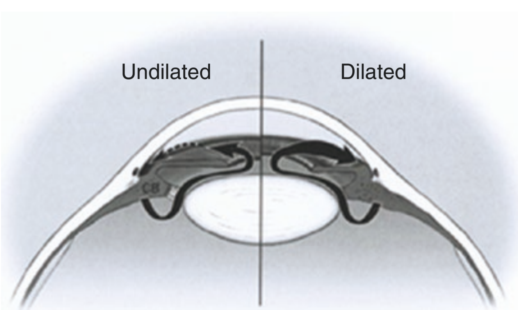

Fig. 3.6 Plateau iris

Contraindications include severe corneal edema and peripheral anterior synechiae. Laser peripheral iridoplasty will generally not open an angle that is scarred closed by peripheral anterior synechiae. Corneal opacities can also be contraindications; however, opacities that cover only a portion of the peripheral iris—such as pterygium—still allow for treatment of the remainder of the iris.

Techniques

- Topical anesthetic and miotic medications are applied preoperatively.
- Argon laser is used to create a photocoagulative effect to large areas of the peripheral iris circumferentially.
- Gonioscopy is used to ensure that the angle has deepened.
- IOP-lowering medications are used perioperatively. Corticosteroids are used postoperatively for inflammation.

Pre-operative Management

Topical anesthetic is sufficient to provide anesthesia. Pilocarpine is applied topically to constrict the pupil which will have the effect of thinning the iris tissue by virtue of spreading it over a larger area (i.e. place the iris under stretch). Apraclonidine or brimonidine is usually given before and after the procedure to reduce the risk of intraocular pressure elevations.

Description of the Technique

The argon laser is used for its coagulative effect to form contraction burns. The spot size is large (500 μm) with low power (200–400 mW) and long duration of delivery (0.5 s). The beam is aimed at the most peripheral iris to apply 20–24 spots are placed circumferentially, avoiding large radial vessels.

Post-operative Management

The peripheral anterior chamber should deepen immediately; therefore gonioscopy can be performed to confirm that the procedure was successful. Apraclonidine and topical steroid are given postoperatively to reduce the risk of intraocular pressure elevations and control inflammation. Topical anti-inflammatory treatment is continued for 3–5 days.

Adverse Events

- Side effects and complications are similar to those of laser iridotomy.
- Additionally, there is the risk of iris necrosis, which can be avoided with appropriate spacing of the laser spots.

Side Effects/Complications: Prevention and Treatment of Side Effects/Complications

Side effects include intraocular pressure elevations and inflammation. Their treatment is described above. Complications are similar to those of laser iridotomy. Additionally, *iris necrosis* may occur if the spots are placed too closely together. Spots should be spaced with 1–2 spot diameters apart.

Laser Trabeculoplasty

Laser trabeculoplasty is the application of laser to the trabecular meshwork with the intention of increasing aqueous outflow to reduce IOP in patients with OAG. It can be used as first line therapy, or after failed medical management. L laser trabeculoplasty can be offered as the initial treatment for patients with open-angle glaucoma as an alternative to medications in patients with early stage disease or in patients who are unable or prefer not to use topical medications.

The mechanism of increased aqueous outflow after laser trabeculoplasty is not well-understood. Three theories have been proposed to explain the efficacy of laser trabeculoplasty: mechanical, biologic, and cellular repopulation theories. The mechanical theory suggests that a thermal burn to the collagen results in local tissue contraction with mechanical stretch to the adjacent tissue. Presumably, the adjacent areas would have increased aqueous outflow. The biologic theory suggests that thermal energy stimulates trabecular endothelial cells to release matrix metalloproteinase enzymes, and recruits macrophages, which results in trabecular meshwork remodeling. The theory proposes that the resultant remodeling of extracellular matrix will increase aqueous outflow. The repopulation theory suggests that the laser energy stimulates trabecular endothelial cell division with downstream effects resulting in increased aqueous outflow.

The mechanisms above are potential explanations for the effect of laser trabeculoplasty performed with argon and diode lasers, techniques that were first proposed by Wise and Witter in 1979. Both of these types of lasers are equally effective in the long term (5 years); however, there are differing results in the short term (3 months), some suggesting a slight benefit to argon laser trabeculoplasty (ALT). ALT may also be technically easier since the end-point of laser application is more evident. A potential disadvantage of ALT is more post-laser pain and inflammation.

In 2001, a technique called selective laser trabeculoplasty (SLT) was approved by the Food and Drug Administration. SLT uses a non-coagulative double frequency Nd:YAG laser to selectively target pigmented trabecular meshwork cells without causing a coagulative effect. The absence of thermal burns suggests that the mechanical theory does not play a role in SLT.

More recently, a new technique called MicroPulse laser trabeculoplasty (MLT) has also come into use for OAG. This laser uses a 15% duty cycle rather than continuous laser wave (100% duty cycle). See "Future Directions" section for further discussion regarding MLT.

Laser trabeculoplasty has gained popularity in recent years. The number of laser trabeculoplasties performed decreased by 57% between 1995 and 2001 (perhaps as a result of the release of several new classes of topical antiglaucoma medications during this time), and then doubled from 2001 to 2004.

Indications and Contraindications

Indications

- Insufficient IOP control with medication
- Poor compliance with medical management
- Adult open-angle glaucomas (with the exclusion of uveitic glaucomas)

Contraindications

- Poor visualization of the trabecular meshwork (e.g. Angle closure, peripheral anterior synechiae)
- Hazy media
- Corneal edema
- Uveitic glaucoma
- Juvenile glaucoma
- Patients younger than 35 years unless their OAG is due to pigment dispersion syndrome

Relative Contraindications

- Patients with intraocular pressures >35 mmHg
- ALT should be withheld in patients with very narrow angles due to the risk of peripheral anterior synechiae; SLT may be used in these situations

The general approach to managing primary and secondary open angle glaucomas was previously to use topical anti-glaucoma medications, such as topical prostaglandin analogs, beta-adrenergic antagonists, carbonic anhydrase is treated initially, and if this fails to control IOP, the ophthalmologist may choose to treat the other 180°.

Smaller prospective randomized controlled studies have shown SLT is at least as effective as modern topical antiglaucoma medications. SLT may have a larger role than

ALT because mechanistically it does not cause as much tissue destruction. Hence, theoretically, SLT treatments can follow ALT treatments or SLT can be used exclusively for multiple treatments. The former has been investigated in a few studies, and results suggest that SLT is effective following both successful and failed ALT treatment. Typically, 180–360° of trabecular meshwork is treated.

Laser trabeculoplasty should not be performed if laser cannot be applied to the trabecular meshwork safely. This includes corneal edema or any corneal opacities, hazy aqueous, or angle closure including peripheral anterior synechiae. Uveitic glaucoma is also a contraindication, as the laser trabeculoplasty is ineffective and may aggravate an existing inflammatory state.

Techniques

Inhibitors, and selective alpha2-adrenergic agonists, as first-line treatments, and laser trabeculoplasty in patients that remain inadequately controlled. However, laser trabeculoplasty is now being used as first line therapy as an equally effective alternative to medical therapy due to its effective IOP lowering and repeatability. Incisional filtering surgical procedures are generally used when all other measures have not successfully controlled the eye pressure. Studies suggest that ALT has similar efficacy as first-line treatment compared with the medications available at that time. The Glaucoma Laser Trial was a randomized control trial that followed patients treated with medication or ALT for 7 years. The final IOP in the ALT group was 1.2 mmHg lower than the medically treated group, and their visual fields were slightly better concluding that ALT is at least as effective as medication as a first-line treatment. A study by Bovell which compared SLT to ALT found that SLT reduced IOP by over 6.5 mmHg at a 3 year follow-up, and that the efficacy of SLT was equivalent to ALT. A study done by Realini in patients from St. Lucia showed a mean 7.3–8.3 mmHg drop in IOP after patients were washed out from medical therapy. A Cochrane review concluded that laser trabeculoplasty controls IOP at 6 months and 2 years better than the medications used before the 1990s. Usually 180° of trabecular meshwork.

Pre-operative Management

Topical anesthetic is sufficient to provide anesthesia. Apraclonidine or brimonidine is usually given before the procedure to reduce the risk of intraocular pressure elevations.

Description of the Technique

A mirrored contact lens such as the Goldmann gonioscopy lens, Ritch lens, or Latina lens is used to stabilize the eye and visualize the angle at the slit lamp (Fig. 3.7). The laser beam is focused at the junction of the posterior trabecular pigment band and the anterior meshwork (Fig. 3.8). The specifics of the laser application depend on the type of laser being used.

- Topical anesthetic and miotic medications are applied preoperatively.
- Argon or diode laser is typically applied to 180° of the trabecular meshwork circumference with power settings adjusted to produce minimal blanching.
- Selective laser trabeculoplasty is typically applied to 180–360° of the trabecular meshwork circumference.
- Alpha agonists are used perioperatively. IOP should be rechecked perioperatively, and again after 1–3 weeks to determine the success of the procedure.

ALT and DLT generally require 40–50 spots over 180°. Power settings for ALT range from 400 to 1200 mW with adjustment to produce blanching and occasional gas bubble formation. DLT power settings similarly range from 570 to 850 mW but blanching is usually less noticeable. As a result, the surgeon must be more attentive with regards to which portions of the meshwork have been treated. The spot size with ALT is typically 50 μm with 0.1 s exposures. DLT spot sizes range from 75 to 100 μm with exposures ranging from 0.1 to 0.5 s. With both ALT and DLT, one should try to space the application spots by 1–2 application spot widths apart.

SLT requires a similar technique to ALT and DLT but the 532 nm frequency-doubled q-switched Nd:YAG laser is used with very different parameters. Seventy to 120 spots are applied over 360°. Laser may be applied to 90°, 180°, or 360° of the meshwork, with guidelines still in evolution; in general, it is recommended to treat 180–360° with most practitioners treating 360°. Only a small fraction of the energy applied in ALT is needed for SLT treatment. The duration of exposure is 3 ns. The power setting is on the same order of magnitude; however, because of the short duration of exposure the energy applied is 0.5–1.2 mJ versus approximately 100 mJ for ALT. Moreover, the difference in energy density is even greater because the spot size used for SLT treatments is 400 μm (0.5 mJ/μm^2 for ALT versus 10−5 mJ/μm^2 for SLT). The application spots should be spaced approximately 1–2 application spot widths apart.

Fig. 3.7 Patient position at slit lamp-mounted laser

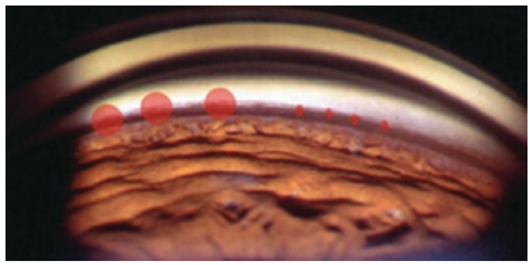

Fig. 3.8 Approximate sizes and locations of SLT (*left*) and ALT (*right*) laser spots

Post-operative Management

Glaucoma medications can be given postoperatively to reduce IOP elevations. IOP should be checked 30–120 min after the procedure and 1–2 weeks later. IOP reductions can be expected 4–6 weeks later, but can be seen as early as 2 weeks. If IOP reduction is inadequate, the remaining meshwork may be treated (for ALT and DLT or if only 180° of the meshwork were treated by SLT). There is no consensus on the treatment of post-operative inflammation following laser trabeculoplasty.

Adverse Events

- Transient and persistent IOP elevations may occur.
- Hyphema is rare and self-limited.
- Appropriate power settings and treatment locations will help avoid peripheral anterior synechiae.
- Mild iritis is common after ALT.

Side Effects/Complications: Prevention and Treatment of Side Effects/Complications

Transient as well as sustained *IOP elevations* may occur. *Hyphema* is rare and self-limited but can be treated by applying pressure to the globe with the goniolens or by photocoagulating with argon laser. *Peripheral anterior synechiae* are more common when areas posterior to the trabecular meshwork are treated. This should be avoided, and only the minimum power required to cause blanching should be used. Mild *iritis* is common after laser trabeculoplasty. Topical anti-inflammatories can control the inflammation, but is used judiciously as it can reduce the efficacy of the procedure. Laser trabeculoplasty is generally not helpful in patients with uveitic glaucoma and therefore should not be performed in most circumstances.

Cyclophotocoagulation

Cyclophotocoagulation is the use of laser energy to destroy ciliary body tissue usually in cases of refractory glaucoma. In contrast to all other procedures that have been described, the mechanism of IOP reduction for this procedure is a decrease in aqueous humor production, although some newer cyclophotocoagulation lasers may also increase outflow as well, which will be discussed later in the chapter. There are four approaches to cyclophotocoagulation: contact transscleral, noncontact transsceral, transpupillary, and endoscopic. Contact transscleral cyclophotocoagulation can be further separated into a traditional transscleral cyclophotocoagulation diode (TSCPC) and a micropulse transslceral cyclophotocoagulation diode (MPCPC) Cyclodestructive procedures were traditionally used as a last resort for refractory glaucomas because of their relatively high rates of complications and side effects. However, with new advances, certain types of cyclophotocogulation procedures, such as MPCPC and endoscopic cyclophotocoagualation (ECP), are being used more commonly. These newer procedures have gained popularity over other cyclodestructive procedures such as cyclocryo-destruction because of its relatively lower rate of complications and side effects. The developmental trend with cyclophotocoagulation has been the use of lower power due to improved targeting; the lower power settings have improved the safety profile of these laser procedures.

Indications and Contraindications

Indications

- Refractory glaucomas
- Open-angle glaucoma in which other treatments are contraindicated (e.g. neovascular glaucoma)
- Glaucomatous patients with low visual potential or blind, painful eyes
- Poor candidates for incisional surgery

Relative Contraindications

- Glaucomatous patients with high visual potential, for transscleral cyclophotocoagulation

Traditional transscleral cyclophotocoagulation is usually for refractory glaucoma or glaucoma in which other treatments are contraindicated. Patients are already on maximal medication therapy with inadequate control. Filtering procedures have failed or may be high risk for the patient because of aphakic glaucoma, neovascular glaucoma, or perhaps glaucoma after penetrating keratoplasty. A less invasive procedure is also more appropriate for patients with low visual potential due to a decrease in post-operative procedures and visits. Cyclophotocoagulation can also be a procedure of choice for eyes that have very distorted anatomy or eyes with an opaque cornea. ECP was traditionally used for refractory glaucoma, however, is recently being used in less advanced glaucoma cases with cataract surgery, and can help to reduce eye-drop use. A study done by Roberts included 91 eyes in 73 patients who underwent ECP in combination with cataract extraction. The mean number of medications decreased from 1.88 ± 1.07 at baseline to 1.36 ± 1.18 at 1 month, 1.17 ± 1.14 at 3 months, 1.36 ± 1.19 at 6 months, and 1.48 ± 1.27 at 1 year. ECP allows for direct visualization of the ciliary processes allowing for the surgeon to titrate the amount of energy used. This leads to less complications, and compared to transscleral cyclophotocoagulation, ECP has less risks of hypotony, phthisis inflammation and can spare the conjunctiva and sclera in case of need for incisional glaucoma procedures.

Techniques

- Retrobulbar anesthesia is administered preoperatively if the procedure is done in the minor room. In an operating room setting, intravenous sedation can be used.
- Nd:YAG and diode lasers are the two most commonly used.
- The contact transsceral approach utilizes a fiber-optic probe to apply laser through the conjunctiva.
- The noncontact and transpupillary approaches utilize a slit lamp to apply the laser.
- Approximately 270° of the circumference of the ciliary processes are treated so as to reduce the risk of hypotony.
- Endoscopic delivery of laser for photoablation of the ciliary body is performed as an operative procedure due to the need to have an incision in the eye.
- MPCPC uses a hemispheric tip that is applied 1–2 mm posterior to the limbus, and is applied in a sweeping motion superiorly and inferiorly over 160–240 s

Pre-operative Management

Retrobulbar anesthesia is usually given for pain during and after the procedure. For the contact transscleral approach the eye is exposed with a speculum and the ocular surface is moistened with a saline solution before applying a fiber-optic probe to the conjunctiva. A slit lamp is used for noncontact transscleral and transpupillary approaches. Endoscopic cyclophotocoagulation is done in the operating room setting in patients who are already pseudophakic or in combination with a cataract extraction. MPCPC can be done in a minor procedure room with retrobulbar anesthesia or in an operating room with intravenous sedation, which is usually a less painful experience for the patient, and eliminates the need for patching the eye.

Description of the Technique

There is no standardized protocol for cyclophotocoagulation procedures, and studies report varying success and complication rates. The two most commonly used lasers are Nd:YAG and diode lasers. A prospective study comparing the lasers found no significant difference in visual acuity or IOP reduction between the two lasers; therefore, the diode laser is often preferred because of its portability and lower energy requirements to achieve the same tissue result. A retrospective review of recent data from transscleral cyclophotocoagulation procedures concluded that the diagnostic category and age of the patients influence outcome more than the specific laser protocol or total energy used. Usually, the circumference is treated while avoiding the 3 and 9 o'clock positions to avoid the long ciliary nerves. Treating more increases the risk of hypotony. Spot size is 100–400 μm with the 810 nm diode laser and 900 μm with the Nd:YAG laser. With the noncontact approach the laser is focused 3.6 mm beyond the surface of the globe; noncontact techniques are currently not favored. Pulse duration is 2–4 s at 1300–2300 mW with a total of 18–24 applications. The power setting is adjusted so that it is just below the power required to cause a barely audible ‘pop.’ The transpupillary approach may be used if the aqueous is clear and the pupil is sufficiently dilated so that ciliary epithelium can be directly visualized. Endoscopic cyclophotocoagulation is done through the anterior segment, or the pars plana. These procedures must be done in the operating room, and are often done in adjunct with cataract extraction. After a clear corneal incision is made, a high molecular weight viscoelastic should be inserted into the sulcus to lift the iris and facilitate visualization of the sulcus. An 18–23 gauge probe, 810 nm diode laser, 175-W xenon light source, helium-neon aiming beam, and video imaging are all within a fiber optic cable, which inserted into the anterior chamber via a clear corneal incision. The settings are between 250–350 mW, and 200–360° of the ciliary body are photocoagulated depending on the visualization of the angle. The ciliary processes can be visualized on a screen with an endpoint of photocoagulation leading to whitening and contraction of the processes without rupturing them. After the ECP procedure is completed, the viscoelastic should be aspirated from the eye. The approach for the MPCPC will be described in the “Future Directions” section.

Post-operative Management

Antibiotic and steroid ointments are given and the eye is patched overnight for transscleral cyclophotocoagulation due to the use of a retrobulbar block anesthesia. For ECP, patients may receive intracameral steroids or a subconjunctival injection of steroids in addition to topical drops after the procedure. Glaucoma medications are continued until IOP decreases, which may take several weeks. Retreatment may be necessary if IOP reduction is inadequate after weeks. It is not uncommon to require multiple treatments.

Adverse Events

- Pain is usually managed with systemic acetaminophen, ibuprofen, or cycloplegics depending on the source of the pain. Topical corticosteroid anti-inflammatory agents are also prescribed
- Hypotony, phthisis, hyphema, cataract, and synechia are significant risks

Side Effects/Complications: Prevention and Treatment of Side Effects/Complications

Common side effects include *pain, inflammation, postoperative IOP increases, iritis, reduced vision and macular edema*. Pain is usually managed with acetaminophen or ibuprofen. Pain secondary to iridocyclitis may be relieved with cycloplegics. *Hypotony* may develop after 6–36 months, and is one of the reasons that transscleral cyclodestructive procedures are a last resort. *Phthisis* is also a possible complication. However, these risks are lower with ECP compared with transscleral cyclophotocoagulation.

Miscellaneous Procedures

There are a number of other applications for laser in glaucoma that are either adjuncts to or very similar to surgical procedures for glaucoma.

Laser can be used to *cut subconjunctival sutures* placed in a number of different surgical procedures. The laser is preferred because the laser can cut the suture without having to incise the conjunctiva. Dark nylon or proline sutures that are too tight can be severed with argon laser. For example, trabeculectomy scleral flap sutures are usually placed tightly to avoid post-operative hypotony. To achieve the appropriate IOP reduction in the long-term, some of these sutures may be lysed with laser post-operatively.

Cyclodialysis clefts occur when ciliary muscle separates from the underlying sclera. This was once a treatment for glaucoma, but can also occur as a result of trauma or a complication of other surgeries. It results in hypotony and decreased vision. Use of the argon laser to deliver photocoagulative burns to the internal surface of the scleral in an attempt to scar these clefts closed has been described.

The iridocorneal angle may become vascularized eventually leading to neovascular glaucoma. This can result from a number of ischemic phenomena including diabetes mellitus and central retinal vein occlusion. Although panretinal photocoagulation is the primary treatment for these conditions because it is treating the source of the ischemic stimulus, *goniophotocoagulation* may be used as adjunctive treatment. Indications include anterior segment vascularization that is unresponsive to panretinal photocoagulation and cases in which angle vascularization is already present when panretinal photocoagulation is begun.

Laser sclerostomy is the use of laser to perforate the sclera at the iridocorneal angle has been investigated as an experimental treatment for glaucoma. Although not exactly the same, it can be thought of as the laser counterpart to a trabeculectomy, which is a guarded filtering surgery that is performed if glaucoma is not controlled with medication and laser trabeculoplasty. The laser can be applied externally with a goniolens or under a conjunctival flap, or internally. Numerous lasers have been studied and antifibrotic agents such as mitomycin C are sometimes used as adjunctive treatment; however, the role of laser sclerostomy in comparison to the well-known trabeculectomy surgery remains undetermined.

Future Directions

Laser-based procedures have been become much more common in all areas of glaucoma treatments. Their less invasive nature and lower rates of complications are appealing and seem to be motivation for research to refine existing procedures and for continued innovation in the field.

MicroPulse laser trabeculoplasty is a new technology. It uses a 15% duty cycle to deliver 300 μm pulses to the pigmented cells of the trabecular meshwork. The laser is believed to lead to release of inflammatory cytokines which increases the permeability of the trabecular meshwork and lead to decreases in IOP. The laser uses a longer wavelength of 532 or 577 nm in comparison to ALT, and is believed to cause less overall damage as it does not cause trabecular meshwork scarring like ALT, or destroy the pigmented trabecular meshwork cells like SLT does. Early, small scale studies have shown comparable IOP reduction between MLT and SLT.

Transscleral, transpupillary, and endoscopic-cyclophotocoagulation procedures have been described above. The micropulse transccleral cyclophotocoagulation diode is a newer method of transscleral cyclophotocoagulation. Its mechanism of action is not completely understood yet, but it appears to be multifactorial with belief that the diode causes ciliary body destruction, likely increases outflow through the uveoscleral pathway, and possibly causes a trabeculoplasty-like effect as well. MPCPC is believed to cause scleral shrinkage with ciliary body rotation and opening of the conventional outflow pathway. The diode is done transsclerally, but one of the differences between MSCPC and TSCPC is that micropulse diodes are delivered continuously with repeated times of short bursts of energy followed by rest. MPCPC has 0.5 ms in an active phase followed by 1 ms in a rest phase, with an overall duty cycle of 31.3%. The standard MPCPC settings are 2000 mW of 810 nm infrared diode laser on micropulse mode. The laser is then delivered over 360°, sparing the 3 o'clock and 9 o'clock positions, over 160–240 s. In contrast to TSCPC which uses a G probe, the MPCPC uses a G6 probe which has a hemispheric tip that protrudes 0.7 mm from the hand piece, and is held 1–2 mm posterior to the limbus during treatment. Given the duty cycle of the MPTCP, it is less inflammatory than the TSCPC. Although the procedure itself is painful, the post-operative pain is minimal. For this reason, the procedure can be done in a minor procedure room with a retrobulbar block, or in the operating room setting with intravenous sedation without a retrobulbar block. After the procedure, patients will be started on a topical steroid and atropine, and they should continue their current treatment for glaucoma. This procedure is repeatable if needed. Further studies must be done to understand the length of efficacy of the laser as well as the optimal patient.

Goniopuncture is the creation of a hole in the trabecular meshwork that results in a direct connection between the anterior chamber and Schlemm's canal and therefore, theoretically, increased aqueous outflow facility. The technique was initially proposed in 1950 by Harold G. Scheie but has been more intensively studied in the last 10 years as a treatment for open angle glaucoma. An erbium:YAG laser is used endoscopically often in combination with phacoemulsification cataract surgery. The erbium:YAG laser is a 2.94 μm wavelength laser that has a photoablative effect on ocular tissues with minimal thermal damage. One study found IOP reductions after 1 year similar to those after trabeculectomy. Another study found comparable IOP reductions at 1–3 years. Such a new procedure will require studies with longer follow-up and standardization of the technique and laser settings before it is fully incorporated into glaucoma management.

Conclusion

Glaucoma is a multifactorial optic neuropathy resulting in potentially progressive vision loss. Although there are many modalities of treatment that can be successfully employed to slow or stop the progression of glaucoma, the major and only treatable risk factor for glaucoma is elevated intraocular pressure. Diagnosis of glaucoma requires measurement of intraocular pressure, optical coherence tomography of the retinal nerve fiber layer, evaluation of visual fields, funduscopy, and differentiation of closed-angle glaucoma (CAG) and open-angle glaucoma (OAG) by gonioscopy. The management differs for CAG and OAG. CAG with a pupillary block component is treated by laser iridotomy. CAG without pupillary block may benefit from peripheral laser iridoplasty. Laser trabeculoplasty has been traditionally reserved for those requiring modest, IOP reduction; however, studies suggest that it is equally effective in lowering IOP as medications, and laser trabeculoplasty is a possible alternative as first line treatment for OAG If IOP remains inadequately controlled, filtration surgical procedures may be used. Cyclodestructive procedures such as cyclophotocoagulation have traditionally been reserved for refractory glaucoma because of their relatively higher rates of side effects and complications.

Iridotomy is the creation of an opening in the iris that provides an alternate route for aqueous to enter the anterior chamber bypassing the space in-between the iris and lens on its way to the pupil. The procedure is treatment for all forms of closed-angle glaucoma that involve pupillary block (i.e. increased resistance through or total occlusion of the space between the iris and lens). Patients with easily occludable anterior chamber angles may also require an iridotomy. Contraindications include an opacified cornea, an extremely narrow angle, or an inflamed eye. A topical anesthetic and miotic medications are applied preoperatively. The argon, diode, or Nd:YAG laser is used to apply laser to the superior peripheral iris through a focusing iridotomy lens. Absorption of argon laser energy causes photocoagulation and is dependent upon pigmentation and therefore techniques vary for irises of different colors. On the other hand, the Nd:YAG laser is photodisruptive and therefore does not dependent upon tissue pigmentation. IOP-lowering medications are used perioperatively, and corticosteroids may be used postoperatively for inflammation. If the angle remains narrow after treatment, laser peripheral iridoplasty may be considered.

Argon laser peripheral iridoplasty causes circumferential contraction of the iris away from the trabecular meshwork. It is another treatment for closed-angle glaucoma, and is often attempted when laser iridotomy fails or is not indicated because the pathophysiology does not involve pupillary block. This includes plateau iris and anterior displacement of the iris by posterior structures such as an enlarging lens. The procedure may be performed prior to laser trabeculoplasty to deepen focal areas of angle narrowing, and prior to laser iridotomy if the eye is acutely inflamed. Severe corneal edema or peripheral anterior synechiae are contraindications. A topical anesthetic and miotic medications are applied preoperatively. Argon laser is applied circumferentally to the peripheral iris to cause contraction burns. The effect should be immediately evident. IOP-lowering medications are used perioperatively, and corticosteroids may be used postoperatively for inflammation. Adverse events are similar to those of laser iridotomy with the addition of iris necrosis, which can be avoided by appropriately spacing laser spots. Laser trabeculoplasty is the application of laser energy to the trabecular meshwork with the intention of increasing aqueous outflow to reduce intraocular pressure in patients with open-angle glaucoma. The precise mechanism by which laser trabeculoplasty increases aqueous outflow is not fully elucidated. There is most support for a biologic mechanism involving enhanced turnover of extracellular matrix and induced trabecular meshwork cell division. Laser trabeculoplasty is now being used as first line treatment for OAG, and especially before filtering surgical procedures are performed for both primary and secondary open-angle glaucoma. Studies strongly suggest that both ALT and SLT are at least as effective as medications for initial treatment. MLT is a newer procedure which is believed to cause less scarring and destruction to the pigmented trabecular meshwork cells in comparison to ALT and SLT. Small scale studies have shown that it is equivalent to ALT and SLT in lowering IOP, however, larger scale studies are yet to be completed. Laser trabeculoplasty is not very effective in patients younger than 40 years and is contraindicated for uveitic glaucoma. It is also contraindicated if the angle cannot be appropriately visualized. The procedure requires topical anesthesia and IOP-reducing medications. Laser is applied to the trabecular meshwork using a mirrored contact lens. IOP reductions can be expected after 4–6 weeks. Complications include transient or persistent IOP elevations, hyphema, and iritis.

Cyclophotocoagulation is the use of laser to destroy ciliary body tissue in order to decrease aqueous humor production and therefore reduce intraocular pressure. Because of its higher rate of side effects and complications, it is usually reserved for refractory glaucoma. Cyclophotocoagulation has gained popularity over other cyclodestructive procedures such as cyclocryodestruction because of its relatively lower rate of complications and side effects. There are four approaches to cyclophotocoagulation: contact transscleral, noncontact transscleral, transpupillary, and endoscopic. Retrobulbar anesthesia is administered. Beyond general management the technique has not been standardized, and studies report varying success and complication rates. Most commonly, the Nd:YAG laser or diode laser is used to destroy most but not all of the ciliary processes so as to avoid hypotony. The contact transscleral approach utilizes a fiber-optic probe. MPCPC is a newer contact transscleral approach which is believed to work by causing ciliary body rotation and increase output through the uveoscleral and conventional pathways. In comparison to traditional TSCPC, it is less inflammatory and has fewer side effect. It causes less post-procedural pain in comparison to traditional TSCPC, and can be done in operating room with intravenous sedation, without a retrobulbar block. The noncontact transscleral and transpupillary approaches utilize a slit lamp to apply the laser. Glaucoma medications should be continued until IOP decreases, which may take several weeks. It is not uncommon to require multiple treatments.

Laser-based procedures have been become much more common in all areas of glaucoma treatments, in many cases replacing their surgical counterparts. Their less invasive nature and lower rates of complications are appealing and seem to be motivation for research to refine existing procedures and for continued innovation in the field.

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4 Laser/Light Application in Dental Procedures

Steven Parker

Abstract

The oral cavity is a relatively confined anatomical region, with a close approximation of hard and soft tissue structures. The comparatively delicate nature of each tissue structure places demands on surgical techniques using lasers and the maximum power parameters used.

The predictable application of any laser wavelength currently commercially-available may be viewed as an expression of incident power and the targeting of a predominant chromophore in the exposed tissue. By way of exploring laser use in dentistry, this may be summarised as surgical management of oral hard tissue and soft tissue, non-surgical application and anti-bacterial applications.

Laser use in clinical dentistry has spanned 25 years. Although early laser use in general surgery (notably Carbon Dioxide, wavelength 10.6 µm) was applied to soft tissue surgical procedures in the mouth, the first true dental laser was a Neodymium YAG (1.064 µm) which was launched in 1989. From there the next 5 years witnessed the emergence of other major wavelengths, notably the two Erbium wavelengths (Er:YAG and Er,Cr:YSGG) and Diode group of semiconductor based technology. Latterly, the most recent 5–10 years has seen an emergence of technical developments to optimise the interaction of chosen laser photonic emission with target oral tissue; this manipulation of energy and time parameters shows may herald even greater application of lasers in dentistry.

The current commercial developments in wavelength application in dentistry have resulted in lasers whose emissions span the visible, near-, mid- and far-infra-red portions of the electromagnetic spectrum.

Non-surgical, low level laser applications include photo-biomodulation, diagnostics, photo-activated anti-bacterial processes, laser tooth whitening and laser-scanning of tooth cavity preparations.

Keywords

Laser dentistry · Oral soft tissue · Oral hard tissue · Photothermolysis · Photobiomodulation · Spallation · Antibacterial photodynamic therapy

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© Springer International Publishing AG, part of Springer Nature 2018
K. Nouri (ed.), *Lasers in Dermatology and Medicine*, https://doi.org/10.1007/978-3-319-76220-3_4

Perceptions of Laser Use in Dentistry

There is a general paradox surrounding the use of lasers in dentistry; for the majority of patients, dental treatment only extends to the treatment of dental caries ("tooth decay") and, latterly the possibility of cosmetic improvement of teeth including veneers and tooth whitening. The greatest disincentive to dental treatment of this nature has been a perception (or reality) of pain associated with the procedure. Any treatment modality that could address this aspect would be eagerly accepted and the overall marketing concept of the word "laser" only serves to endorse the potential appeal of this instrument in delivering a (supposed) quick, painless and "high-tech" resolution of their dental condition.

For the dentist, the historical approach to the treatment of dental disease and associated procedures has been to use rotary instruments at high speed to remove carious tissue and develop tooth cavities that would be retentive for silver-amalgam restorative material. In addition, the scope of practice of most dentists would extend to treatment of associated soft tissue structures in the mouth, where a majority of procedures would be carried out with a scalpel. Although acknowledgement exists as to the need to control bleeding and post-operative sepsis in soft tissue surgery and tooth damage such as heat, micro-cracking and gross tissue destruction in using a drill, there remains a dogma (not least underlined through undergraduate teaching) that such consequences remained but incidental to conventional instrumentation that could deliver rapid treatment procedures.

In addition, the move away from gross tooth tissue removal and amalgam restoratives, towards a minimalistic, more interceptive and preventative approach to caries treatment has led to a dramatic growth in the use of micro-retentive, bonded non-metallic restorative materials that address the early carious lesion. The wish to employ adjunctive soft tissue management procedures during tooth tissue surgery places a great need for haemostatic incisions that are not subject to bacterial contamination and additional emerging treatment of periodontal, endodontic and implant-related structures, all constitute needs that can be addressed through laser technology. As such, the complexity and demands of oral tissue treatment has led to the development of laser wavelengths and machines that specifically address the treatment whilst minimising collateral damage. Far from the "nomadic" intrusion of lasers in general into dentistry, the speciality has justified the production of procedure-specific lasers. With such refinement has come responsibility and an ever-growing shift from anecdote and single case presentation, to evidence-based and statistically-robust investigation. For example, a simple search of peer-review papers using keywords "laser" and "dentistry", provides almost 10,000 individual studies.

Dynamics of Laser Light in Dental Procedures

The preferred laser-tissue interaction is effected through the maximal absorption of incident laser light by a predominant tissue (or other structural element) chromophore; in surgical use, such absorption leads to the conversion of photonic energy into thermal energy which, if controlled leads to predictable target change with minimal collateral, non-target damage. The complexity of most oral and dental tissue, together with the close approximation of hard and soft tissue elements, places great demands on the clinician to observe care in the selection of laser wavelength, of sufficient incident power to ablate tissue but not to cause adjacent damage. Optimally, the laser wavelength should be one that is maximally absorbed by the predominant tissue chromophore (Fig. 4.1).

Within the short space of time that lasers have been used in dentistry, there has been a greater understanding that, apart from the absorption/chromophore phenomenon there exists the effect of incident energy dynamics in relation to a desired target tissue effect.

Reference to Fig. 4.2 provides a simple schematic to the pathway of photonic energy absorption leading to irreversible dissociation of a target chromophore. In an ideal surgical (ablative) laser-tissue interaction, this process would predominate; however, often the wider implica-

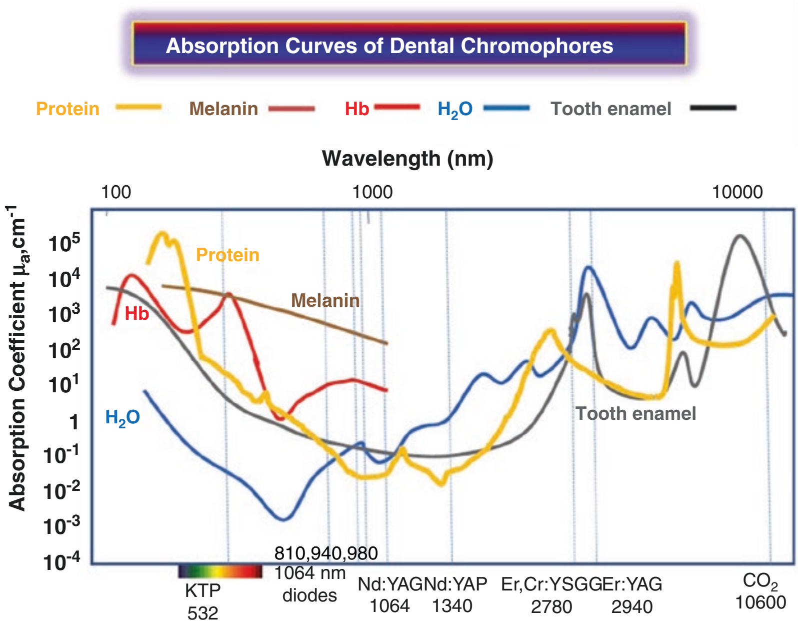

Fig. 4.1 Absorption coefficient values of predominant chromophores (Haemoglobin, Melanin, apatite crystalline solids and Water) relative to common laser wavelengths used in dentistry

Fig. 4.2 Fibroma of traumatic origin, lateral border of the tongue

tion of (secondary) conductive thermal events provides a greater understanding of true photothermolysis, that combines a pure consequence of laser photonic irradiation with the outcome of hyperthemic tissue effects.

The early surgical lasers of the 1960s—for example the CO_2 laser, emitted laser energy at 10,600 nm (10^{-9} m) which would be preferentially absorbed by water present in target tissue. The continuous wave emission mode led to unremitting thermal effects in the tissue, which potentiated the prospect of conductive heat damage to adjacent structures. With no thermal relaxation, the greater the incident laser power, the greater the rise in temperature. With the introduction of gated- and free-running-pulsed laser delivery, the thermal relaxation potential became greater and higher peak power values could be achieved, whilst retaining a low average power.

Laser photonic energy is a form of electromagnetic energy and the concept of both energy transfer and conversion belies the dynamics of laser-tissue interaction. Figure 4.3a provides a schematic of how, within a "pulse" of laser emission, the extent and value of energy delivered can be appreciated and measured. As may be seen in Fig. 4.3b, if the wave-trace of the pulse has equal rise and fall gradients, it is representative of a time period during which the photonic energy is transferred to the target tissue; in terms of photothermal exchange, this ideal represents an equal amount of tissue heating and thermal relaxation. The total time period if seen in terms of thermal change, represents a "footprint" of energy delivery and capacity of the target tissue to cool.

Soft tissue laser treatment demands efficient tissue ablation together with (mostly) optimal haemostasis; both effects can be achieved through a temperature rise of between 60 and 100 °C. With a shorter wavelength laser (500–1400 nm) the pro-

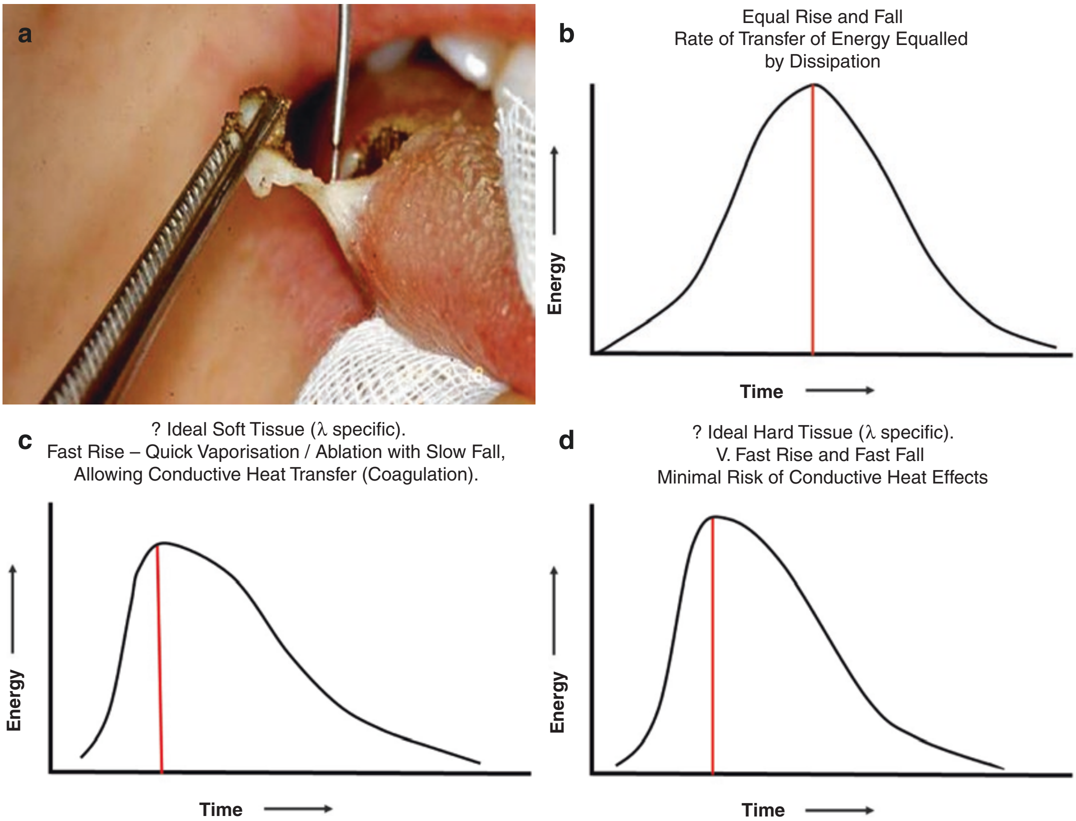

Fig. 4.3 Nd:YAG (1064 nm) laser used to resect the lesion (320 μm fibre/contact/200mj pp./10 Hz/Av. Power 3.0 W)

tein denaturation of pigmented tissue components occurs, whereas with longer (2000–11,000 nm) wavelengths, tissue ablation occurs through water vaporisation. To deliver free-running-pulsed laser energy in a micro-second symmetrical peak-wave configuration with shorter wavelengths, the tissue effect is desirous in achieving ablation and haemostasis. Similar wave configuration with longer wavelengths achieves the vaporisation of water, but insufficient conductive thermal exchange occurs to achieve haemostasis. In these cases, it is preferable to use a laser light waveform that has a rapid energy rise and a slower decline to allow diffusion of energy into the tissue (Fig. 4.3c).

With hard tissue ablation, the demands of energy transfer are much more significant, if unwanted effects of thermal cracking, carbonisation and pulpal damage are to be avoided. Here, the need is to deliver a waveform that has a rapid high-energy rise with an almost-instantaneous fall (Fig 4.3d).

The predominant laser-tissue effect in hard tissue ablation is dislocation of structure through interstitial water vaporisation, although the future development of micro-second "pulsed" CO_2 (predominately 9300 nm) lasers already provides great potential for the true ablation of the mineral component of tooth tissue. To this extent and beyond, nano-and femto-second photonic delivery mechanisms provide opportunity to capture near-plasmolytic power density effects of disparate laser wavelengths applied to host tissue and effecting predictable ablation without reference to target chromophores.

Use of Lasers with Oral Soft Tissue

The use of a laser, as with more conventional instruments, demands of the clinician basic surgical skills which should remain paramount.

Knowledge of the anatomical site, sound diagnostic skills, appreciation of the desired post-surgical outcome and functional needs should be combined with a thorough understanding of the patient's dental and medical history. Where appropriate, the nature of any pathology should be assessed prior to surgical intervention and referral protocols for specialist care should apply, if necessary.

In an otherwise healthy individual, the biological mechanisms that allow healing to take place will always follow the same pathways, irrespective of whether tissue injury is due to a scalpel, thermal, chemical or traumatic cause [1]. Consolidation of the wound—blood clotting and plasma retention, elimination of bacterial contamination and aspects of the inflammatory response—is followed by an in-growth of epithelial and endothelial cell types, which then proceeds to a maturation of wound healing over time. Any potential for scar tissue formation can be affected by the type of tissue, the cause of the wound, presence of tissue mediators and growth factors, whether healing is by primary or secondary intention and, occasionally, racial type [2, 3]. In an ideal situation, the post-surgical healing will be such as to restore stability, form and function to the tissue. In oral soft tissue surgery, where appropriate, the aesthetic appearance of the tissue will be maintained or, as is often the desired outcome improved with regard to dental restorations.

All currently-available laser wavelengths can be used in soft tissue surgical procedures [4, 5]. The structure of oral epithelium—an outer epithelial layer overlying deeper endothelial elements, offers a predominant water chromophore superficially which will absorb longer wavelengths, whereas deeper structures containing pigmented protein—melanin and haemoglobin will absorb shorter wavelengths.

With laser use in surgical soft tissue procedures, assuming correct laser wavelength per tissue site and appropriate power parameters, the healing of oral soft tissue is often termed 'uneventful' [6, 7]. Often, if not always, the need for dressings or sutures is avoided. Irrespective of the wavelength, all soft tissue healing will be by secondary intention. Of note, however, is the phenomenon of lack of post-incisional contamination by bacteria, due to a possible reduction in bacteria during tissue ablation [8], but certainly through the protective layer of coagulum of plasma and blood products—a tenacious film that allows early healing to take place underneath [9, 10]. Additionally, studies with longer wavelengths show that there is a lack of fibroblast alignment associated with the incision line and consequent reduced tissue shrinkage through scarring [11]. Such findings are often borne out in the clinical setting (Figs. 4.4, 4.5, 4.6, and 4.7).

The objective of correct ('safe') laser energy per surgical site shall be to use a minimum

Fig. 4.4 Immediate post-treatment. The site shows a central area of ablation, surrounded by a zone o reversible oedema. Haemostasis is good

Fig. 4.5 Healing at 3 weeks

Fig. 4.6 Denture granuloma lingual aspect of edentulous lower ridge

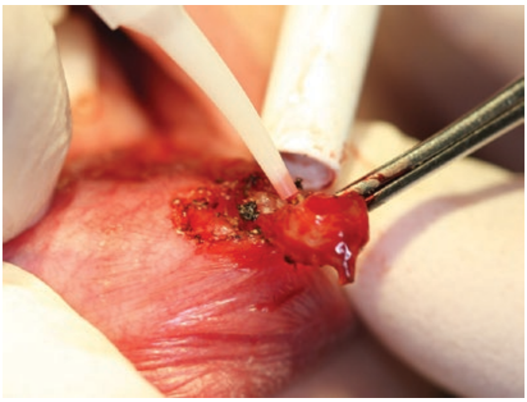

Fig. 4.7 Diode (810 nm) laser used to resect excess tissue (320 µm fibre/contact/CW Av. Power 1.0 W)

level commensurate with the desired effect. Insufficient laser energy levels may only warm the tissue and not initiate tissue ablation, whereas excessive levels can lead to carbonisation and possible deep collateral thermal damage. Carbon, whether present as a build-up on a fibre tip or tissue surface, absorbs all light wavelengths and quickly over-heats. This becomes a source of secondary thermal energy and acts as a 'branding iron', leading to conductive thermal damage [12]. For most intra-oral minor surgical procedures, irrespective of the wavelength chosen an average laser power setting should be in the range of 1–3 W. This is based on personal experience and recommended levels found in manufacturers' user manuals.

Care should always be given to the delicate nature of oral soft tissue and the close anatomical association of bone and/or dental structures. Deep penetration of shorter wavelengths, especially in the absence of a water spray or in continuous-wave or gated CW emission modes may cause overheating and carbonisation of hard tissue. Longer wavelengths used without water spray or scant regard to thermal relaxation can similarly affect adjacent structures. The Erbium group of wavelengths (Er:YAG—2940 nm, Er,Cr:YSGG—2780 nm) are commonly used with a co-axial water spray and a short-pulse emission mode, which poses little danger of overheating. Nonetheless, unwanted ablation of hard tissue may occur with inadvertent or careless use in close association with such structures.

In certain areas of the mouth (sub-glossal, lingual aspect of the retromolar area and the mental foramen in the lower jaw and incisive foramen in the upper jaw), vital structures (submandibular duct and nerves respective to foramina) lie very close to the surface and care must be observed when using lasers in these areas [13].

'Safe' soft tissue cleavage, avoiding the potential of collateral thermal damage is related to correct wavelength/tissue assessment, minimum laser power values to achieve tissue cleavage and thermal relaxation measures to prevent heat build-up. In some cases, it is advisable to pre-cool the tissue with gauze soaked in ice-water, although the close approximation of high-speed suction will assist in providing external tissue cooling. Shorter laser wavelengths (KTP—532 nm; Diode—810, 940, 980 nm; Nd:YAG, 1064 nm) transverse the epithelium and can penetrate 2–6 mm into the tissue, whereas longer wavelengths have minimal penetration [14]. Shorter, visible and near-infrared wavelengths are readily absorbed by pigmented tissue. This can be used advantageously in the treatment of small lesions, especially those of possible traumatic origin [15–18] (Figs. 4.8, 4.9, 4.10, and 4.11).

Fig. 4.8 Immediate post-treatment

Fig. 4.9 Healing at 3 weeks. Denture border adapted to new periphery

Fig. 4.10 Combined gingivoplasty/full veneer crowns. Pre-treatment

Fig. 4.11 Gingivoplasty. Erbium YAG (2940 nm) laser (400 µm tip/non-contact/150 mj pp./10 Hz/+H_2O/Av. Power 1.5 W)

With longer wavelengths (Er,Cr:YSGG—2780 nm; Er:YAG—2940 nm; CO_2—10,600 nm) the risk of deep penetration is minimised and surgical incisions can be deemed less potentially damaging [5].

Probably, the most common procedures include the use of lasers in a range of gingival adaptation procedures, both to allow hard dental tissue restoration and to provide access to crown and tooth cavity margins during restorative procedures. Another large area of clinical activity is the resection of excess gingival tissue (gingivoplasty) associated with the cosmetic enhancement of the appearance of the teeth, either as a stand-alone procedure or in connection with the provision of laminate veneers or crowns. Care should be exercised to avoid violation of the biologic width and to preserve a sufficient width of attached gingiva [19–24] (Figs. 4.12, 4.13, 4.14 and 4.15).

The facility to combine soft tissue management with hard tissue treatment is a major benefit of laser use, when compared to more conventional therapy. This represents considerable advantage to the clinician and the patient management is deemed less complicated, as appointments can be condensed and sutures and dressing packs avoided. Very often, a tooth fracture, otherwise committed to

Fig. 4.12 Immediate post-treatment. Associated upper labial frenectomy using CO_2 laser

Fig. 4.13 Completed case at 12 months

Fig. 4.14 Mucocele lower lip

extraction, can be treated and restored successfully, resulting in many more years of function. In the surgical adjunct to orthodontics, from gingival hyperplasia associated with

Fig. 4.15 Diode (810 nm) laser used to resect excess tissue (320 μm fibre/contact/CW Av. Power 1.5 W)

orthodontic appliances to the exposure of unerupted teeth, the use of laser wavelengths can often enable simple procedures to be carried out without subjecting the child patient to additional anxiety. Both short and long wavelengths can be used, taking care not to cause damage to the underlying tooth or bone, relative to wavelength employed [25–27]. The control of bleeding will allow the placement of bonded orthodontic brackets without undue risk of failure.

The range of benign pathology affecting the muco-periosteal tissue of the dento-alveolar complex includes the following: epulis, giant cell granuloma, inflammatory and drug-induced gingival hyperplasia and cosmetic melanin removal. In addition, pathology affecting non-keratinised gingival tissue and all other accessible soft tissue structures may be commonly-seen within general dental practice; this would include the removal of fibromata, mucocoele, small haemangiomata, denture granulomata, labial and lingual frenectomies and treatment of non-erosive lichen planus and mucocytosis [28].

The aetiology of the lesion should be assessed, together with an understanding of the tissue composition, which will assist in wavelength choice and power parameters used. As with a scalpel, the tissue should be placed under tension, if possible to allow accurate and easier cleavage. In most cases, the laser hand-piece tip is held in close approximation to, and just out of contact with, the tissue surface. In this way the laser energy is allowed to effect the incision and minimise the build-up of debris on the laser delivery tip (Figs. 4.16, 4.17, 4.18 and 4.19).

With simple hyperplasia, wherever possible the laser beam should be directed into the discard tissue and excision completed in a careful and deliberate manner. With a more pedunculated epulis, it should be possible to aid excision by placing the lesion under tension. Aetiological factors should obviously be addressed to prevent recurrence. The use of lasers to treat drug-induced gingival hyperplasia can be of great assistance where either the general medical condition merits a simple surgical procedure, or the underlying blood-picture is compromised.

Fig. 4.17 Healing at 1 month

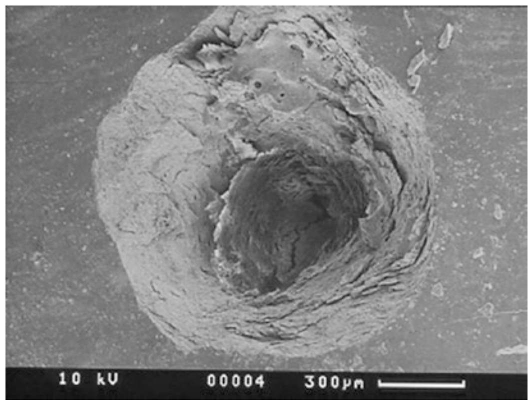

Fig. 4.18 Scanning electron micrograph of human enamel exposed to Er:YAG 2940 nm laser energy. Note the fragmented margin and absence of thermal cracking. Magnification ×500

Fig. 4.16 Immediate post-treatment

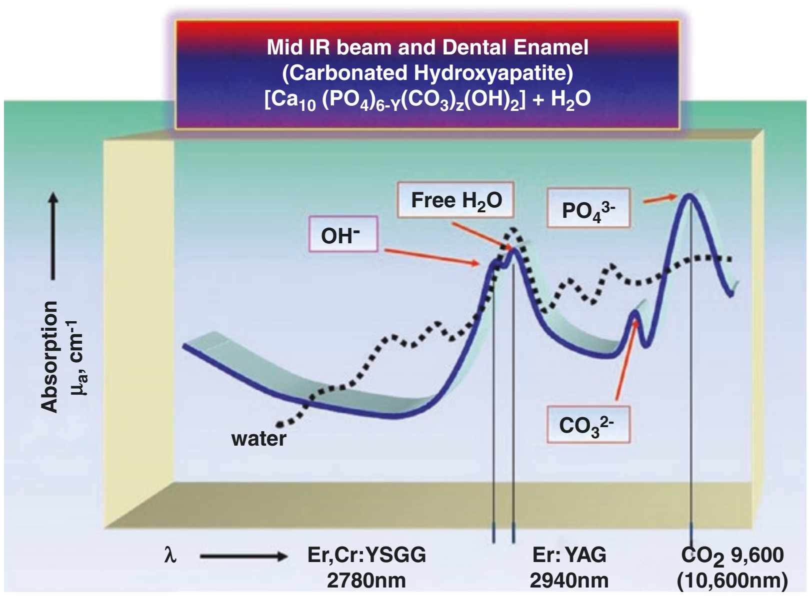

Fig. 4.19 Absorption coefficients of carbonated hydroxyapatite verses laser wavelength. The absorption peaks represent component radicals of the molecule (hydroxyl, free-water, carbonate, phosphate). The dotted line represents the absorption of laser energy in whole water

Where aesthetics are compromised by melanin patches on the attached gingiva, often seen in Asian and African ethnic groups, an alternative approach to a 'dermabrasion' technique is to use laser energy. Most current wavelengths have been advocated, citing either selective pigment ablation with short wavelengths or superficial layer ablation of the tissue with longer wavelengths [29, 30]. The correct use of the selected laser results in little or no discomfort or inflammation compared to removal using rotary instrumentation [31, 32].

Use of Lasers with Oral Hard Tissue

The cutting of dental hard tissue during restorative procedures presents considerable demands on the ability to selectively remove diseased carious tissue, obtain outline and retention form and maintain the integrity of supporting tooth tissue without structural weakening. In addition, the requirement to preserve healthy tissue and prevent further breakdown of the restoration places the choice of instrumentation and clinical technique as prime factors for the dental surgeon. Laser use, when compared to conventional rotary instrumentation may offer the following advantages:

- Precise ablation of hard tissue
- Selective ablation of diseased tissue over healthy tissue
- Ability to utilise micro-retentive cavity design
- Less risk of pulpal injury
- Less risk of thermal and mechanical cracking of tooth structure
- Reduction in bacterial contamination of the tooth cavity
- Less discomfort for the patient

The prime chromophore in current laser application with hard tissue is water; the absorption peak at around 3.0 μm wavelength identifies the Er:YAG (2940 nm) and Er,Cr:YSGG (2780 nm), collectively "Erbium" laser wavelengths as the lasers of choice.

Enamel is composed, by volume 85% mineral (predominately carbonated hydroxyapatite) 12% water and 3% organic proteins. The majority of free water exists within the peri-prismatic protein matrix. Of the major hard tissues, enamel exhibits greatest resistance to laser ablation and this is seen most in healthy, fluoridated, occlusal sites, where ablation rate is approximately 20% of that achieved with a turbine [33–36]. Fluoridated enamel presents a greater resistance, due to the combined effects of a harder fluorapatite mineral and the replacement of the hydroxyl group by fluoride.

Dentine has a higher water content and less mineral density than enamel, being 47% by volume mineral (carbonated hydroxyapatite), 33% protein (mostly collagen) and 20% water. Consequently, ablation rates are faster than for enamel and power parameters can be correspondingly lower. Similar differences occur in the use of Erbium lasers on deciduous tooth tissue [37].

With the Erbium group of lasers the free-running micro-pulse (FRP) emission mode results in rapid and expansive vaporisation of interstitial water and dissociation of the hydroxyl radical in the hydroxyapatite crystal causing an explosive dislocation of the gross structure [33, 38, 39]. Early study into the use of FRP photonic energy at 3.0 μm assumed this dislocation—termed spallation—occurred at normal temperature and pressure [40]. However, the exact mechanism whereby target enamel and dentine may be ablated proposes that absorption of mid-infrared radiation by water within the crystalline complex of carbonated hydroxyapatite (CHA) is a function of temperature and pressure, both of which rise rapidly during an ablative laser pulse train [41]. In some circumstances, the close approximation of laser delivery tip to the tooth surface, the presence of co-axial water in abundance and the prospect of superheated vaporisation may suggest precise ablation at high temperature, with associated cavitation phenomena assisting in the dislocation of crystalling tooth tissue [42, 43] (Fig. 4.20).

The Er,Cr:YSGG laser has a lower absorption coefficient in water than Er:YAG (4000 cm^{-1} vs. 13,000 cm^{-1} for Er:YAG). When one examines the absorption curve of CHA (enamel), there is a peak, coincident with 2700 nm, representing absorption by the hydroxyl group (OH-) contained in the mineral molecule. It is thought that the simultane-

Fig. 4.20 Scanning electron micrograph of human dentine exposed to Er:YAG 2940 nm laser energy. Note the absence of smear layer. Magnification ×1500

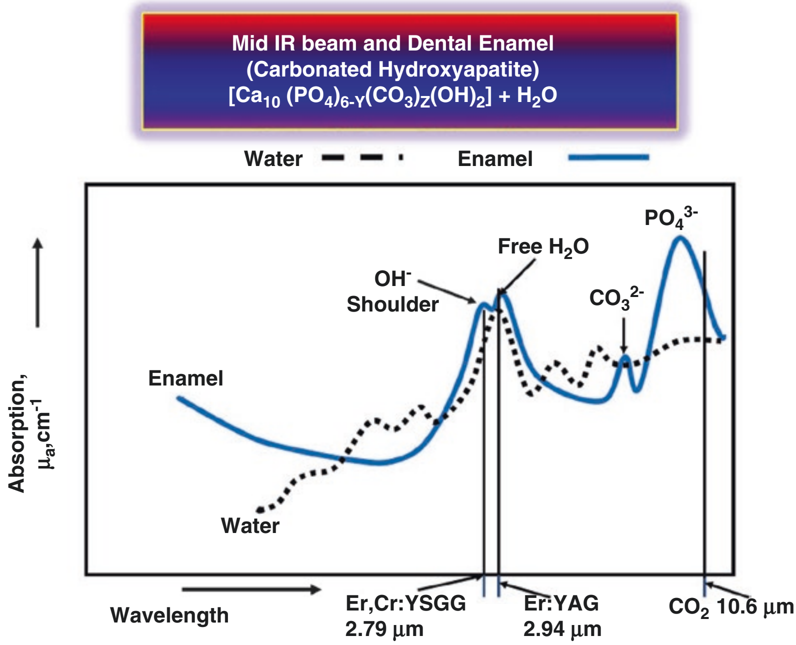

Fig. 4.21 Carious cavity buccal margin upper left bicuspid. Caries removed and cavity prepared using the Er:YAG 2940 nm laser (800 μm sapphire tip/contact/350mj pp/10 Hz/Water spray/Av. Power 3.5 W). Insert SEM of margin. Magnification ×1000

ous ablation of this radical, with concomitant rapid heating of the mineral together with some direct vaporisation of whole water in hard tissue, contributes to the explosive dislocation of the target tissue when using this laser [44] (Fig. 4.21).

The 160 nm difference in wavelength measurement between Er,Cr:YSGG and Er:YAG has appreciable effect in terms of the absorption in water; this amounts to a 300% difference between the higher (Er:YAG) absorption and the lower Er,Cr:YSGG [45], but although differences appear in terms of ablation threshold [46], this does not amount to discernable differences in clinical use [47].

Clinically, this is seen as ejection of microfragments of tooth tissue within the laser plume and the change in pressure in the immediately surrounding air results in an audible "popping" sound. In target tissue that has greater water content (caries > dentine > enamel), the popping sound is louder. With experience, this can aid the clinician in selectively ablating carious verses non-carious tissue. Compared to near infra-red wavelengths, the explosive outward effect of Erbium laser energy results in minimal thermal diffusion through the tooth structure. With carious dentine there is a potential in gross caries for the laser beam to quickly pass through the surface layer, thus leading to dehydration in deeper layers. Where gross caries is present it is advisable to use an excavator to remove bulk volume, both to prevent heat damage and to expedite cavity preparation. In addition, compared to bur preparation, there is an absence of smear layer and no alteration in composition or hardness of the cut tooth tissue surface [48]; as

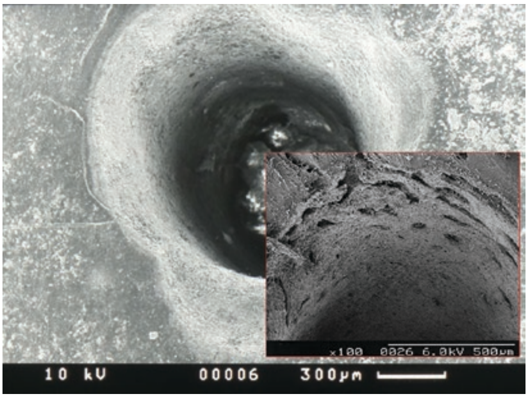

Fig. 4.22 Scanning electron micrograph of porcine bone exposed to Er:YAG 2940 nm laser energy. Note the clean cut margin and absence of thermal cracking. Magnification ×500

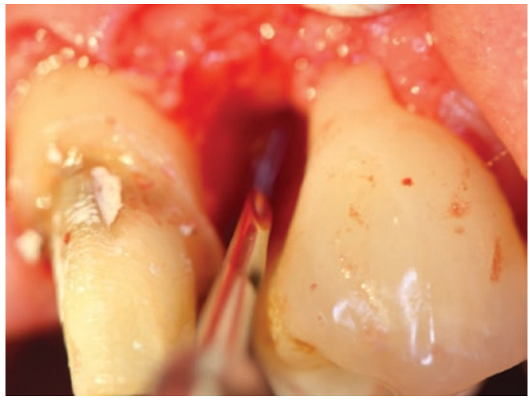

Fig. 4.23 Use of 400 μm hollow tip with Er:YAG laser

Fig. 4.24 Use of laser energy in debridement of the inflamed periodontal pocket. The quartz optic fibre (diameter 200–320 μm) allows easy access when using near IR wavelengths

such it is advisable to use a dentine protector on open tubules exposed by the ablation process [49] (Fig. 4.22). Co-axial with this laser is a water spray, to aid in dispersing ablation products and to provide cooling of the target site.

With laser-assisted cavity preparation, it is not possible to create sharp cavo-surface line angles and retention form has been addressed through the possibility of micro-retention of composite resin materials [50]. Clinical procedures that may be considered under this heading include fissure sealing, direct composite resin veneers and orthodontic bracket placement.

There is some controversy over the marginal seal and stability of the composite restoration when the cavity has been prepared with a laser. Certainly, the gross appearance of the cavity margin when dried resembles an etch-like appearance, but this is due to the fragmentation of the tooth structure (Fig. 4.23). A majority opinion exists to advocate the additional acid-etch of the cavity margins [51–57], although some studies have suggested that the strength of the seal is less than in conventionally-prepared restorations [58] (Fig. 4.24).

There have been many claims—mostly anecdotal—that in the clinical setting, laser-assisted tooth cavity preparation is painless. Perhaps what is more accurate and borne out through many studies, is the reduced discomfort of laser action, compared to high-speed rotary instrumentation [59–62].

By far the greater application of photonic energy in tooth tissue ablation has been through the Erbium group at approximately 3.0 μm. During the past 10 years, experimental action has given way to clinically-applicable devices whereby ultra-short laser pulses of Near-Infra-Red and Far-Infra-Red irradiation can be used to efficiently ablate tooth tissue. Notable in this regard has been the utilisation of the 9.3 μm wavelength which is highly absorbed by the phosphate radical within the carbonated hydroxyapatite crystal lattice. Hitherto, Carbon dioxide laser wavelength has been emission at 10.6 μm, with preferable absorption in water; the CW or gated CW emission would lead to rapid and destructive thermal rise. The new, filtered, shorter wavelength is delivered at micro-second emission (pulse duration of 10 to 15 μs and repetition rate of 300 Hz) with minimal thermal "foot-print" [63, 64]. Added to this, an ultra-short pulsed laser (Nd:YVO_4 $\lambda = 1064$ nm $\zeta_p = 8$ ps/500 kHz) has been shown to offer similar ablation efficiency [65–67].

Laser ablation of bone: Early study into the effect of the Er:YAG laser on bone showed that, as with enamel and dentine ablation, tissue cutting is a thermally induced explosive process [68].

Laser-assisted surgical removal of alveolar bone can form part of a range of treatments including surgical removal of teeth, tooth apical surgery, access to bony pathology and periodontal bone management. Additionally, the development of delivery tips for use with Erbium lasers has prompted osteotomy site preparation for the placement of implants. The use of erbium lasers in dento-alveolar surgery represents a less-traumatic experience for the patient, when compared to the intense vibration of the slow-speed surgical bur—clinically with maxillary alveolar bone, the speed of laser cutting is comparable with that of a bur and slightly slower in the mandible, reflecting the greater cortical bone composition.

The micro-analysis of the cut surface reveals little evidence of thermal damage and any char layer appears to be restricted to a minimal zone of 20–30 μm in depth [69, 70] (Fig. 4.25). Studies into the healing of lased bone would support the contention that the reduced physical trauma, reduced heating effects and reduced bacterial contamination, together with some claims to an osteogenic potential, lead to uncomplicated healing processes, when compared to conventional use of a surgical bur [71–74].

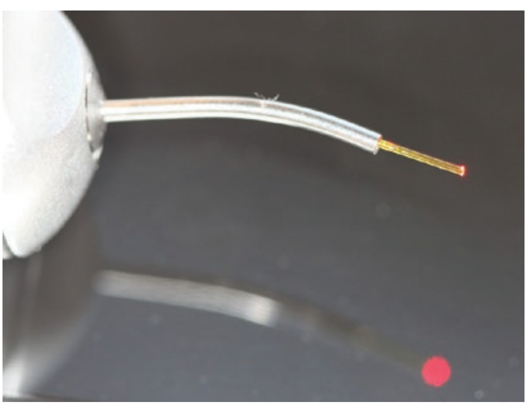

Fig. 4.25 The 320 μm diameter quartz optic fibre

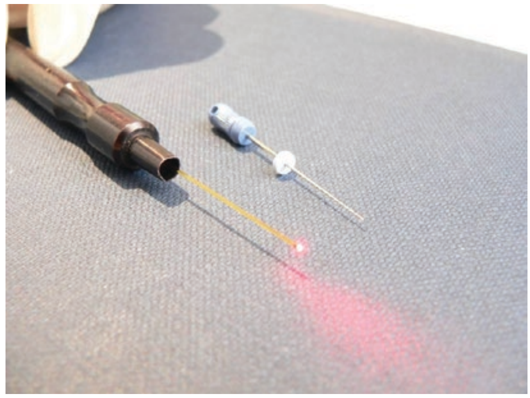

Fig. 4.26 The 200 μm diameter quartz optic fibre compared to a ISO # 15 hand file

An advantage of the fine diameter laser tips available allows a more precise removal or remodelling of crestal alveolar bone associated with periodontal pockets or crown lengthening procedures (Fig. 4.26). With a closed flap approach to crown lengthening, the end-cutting nature of the tip is an absolute advantage over rotary instrumentation and has led to a growth in this treatment modality [75–78]; however, there is always the danger of not being able to visualise the target tissue and caution must be exercised in this respect.

Use of Lasers in Anti-Bacterial Techniques Adjunctive to Dental Surgery: Laser Use in Periodontology, Endodontics, Implantology

Laser Use in Periodontology: There can be no compromise over the employment of thorough and evidence-based therapeutic measures in the dental specialties of periodontology, endodontics and implantology. All aetiological and pre-disposing factors must be evaluated and applied against the presenting condition in order to define the type and scope of therapy. Successful and predictable outcome is mandated in that a correct diagnosis is made and proper treatment implemented to achieve a stable result. Within such protocols, the use of lasers must be viewed as adjunctive.

Periodontal disease is a multi-factoral, predominately chronic inflammatory process whereby bacterial deposits associated with the gingival tissues produce toxins that evoke tissue reaction. Genetic, functional, lifestyle, systemic and local influences will all determine the host tissue response and, consequently, the course and outcome of the disease.

The use of surgical lasers in periodontology can be seen in three areas of treatment: removal of diseased pocket lining epithelium, bactericidal effect of lasers on pocket organisms and the removal of calculus deposits and root surface detoxification. When integrated into a sound approach to pocket reduction, all current dental wavelengths have been advocated for the removal of diseased epithelium [79–83]. Added to the current wavelengths is the recent development of a frequency-doubled (wavelength halved) Nd:YAG laser at 532 nm, termed the KTP laser which has a range of action similar to that of the 810 nm diode. Delivery fibres and tips can be fine enough to facilitate easy access into periodontal pocket (Figs. 4.27 and 4.28). The haemostatic advantage of using laser energy confers a controlling factor that is beneficial to both clinician and patient. Conceptually, in a periodontal pocket that is essentially supra-bony, the removal of hyperplastic soft tissue together with a reduction in bacterial strains, renders the post-laser surgical site amenable to healing within normal limits. Where the pocket is infra-bony, a number of procedures have been advocated, including laser-ENAP (excisional new attachment procedure) where the Nd:YAG (1064 nm) laser is used in a non-flap procedure to reduce pocket depths of several millimetres through a succession of treatment appointments [84, 85].

Fig. 4.27 320 μm diameter quartz optic fibre inserted into a root canal. The red aiming beam shows the extent of light distribution that might be expected with IR laser energy

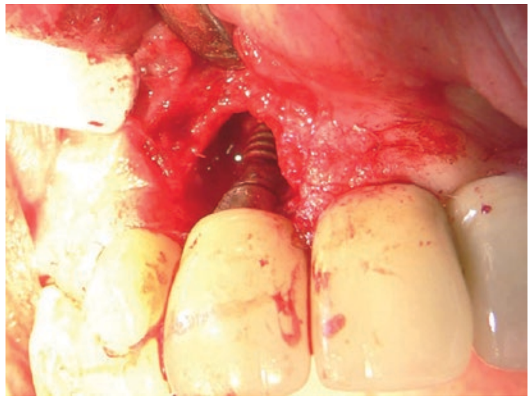

Fig. 4.28 Peri-implantitis associated with upper anterior implant fixture. Lesion shows the amount of bone destruction. Soft granulation tissue removed

Among the bacteria most implicated in periodontal disease and bone loss are *Actinobacillus actinomycetemcomitans*, *Porphyromonas gingivalis* and *Bacteroides forsythus*. Other bacteria associated with periodontal disease are *Treponema denticola*, *T. sokranskii* and *Prevotella intermedia*. These latter bacteria, together with *P. gingivalis*, are frequently present at the same sites and are associated with deep periodontal pockets. Most studies reported in the literature focus on the *in vitro* action of various laser wavelengths on these selected bacterial species. The effectiveness of any laser wavelength is dependent upon the absorption characteristics of the target bacterial structure (water, pigment) being matched by the incident beam. In addition, *in vivo* the difficulty within the pocket of definable parameters of laser energy dosage, concentration of bacterial colonies and accuracy of exposure, may give rise to some scepticism as to the predictability of this therapy.

Nevertheless, a number of studies have been carried out to support the action of laser energy on various bacterial strains implicated in chronic periodontal disease [86–92]. Short wavelength lasers interact with pigmented strains, whereas longer wavelength laser energy is absorbed by cellular water, leading to fragmentation of cellular structure. Calculus, being a non-uniform mixture of inorganic salts, organic material, bacterial strains and water, can be viewed as a ready absorber of all wavelengths. However, the close association of calculus deposits with tooth and periodontal structures does pose a potential risk of collateral damage. Of the wavelengths investigated, Erbium YAG (2940 nm), Erbium Chromium YSGG (2780 nm) and the experimental frequency-doubled alexandrite (377 nm) have been shown to interact and remove calculus selectively [93–96].

Laser Use in Endodontics: In common with laser use in periodontology, the confines and difficult access posed by the root canal present specific challenges in endodontic treatment. Peri-radicular lesions are either primarily or secondarily caused by micro-organisms and conventional treatments suggest the combination of mechanical debridement and chemical anti-bacterial agents [97–101]. In order to address the end-on emission of laser light from the delivery system, modified intra-canal instruments have been developed and experimental devices to produce non-axial laser light propagation have been investigated [102–104]. The fine (200–320 μm) diameters of quartz optic fibres used with the range of Diode and Nd:YAG lasers have enabled these wavelengths to be easily used in bacterial decontamination of the root canal [105–109] (Figs. 4.29 and 4.30). Of the current lasers available, the CO_2 wavelength would appear least suc-

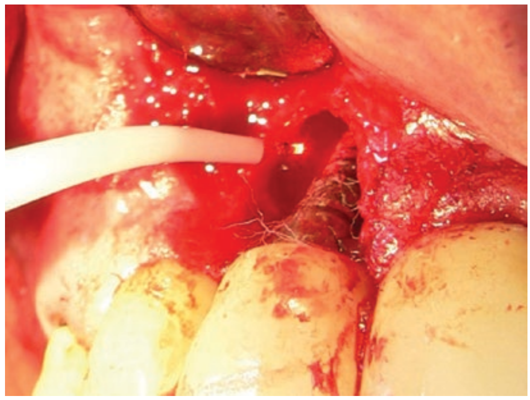

Fig. 4.29 Bacterial decontamination of titanium implant surface using the Diode 810 nm laser (320 μm fibre/non-contact/1.0 W CW)

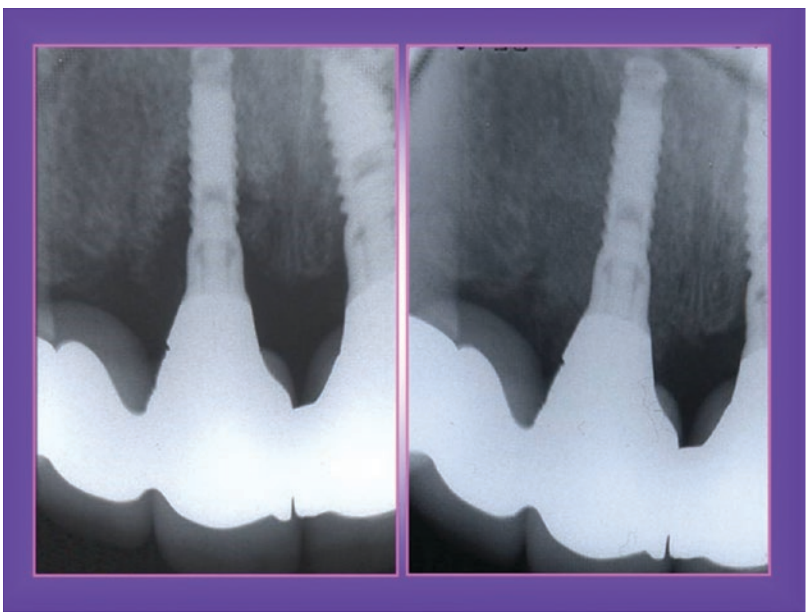

Fig. 4.30 Peri-apical radiographs of the affected implant. Left: the extent of the bone destruction, Right: following surgery and use of bone graft matrix, healing at 3 months

cessful in effecting bacterial decontamination and the effectiveness of laser use appears to depend on fluence values and direct access [110]. In addition, some concern has been expressed that the plume produced during laser action might allow bacterial contamination to spread [111, 112]. As with laser anti-bacterial action in other clinical sites, sub-ablative energy levels should be employed for all wavelengths. Comparative studies on two common bacterial pathogens, *Escherichia coli* and *E. faecalis* have shown that the more complex cell wall of the latter (layered murein, lipoprotein and lipopolsaccharide) can reduce the effectiveness of laser action in that the structure is more resistant to the sub-ablative energy levels [113]. Studies undertaken using the erbium group of lasers on *E. faecalis* have underlined the effectiveness of these lasers in removing dentinal structure and allowing direct action on this bacterium [114].

In recent years, greater emphasis has been shown to recognise and investigate the influence of biofilm structure and physical debridement of the root canal walls [115–118], together with the emergence of multi-wavelength combined procedures using ablative and sub-ablative energy levels. As such, this merging of surgical laser photoonics with low-level aPDT techniques shows promise in maximising adjunctive laser use in endodontic procedures.

Laser Use in Peri-implantitis: The success of osseointegrated root-form titanium dental implants as abutment support for fixed restorative prosthetics has given rise to an explosion in uptake world-wide. During the past 10–15 years, there has emerged a growing awareness of failure in soft tissue (peri-mucositis) and hard tissue support (peri-implantitis) for fixtures [119–123].

Peri-implantitis is recognised as a rapidly progressive failure of osseo-integration [124] in which the production of bacterial toxins precipitates inflammatory change and bone loss [125]. The development of peri-implantitis is not restricted to any one type of implant design or construction [126–128] and is cited as one of the greater causes of implant loss [129, 130].

Peri-mucositis is considered a component of support failure, but one where the inflammatory signs are limited to the soft tissue cuff and there is no evidence of marginal bone infiltration. Given that the aetiological factors associated with individual sites can be addressed, the therapy directed at resolving the soft tissue condition might be considered similar to that in early marginal periodontitis [131].

When breakdown has involved supporting bone, direct action is indicated to prevent further tissue failure (Figs. 4.31, 4.32 and 4.33). Therapy is viewed through the following stages: establishing and neutralising aetiological factors, debridement, decontamination, re-establishment of biocompatibility, structural matrix as required, with on-going maintenance and review to optimise health and stability. Laser-assisted therapy

Fig. 4.31 Low-level laser probe in use in the treatment of pulpitis. The laser device is hand-held

Fig. 4.32 Use of the DiagnDent (Kavo, Germany). The tip is applied to the tooth surface and findings recorded using the analogue score

Fig. 4.33 Non-vital upper left central incisor prior to bleaching

may be seen as appropriate through many of these stages [132].

Laser-assisted debridement: Hyperplastic gingival tissue and intra-bony granulation tissue may be ablated using any of the clinically-available surgical laser wavelengths. Concerns amount to be able to access all aspects of the implant site in order to ablate the diseased tissue without exposing metal or bone to direct photothermal energy. A combination of laser and sharp curette may help to overcome difficulties.

Laser decontamination of implant surface: studies have investigated the use of all laser wavelengths in defining significant pathogen reduction and the ability of laser energy in bacterial decontamination appears to place its use above that of other modalities [133–136].

However, there is less evidence of beneficial use where the implant is coated with a ceramic or hydroxyapatite; this may be mostly due to the micro-complex surface irregularities which have been shown to harbour bacteria and foreign ions in a failing situation [137, 138].

As with periodontal bacterial reduction, emphasis is now placed on investigations of biofilm complexes over planktonic solution of single strains and the significance of bacterial CFU reduction in terms of a $\log_5$ level of difference between modality and control [138, 139].

Additionally, the use of combined therapies (surgical laser plus aPDT) is an emerging concept which attracts investigation [140–142].

Low-Level Laser Use in Dental Surgery

The use of LLLT in dental patients almost exclusively involves red and near-infrared light. There is a so-called "optical window" of these wavelengths in tissue (approx. 650–1100 nm), where the effective tissue penetration of light is maximised. Principal tissue chromophores (haemoglobin and melanin) have high absorption bands at shorter wavelengths, tissue scattering of light is higher at shorter wavelengths and water strongly absorbs infrared light at wavelengths >1100-nm [143].

Light energy is absorbed within living tissue by cellular photoreceptors, e.g. cytochromophores. The incident electromagnetic energy is converted by cellular mitochondria into ATP (adenosine tri-phosphate) [144]. Consequently, the stimulated increase in ATP production would suggest an increased cellular activity in e.g. fibroblasts involved in tissue healing [145]. In addition, the conversion of some of the incident energy into heat would suggest an increase in local micro-circulation through vasodilation.

According to the first law of thermodynamics, the energy delivered to the tissue must be conserved and three possible pathways exist to account for what happens when low level laser therapy is delivered into tissue.

First pathway—photonic energy is absorbed by a tissue/cellular chromophore and this raises the energy state of the chromophore to an unstable upper level. A chromophore is a molecule (or part of a molecule) which imparts some decided "colour" (absorptive capacity) to the tissue of which it is a component. The consequent first excited singlet state of the chromophore undergoes a transition from a higher to a lower electronic state and the energy of the electronically excited state is given off to vibrational modes of the molecule, i.e. the excitation energy is transformed into heat [146]. Examples of chromophores can be seen in haemoglobin, cytochrome c oxidase (Cox), myoglobin, flavins, and porphyrins [147].

Second pathway—Fluorescence. Fluorescence is a luminescence in which the molecular absorption of a photon triggers the emission of another photon with a longer wavelength. The energy difference between the absorbed and emitted photons ends up as molecular vibrations or heat.

Third pathway—Photochemistry. The level of irradiation and energy of the photons involved is insufficient to cause covalent bonds to be broken. The energy however is sufficient for a first excited singlet state to be formed and this can undergo intersystem crossing to the longer-lived triplet state of the chromophore. This allows reactions to occur, such as energy transfer to ground state molecular oxygen to form the reactive singlet oxygen (ROS).

Alternatively the chromophore triplet state may undergo electron transfer (reduction) to form the radical anion that can then transfer an electron to oxygen to form superoxide. A third photochemistry pathway that can occur after the absorption of a photon is the stimulation of the mitochondrial respiratory chain.

In summary, the absorption of photonic energy by cell mitochondria and associated chromophores leads to biochemical pathway changes (positive and negative), cell and transcription signalling, from which examples of enhanced tissue repair and healing may be seen.

First pathway effects—photobiomodulation: There is growing evidence that LLLT works well on a range of oral pathologies; these include improvements in:

Reported effects of LLLT photo-biomodulation in clinical dentistry may include the following [148–153]:

- Dentine hypersensitivity
- Post-extraction socket/post-trauma sites, drug-induced/X-Ray-induced osteonecrosis
- Bone density, Orthodontic tooth movement
- Viral infections: herpes labialis, herpes simplex
- Neuropathy: trigeminal neuralgia, paraesthesia, Bell's palsy
- Apthous ulceration
- Osseointegration of implants
- TMJDS, Trismus
- Post-oncology: mucositis, dermatitis, post-surgery healing

The stimulatory effects of LLLT include the following [154–157]:

- Proliferation of macrophages
- Proliferation of lymphocytes
- Proliferation of fibroblasts
- Proliferation of endothelial cells
- Proliferation of keratinocytes
- Increased cell respiration/ATP synthesis
- Release of growth factors and other cytokines
- Transformation of fibroblasts into myofibroblasts
- Collagen synthesis.

In addition, there is evidence to support the analgesic effects of LLLT, through an enhanced synthesis of endorphins and bradykinins, decreased c-fibre activity and an altered pain threshold. Therapeutic analgesic effects may also occur, through the release of serotonin and acetylcholine centrally and histamine and prostaglandins peripherally [158, 159].

Photobiomodulation (PBM) is the manipulation of cellular behaviour using low intensity light sources. Laser therapy (application of photonic energy at specific wavelengths) works on the principle of inducing a biological response through energy transfer. Photonic energy delivered into the tissue modulates biological processes within that tissue and within the biological system of which that tissue is a part (Fig. 4.34).

PBM has no appreciable thermal effect in irradiated tissue.

Fig. 4.34 Tooth appearance after laser tooth whitening

Second pathway effects—fluorescence: Fluorescent- and photodynamic-diagnosis may provide screening facility or part of a hierarchical series of tissue investigation.

Suspect lesions of the oral mucosa must be subjected to biopsy and other investigations. Auto-fluorescence imaging may give good results for the distinction of lesions from normal mucosa, although it is inappropriate to place auto-fluorescence investigation in any role other than as an adjunctive scanning technique.

If possible, auto-fluorescence spectroscopy could be used to find the optimal, most dysplastic location for biopsy. Unfortunately, the literature shows that auto-fluorescence is not specific enough for this purpose.

The use of fluorescence in caries detection was first suggested more than a century ago, but received greater significance with introduction of laser technology into dentistry. Wavelengths used are commonly between 405 and 670 nm. In the 1980s, a clinically applicable visual detection method, focussing on the natural green fluorescence of tooth tissue was developed [160, 161]. The technique used a 488 nm excitation wavelength from an argon-ion laser to discriminate bright green fluorescing of healthy tooth tissue from poorly fluorescing carious lesions. The technique was developed further in the early 1990s into what is now known as quantitative light-induced fluorescence (QLF), where the digitisation of fluorescence images is used to quantify the measure of mineral loss [162].

Around that time, a red fluorescence method emerged. The red fluorescence, excited either using long UV (350–410 nm) or red (550–670 nm) wavelengths, was observed in advanced caries as well as plaque and calculus on teeth. As opposed to the green fluorescence loss observed in caries, a substantial red fluorescence occurs between 650 and 800 nm in caries lesions and this is much brighter than that found with sound enamel or dentine [163, 164]. The first commercially available unit using a red laser was manufactured by Kavo (Kavo GmbH) in 1998, with an emission wavelength of 655 nm (Fig. 4.35).

Dental caries is multifactorial in aetiology. Diagnosis and treatment should be respectful of aetiology, lesion site and 3-D extent. Detection methods include tactile, radiographic, chemical and illuminescence and photo-diagnostic fluoroscopy [165] techniques. Studies appear to suggest that combination techniques offer greater accuracy.

Fig. 4.35 Application of methylene blue solution as photosensitiser. The application follows initial pocket debridement

Laser irradiation promotes differential fluorescence of tooth tissue/caries/plaque/calculus. Fluorescence is a product of Laser wavelength (photonic energy). Narrow waveband (non-coherent) irradiation may allow differential spectrometry.

Laser fluorescence may be a useful adjunct in the detection of early enamel caries. The level of energy used in this application poses little risk to the patient and offers potential benefits [166].

Optical Coherence Tomography [167] (OCT) is a technique for obtaining sub-surface images of translucent or opaque materials at a resolution equivalent to a low-power microscope.

Conceptually it is equivalent to an ‘optical ultrasound’, imaging reflections from within tissue to provide cross-sectional images [168, 169].

Not all methods accurately detect early lesions, and false positives and false negatives may occur. Detecting early lesions in combination with assessing activity status is essential for establishing the prognosis and threshold required for preventive intervention [170].

Third pathway effects—photochemistry: The clinical application of laser-initiated photochemical actions include tooth whitening, scanning techniques and photodynamic antimicrobial chemotherapy.

Tooth whitening: Differing treatment modalities have been developed to address the phenomenal growth in demand for tooth whitening. Originally, the Argon 488 nm laser wavelength was marketed to provide intense photonic energy to assist the action of hydrogen peroxide on stained enamel and dentine, but the cost of the unit together with the safety requirements led to its decline in use [171]. Other techniques emerged, ranging from the use of LED and plasma-arc lights to home-use kits, using a preformed custom tray system.

The present resurgence in laser-assisted tooth whitening has been the development of a diode-based KTP (Potassium Titanyl Phosphate) 532 nm laser. This laser interacts with bleaching gel containing carbamide peroxide in a photo-activated way, as opposed to the longer (Diode 810 nm, CO_2 10,600 nm) wavelengths, which act in a photothermal way to provide heat to the gel and consequently accelerate the chemical reaction [172] (Fig. 4.36).

With the KTP laser technique a red gel, containing Rhodamine B and hydrogen peroxide is applied to the tooth and exposed to the laser energy. The Rhodamine B molecule has its maximal absorption at 539 nm. When this dye is exposed to 532 nm light, it absorbs photons of energy with subsequent electron transition to the singlet excited state. The molecule may then undergo reactions with molecular oxygen, resulting in the production of hydroxyl radicals, superoxide ions, peroxides, labile singlet oxygen, or reactive oxygen species. In this way, the interaction between the KTP laser energy and the dye is a photochemical process [173].

Fig. 4.36 Methylene blue photosensitiser exposed to diffuse laser photonic energy (λ = 670 nm/200 mW/60 s per site)

A portion of the KTP laser energy aborbed into the Rhodamine B dye is also transferred from the excited molecule into the bleaching gel in the form of thermal energy. This transfer results in controlled heating of the gel and not the tooth, minimising the possibility of thermal damage to the pulp. This superficial heating of the gel accelerates the breakdown of hydrogen peroxide, which furter boosts the overall yield of perhydroxyl radicals over a given time [173].

Apart from extrinsic staining due to lifestyle factors, a common source of intrinsic staining is due to the administration of tetracycline antibiotics during tooth formation. Such staining has been shown to be resistant to chemical bleaching agents that produce oxidising radicals, whereas the tetracycline molecule can be photo-oxidised with the 532 nm laser [173].

Scanning and spectrometry: The development of laser-based measuring devices (e.g. the confocal micrometer), utilising beam-splitting of a low-energy laser and an optical detector, has enabled accurate replication of the morphology of dental and oral structures and materials used in restorative dentistry. The earliest use of laser scanning was in the field of orthodontics and facial development to provide 3D imaging and recording of pre- and post-treatment of deformities [174–176]. Scanned data was linked to computer software using CAD (computer-assisted design). This concept has been expanded during the last decade, to enable the scanning of restorative cavities prior to the production of cast or milled indirect restorations and the recording of oral and facial swellings [177, 178].

The development of laser Doppler flowmetry into applications in dentistry has allowed detailed analysis of pulpal and gingival blood flow, to assist in treatment planning [179–181].

An additional associated use of laser light in oral medicine is through Raman spectroscopy. A Raman spectrum represents the scattering of incident laser light by molecular or crystal vibrations.

Such vibration is quite sensitive to the molecular composition of samples being investigated, and areas of research include the in vitro and in vivo study of disease processes such as cancer, atherosclerosis and bone disease. With regard to the latter, Raman spectroscopic analysis in vivo of mineral and matrix changes has been shown to be useful in mapping early changes in bone tissue [182].

Photo-activated antimicrobial chemotherapy: The concept of light-activated drug-therapy is well-established in medicine in the form of photodynamic therapy. Photo-activated antimicrobial chemotherapy is a development over and above the conventional use of chemicals to achieve bacterial decontamination in aspects of periodontal and restorative dentistry. Acronyms to describe this therapy abound and consensus has tended to adopt the use of antimicrobial photodynamic therapy—aPDT. Currently, topical application of a photosensitizer on infected tissues and subsequent illumination seems to be the most promising feature of antimicrobial photodynamic therapy [183].

The technique involves the application of a suitable chemical—a photosensitiser—to the treatment site. A photosensitiser is a chemical compound that readily undergoes photo-excitation when exposed to laser irradiation and then transfers its energy to other molecules. Host tissue oxygen, when in close proximity will undergo intersystem crossing to form oxygen radicals (O_2^-) and other free-radicals (H_2O_2 and OH^-). Additionally, the production of reactive oxygen species (ROS)—electronically excited and highly reactive state of oxygen, known as singlet oxygen ($^1O_2$) which can interact with a large number of biological substrates inducing oxidative damage on the cell membrane and cell wall [184]. These destructive reactions will kill cells through apoptosis or necrosis.

A number of photosensitisers have been used to investigate aPDT. Each photosensitiser has a unique absorption peak corresponding to applied laser wavelength. Examples of commercially-available dyes are as follows:

Circumin (Yellow)—430 nm
Methylene Blue—660 nm
Radachlorin (chlorophyll derivative)—660 nm
Toluidine Blue—680 nm
Indocyanine Green—810 nm

And these have been shown to exert statistically-significant bacteriocidal effects on a range of periopathic bacterial species [185–187].

Photosensitiser triplet state molecules excited by $\lambda > 850$ nm have insufficient energy to induce ROS in adjacent tissue O_2 [188]. The peak absorption with Indocyanine green at 810 nm has given rise to belief that it's action is not purely photodynamic, but is predominately photothermal [189, 190].

Investigations in the early 1990s, notably by Wilson and Pearson at the Eastman Dental Institute, London, determined the susceptibility to aPDT of *Streptococcus mutans* when the organism was present in a collagen matrix—an environment similar to that which would exist within a carious tooth [191]. If bacterial contamination of the prepared cavity could be rendered sterile, the hypothesis suggested that the potential for recurrent caries might be significantly reduced. The concept has also been expanded to consider a more-interceptive treatment of demineralised, but otherwise intact enamel surfaces, where bacterial elimination and fluoride therapy might prevent development of a more significant carious cavity [192]. Recent in vitro and in vivo studies into the use of PAD in endodontics [193, 194] have demonstrated the effectiveness of this therapy against a number of anaerobic bacterial strains associated with endodontic infections (*Fusobacterium nucleatum*, *Peptostreptococcus micros*, *Prevotella intermedia* and *Streptococcus intermedius*). In addition, PAD has been shown to be effective against *Enterococcus faecalis* [195].

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Laser/Light Applications in Otolaryngology

Carolyn Orgain, Vanessa Rothholtz, and Brian J. F. Wong

Abstract

Lasers have been ubiquitous in otolaryngology since Jako and Strong first introduced the CO_2 laser in 1970. Since that time lasers have traditionally been used like a scalpel, able to cut and cauterize precisely. More recently, the role of lasers has been expanded in otolaryngology depending on the specific laser wavelength and dosimetry parameters. Not only can lasers be utilized to extirpate cancer, but also used to recover hearing, improve the airway, treat epistaxis, and even break up salivary stones for easy removal. The individual characteristics of the laser are important for the specific application. However, the otolaryngologist often works in areas that are either difficult to access using classic methods or require extreme precision, and the mechanism and method for delivering the laser energy is often equally important. In this chapter, we describe the many ways lasers are used in otolaryngology treat both benign conditions to life-threatening diseases. New and innovative applications are also discussed.

Keywords

Carbon dioxide laser · Potassium titanyl phosphate laser · Laser safety · Laryngeal cancer · Laryngomalacia · Laryngeal polyps · Laryngeal papillomas · Cholesteatoma · Stapedectomy · Laser myringotomy · Laser assisted uvulopalatopharyngoplasty · Zenker diverticulum · Oropharyngeal cancer · Sialendoscopy · Hemorrhagic telangiectasias · Choanal atresia · Subglottic stenosis

Introduction

History of Laser Use in Otolaryngology

In otolaryngology, the laser has been traditionally used like a scalpel or cautery to precisely incise, cauterize, and coagulate tissue particularly where a collimated beam could provide non-contact and precise tissue ablation for tissue targets that would be difficult to treat using conventional instruments. Over time other applications of lasers have evolved in the head, neck, and upper airway which capitalize not only on the precision realized by the laser, but also on it's ability to

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© Springer International Publishing AG, part of Springer Nature 2018
K. Nouri (ed.), *Lasers in Dermatology and Medicine*, https://doi.org/10.1007/978-3-319-76220-3_5

achieve selective photothermolysis, spatial selective, confined thermal injury, and the generation of photoacoustic waves. By selecting the correct laser wavelength and appropriate dosimetry parameters, surgeons can control both the temporal and spatial evolution of heat within the target site leading to any of the above referenced laser-tissue interactions. Light is variably absorbed and scattered as it propagates through tissue, and the distribution of light in tissue determines the nature of the specific interaction [1].

As in dermatology, the selection of the appropriate laser in head and neck applications is critically important, and the selection of a specific device and mode of delivery are just as important as wavelength and dosimetry.

The otolaryngologist—head and neck surgeon frequently works in areas that are either difficult to access (e.g. larynx, skull base) or require extreme precision (e.g. middle ear), and in these circumstances laser technology can be extremely valuable. For example, during microsurgery of the vocal fold or stapes, a micromanipulator or microscope-mounted scanner, is needed to precisely focus and translate a laser beam as small as 100 mm. In surgery of the subglottis and trachea, flexible optical fibers (fiberoptics) or waveguides are used to deliver laser light to these difficult-to-access locations. In minimally invasive laryngeal cancer operations, high power CO_2 lasers (λ = 10.6 μm) are needed to cut tissue while maintaining hemostasis.

Frequently Used Lasers in Otolaryngology

The workhorse in Otolaryngology—Head and Neck Surgery is the carbon dioxide laser. It is used extensively in surgery of the larynx and ear because it can cut tissue precisely, seal small blood vessels and even ablate bone. In cancer surgery, CO_2 lasers may seal lymphatics potentially reducing the spread of disease. Since infrared light is invisible, the CO_2 laser is always used with a visible aiming beam. The potassium-titanyl phosphate (Neodymium-doped:YttriumAluminum-Garnet), KTP(Nd:YAG) (λ = 532 nm), laser is also becoming used increasingly more commonly in laryngotracheal surgery as well as surgery of the oropharynx and nose. The KTP(Nd:YAG) laser is most frequently used for vascular lesions because of its absorption by oxyhemoglobin. In the nose, the KTP(Nd:YAG) laser is most frequently used for treatment of hereditary hemorrhage telangiectasias (Osler-Weber-Rendu disease). This is a visible wavelength laser and hence easily transmitted using low-cost optical fibers. It can be made to produce a pulsed output beam, also known as giant pulse laser or Q-switching. This allows for the delivery of nanosecond pulses, which lead to less tissue injury to the surrounding structures [2]. Nd:YAG lasers (λ = 1064 nm) are used in otolaryngology as well, however the deep penetration depth of this wavelength has resulted in limited use (primarily for very large venous malformation coagulation in the oral cavity and pharynx); though in contact mode, this laser has applications as a precise cutting device [3–6].

The Argon laser (λ = 514 nm) is also used for nasal and middle ear surgery. It is absorbed by hemoglobin and melanin and is generally used in continuous-wave mode. The Holmium:YAG (Ho:YAG) (λ = 2.1 μm) laser is a mid-infrared laser wavelength that is moderately absorbed by water, its principal chromophore. It is valuable because it has a relatively shallow optical penetration depth like the carbon dioxide laser, but can be transmitted using low-cost silica fibers. Its use in otolaryngology has been very limited thus far due to the lack of availability of these devices in most medical centers. The Erbium:YAG laser (λ = 2.94 μm) is used for middle ear surgery, surgical planning in rhinophyma, and cosmetically for skin resurfacing. It has high absorption in soft tissue and bone and minimal thermally-induced peripheral damage. It also has a tolerable photoacoustic wave effect in the surrounding tissue [7]. Pfalz, Fisch and others have developed Erbium:YAG lasers for middle ear surgery, and has more recently been shown to have equal surgical outcomes when compared to the CO_2 laser (Table 5.1) [8].

Table 5.1 Laser applications in otolaryngology

Laser type	Wave length	Penetration depth	Delivery methods	Indications/applications
Argon	514 nm	0.8 mm	Fiber Micromanipulator Focusing handpiece	Ear—Stapes surgery Nose—telangiectasias
CO_2	106,000 nm	30 µm	Articulated arm Micromanipulator Hollow wave-guide scanner Focusing handpiece	Glottis/subglottis/larynx/oropharynx Benign/malignant Tonsils Lingual Oral cavity/tongue Benign/malignant Nose Turbinate hypertrophy
Erbium:YAG	2940 nm	3 µm	Articulated arm Sapphire fiber	Nose Rhinophyma Cosmetic Laser resurfacing
Holmium:YAG	2120 nm	0.4 mm	Fiber/bare fiber contact Hanpiece	Oral Cavity Lithotripsy Nose Sinus surgery Turbinate hypertrophy
KTP (Nd: YAG)	532 nm	0.9 mm	Fiber/bare fiber contact Side-fire Focusing handpiece Diffuser tip Micromanipulator	Nose Polyps Epistaxis Oropharynx/palatine tonsils Obstructive sleep apnea Vascular malformations Nose Telangiectasias Trachea Stenosis Subglottic hemangioma
Nd: YAG	1064 nm	4 mm	Fiber/bare fiber Contact tips	Vascular malformations Tumor removal (contact mode) Turbinate surgery

Laser Safety in Otolaryngologic Applications

As in dermatology, laser safety needs to be considered for the patient, surgeon and surgical staff. The use of a laser near the eyes and in the airway warrants the diligent practice of laser safety at all times. Blindness, burns to the skin, airway injury and death may result if precautions are not taken to prevent these devastating events. The safety precautions and measures to prevent eye injury in head and neck surgery are identical to those used in dermatology, with the exception that the laser dosimetry is often significantly more powerful than that used to treat the skin. Eye protection measures are reviewed elsewhere. The use of lasers in surgery in the airway presents a major challenge that is unique to otolaryngology—head and neck surgery. Airway fires are a serious risk in laser surgeries involving the airway. Flammable anesthetic gases provide an oxidizing agent that can initiate the fire in the presence of an ignition source such as a laser. The endotracheal tube or other surgical supplies typically used to protect the airway can serve as fuel to propogate the reaction [9]. Specialized laser-safe endotracheal tubes (Fig. 5.1) exhibit prolonged mean times to ignition in comparison to standard endotracheal tubes. Reflective metallic tape wrapped around the

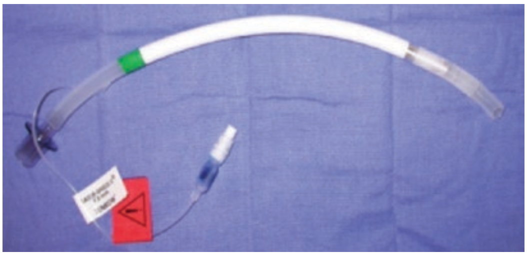

Fig. 5.1 Laser-specific endotracheal tube wrapped with reflective metallic tape. Laser-Shield II® Endotracheal Tube—Medtronic

endotracheal tube is shown to reduce the risk of ignition of all tubes [10, 11]. Each specific laser interacts differently with these laser-safe endotracheal tubes and many studies have been preformed to evaluate the safety of laser surgery in the airway [12–15]. For example, it has recently been shown that the KTP laser is unable to penetrate even PVC endotracheal tube, and suggests that laser safe endotracheal tubes may be unnecessary. However, this laser does interact with the black writing on the endotracheal tube to produce a spark and care must be taken to prevent the KTP laser from coming into contact with these markings [16].

Laryngology and Hypopharyngeal Pathology

Jako and Strong pioneered the use of the CO_2 laser in laryngeal surgery in the 1970s. They were among the first to describe the laser excision of an early laryngeal cancer [17–19]. Lasers gained popularity in the 1980s for removal of benign laryngeal lesions such as recurrent respiratory papillomatosis [20]. During this time, Steiner began his seminal work expanding the scope of laryngeal laser surgery to treat more extensive malignant tumors of the larynx and upper-aerodigestive tract. His pioneering work is perhaps the greatest contribution to organ sparing laryngeal surgery over the past 20 years and demonstrated the advantages of utilizing microsurgical laser techniques in the treatment of early-stage laryngeal cancer [21].

The CO_2 laser was the first wavelength used in laryngeal surgery and remains the laser of choice for the majority of laryngeal operations. Recent advances in laser technology, anesthesia, and surgical instrumentation have made minimally invasive laryngeal procedures more common. These new approaches have led to better organ preservation rates, improved post-operative functionality and reduced recovery time.

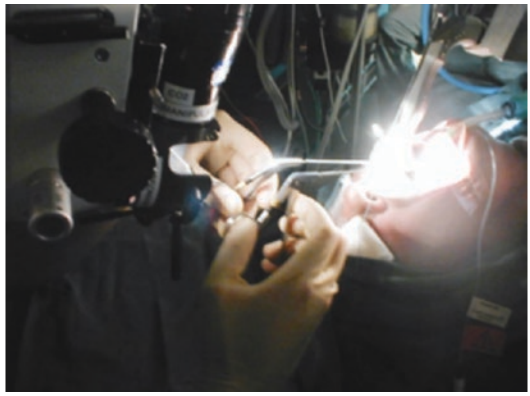

Fig. 5.2 Micromanipulator coupled surgical laser with patient placed in suspension (Photograph provided courtesy of Dr. Brian Wong)

Chiefly among these advances, lasers can be precisely focused to provide surgeons with a cutting tool capable of incising tissue even at distances of 400 mm. Using a micromanipulator-coupled surgical laser (Fig. 5.2) at 25× to 40× magnification can allow for simultaneous use of both hands as well as focus an extremely accurate laser beam (Fig. 5.3). The line-of-sight lasers that are coupled to the micromanipulator are limited in that they cannot reach around corners, however. Newer hollow waveguides and fiberoptics continue to expand the role of lasers airway surgery. The most commonly used fiberoptic lasers used in otolaryngology at this point in time are the KTP(Nd:YAG) and CO_2 lasers. These lasers can now reach areas that are otherwise difficult to access without performing an open procedure.

Cancer

Transoral endoscopic laser laryngeal microsurgery depends upon the ability of the surgeon to determine the extent of tumor invasion prior to excision. This can be done by detailed physical

Fig. 5.3 Micromanipulator coupled surgical laser. Note the bimanual instrumentation allowed by placing the patient in suspension (Photograph provided courtesy of Dr. Brian Wong)

examination performed under general anesthesia and imaging studies. The primary objective is to achieve complete resection of the cancer with clear margins, while maintaining as much organ function as possible. Primary goals are to preserve swallowing, voice, and airway.

While transoral laser laryngeal microsurgery (TLM) has many advantages such as decreased post-operative morbidity and reduced recovery time. The potential for organ preservation, recurrence or incomplete resection are significant risks. Hence, making the decision to proceed with TLM requires skill and sound clinical judgment. It is generally contraindicated in patients with known extensive invasion into other structures and recurrent cancer in previously irradiated areas [22]. In TLM, tumor is excised piecemeal using a laser, with frozen section guidance, much like Mohs surgery, albeit over complex three-dimensional surfaces with composite tissue structures.

Glottic Carcinoma

The larynx ("voicebox") is composed of the supraglottis, glottis, and subglottis. The glottis includes the vocal cords. Use of the laser to excise glottic cancer is well established for lesions staged at T1 and early T2. For all T2a carcinomas of the glottis, laser excision is recommended regardless of the pattern of the spread of the tumor [19, 23, 24]. Provided the tumor is superficial, it is of limited significance whether the disease involves the supraglottis, subglottis or the anterior commissure. The superficial location of the tumor in T1 and early T2 disease allows it to be excised by partial mucosectomy or cordotomy. Laser-assisted endoscopic excision of T3 and T4 laryngeal carcinomas is controversial. Most experts in the field reject the idea of laser microsurgical excision of these advanced tumors unless a classic laryngectomy is not an option due to underlying co-morbid disease. Patients with T3 or T4 laryngeal lesions require the widest possible endoscopic excision followed by post-operative radiotherapy to the primary site and surrounding groups of lymph nodes; however they more often undergo a classic open total or partial laryngectomy [25, 26]. Steiner groups patients T2b, T3, and T4 together and routinely treats these tumors with laser-assisted endoscopic surgery [25].

Supraglottic Carcinoma

The supraglottis is the subsite of the larynx superior to the true vocal cords. Supraglottic tumors typically occur either in the suprahyoid epiglottis and false cord area or in the infrahyoid/epiglottic area. It is relatively rare that small, well-circumscribed tumors are diagnosed in the supraglottic area because the tumors tend to be much more advanced when the start to produce symptoms. Laser resection of early stage supraglottic carcinomas is now more commonly being performed [27]. Tumors in the suprahyoid epiglottis and false cord area are easily removed. Laser excision is indicated because wide margins can be taken without the concern of adversely affecting function. Newer techniques in otolaryngology are now progressing to transoral robotic surgery (TORS) in the resection of early supraglottic carcinomas [28]. Preliminary results shows TORS more often had positive margins on pathology, but shorter operative times. This was attributed to improved exposure in TLM.

Infrahyoid epiglottic cancers are difficult to assess preoperatively even with imaging studies and are at risk for infiltrating the pre-epiglottic space. There are conflicting opinions regarding endoscopic laser resection of carcinoma that involves the pre-epiglottic space. Iro urges caution and restraint in treatment of T3 staged supraglottic cancers with transoral laser surgery [29]. Whereas Rudert believes that even these supraglottic cancers that invade the pre-epiglottic space are candidates for endoscopic laser resection [30].

Hypopharyngeal Carcinoma

Pre-resection analysis of the airway during surgical endoscopy under general anesthesia may not be able to identify the true extent of hypopharyngeal tumors. Imaging studies can aid in this endeavor. Tumors involving the piriform sinuses can typically involve the thyroid cartilage, arytenoids, paraglottic and pre-epiglottic space as well as other soft tissues of the neck with little or no evidence seen on endoscopy. Because of these factors, the majority of laryngologists agree that partial pharyngo-laryngeal resection utilizing only a laser is insufficient for complete eradication of disease and cannot be justified. Classic open surgery (i.e., laryngectomy, laryngopharyngectomy) remains the standard of care.

Palliative Therapy

The laser is a useful tool in debulking tumors that obstruct the upper airway and may be an alternative to tracheostomy [31, 32]. Avoiding a tracheostomy greatly improves a patient's quality of life. Palliative airway surgery requires experience and judgment. If too little tumor is resected, the obstruction will persist and ultimately lead to a tracheostomy. However, aggressive resection of tumor may lead to aspiration and the need for a tracheostomy to protect the airway and provide pulmonary toilet. Laccourreye published a 10-year experience describing the use of the CO_2 laser to debulk obstructing endolaryngeal carcinomas in 42 patients for the avoidance of a tracheostomy. Ninety-three percent of patients avoided tracheostomy [33].

Recanalizing the upper digestive tract by subtotally ablating hypopharyngeal and esophageal outlet tumors poses a serious risk of hemorrhage and will only provide temporary improvement in swallowing. Placement of a percutaneous gastrostomy tube (PEG) tube is often a safer and better option for these head and neck cancer patients with dysphagia. If palliative laser surgery is considered, one should aim for sustainable symptomatic relief.

Benign Disease

The CO_2 laser has a firmly established role in the treatment of benign laryngeal disorders such as papillomas, polyps, vascular malformations and strictures (see Table 5.2). Since Jako and Strong first introduced the CO_2 laser in 1970, several groups, including those led by Shapshay, Zeitels, Ossoff, Steiner, Motta and Rudert, have published extensively on their experiences with laser surgery in benign laryngeal disease [34]. The use of other lasers such as the KTP(Nd:YAG) laser and the pulsed dye laser ($\lambda = 585$ nm) has also been reported.

Polyps

Vocal cord polyps are generally unilateral, sessile and appear to be spherical and well circumscribed. They typically originate at the free edge on the anterior two thirds of the vocal cord (Fig. 5.4). The vocal cords have a delicate subepithelial tissue layer that can be damaged as a result of repetitive collisions and shearing forces. Voice abuse and chronic inflammation from tobacco smoke irritation are common causes of injury to the vocal cord epithelium and lead to damage within the epithelial basement membrane. A large percentage of patients with polyps are heavy smokers or are exposed to a large amount of secondary tobacco smoke. When conservative

Table 5.2 Benign lesions (in laryngology section)

Disorder	Laser treatment
Polyps	CO_2 or KTP (Nd:YAG) laser excision
Papillomas	CO_2 or KTP(Nd:YAG) laser ablation
Vascular malformations	Pulse dye laser photocoagulation
Hemangiomas	CO_2 or KTP(Nd:YAG) laser for coagulation and excision
Vocal cord paralysis	CO_2 laser for enlarging glottic chink
Laryngomalacia	CO_2 laser excision of redundant tissue

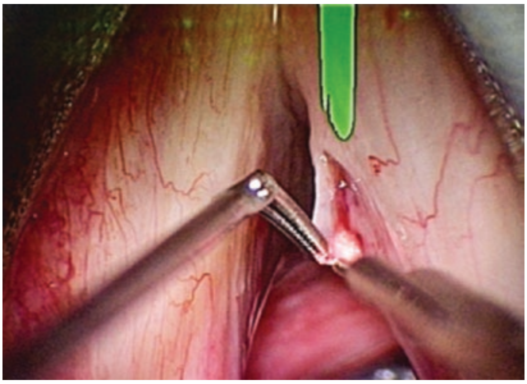

Fig. 5.4 Pulsed 532 nm KTP laser assisted subepithelial resection of fibrovascular mass (hemorrhagic polyp) on the middle 2/3 of the left true vocal cord. The green area is refraction from the laser light (Photograph provided courtesy of Dr. Steven Zeitels)

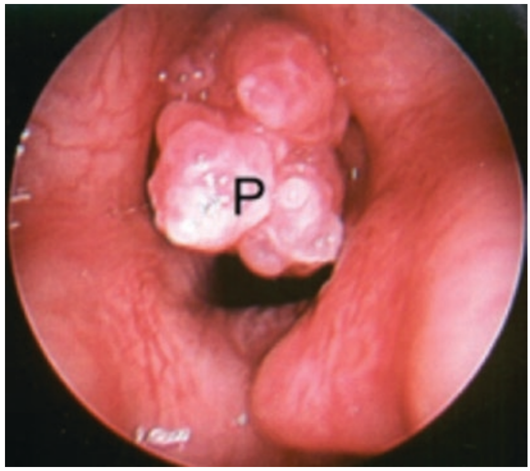

Fig. 5.5 Laryngeal papilloma (P) at the level of the glottis (Photograph provided courtesy of Dr. Gupreet S. Ahuja)

methods (i.e., voice rest, speech therapy, etc.) fail, treatment is surgical removal. It is important to always send the excised polyps for histology to exclude an early malignancy. For this reason, these polyps should never be vaporized with the laser.

Papillomas

Laryngeal Papillomas are typically caused by HPV types 6 and 11 and can affect any age group (Fig. 5.5). The distribution of disease is bimodal, affecting children and middle-aged adults most often [35]. The virus causes formation of benign epithelial papillomas of the larynx. Diagnosis is made with flexible fiberoptic laryngoscopy or microlaryngoscopy. Although papillomas most commonly occur on the vocal cords, the larynx, esophagus and trachea must be comprehensively examined during endoscopy because the papillomas can occur anywhere along the aerodigestive system. While the CO_2 laser is still used to ablate these lesions, the concern over aerosolization of viral particles has made mechanical laryngeal microdebriders an increasingly more common treatment approach. The KTP(Nd:YAG) laser is particularly helpful in surgery for laryngeal papillomas. The advent of fiberoptic cables for the KTP(Nd:YAG) and CO_2 laser has even made it possible to treat papillomas in the clinic with the use of a flexible fiberoptic laryngoscope [36].

Hemangiomas and Vascular Malformations

Subglottic hemangiomas present with persistent cough, hoarseness or stridor, and manifest as reddish, well-circumscribed masses during surgical endoscopy. Surgery involves primarily vaporization and ablation rather than excision [37]. The CO_2, KTP or Nd:YAG laser can all be used with low power settings (1–3 W). High power settings can lead to tracheal perforation, pneumothorax or intractable bleeding.

Vascular malformations typically are located in the supraglottic area and are generally asymptomatic. Symptoms of a laryngopharyngeal vascular malformation may include foreign body sensation or mild stridor of unknown origin. Carbon dioxide laser excision or Nd:YAG coagulation is the treatment of choice, though other wavelengths can be used as well with appropriate dosimetry. Use of the Nd:YAG laser has a higher rate of postoperative scarring and stenosis due to the deeper penetration depth of this wavelength, but is extremely valuable in treating large vascular malformations where volumetric heating of large regions of tumor are required. These extensive tumors are more commonly found in the oropharynx and oral cavity [38]. Ectatic blood vessels along the vocal cord surface (Fig. 5.6) may alter the pitch and timbre of the voice and can be problematic for singers and other

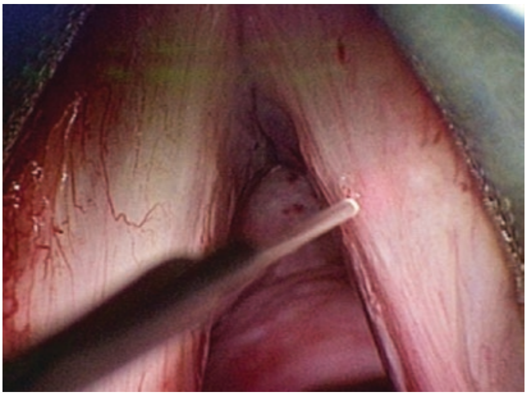

Fig. 5.6 Pulsed 532 nm KTP laser assisted photoangiolysis of ectatic blood vessels in a singer (Photograph provided courtesy of Dr. Steven Zeitels)

professionals. They are commonly treated using a pulse dye laser and KTP(Nd:YAG) [39].

Laryngomalacia

Stridor in children is most commonly caused by laryngomalacia, and 60–75% of childhood cases of stridor are associated with laryngomalacia [19]. Approximately 20% of these cases do not resolve spontaneously or cause symptoms severe enough to require surgical intervention. Dysphagia, apnea and respiratory distress are all indicators for surgical intervention. Laryngomalacia will be discussed in a later section along with subglottic hemangiomas.

Vocal Cord Paralysis

Patients that have bilateral vocal cord paralysis may develop severe respiratory distress and airway obstruction from the diminished patency of the glottic airway. Vocal cord paralysis commonly presents following surgery where the recurrent laryngeal nerve is inadvertently injured (i.e., during thyroid tumor surgery). In the immediate post-operative period the patient sometimes develops stridor and respiratory insufficiency. Acutely, treatment may involve intubation and tracheostomy. For long-term treatment, CO_2 lasers can be used to enlarge the glottic chink and increase airway patency [40] This is challenging surgery because it is important to strike a balance between airway patency and voice quality when enlarging the glottis.

Contraindications for Surgery of Benign Airway Lesions

There are few contraindications to Transoral Laser Microsurgery (TLM) for benign lesions. One important rule is that surgeons should avoid unnecessary disruption or excision of the anterior commissure and the free edge of the vocal cords. Disruption of the anterior commissure may result in change in the patients voice, extensive scar formation, or an anterior glottic web. If there is epithelial disruption of the free edges of both vocal cords, this can lead to post-operative scarring and webbing. It is imperative that the surgeon only work on the epithelium of one vocal cord at a time to prevent these complications.

Pre-operative Management

In the pre-operative evaluation, patients always undergo an indirect mirror or a flexible fiberoptic laryngoscopy examination to determine the extent of the lesion and vocal cord mobility. Video stroboscopy of the vocal cords may be included in the pre-operative evaluation to determine the dynamics of vocal cord movement. Some patients may undergo diagnostic imaging (CT or MRI of the neck) to determine the extent of disease. Vocal cord polyps warrant a trial of speech therapy for vocal coaching and training in proper voice use prior surgery. Patients with carcinoma of the larynx and recurrent papillomatosis must be strongly encouraged to quit smoking.

The most common parameters for the CO_2 laser beam using a micromanipulator is a 250 mm spot size with a working distance of 350 mm. Laser power is usually below 8 W. In the superpulse mode, where exposure time is 0.1 s or less, a low power setting of 2–3 W is used. The superpulse mode is useful in achieving maximum ablation through minimal penetration and maximum energy absorption at the surface of interest. There is almost no charring due to the minimal thermal diffusion in the surrounding areas around the target. In preparation for incision of epithelium, microvascular coagulation is required. For this, the laser is typically set for a 0.05 s pulse of 1 W of power using an unfocused beam [20].

Recently, flash scanner technological originally developed for use in dermatologic applications has been re-purposed and adapted for use in laryngeal microsurgery. This technology spreads the laser energy uniformly over the target area by using two nearly parallel, rapidly rotating mirrors [41]. It creates a uniform area of laser energy approximately 3 mm in diameter in 1 ms. The laser is able to provide surface ablation with little to no char at a depth of 0.15 mm. The high cost of these systems has limited the broad adoption of this technology.

Description of Technique

Suspension microlaryngoscopy provides a method in which the surgeon is able to directly visualize the larynx and its surrounding structures. Gustav Killian was among the first to describe suspension laryngoscopy in 1912 and later developed the Killian-Lynch suspension laryngoscope along with Robert Clyde Lynch. Zeitels showed effective use of suspension laryngoscopy in 120 cases in a prospective assessment [42]. Suspension allows for bimanual direct laryngoscopic surgery [43]. Furthermore, suspension laryngoscopy permits the use of a laryngoscope with a larger bore thereby enhancing exposure. Figure 5.7 demonstrates the positioning of a patient in suspension and Fig. 5.8 shows the normal anatomy of the larynx as visualized under suspension microlaryngoscopy.

With the patient anesthetized and lying supine, the head is fully extended. A rigid laryngeal endoscope is introduced through the oral cavity and past the epiglottis into the larynx until the desired endolaryngeal structures are visualized. The vocal cords should be clearly visualized from the anterior commissure to the vocal process on both sides. The rigid laryngoscope is then stabilized and secured using a suspension arm. Surgery is performed using a microscope with a 400 mm focal length lens or using a Hopkins rod endoscope inserted thru the laryngoscope bore. There are several instances that make suspension microlaryngoscopy very difficult or even impossible. Abnormal anatomy such as a short, stiff neck, long or protruding maxillary teeth, displaced larynx and lesions or a mass at the base of tongue may limit and prevent suspension laryngoscopy in these patients [42]. Utilizing paralysis is often necessary for successful laryngoscopy.

Suspension laryngoscopy provides a direct airway in which anesthesia may be administered either through an endotracheal tube that is inserted parallel to the laryngoscope or via jet ventilation. This direct airway also provides an

Fig. 5.7 Suspension laryngoscopy (Photograph provided courtesy of Dr. Roger Crumley)

Fig. 5.8 View of the glottis through the laryngoscope. A arytenoids, E epiglottis, V (black) vocal cords, V (white) vallecula (Photograph provided courtesy of Dr. Gupreet S. Ahuja)

unimpeded path for the surgeon to access the vocal cords and other structures in the larynx. When using an endotracheal tube in laser surgery, it is important to use a laser-safe endotracheal tube to minimize the risk of an airway fire. These techniques allow for a minimally invasive approach to laryngeal surgery where traditional approaches have involved large external incisions and significant morbidity.

Lasers and Laser Devices

Since Jako coupled the carbon dioxide laser to the operating microscope in 1972 for laryngeal surgery, the CO_2 laser has been the wavelength of choice. The CO_2 laser is used in the majority of operations because of its widespread availability in most medical centers and its efficiency in simultaneously cutting tissue and maintaining hemostasis. Other commonly used lasers in otolaryngology include the KTP(Nd:YAG) laser and the argon laser. In laryngeal surgery, the CO_2 laser is often coupled to a micromanipulator attached to the microscope. This allows the surgeon to use microsurgical instruments and the laser at the same time. It also provides maximum surgical field visualization with high magnification and an unobstructed view of the lesion. The CO_2 laser has several advantages over conventional surgical instruments that cut or cauterize in that traditional devices may obstruct the field of view or amplify the surgeon's intention tremor via a lever arm of up to 20 cm.

The thermal damage zone when using micromanipulators introduces limited artifact into the histological assessment, and it coagulates small blood vessels and seals lymphatic channels thus minimizing the incidence of metastases [20]. The diameter of the laser beam, pulse duration and irradiance can be adjusted to produce different tissue effects. Spot sizes between 1 to 4 mm are used for tissue ablation and 0.2–1 mm used for cutting with powers varying anywhere from 2 to 10 W. Some micromanipulators further focus the beam down to an even smaller spot size, and combined with short pulse durations or flash scanner technology, can ablate tissue with minimal to no charring just as in skin resurfacing [41, 44]. Morbidity of using the CO_2 laser when appropriate is far less than cold surgery, and the cost effectiveness is much greater [45].

In certain cases where lesions extend out of the surgeon's visual field, the CO_2 laser can be delivered by a flexible hollow waveguide. However there are limitations with the use of the hollow waveguide due to its limited angulation, the diameter of the laser spot and the significant and variable loss of power during transmission [20]. Regardless, recent techniques using hollow fiber technology are evolving [46–50]. Additionally, the KTP(Nd:YAG) laser energy is similarly delivered through a fiber optic cable and various hand-pieces.

Cancer

Glottic Carcinoma

T1 and T2a carcinomas of the glottis are typically resected en bloc and clear margins of 1–3 mm are obtained. However with laser surgery, it is possible to maintain more narrow margins that allow for preservation of vocal function and reduction in post-operative edema.

Transoral Laser Microsurgery (TLM) has yielded good functional results and low rates of recurrence from multiple groups since the 1990s. Studies have shown that it is possible to preserve the larynx in over 92% of cases with a 5 year local control rate that ranges from 80% to 94% [51, 52]. Treatment of early glottic cancer with TLM has a distinct advantage over other procedures in that it maintains the availability of all treatment options for patients with local or secondary tumor recurrence including laser re-excision, radiation therapy or open partial laryngectomy [53, 54]. T2b and T3 carcinoma of the glottis typically involves the vocal cords with supraglottic or subglottic extension. The operative technique using lasers for these tumors involves subdividing the tumor into several pieces for removal. Resection of these tumors may involve the cricoid and thyroid cartilage, the arytenoids, the cricothyroid ligament and any involved laryngeal soft tissue.

The application of laser assisted endoscopic surgery via suspension laryngoscopy draws comparisons to Mohs surgery because resections are driven by frozen section histology. One of the greatest differences between endoscopic laryngeal surgery and cutaneous Mohs surgery lies in the fact that Mohs surgery aims to achieve the best cosmetic result as possible while attempting to remove as little tissue as possible without compromising the tumor resection. In laryngeal surgery, functionality remains essential post-operatively in laryngeal cancer patients. Laser assisted endoscopic laryngeal surgery has potential to allow surgeons to excise cancer piecemeal with frozen section guidance. Frozen section guidance of surgical resections in the larynx is difficult due to the complex geometry of the structures within the larynx, making this radically more complicated than Mohs surgery for cutaneous disease. It is important for the surgeon to carefully label the surfaces of the specimens and work closely with pathologists during surgery. Ambrosch's experience of 167 patients undergoing laser excision of T2b and T3 laryngeal tumors showed a 5-year rate of definitive local control to be 87%. The recurrence-free survival rate over 5 years was 62%. None of these patients required a tracheostomy after the primary resection [55].

Supraglottic Carcinoma

T1 and T2 carcinoma of the supraglottis is defined as tumor that has not infiltrated the pre-epiglottic fat, immobilized a vocal cord, or metastasized to a local lymph node. Vaughan first described carbon dioxide laser resection of supraglottic carcinoma. Since then, Steiner, Davis and Zeitels have used TLM for supraglottic resections [21, 56–58]. Laser excision of tumors in this area typically involve extensive dissection and removal of involved muscle, cartilage and even portions of the base of tongue and piriform sinuses in advanced cancer. Tracheostomy is unnecessary in most cases due to limited postoperative edema even after extensive laser dissection. However it should be considered in a procedure with high blood loss or elderly patients with decreased pulmonary function.

There are relatively few reports on laser resection of T1 and T2 cancers in the supraglottis. Ambrosch reports a series of 48 patients with supraglottic T1 and T2 carcinoma in which there was 100% and 89% local control rate for pT1 and pT2 tumors respectively at 5 years. The recurrence free survival rate over 5 years was 83%, and the overall 5-year survival rate was 76%. In patients who experienced a recurrence, none needed a laryngectomy as a secondary treatment [51]. T3 carcinoma of the supraglottis treated with laser excision is not a common practice. Hinni et al. described a series of 117 patients with T2 to T4 lesions treated with TLM [59]. Five-year Kaplan-Meier estimates were local control in 74%, locoregional control in 68%, disease free survival in 58%, and overall survival in 55%. At 2 years 92% had a functional larynx. This study concluded TLM with or without radiation is a valid treatment strategy for organ preservation.

Hypopharyngeal Carcinoma

Carcinoma located in the hypopharynx carries the worst prognosis of all upper aerodigestive tract tumors. Reasons for poor prognosis lie in the high rate of local recurrence and the increased likelihood of the presence of metastasis in cervical lymph nodes at diagnosis. Though advances have been made in diagnostic imaging, surgery, radiotherapy, and combined approaches, the mortality rate from these tumors does not reflect any improvement in survival. Though there are reports of use of TLM in excision of hypopharyngeal cancer, there are few that report any treatment results.

Steiner and Ambrosch describe a series of 129 patients with carcinoma of the piriform sinus treated with laser excision. The 5-year Kaplan-Meier survival rate was 71% for stages I and II and 47% for stages III and IV disease and the 5-year recurrence-free survival rates were 95% for stages I and II and 69% for stages III and IV [52].

Benign Lesions

Papillomas

Transoral laser microsurgery of laryngeal papillomas is done with the laser on a low power setting. This has been described by using CO_2, KTP, and pulse dye laser in both an operating room and in-office setting. This allows the surgeon to ablate the disease in a controlled manner that limits disruption of the normal surrounding tissue and ablates only the mucosa affected by the papillomas (Fig. 5.9). Small islands of healthy mucosa left between the ablated areas promote quicker re-epithelialization [19]. In cases where there is bilateral vocal cord or anterior commissure involvement, a conservative approach is advised. It is better to leave small papillomas behind than to have post-operative scarring and synechiae of the anterior commissure, also known as an anterior glottic web, which can lead to voice changes. Corticosteroid administration (3 mg/kg Prednisone) perioperatively assists decreasing edema after extubation, even if there has been extensive resection. Figure 5.10a, b show a before and after images of juvenile laryngeal papillomas. Alternatively, microdebriders have been increasingly used to debulk papillomas and are slowly replacing lasers as the method of choice for treating papillomas [60].

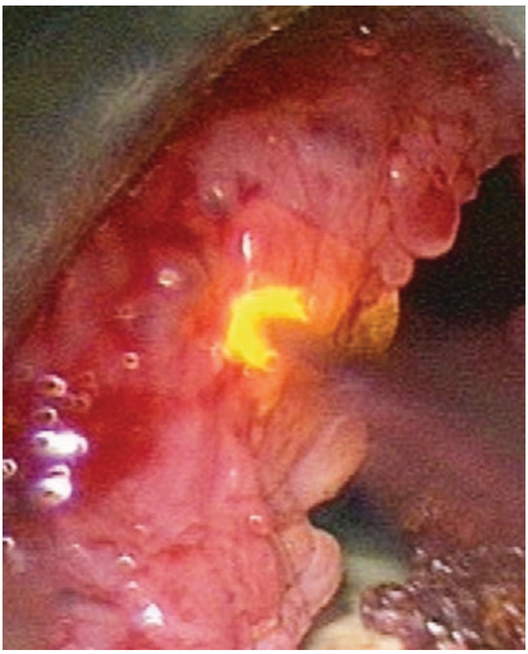

Fig. 5.9 Pulsed 532 nm KTP laser photoangiolysis and ablation of glottal papillomatosis (Photograph provided courtesy of Dr. Steven Zeitels)

Laryngomalacia

Anatomically, the cause of the problem in laryngomalacia is an inward collapse of the supraglottic mucosa during inspiration. If conservative measures fail, the surgical treatment for laryngomalacia is a supraglottoplasty. Bilateral laser incision of the aryepiglottic folds and the arytenoid cartilage region is the treatment if the cause of the stridor is from shortened aryepiglottic folds. If the stridor is caused by inward collapse of the epiglottis during inspiration an epiglottopexy is the surgery of choice. This will be described in more detail in a later section on laser use in the pediatric population.

Vocal Cord Paralysis

The most common laser-based procedure for vocal cord paralysis is unilateral microsurgical laser arytenoidectomy. In Steiner and Werner's experience, excision of the posterior portion of the vocal cords bilaterally with the microsurgical laser offers several benefits. Most of the vibrating parts of the vocal cords and arytenoids cartilage are preserved preventing aspiration while maintaining good voice quality [19].

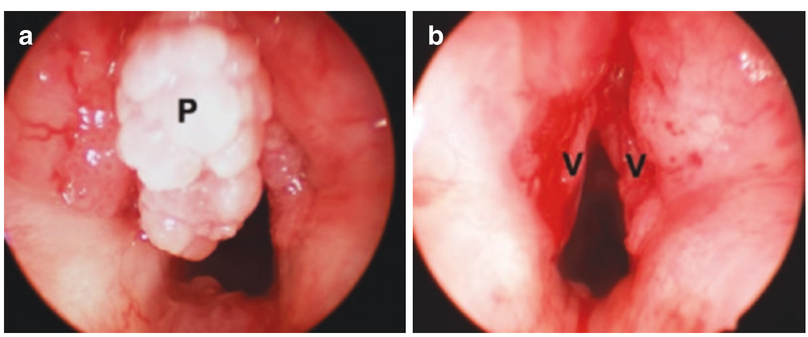

Fig. 5.10 Papilloma in the pediatric airway, before (**a**) and after (**b**) laser excision. P papilloma, V vocal cords (Photograph provided courtesy of Dr. Gupreet S. Ahuja)

Hypopharyngeal Diverticula

To perform a Zenker's diverticulectomy, the patient is suspended in a similar fashion to that which was described previously. Treatment of Zenker's diverticulum consists of suspending the hypopharynx with a specialized "Weerda" endoscope, then taking down the "party wall" that exists between the herniated pocket and the upper portion of the esophagus [61]. Traditionally, this required a large cervical incision to excise the diverticulum and perform a myotomy of the cricopharyngeus muscle. The use of the CO_2 laser to take down the party wall endoscopically has been found to be comparable to traditional, open procedures in terms out outcomes [62, 63]. Laser myotomy is improved compared to the traditional approach in that it does not require a neck incision and requires significantly less operative time. Almost 90% of patients report normal swallowing function after undergoing the procedure.

Post-operative Management

Patients who are otherwise healthy and undergo a limited resection are routinely given a single dose of intravenous steroids, observed in the post-operative care unit and discharged on the same day. Patients who have multiple medical problems or have more extensive surgical excisions, and therefore have a higher possibility for airway compromise, are admitted overnight at minimum for airway observation and scheduled steroid dosing. Post-operative antibiotics are not routinely administered. Strict voice rest for the first 48 h is observed followed by modified voice rest (no screaming, no whispering, limited talking) for the next 1–2 weeks. Patients are then monitored in clinic with repeat flexible fiberoptic laryngoscopy exams. Any change in voice, difficulty breathing or weight loss is monitored closely and may necessitate repeated exams and procedures.

In general suspension laryngoscopy is safe for patients as long as the patient has gone through proper pre-operative evaluation by the otolaryngologist and anesthesiologist. There are several situations that preclude the use of suspension laryngoscopy that include anatomy such as a short, stiff neck, long or protruding maxillary teeth, displaced larynx and lesions or mass in the base of tongue [42]. Complications associated with TLM are more pertinent to the use of the laryngoscope instead of the actual laser itself. Difficult intubation or forceful endoscopic suspension can easily chip, loosen, or fracture teeth if the surgeon is not careful with the orientation of the laryngoscope in the oral cavity. In a study of 339 microlaryngoscopy patients, 75% were found to have small mucosal lesions of the oral cavity, oropharynx and lip [64]. Though the injuries were minor, they were a source of major concern for the patients postoperatively.

Other complications associated with laser microsurgery include lingual and hypoglossal nerve palsy. Prolonged displacement of the tongue can cause severe contusion and swelling that often leads to dysphagia and sometimes-permanent dysesthesia (sensory disturbance) in the tongue.

There are many general safety considerations involving the use of surgical lasers in surgery that were discussed earlier in this chapter. In particular to laryngeal surgery where high-powered lasers are used in small confined areas with flammable gas, the use of caution cannot be emphasized enough. Stray laser light is not a rare event and is capable of causing burns in unwanted areas. It is recommended practice to cover areas beyond the target site to protect from unwanted burns. Control of oxygen content, inhalation agents, and use of special laser endotracheal tubes in these procedures is important.

Though TLM rarely requires tracheotomy post operatively, it is nevertheless a real possibility in the intermediate and advanced cases. Surgeons must always be aware of certain indicators for tracheotomy. Prolonged compression of the tongue during TLM can cause lingual edema that can lead to airway compromise. Sudden secondary hemorrhage is a major risk in TLM and may necessitate a tracheotomy. Large arteries and vessels should not only be cauterized but clipped as well to avoid sudden secondary hemorrhage.

TLM typically causes the formation of large granulomas if cartilage is exposed by the surgical procedure. These granulomas are perpetuated by small osseocartilaginous sequestrae unless they are removed [22]. TLM involving the anterior commissure often results in a round anterior glottic effect, and this often leads to breathiness and hoarseness [65]. Laser surgery for benign lesions in the larynx is relatively safe compared to most other treatment modalities. It is a minimally invasive technique with almost no complications attributed to the laser itself.

Future directions of laser use in laryngology involves new devices for delivery, office based laser applications, the use of the laser for welding tissue and the creation of lasers that are even more precise than those which are currently available. An important recent technological advance (Omni Guide, Boston, MA) has provided surgeons the use of CO_2 lasers through a flexible fiber referred to as a "photonic band gap fiber." The fiber is placed in a handpiece coupled with a suction that eliminates the need for a micromanipulator and allows the surgeon to have the freedom of a laser cutting tool in his or her hand. The Omni Guide Beam Path has proven useful in the surgery of both benign and malignant lesions in cases where exposure is difficult [65].

Another new delivery device has recently been described by combining TORS with the CO_2 laser in resecting upper aerodigestive tract tumors. Studies to date have been proof-of-concept and no long term follow up data has been described [66, 67]. However, these reports have been encouraging. The flexible CO_2 laser provided fine incisions, excellent hemostasis, and minimal peripheral tissue injury. The exposure provided by TORS improved typical exposure and provided more range of motion than typical TLM. Further study must be performed to determine long-term outcomes and cost effectiveness of these powerful tools.

Awake office based laser surgery is gaining popularity in the treatment of benign laryngeal lesions because of the relative safety of lasers and the quick recovery period post procedure. Though the CO_2 laser has traditionally been the laser of choice for laryngeal surgery, different lasers have been reported to be useful in office-based surgery. In the office, new technologies such as distal chip endoscopy and rare-earth doped fiber lasers have allowed for creative and innovative surgical techniques. Typical diseases treated with these new techniques are dysplasias and papillomas. A 585 nm pulsed dye laser was originally the laser of choice for vascular lesions; however the 532 nm pulsed KTP laser has proven to be superior. The use of the Thulium laser ($\lambda = 2013$ nm) which mimics the CO_2 laser closely may become useful as an office based laser as well [68, 69]. Even though otolaryngologists are performing more office procedures that incorporate lasers, the breadth of procedures remains limited for important reasons such as airway compromise, which is poorly handled in the office setting.

Otology

Laser applications in otology include the treatment of vascular lesions in the external auditory canal (EAC), exostoses in the EAC, debulking of inoperable tumors, Eustachian tube dysfunction, myringotomy/tympanostomy in otitis media, graft fixation in tympanoplasty, stapedectomy/stapedotomy in otosclerosis, tympanosclerosis, removal of cholesteatoma, cochleostomy, labyrinthectomy in benign paroxysmal positional vertigo, endolymphatic hydrops and facial nerve decompression [70]. The use of the laser in middle ear surgery is one of the most elegant examples of laser technology use and applications. Perkins pioneered the use of the argon laser in middle ear surgery in the late-1970s performing the first laser stapedotomy for otosclerosis. Otosclerosis is a localized disorder of bone resorption and deposition (remodeling) in the middle and inner ear that causes progressive conductive hearing loss that typically begins in the third to fifth decade of life. This defect in bone remodeling in the vicinity the stapes footplate and oval window leads to reduced mobility of the stapes and conductive hearing loss. Mechanical causes of hearing loss can be corrected through surgery [71, 72]. Patients with otosclerosis benefited from the argon laser through its precise vaporization of the stapedial tendon, mobilizing the posterior crus of the stapes, and in stapes footplate fenestration [71, 73]. This is procedure is called a stapedectomy or stapedotomy, and is performed in order to recreate ossicular chain mobility and decrease conductive hearing loss. Knowledge of middle ear anatomy is critical in obtaining good post-operative results with minimal complications. Avoidance of injury to the facial nerve and the chorda tympani nerve is the standard of care [70, 72, 74–88].

DiBartolomeo described other uses of the argon laser in the field of otology. He utilized this laser in the tympanoplasty (repair of the tympanic membrane), stapedectomy, lysis of adhesions and myringotomy (placement of a hole in the tympanic membrane). He describes the “spot welding” technique of the laser that allows for the adherence of a fascial graft placed in substitution of the tympanic membrane onto the soft tissue annulus [85]. Delivery of a laser to the ear and temporal bone can be either via a fiber (KTP and argon) or via a micro-manipulator such as those used with CO_2 lasers [89].

Eustachian tube dysfunction is a common ear disorder in which patients may experience chronic recurrent ear infections or difficulty in clearing a blocked sensation of their middle ear. A laser myringotomy may be performed to equalize the pressures between the middle and outer ear, and to assist the ear in draining fluid [90–95]. Some studies have found improvement in postoperative outcomes such as length of temporary perforation and resolution of middle ear effusion [95]. However, it is considerably more expensive.

Laser Eustachian tuboplasty (LETP) is the practice of utilizing a diode or an argonlaser to vaporize select areas of hypertrophic mucosa and submucosa tissue along the length of the Eustachian tube. In a small number of studies with small patient numbers, it has been found that medical management combined with LETP on a select group of patients can be successful in eliminating chronic middle ear effusions [96–98].

A cholesteatoma is not a mass made of cholesterol as the name implies. Instead, it is a collection of keratinized epithelium that is located in an abnormal location at the external auditory canal, middle ear, petrous bone or mastoid. It is either congenital in etiology or is acquired due to repeated infection. It is not invasive, but it is destroys the bones of the middle ear leading to a conductive hearing loss. It can also erode the mastoid bone and tegmen that can possibly lead to a cerebral spinal fluid leak. Therefore, the cholesteatoma needs to be removed in its entirety to prevent progression and recurrence [99]. The use of a laser in this surgery may assist the surgeon in removing the mass in more difficult to reach areas of the middle ear and mastoid [100, 101]. This often requires improved visualization with endoscopy in addition to the use of laser energy directed by curved fiberoptic cables.

Contraindications to laser use for otologic applications include performing a stapedectomy in the presence of active otitis media or in an only-hearing ear that responds well to amplification. Additionally, the presence of vertigo and endolymphatic hydrops, certain inner ear malformations or an overhanging facial nerve that completely obstructs access to the oval window niche are contraindications as well. Laser stapedectomy in patients with a perforated tympanic membrane must be postponed until the perforation is fixed. In this case of an overlying facial nerve, preservation of the facial nerve is most important, and conventional instruments are used to perform the operation rather than the laser to minimize the risk of injury.

Pre-operative Management and Laser Selection

Pre-operative management of patients undergoing laser-assisted otologic surgery includes a full history and physical, an audiogram and usually a noncontrast computer tomography (CT) imaging of the temporal bone and internal auditory canal. When choosing a laser to use near a neurosensory organ like the ear, it is important to consider the potential collateral damage. The thermal and photoacoustic effects in laser use are a function of dosimetry and tissue optical and thermal properties. Bone has substantially smaller water content than skin or other soft tissues and visible wavelengths are not well absorbed. In the absence of any distinct chromophore, using an argon or a KTP(Nd:YAG) laser to ablate bone requires an initiator. An initiator absorbs laser light and undergoes pyrolysis. In middle ear surgery, a small droplet of blood or charred tissue placed on the laser target to serve this purpose. Accordingly, there is a risk of thermal injury, as considerable temperature elevations occur within this region, and ablation occurs with at best modest thermal confinement [87].

In contrast, infrared wavelengths are well absorbed by both the hydroxyapatite crystals in bone and the interwoven collagen fibers. Ablation proceeds by the classical mechanisms, though photoacoustic transients may be generated leading to audible pops. These mechanical transients may propagate through the inner ear and may result in injury to the delicate neuroepithelium. In general, shorter laser pulse durations lead to less thermal injury provided the conditions for thermal confinement are met [102, 103]. However, repeated pulses in rapid succession may lead to the build up of heat in the target site; hence successive pulses should be separated by a sufficient amount of time to allow for complete thermal relaxation. Short pulse laser systems (e.g., Erbium:YAG) generate an acoustic pressure wave that lead to a vibration of the ossicular chain that may result in "noise trauma". The heat generated by the laser may also cause "convection currents" that also lead to vibratory stimulations. Both of these stimulations that can lead to acoustic injury and should be controlled by appropriate dosimetry selection. Regardless, the mechanical transients produced during laser ablation are comparable or even less harmful than the vibratory effects produced using conventional methods to perform surgery [7, 70, 87, 104, 105].

Description of Technique

In addition to the argon, CO_2, and KTP laser, more recently the erbium-YAG laser has been used to perform stapedectomy or stapedotomy in patients with otosclerosis. In the stapedectomy and stapedotomy, the stapedial tendon is vaporized with the laser, then the incudostapedial joint is disarticulated using mechanical instrumentation, and the posterior crus is severed with the laser (Fig. 5.11a, b). The anterior crus of the stapes is then fractured manually and the stapes superstructure is removed. The laser is then used to place a single large hole or a set of smaller holes generating a "rosette" type pattern in the stapes footplate to accommodate the prosthesis (Fig. 5.11c). A mobile prosthesis is put into place [70, 72, 75–88]. Despite multiple recent attempts, no study to date has demonstrated which laser among the three most commonly used in stapes surgery (argon, KTP and CO_2) is best [106–108]. Recently, erbium:YAG lasers have been developed for use in performing this operation, however the high cost of these lasers has limited broad adoption [8, 76, 109]. The success of laser stapes surgery is based on audiometric analysis (hearing tests) and complication rates.

Smaller cholesteatomas and residual tissue in previously attempted excisions of cholesteatoma have been vaporized with the CO_2, Argon, and KTP lasers with some reports of lower recurrence rates [70]. Laser use is particularly beneficial when removing cholesteatoma from the delicate bones of the middle ear such as the stapes or in removing disease that traverses the obturator foramen of the stapes. When using the laser in this application, its energy is absorbed more by the cholesteatoma than by the bony surroundings [100, 101]. Endoscopic cholesteatoma surgery can be helpful in obliterating cholesteatoma from hard-to-visualize locations such as the sinus tympani [110]. The laser can also be directed towards these locations using a curved, adjustable laser fiber.

Use of the laser in myringotomy and tympanoplasty is currently a boutique interest in otolaryngology, primarily due to cost. Myringotomy is performed by using an Argon, CO_2, or KTP laser directed by a fiber delivery system to create an incision in a patient's eardrum. It most often performed in patients with chronic otitis media with effusion. Use of the laser instead of a myringotomy knife has shown to be beneficial by preventing the necessity of tympanostomy tube placement; however laser myringotomy without tube placement only creates a temporary

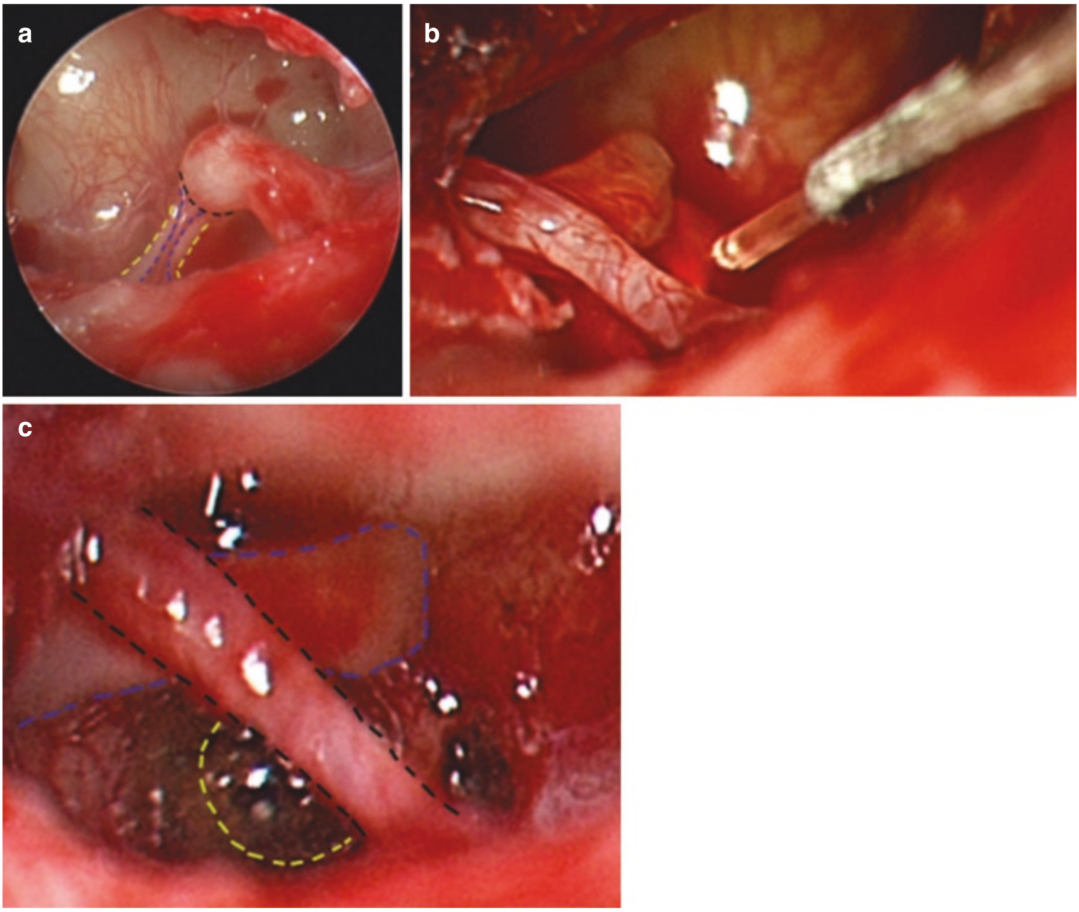

Fig. 5.11 (**a**) In stapedectomy, the stapes tendon (blue dashed line) is vaporized with the laser and the incudostapedial joint (black dashed line) is disarticulated. The posterior crus (yellow dashed line) is then severed with the laser. (Photograph provided courtesy of Dr. Hamid Djalilian). (**b**) Intraoperative image of an argon laser directed at the posterior crus of the stapes after having displaced the chorda tympani nerve from the line of fire. (Photograph provided courtesy of Dr. Hamid Djalilian) (**c**) Intraoperative image of the oval window after laser stapedectomy. Notice the charred appearance of where the stapes was located (yellow dashed line). Also note the preservation of the chorda tympani nerve (black dashed line). The long process of the incus (blue dashed line) is still intact above and will be used to anchor the stapes prosthesis (Photograph provided courtesy of Dr. Hamid Djalilian)

perforation in the tympanic membrane that lasts <6 weeks. As with traditional myringotomy, patients with recurrent or persistent episodes of otitis media with effusion may need tube placement at a later date. Office-based laser assisted tympanic membrane fenestration with a hand-held otoscope combined with the CO_2 flashscanner laser, OtoLAM (ESC/Sharplan, Yokneam, Israel) and placement of a pressure equalization tube under local anesthesia has been described as well. Outcomes have shown improvement in hearing and reduced incidence of tube plugging, however this was performed in a non-randomized population [84–94, 111]. Again, these systems are very expensive, and the procedure has not been widely adopted.

Tympanoplasty is the repairing of a defect in the eardrum by placing fascia or perichondrium over the defect. In this application, the KTP laser can be used to weld the collagen fibers together along their edges [100, 101, 112–114]. While promising, neither laser application of myringotomy nor tympanoplasty been widely adopted due to the extensive cost of the system.

CO_2 laser use in acoustic neuroma surgery has shown to be advantageous due to its precision in cutting and coagulating around the facial and vestibular nerves [115]. The use of KTP and Argon lasers for acoustic neuroma excisions have also been noted, but are not widely used [116, 117]. Laser use is limited by the size of the tumor, approach to the lesion, and the surgeon's experience. For smaller tumors (2–3 cm), stereotactic radiation is beneficial in preventing further growth of the mass and preserving facial nerve function and hearing [70].

Laser use in endolymphatic hydrops [118] and labyrinthectomy for benign paroxysmal positional vertigo (BPPV) have been described, but have not been adopted due to their potentially high rate of hearing loss compared to traditional surgery [119–121]. Laser use in the decompression of the facial nerve has also been successfully performed [122].

Post-operative Management

The majority of patients are sent home on the same day of surgery. They are told to keep their ear canal and surgical site water free. Packing is frequently left in the external auditory canal for up to 2 weeks for removal by the surgeon at a postoperative visit. A repeat audiogram is performed at approximately 6 weeks post-operatively. Patients who undergo cholesteatoma surgery are followed approximately every 4–6 months or more frequently to monitor for recurrence and to adequately maintain the cleanliness of the mastoid bowl. Depending on the surgical approach, a second surgical procedure may be indicated to evaluate for recurrence at 6–12 months postoperatively. Patients with decompression of the facial nerve may need post-operative steroids.

Side Effects/Complications

Complications of laser use in otology occur at a rate that is equal to or less than conventional surgical techniques. Noted complications include temporary or permanent hearing loss, intra-operative or post-operative vertigo, cerebrospinal fluid fistula, tinnitus, prosthesis displacement, incus necrosis, fibrosis, postoperative granuloma formation, tympanic membrane fistula facial nerve injury and chorda tympani injury (dysguesia). Accidental fracturing of the stapedial footplate may also occur [75, 123]. As described above, photoacoustic or thermal injury to adjacent structures may occur. The addition of lasers in otologic surgery has been shown to reduce complication rates, but the evidence in comparing various lasers for a specific procedure use is limited.

Prevention and Treatment of Side Effects/Complications

Facial nerve monitoring is the electromyographic monitoring of facial muscles intraoperatively that is proven to be cost effective and reduce the incidence of iatrogenic facial nerve injury during surgery. It is the standard of care in any otologic procedure that is in the vicinity of the facial nerve [124]. Facial nerve monitoring also detects facial nerve injury due to the heat generated by carbon dioxide lasers thereby preventing injury [125].

Future Directions

Future directions include the adoption of all of the above techniques in routine otologic operative procedures. Laser use in acoustic neuroma surgery, tympanoplasty and myringotomy and the use of the laser Doppler vibrometry are all techniques that are emerging as methods that may become standard. Other otologic applications that are being explored include Eustachian tuboplasty for chronic otitis media and Eustachian tube dysfunction and benign paroxysmal positional vertigo [98, 121, 126].

Oral Cavity and Oropharyngeal Pathology

The carbon dioxide laser is utilized for transoral resection of T1 and limited T2 squamous cell carcinoma (SCCA) of the oral cavity and tongue. Its advantages in the oral cavity are due to its ability to simultaneous cut tissue and coagulate small blood vessels [127–134]. Oral cavity cancer has an overall poor prognosis with a high tendency to recur at the primary site and metastasize to the locoregional lymph nodes. However it has been shown recently to be an effective tool in the treatment of T1 and T2 oral cavity squamous cell carcinoma [135]. The CO_2 laser is also used to remove certain benign lesions such as persistent or suspicious leucoplakia in high-risk individuals and papillomatous lesions [136, 137].

Uvulopalatopharyngoplasty (UPPP) is a procedure that involves the reduction and removal of soft tissue in the oropharynx, such as the soft palate and the uvula, in the hopes of treating snoring and obstructive sleep apnea (OSA). If necessary, a tonsillectomy is performed as well. In the past two decades, laser assisted uvulopalatopharyngoplasty (LAUP) with a carbon dioxide laser emerged as an alternative to traditional methods of reshaping the soft palate and uvula and removing this redundant soft tissue in order to treat snoring. However, it is contraindicated in obstructive sleep apnea, and its efficacy has not been fully proven [138–145]. Laser midline glossectomy has also been attempted to treat obstructive sleep apnea in patients who failed traditional UPPP [146].

Zenker's diverticulum is a progressive herniation of mucosa and submucosa through the posterior wall of the esophagus at the junction of pharynx. Patients most commonly complain of dysphagia and the regurgitation of undigested food. Endoscopic laser excision of the wall that exists between the herniated pocket and the upper portion of the esophagus is becoming a more common procedure in otolaryngology instead of the traditional open approach via the lateral neck.

Finally, the recent development of sialendoscopy has lead to the treatment of recurrent sialoadenitis caused by sialolithiasis with the Ho:YAG laser. Preliminary studies have shown improvement in symptoms following sialendoscopy with removal of sialoliths [147–149]. Results thus far do not show a difference in outcomes depending on the salivary gland affected. In the case of large sialolithiases, laser lithotripsy is necessary to remove the sialolith. Laser lithotripsy with the Thalmium:YAG laser has also been described [150].

Pre-operative Management

Pre-operative management of squamous cell carcinoma of the oral cavity includes imaging studies of the head and neck and flexible fiberoptic laryngoscopy in the office to determine the extent of the lesion and assist in planning the surgical approach. Prior to starting the excision, the patient undergoes a direct laryngoscopy, esophagoscopy and bronchoscopy to rule out synchronous primaries and to stage the neoplasm.

To determine whether a patient has sleep apnea or simply bothersome snoring prior to an LAUP, he or she may undergo a polysomnogram. This may determine if it is more appropriate to perform an LAUP, radiofrequency ablation of the posterior tongue, a traditional UPPP, or one of many other sleep procedures.

A swallowing study is frequently performed prior to a Zenker's diverticulectomy to diagnose the condition. Before the procedure, the oral cavity, hypopharynx and supraglottis are examined thoroughly to rule out any other causes of dysphagia.

Preoperative noncontrast CT scan in patients with recurrent sialoadenitis can evaluate for sialolithiasis. Typically stones >4 mm would indicate the potential need to use the Ho:YAG laser intraoperatively [114].

Description of Technique

For safety and access when using a laser in the oral cavity, patients commonly undergo a nasotracheal intubation for enhanced surgical access and exposure. The mouth is retracted open by placing a bite block between the teeth or a Dingman mouth gag. The laser can be controlled by a micromanipulator while the operating field is visualized through an operating microscope or alternatively a hand-held fiberoptic hand piece can be utilized like a scalpel.

T1 and limited T2 oral cavity carcinoma is excised utilizing a carbon dioxide laser with margins acquired and sent for intra-operative frozen section to confirm the complete excision of neoplasm. Depending on the presence of neck disease as well as the size, location, and depth of invasion of the mass, patients may undergo a unilateral or bilateral neck dissection. Two to five-year follow-up for local control of stage I and II oral cavity carcinoma has been reported to range from 60% to 100% [128, 130, 151–154]. Local control rates for stage III and IV oropharyngeal carcinoma treated with laser excision and post-operative radiotherapy is reported to be around 50%. This is reduced to 34% for stage III and IV carcinomas located in the floor of the mouth [127]. Disease-free survival at 5 years for previously untreated T1 and T2 oral tumors is reported to range from 80% to 88%. Patients who have undergone selective neck dissections or post-operative radiation therapy and who have stage III or IV disease tend to have lower survival rates [130].

Patients who have disease located in the tonsil or tongue base have a worse prognosis than those who have more anteriorly based carcinoma of the oral cavity regardless of the technology utilized in its resection. This is attributed to the fact that posteriorly-based oral cavity SCCA is more difficult to detect and is therefore discovered later in the course of the disease at more advanced stages. Resection of tongue carcinomas by CO_2 laser oftentimes allows for the wound to be closed by primarily or it is left to heal by secondary intention without flaps or reconstruction. This can result in less postoperative scarring and tethering of the tongue than traditional surgical methods thereby allowing for more tongue mobility [155–157].

Laser assisted uvulopalatopharyngoplasty has been demonstrated to treat patients with snoring. As described above, LAUP) reshapes the soft palate and uvula, removing redundant soft tissue that may lead to snoring. When comparing thermal damage to the soft palate by the CO_2 and Nd:YAG lasers, Laranne did not find any appreciable differences [142]. The use of both the CO_2 and Nd: YAG lasers to treat snoring have been supplanted by office-based radiofrequency (RF) ablation of the palate and base of tongue. While RF ablation may not significantly benefit OSA and repeat treatment may be necessary, patients have experienced success in the reduction of snoring with RF ablation of the soft palate, tongue, uvula and inferior turbinates with less associated morbidity from the procedure [158–160].

Oral exposure in sialendoscopy is ideally performed with both a cheek retractor as well as a bite block. Technique is slightly different depending on if submandibular or parotid sialendoscopy is performed, but the overall concepts are the same. First dilation of the papilla is achieved using lacrimal probes. Once the duct is catheterized with a guide wire, further dilations using the Seldinger technique are performed until the introducer can be catheterized. This introducer stays in place throughout the procedure [161, 162]. The endoscope is then guided through the introducer to diagnose the obstruction, which is typically stenosis versus sialolith. There is a working port that can feed baskets and wires into the duct to capture and remove sialoliths. Alternatively, medicines such as kennalog can be introduced through the working port to decrease postoperative inflammation. When sialoliths are too big to be removed with a wire basket, lasers are utilized to first break up the stone into smaller components that can be removed. It is important not to force a stone that is impacted, as it may result in the avulsion of the duct or breakage of the basket. This procedure is still in its infancy and limited in patient numbers. Long-term follow up with large patient populations has not yet been described.

Post-operative Management

Patients with extensive resections of SCCA in the oral cavity or those who have SCCA involving the base of tongue are typically kept in an intensive care unit setting overnight for airway monitoring. Occasionally, if swelling is severe, the patient remains intubated and is administered steroids until the edema subsides. Rarely, a tracheotomy is necessary if the patient cannot be intubated or if the airway obstruction is anticipated to be long-term. Any patient with surgery performed in the oral cavity is placed on a liquid diet post-operatively and slowly advanced to a soft diet on which he or she remains for at least

2 weeks. The oral mucosa heals quickly, and patients are encouraged to drink as much fluids as they can handle to decrease xerostomia, infection and post-operative pain.

Patients who have undergone a Zenker's diverticulectomy are sometimes placed on a full liquid diet for at least 2 weeks or the decision is made to feed the patient by tube feeding exclusively until a negative gastrograffin swallow study is obtained. These patients are watched closely for symptoms that may indicate a dehiscence of the operative site and mediastinitis including chest pain, shortness of breath or the return of dysphagia.

Postoperative care following sialendoscopy is minimal. The decision to put the patient on post-operative antibiotics is made on an individual basis. The patient is encouraged to maintain strict oral hygiene.

Side Effects/Complications

Complication rates are significantly higher (90%) in patient with oral SCCA who have been previously irradiated than those who have not had radiation treatments (10%) [163]. Complications reported in patients who have received radiation therapy include uncontrolled pain, bleeding, infection, delayed healing and edema [164]. As discussed above, patients may have post-operative edema of the tongue and oral cavity soft tissue leading to airway obstruction. When obstruction is severe enough, intubation or a temporary tracheostomy may be warranted.

Post-operative bleeding in any oral cavity laser procedure is rare, but may be insidious in onset and potentially life threatening. If suspected, the patient must be carefully examined, and if found, the patient must be brought back to the operating room to control the bleeding.

Complications of both open and endoscopic Zenker's diverticulectomy include post-operative fever with or without mediastinitis, esophageal injury and need for re-operation. Generally, the use of the laser is less morbid than the open procedure [62, 165, 166]. Temporary edema of the affected gland is an expected postoperative outcome. Infection of the affected gland is the most common potential side effect of sialendoscopy. Ductal perforations are possible and are typically treated with a salivary stent for 2 weeks. In addition, a rare but significant complication is the fixation of the wire basket within the duct and inability to remove it from the gland. If this is to happen, the case has to be converted to an open procedure with open exploration and possible excision of the gland in order to free the foreign body from the gland [167].

Prevention and Treatment of Side Effects/Complications

Complications of oral cancer excisions can be minimized by obtaining good visualization of the surgical field and by obtaining adequate hemostasis intraoperatively. Encouraging fluid intake by mouth is important in preventing post-operative pain and dehydration. Airway obstruction may be minimized with post-operative steroids, however the primary concern is in preventing an emergent situation. This is averted by thorough preparation and close monitoring of the patient in the immediate postoperative period.

Currently, the use of the laser in head and neck SCCA is limited by the size, location and stage of the disease. Future therapeutics that may lead to the improved treatment of advanced head and neck cancer include interstitial laser therapy (ILT) with the Nd:YAG laser. Laser use in the involved tissues leads to an increase in thermal energy at the site. This is currently only used palliatively [168]. Chemotherapeutic agents, such as cisplatin are activated by this thermal energy and create a more precise and minimally invasive technique to ablate higher-staged or unresectable neoplasms [169, 170]. This has been shown to be effective in mouse models and in one case report. Further study is necessary to determine the role in cancer treatment.

Photodynamic therapy (PDT) has been proposed as a potential adjuvant treatment of head and neck cancers and pre-cancerous lesions [171, 172]. PDT takes advantage of energy that has been created by the absorption of laser light in that it can induce specifically directed photochemical changes in tissue. Photosensitizers are administered to a patient, accumulate in targeted tissues and undergo light-induced chemical reactions that may lead to selective tissue necrosis and cell death. To date, in the field of otolaryngology, photodynamic therapy has been attempted in patients with soft palate squamous cell carcinoma, recurrent nasopharyngeal carcinoma, early laryngeal malignancies, and laryngeal papillomatosis. Dosing and distribution of the photosensitizer has been difficult to track and quantify. Additionally, patients may experience symptoms of overstimulation such as anaphylaxis if exposed to daylight or neon light during treatment. However, the pilot studies show potentially promising results [173–180].

Rhinology

The area in which lasers are most commonly and successfully used in nasal surgery are in patients who have persistent recurrent epistaxis due to intranasal hereditary hemorrhagic telangiectasias (HHT). HHT is an autosomal dominant condition of the vascular tissue that presents in a person at the ages of 20–40. Friable angiodysplastic lesions that bleed easily and are millimeters in size can present anywhere, but often are located on the mucosa of the nasal cavity, tongue, lips and cheeks. Patients frequently present with epistaxis as the first sign of the disease [181].

Other areas of rhinology that are utilizing lasers, albeit in a limited fashion, include functional endoscopic sinus surgery (FESS), rhinophyma reduction, inferior nasal turbinate reduction, choanal atresia and laser cartilage reshaping. Choanal atresia can be either bilateral or unilateral. Bilateral conditions are typically addressed within the first few days of life because the neonate, who is an obligate nasal breather, is unable to breath unless actively crying, which forces the neonate to breathe through the mouth. This obstruction can potentially be remedied with laser ablation [182–184].

Hypertrophic inferior nasal turbinates can cause uncomfortable nasal congestion, a closed nasal airway and obligate oral breathing that can lead to obstructive sleep apnea and snoring. Along with LAUP described above, some patients may also undergo laser reduction of the inferior turbinates with a KTP, Nd:YAG or Ho:YAG laser [185–190].

Contraindications of laser use in nasal surgery include refractory nasal epistaxis and large sinonasal tumors. Concurrent treatment of bilateral lesions is contraindicated as it may lead to necrosis of the septum and the creation of a septal perforation.

Pre-operative Management

Patients with chronic recurrent epistaxis undergo a thorough work-up for coagulopathic disease prior to surgery. A full history and physical are performed which includes looking for cutaneous and intra-oral telangiectasias that may need to be addressed. Nasal endoscopy is performed to evaluate for the presence of tumor. Prior to undergoing FESS, patients obtain a computerized tomography (CT) scan of the paranasal sinuses to determine the extent of the disease and for anatomic surgical planning.

Description of Technique

In HHT, the argon, KTP(Nd:YAG), and more recently diode lasers can be used to photocoagulate these telangiectasias. Low power settings are used for each laser wavelength so that irradiation creates blanching and coagulation of the lesion. While patients often report improvement after one treatment, recurrent treatments are often necessary and more often the rule rather than the exception. Figure 5.12 illustrates the use of a KTP(Nd:YAG) laser and side-firing fiber aimed at a telangectasia on the anterior nasal septum [191–196].

Lasers can also be used in recurrent epistaxis due to other causes. The most frequent site of epistaxis in patients without HHT is Kiesselbach's plexus, located on the anterior septum. This area can be cauterized using laser energy, however is

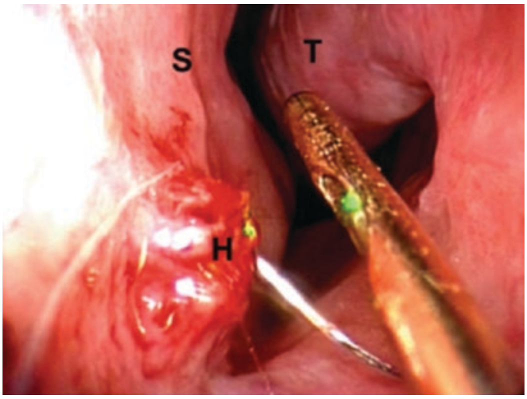

Fig. 5.12 Laser vaporization and hemostasis of a Hereditary Hemorrhagic Telangiectasia (H) along the septum (S). The inferior turbinate (T) can be seen along the lateral wall of the nasal cavity (Photograph provided courtesy of Dr. Brian Wong)

much more expensive than traditional cautery techniques.

Functional endoscopic sinus surgery is a procedure that is performed most commonly in patients with chronic sinusitis or nasal polyposis. Caution must be observed when working within the paranasal sinuses because of the close proximity to the globe, optic nerve, carotid arteries and skull base. Newer fiber optic based laser delivery systems have expanded the ability to use lasers in the sinonasal cavities [197].

When compared to cold or hot steel techniques in rhinophyma reduction, laser use leads to less intraoperative and postoperative bleeding, easier procedures and less discomfort [198, 199].

Unilateral choanal atresia is often treated anywhere from several weeks after birth up to age 12. After the atretic area is opened, a nasal stent is placed and left in for weeks to months. The KTP(Nd:YAG) and the Ho:YAG lasers have been used to treat this condition. While the CO_2 laser was the first to be described, it has fallen out of favor for this application due to the challenge of inserting a relatively large handpiece into the posterior nasal cavity. Reports have found lasers to be beneficial in the treatment of choanal atresia due to the decreased rates of re-obstruction and diminished risk of complications associated with the procedure [182–184].

Side Effects/Complications

A possible complication of laser treatment of hereditary hemorrhagic telangiectasias is the creation of a nasal septal perforation. To avoid this, laser irradiation is not targeted on adjacent septal surfaces in the left and right nasal cavity simultaneously, and treatment may be broken up into multiple separate operations. In any intranasal procedure in which a laser is used, stenosis due to scarring or synechiae may occur, this can be prevented by conservative use of the laser when treating adjacent septal and lateral nasal wall lesions. Laser use in surgery involving the septum has thus far been limited due to the potential risk of septal perforation. Ablative procedures have been performed and work well for septal spurs and other obstructive deformities [200].

Future Directions

Recently, laser cartilage reshaping (LCR) has been developed as a non-ablative way to reshape nasal septal deformities. The benefits of laser use in reshaping the cartilage of the ear in otoplasty has also been explored [201]. LCR involves the use of photo-thermal heating both the septal mucosal and cartilage without the need for incisions. In laser cartilage reshaping, specimens are held in mechanical deformation and then heated using laser radiation. Heat generation accelerates the process of mechanical stress relaxation, which allows tissue to remain in stable new shapes and geometries. Although the mechanisms underlying laser cartilage reshaping have not been completely identified, numerous animal studies have investigated the various biophysical mechanisms underlying shape change, and this method is showing great promise in the field of otolaryngology [202, 203].

Pediatric Otolaryngology

As discussed previously, choanal atresia is a condition present in neonates that can be treated by using a laser directed toward the imperforate area.

The treatment of juvenile onset recurrent respiratory papillomatosis with a CO_2 laser has also been described in a previous section [204]. Other conditions that are present in the neonate and pediatric populations that may be treated with a laser include laryngomalacia, vallecular cysts, subglottic stenosis and subglottic hemangioma.

Laryngomalacia most often presents in the neonate as "noisy breathing". The classification falls under three types. Type I is the most common and least serious. It is characterized by the intermittent prolapse of redundant supraglottic mucosa. Type II laryngomalacia is defined by shortened aryepiglottic folds, and type III is identified by a posteriorly displaced epiglottis. Types I and II can be treated with a CO_2 laser as previously discussed.

Congenital subglottic stenosis is the membranous or cartilaginous narrowing of the larynx at the cricoid area without previous intubation or trauma and may present with biphasic stridor, dyspnea, recurrent croup or other airway difficulties during the first few months of life. In Fig. 5.13a, the airway obstruction produced by the stenotic airway segment (subglottis) is readily apparent. The CO_2 laser was used to excise portions of this obstructive lesion to improve airway patency (Fig. 5.13b) [205–208]. The use of the carbon dioxide laser to treat congenital subglottic stenosis is mostly historical due the possibility of restenosis at the initial site or at a more distal site. More recently, KTP(Nd:YAG) laser has been shown to be helpful in conjunction with open laryngotracheal reconstruction in these patients to ablate portions of thickened cricoid cartilage [209]. Vallecular cysts may also present with noisy breathing and airway obstruction. Their etiology is unknown. Laser excision of vallecular cysts (Fig. 5.14a) is routinely practiced with a high success rate. Typically, a CO_2 laser is used to cut the margins of the cyst, facilitating either removal or marsupialization (Fig. 5.14b).

Subglottic hemangioma presents in a similar fashion to subglottic stenosis with stridor, hoarseness, cough, failure to thrive secondary to dysphagia and cyanosis. Cutaneous hemangiomas are present in 50% of patients with subglottic disease, and therefore suspicion should be high in any

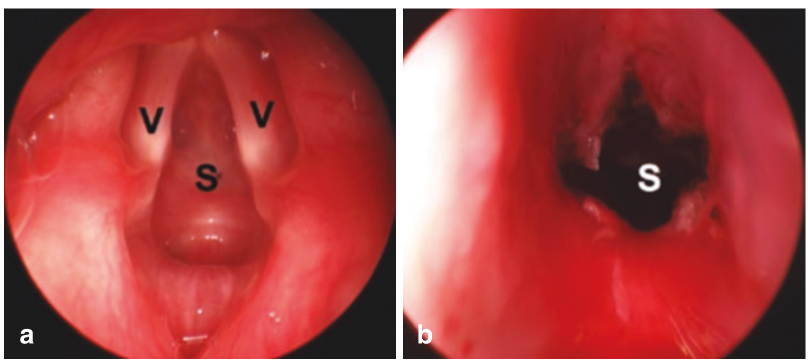

Fig. 5.13 Subglottic stenosis (S) in a pediatric patient before (**a**) and after laser excision from a subglottic view (**b**). V vocal cords (Photograph provided courtesy of Dr. Gupreet S. Ahuja

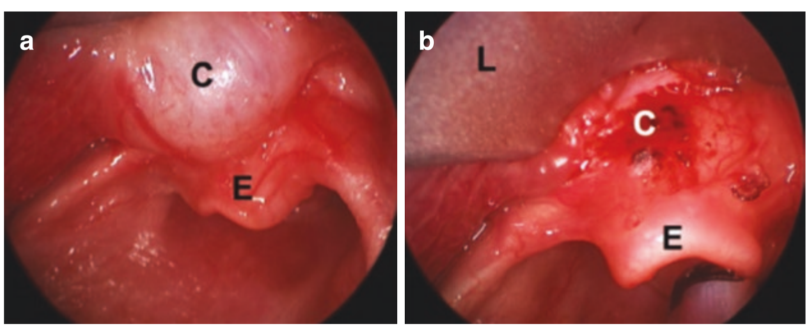

Fig. 5.14 Vallecular cyst (C) in a pediatric patient before (**a**) and after (**b**) laser excision. E epiglottis, L Blade of laryngoscope (Photograph provided courtesy of Dr. Gupreet S. Ahuja)

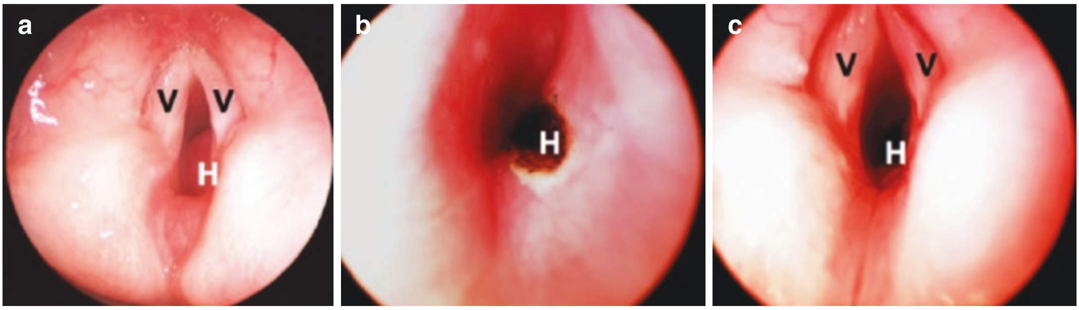

Fig. 5.15 Subglottic Hemangioma (H) in a pediatric patient before (**a**), after laser excision from a subglottic view (**b**) and after laser excision from a supraglottic view (**c**). Note how the airway has increased patency and that the lesion was not circumferential. V vocal cords (Photograph provided courtesy of Dr. Gupreet S. Ahuja)

patient with these symptoms and a history of a cutaneous lesion. Subglottic hemangiomas enlarge rapidly as they undergo proliferation, and appear a smooth, spherical, and often blue hued masses on the subglottic wall (Fig. 5.15a). They present twice as often in girls compared to boys and are typically diagnosed in the first few months of life. While they do spontaneously involute, subglottic hemangiomas have a potential for airway obstruction. To prevent airway compromise, aggressive treatment is warranted, and the laser plays an integral role in this. Tracheostomy may still be required in the short term.

Both laser myringotomy and cholesteatoma excision has been described in previous sections. Laser myringotomy with or without placement of pressure equalization tubes under local anesthesia will reduce the risk of general anesthesia that is typically employed in this procedure. Laser use in creating a myringotomy may also decrease the incidence of tube plugging, persistent bleeding and other complications associated with this procedure. However, these observations have yet to be demonstrated in a large randomized prospective study. Cholesteatoma excision may be assisted routinely by the use of lasers and endoscopy in the areas that are anatomically difficult to access.

Pre-operative Management

Laryngomalacia in a neonate is most often diagnosed using flexible fiberoptic laryngoscopy. Some neonatess might require nasogastric tube feedings due to the risk of aspiration that is associated with this condition. Severe laryngomalacia may necessitate intubatation while awaiting surgery due to frequent oxygen desaturations. Patients may also be placed on peri-operative H2 blockers or proton pump inhibitors for treatment of gastroesophageal reflux disease, a frequent co-morbid condition that can exacerbate symptomatology. Techniques In type I laryngomalacia, the CO_2 laser is used to perform a supraglottoplasty and excise or reduce the aryepiglottic folds. Type II laryngomalacia may be treated by using the CO_2 laser to divide the aryepiglottic folds [207, 210, 211]. The CO_2, Nd:YAG and KTP(Nd:YAG) lasers have been suggested as possible methods to remove hemangiomas in the subglottis (Fig. 5.15a) due to their ability to excise and coagulate these vascular lesions. The KTP(Nd:YAG) laser is favored in this application because it is more easily delivered to the area via flexible fiberoptics and is readily absorbed by hemoglobin. Figure 5.15b is an image of the subglottic region after laser treatment of a hemangioma. Figure 5.15c is a panoramic image of the larynx showing both the supra and subglottic airway after the hemangioma was removed. Most treatment methods produce some degree of subglottic stenosis. However, the stenosis grade typically does not require tracheostomy [206–208, 212–214].

Post-operative Management

All pediatric patients who undergo laser surgery of the airway are sent to the pediatric or neonatal intensive care unit post-operatively for airway observation. Whereas patients who undergo subglottic hemangioma excision via an open approach will receive a tracheostomy, those in whom a laser is used for ablation often do not. Steroids are given to reduce the formation of edema in the airway mucosa. Frequent serial examination with flexible fiberoptic laryngoscopy is performed to monitor for supraglottic edema, stenosis and hemangioma recurrence.

Side Effects/Complications

Possible adverse events that may occur when treating both laryngomalacia and subglottic hemangiomas include tracheal stenosis, granuloma formation and airway compromise. All of these events may lead to intubation of the patient post-operatively and in extreme circumstances, tracheostomy is necessary. Other complications include aspiration, pneumonia, subcutaneous emphysema, bleeding that may require re-exploration and mediastinitis. Additionally, subglottic hemangiomas or stenosis may recur post-operatively. In the immediate post-operative period, patients may experience dysphagia leading to malnutrition and require a feeding tube for supplementary alimentation.

Prevention of Side Effects/ Complications

Tracheal stenosis may be prevented by performing excision of subglottic lesions in a quadrant approach thereby minimizing the chance of circumferential scar formation. An airway emergency is prevented by preparation and monitoring in an ICU setting post-operatively. To prevent aspiration and malnutrition, a prophylactic nasogastric feeding tube is placed intra-operatively and left in until the patient demonstrates safe and adequate consumption of food and drink.

Conclusion

Laser applications in otolaryngology—head and neck surgery are extensive and diverse. While most commonly used in laryngology and otology, laser applications are being developed for use in all areas of the head and neck including the oral cavity, oropharynx, external nose, paranasal sinuses, cranial base, and in the pediatric population. As new devices and delivery systems are developed, new applications will evolve. One element that is critical in all areas of application is laser safety, and this should take the utmost importance when planning and undertaking any procedure.

Lasers are used to treat both malignant and benign laryngeal diseases ranging from cancer to vocal cord paralysis. Middle ear applications have focused on primarily treating conductive hearing loss (stapes surgery), though in recent times new applications include the treatment of Eustachian tube dysfunction and cholesteatoma. Lasers are used to excise tumors in the oropharynx and oral cavity because they precisely cut and coagulate tissue. In rhinology, treatment of hereditary hemorrhagic telangiectasias is a commonplace and elegant example of laser therapy for non-cutaneous vascular lesions. In children, the laser may be used to ablate subglottic hemangiomas, correct laryngomalacia and excise atretic choanae. Laser applications in otolaryngology continually develop and evolve with a plethora of new devices, procedures and applications are emerging each year.

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6 Light/Laser Applications in Gynecology

Cornelia Selma de Riese and Roger B. Yandell

Abstract

The use of CO_2 laser in the treatment of uterine cervical intraepithelial lesions is well established and indications, as well as techniques, have changed very little for over 30 years. The Cochrane Systematic Review from 2000 suggests no obviously superior technique. CO_2 laser ablation of the vagina is also established as a safe treatment modality for VAIN (Vaginal Intraepithelial Neoplasia), and has been used extensively in the treatment of VIN (Vulvar Intraepithelial Neoplasia) and lower genital tract condylomata acuminata. CO_2 laser permits treatment of lesions with excellent cosmetic and functional results. The treatment of heavy menstrual bleeding by destruction of the endometrial lining using various techniques, including Nd:YAG laser ablation, has been the subject of a 2002 Cochran Database Review. Among the compared treatment modalities are modified laser techniques. The conclusion by reviewers is that outcomes and complication profiles of newer techniques compare favorably with the gold standard of endometrial resection. Myoma coagulation or myolysis with Nd:YAG laser through the laparoscope or hysteroscope is a conservative treatment option for women who wish to preserve their child bearing potential.

Keywords

LASER · Vulva · Vagina · Cervix · Dysplasia · HPV · Gynecology

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- Several non-invasive neoplastic and infectious conditions of the external female genitalia are amenable to treatment with a variety of ablative lasers.
- Ablative laser treatment of the vulva, vagina and cervix provides a relatively fast treatment modality and results in healing with little scar formation and excellent cosmetic and functional results, as well as fairly uncomplicated postoperative recovery.
- Intra-abdominal uses of different lasers are valuable alternatives to other thermal or mechanical cutting instruments.
- Severe side effects and complications of laser use can be minimized by careful patient selection, using the most appropriate instruments, proper surgical technique, and meticulous postoperative care.
- Good candidates for laser ablative procedures are generally considered to be individuals who

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K. Nouri (ed.), *Lasers in Dermatology and Medicine*, https://doi.org/10.1007/978-3-319-76220-3_6

have been refractory to medical and/or chemical treatment, and those presenting with extensive disease, as well as patients in whom a single surgical procedure is indicated for medical, psychological, or social reasons.
- With ongoing advancements in laser technology and techniques, improved clinical outcomes with minimal postoperative recovery will be realized.

Introduction

- Gynecologists first used laser in 1973 and have used CO_2, KTP-532, Argon, and Nd:YAG to treat lower genital tract, intrauterine, and intra-abdominal disease.

The use of CO_2 laser in the treatment of uterine cervical intraepithelial lesions is well established, and indications, as well as techniques, have changed very little for over 40 years. The Cochrane Systematic Review from 2013 suggests no obviously superior technique [1]. CO_2 laser ablation of the vagina is also established as a safe treatment modality for VAIN (Vaginal Intraepithelial Neoplasia) and has been used extensively in the treatment of VIN (Vulvar Intraepithelial Neoplasia) and lower genital tract condylomata acuminata. CO_2 laser permits treatment of lesions with excellent cosmetic and functional results. The treatment of heavy menstrual bleeding by destruction of the endometrial lining using various techniques, including Nd:YAG laser ablation, has been the subject of a 2013 Cochran Database Review [2]. Modified laser techniques are among the compared treatment modalities. The conclusion by reviewers is that outcomes and complication profiles of newer techniques compare favorably with the gold standard of endometrial resection. Myoma coagulation or myolysis with Nd:YAG laser through the laparoscope or hysteroscope is a conservative treatment option for women who wish to preserve their child bearing potential. CO_2 laser is the dominant laser type used with laparoscopy for ablation of endometriotic implants. The KTP-532 nm laser also has been used for essentially all of the previously mentioned applications of carbon dioxide. It is less widely available, but does offer certain distinct advantages of significantly less post-operative pain and much better hemostasis. These will be discussed further [3].

History and Procedures

- In 1973 laser was first used in gynecology by Kaplan for vaporization of infected cervical tissue
- The use of the laser through a laparoscope was first described by Bruhat in 1979
- Goldrath first described intrauterine procedures using the Nd:YAG in 1981
- The media used in gynecologic surgeries are CO_2 and argon gases, as well as KTP, Nd:YAG crystals, and diode lasers

Albert Einstein postulated his idea of stimulated emission of radiation in 1917 [4], but it took 40 more years for this idea to be converted into a practical device. In 1958 Arthur L. Schawlow and Charles H. Townes published their initial article covering the basic principles of the laser in the *American Physical Society's Physical Review* [5, 6]. This was followed by their first proposal of gas lasers excited by electrical discharge. In 1960 Ali Javan, William Bennett, and Donald Herriott constructed a helium neon laser, the first laser to generate a continuous beam of light [4]. In 1961 the first continuous operation of an optically pumped solid-state laser Nd:CaW04 by L.F. Johnson, G.D. Boyd, K. Nassau, and R.R. Soder was reported [4]. C.K.N. Patel developed the first CO_2 laser in 1964 [7]. The same year the Nd:YAG laser was introduced by J.F. Geusic and R.G. Smith [4]. The first experimental medical application was reported in 1965 [8].

In 1973 laser was first used in gynecology by Kaplan for vaporization of infected cervical tissue [9]. The following year Bellina reported the first definitive procedures done on the vulva, vagina and cervix using CO_2 [10]. Over the next decade, hundreds of articles were published discussing the techniques of the use of carbon dioxide laser and the treatment of intraepithelial neoplasia and condyloma of the lower genital tract. In 1989 Yandell presented information regarding excisional cone biopsy of the cervix using the argon, KTP-532, and the Nd:YAG lasers, touting marked improvement in hemostasis and application of the energy using the shorter wavelength fiber optic instrumentation [3].

Intra-abdominal and intrauterine applications were also explored. Bruhat first described use of carbon dioxide laser through the laparoscope in 1979 [11]. Three years later, Keye reported on the use of argon laser for the treatment of endometriosis [12]. This was followed very shortly by introduction of the KTP-532 and the Nd:YAG lasers laparoscopically. In 1981 Goldrath first described the use of Nd:YAG laser in the endometrial cavity for the destruction of the endometrium and later, for resection of the uterine septa, submucous myomata, and excision of polyps [13]. In 1984, Rettenmaier first published data on the treatment of gynecologic tumors of the vagina and vulva using photoradiation with hematoporphyrin dyes [14].

Epidemiology of Human Papillomaviruses

Human papilloma virus (HPV) infections, and genital HPV in particular, are serious public health concerns, not just due to their immediate impact on quality of life, but also due to the tremendous economic burden to the affected patient and the public [15]. In the USA, close to $8 billion are spent annually for the treatment of HPV-related conditions [16].

Classifications and Virus Types

Human papilloma viruses only have affinity to the human body. Almost 200 different types have been identified to date. They are subcategorized according to tissue tropism: cutaneous versus mucosal, and oncogenic potential. Depending on the host's immune competence, these infections may be transient or persistent [17].

Emphasis in this chapter will be placed on anogenital tract infections. There are about 10–15 low-risk types, with types 6 and 11 being most prominent, which are responsible for genital wart growth. There are 15–20 high risk or oncogenic types, which are responsible for precancerous and cancerous transformation of genital epithelial tissue. The most prevalent high risk types are 16, 18, 31, 33, 35, 39, 45, 51, and 52 [18–21].

Risk Factors

Genital HPV infections are predominately sexually transmitted. Vertical transmission from delivering mother to newborn is confirmed for respiratory papillomatosis [20]. The risk for virus acquisition is directly correlated with the number of sexual partners [17, 22–25]. Smoking is an additional risk factor, as may be the use of contraceptive pills in women [26]. Condom use appears to provide incomplete protection due to the involvement of uncovered genital contact sites.

Incidence and Prevalence

Estimates of the infection rate within populations are challenging because of the unpredictability of the natural history, the lack of requirements to report the disease, and the large variations between different populations and age groups. The overall risk of infection is ultimately related to sexual behavior and risk factors. HPV is considered the leading sexually transmitted infection in the USA. According to data from the Centers for Disease Control (CDC) and the National Health and Nutrition Examination Survey (NHANES), at least 50% of sexually active men and women will acquire HPV infection at some point in their lives [27]. Not surprisingly, adolescents and young adults show the highest incidence numbers [24, 28]. HPV infections in men are less extensively studied, but infection rates appear similar to those found in women and are estimated to be as high as 73% [26, 29]. Male circumcision appears to decrease the risk of infection for the male and probably the risk of transmission of the virus [30].

Studies on the distribution of different virus types within 11 countries from Africa, Europe, and South America demonstrated geographic variation, with the HPV 16 type being more prominent in Europe [31].

Tissue Tropism and Clinical Infections

Several HPV types have a propensity to infect keratinizing epithelium and cause cutaneous warts, such as common warts and plantar warts (types 1, 2, 4), Butcher's warts (types 2 and 7), and flat warts (type 3 and 10) [32, 33]. Bowen's disease is a form of squamous cell carcinoma in situ from which numerous virus types have been isolated: 16, 18, 31, 32, 34 and others [21, 32, 34, 35]. Several of the above mentioned virus types also infect non-keratinizing epithelial surfaces, especially within the anogenital region, but also within the mouth and pharynx. Condylomata acuminata are the best known genital warts and affect at least 1% of the sexually active population, with the peak prevalence in the young adult age group [22, 23, 25, 35]. Subclinical infections are very common and constitute a major challenge for the treating physician. Colposcopy and acetic acid are required tools for detection of these latent stages.

There is now ample evidence that links persistence of high risk HPV types to the development of cervical cancer and other surface cancers of anal, vulvar, penile, and oropharyngeal origin [21, 36–39]. In the past, cervical cancer was the most frequent malignancy among women in developing countries, but it now ranks second after breast cancer [21].

Outlook

The introduction of the quadrivalent papilloma virus vaccine for adolescent and young adult females in 2006, as well as the newly introduced nonavalent vaccine [40], will positively impact the epidemiology of immunized women in the decades ahead, but generations of already infected women will need attention for many years to come. Since 2011 HPV vaccines are also approved for male adolescents aimed at more efficient immunization of the entire population [41].

Laser Use on Vulva, Vagina and Cervix

Indications

- Intraepithelial Neoplastic Disease
- Condyloma acuminata refractory to medical and chemical treatment
- Cervical Stenosis
- Extensive Disease including extension into anus and urethra/bladder of condyloma acuminatum

Contraindications

- Patients in whom invasive cancer has not been ruled out

Since the instruments first became available to gynecologists, laser has been used in the treatment of pre-malignant (dysplastic) lesions of the lower genital tract. These include cervical intraepithelial neoplasia (CIN), vaginal intraepithelial neoplasia (VAIN), and vulvar intraepithelial neoplasia (VIN).

The vast majority of these intraepithelial neoplasias are of the uterine cervix. The incidence and prevalence has started to decrease after the HPV vaccine introduction, especially in younger population ($\leq$18 years) [42]. At birth, the squamo-columnar junction between the vagina and the endocervical columnar epithelium lies at the outer aspects of the ectocervix. At menarche, the vaginal pH drops substantially from 7.2 to 4.5. This, coupled with a marked effect on the vaginal flora, causes the onset of metaplastic change over the columnar epithelium that is exposed to the vaginal environment. During the course of metaplastic change, this exposed endocervical tissue is covered by a pseudo-stratified squamous epithelium with small infoldings in the surfaces down to the level of the original columnar tissue. These infoldings are frequently, and incorrectly, described as glands or crypts, for lack of a better term. The entire process takes approximately 8–10 years, and during this time the tissues of this transformation zone are extremely susceptible to the virus. Once the HPV is incorporated into the cells, they may undergo neoplastic transformation or simply remain infected, depending on the specific viral subtype. The body may recognize the virus as foreign and mount an immune response, but in many cases, it does not, allowing persistent infection or neoplastic change, which can then advance in severity. The lesion spreads over the cervical surface and as it does so, it also moves down into these "glands" of the newly formed transformation zone.

When the patient presents, usually following an abnormal pap smear, the work up includes colposcopy with biopsy of the most suspicious areas, to determine the severity of the disease. Because the lesion is intraepithelial, destruction of the epidermis is adequate for treatment of the neoplastic lesion; however, it is known that large areas of the normal appearing transformation zone are infected by the virus despite no visible lesions being present on colposcopic exam. The other concern regarding treatment is that because of the infolding of the epithelium, the dysplastic lesion may extend several millimeters below the surface, and into the endocervical canal. With this in mind, the generally accepted treatment is destruction of the entire transformation zone to a depth of 5–7 mm.

Treatment methods used in the past were diathermy, and later cryotherapy. Neither of these modalities allow the physician to discern the depth of destruction at the time of the procedure. The use of laser, however, allows very accurate vaporization or ablation of the transformation zone down to the desired depth, with extension of that vaporization further up into the endocervical canal to visibly and measurably treat the entire extent of the tissue involved.

Evaluation and treatment of vaginal and vulvar intraepithelial neoplasia is similar, and in some ways simpler, because the epithelium involved is completely exposed, unlike that of the uterine cervix. Care must be taken, especially in the vagina, to not destroy more than the affected epithelium, which generally is less than 1 mm in thickness. Problems also arise in treating the portion of vulva in which there is hair because of the spread of the disease down into the follicles. Another concern with VIN is that it tends to be multifocal, requiring very careful colposcopic exams and frequently several biopsies in order to identify the extent of lesions.

Of paramount importance is ensuring that there is no invasive disease prior to using local destructive treatments. Any suspicion of invasion requires further excisional tissue diagnosis. For many years, excisional cone biopsy was performed using the "cold" knife, or "hot" electrocautery. This is a markedly inaccurate procedure which removes the entire ectocervix and the distal and middle portion of the endocervical canal for tissue evaluation. The "cold knife" cone is fraught with potential complications including excessive blood loss; inadequate incision depth, which may make it difficult to discern whether the lesion is invasive or microinvasive if it is incompletely excised; and excessive tissue removal, resulting in incompetent cervix and subsequent second trimester pregnancy loss. Because of their precision and hemostatic characteristics, lasers have been used for excisional cone biopsies by many surgeons for the last 30 years.

The other major indication for the use of laser of the lower genital tract is the treatment of condylomata accuminata. These lesions are generally first treated conservatively using cytotoxic agents such as podophylin, immune modulators such as imiquimod, or acids such as TCA, for the destruction of specific early disease. Cryocautery may also be used for destruction. However, in most cases, each of these requires multiple treatments which can be fairly painful and irritating. The use of cryocautery may also be complicated by excessive destruction into the dermis, which causes scarring and may result in ulceration and infection. Because large areas of skin are infected with the virus and appear normal at the time of initial treatments, it is very common for secondary lesions to become apparent around previously treated lesions. In some cases the local treatment itself may not be adequate to cause destruction of the primary lesions. Frequently, patients present with extensive disease involving large areas of the lower genital tract and local treatment using medical or chemical means is simply impractical. These patients are generally treated primarily with laser in the operating room for the best results. In a significant number of these cases, the condylomata extend into the anal canal and may also extend into the urethra and bladder neck. The KTP-532 laser may be used inside the bladder and urethra for precise destruction of lesions in a fluid environment.

One known complication of conventional cone biopsy of the cervix is stenosis of the cervical os. In this situation, hypertrophic scarring of the surgical defect essentially closes the endocervical canal to the point that menstrual flow may be obstructed, or secondary infertility becomes an issue. The best treatment for this condition is CO_2 vaporization of the scar tissue which has occluded the canal. Following this procedure, the endocervical columnar epithelium typically grows outward as the squamous tissue grows in from the exocervix, creating a more normal patent opening.

Techniques

- Adequate preoperative patient evaluation and education
- Timing of the procedure to closely follow the menstrual cycle
- Antibiotics are rarely indicated if the appropriate depth of destruction is maintained
- The Carbon Dioxide and KTP-532 lasers are both used for the treatment of lower tract disease
- Although the CO_2 laser is the most commonly used, the KTP-532 offers the important benefit of substantially less post-operative pain, which is the single most significant morbidity encountered
- Care must be taken not to ablate too deeply, especially in the vagina and over opposing vulvar surfaces
- Early postoperative evaluation is the key to avoiding major complications

Preoperative Management

There is no consensus among laser experts regarding the most appropriate preoperative regimen for laser use in gynecology. Adequate preoperative patient evaluation and education are paramount because of the relatively long and sometimes painful postoperative course, and the relatively high persistence and recurrence rates of both intraepithelial neoplasia and HPV. It is always best to time the procedure just after the menstrual period to allow the longest time possible for healing before the next menses. In some instances, it is appropriate to postpone menstruation by using hormonal therapy such as injectable depomedroxyprogesterone or oral contraceptive suppression.

It is sometimes advantageous to administer a mechanical bowel prep prior to any extensive procedure. This will decrease exposure of the surgical field to bowel flora. The prep should be administered the day before surgery.

Due to the moist, de-epithelialized state of ablative laser treated skin and the possibility of bacterial contamination and overgrowth over the vulva and vagina, some gynecologic laser surgeons advocate oral or topical antibiotic prophylaxis. This practice remains controversial, due to the lack of results of controlled studies. Antibiotics have not been used for laser procedures on the cervix. The one exception to this is the patient who is found to have bacterial vaginosis at the preoperative evaluation. Because of the high bacterial count of anaerobic organisms in the vagina, this condition should always be treated with metronidazole or clindamycin before surgery.

Description of the Technique

Laser in the Treatment of Cervical Disease

When laser was first introduced as a tool for the gynecologist, it was the CO_2 laser which was used for treatment of cervical disease [9]. In the early reports of laser surgery, Baggish and Dorsey helped to define and establish the techniques used in CO_2 laser therapy. They described using a 0.5–1 mm spot size and power of 25–50 W, resulting in a power density of 2,500–20,000 W/cm^2 to cut, versus a 2–3 mm spot size and 20–25 W for vaporization which has a corresponding power density of approximately 500–800 W/cm^2. This was done under colposcopic guidance with the laser coupled via a micromanipulator. In 1982, they reported a series of over 400 cases with CIN treated by laser with an overall cure rate of almost 96% at about 1-year follow-up [43]. The only significant changes since then have been the use of slightly higher power densities. However, moving above the 1500 W/cm^2 range frequently results in the beam cutting into vessels without first coagulating them and may cause significant bleeding. The higher power density does result in less thermal damage to the specimen, and offers a superior specimen for pathologic evaluation. There are very few current publications on this subject. *Cochrane Systematic Reviews* published in 2002 on surgery for CIN and compared seven surgical techniques. They concluded that the Loop Electrosurgical Excision Procedure (LEEP) appeared to provide the more reliable specimen for pathology but the overall morbidity was lower with the laser conization. The limited evidence suggests that there is no obviously superior surgical technique for CIN [44].

The KTP-532 laser has also been used for excisional and ablative procedures of the cervix, although there is little published data. The fiber is passed through a 9 in. hand piece with a 30° curve at the tip. This allows a free hand excision of the surgical specimen using 10–15 W (power density of 3600–5000 W/cm^2). The most significant benefit is the marked decrease in bleeding encountered, which is generally the most difficult complication to deal with when using other modalities, including the carbon dioxide laser. This is explained by the high photochemical absorption of the 532 nm wavelength in the hemoglobin molecule. The beam passes through the relatively clear vessel wall, coagulating the blood before cutting it. Because of the forward penetration of this wavelength, the fiber is angled toward the patient and away from the specimen to decrease coagulation artifact and increase hemostasis during the incision of tissue. The KTP-532 has been used for the last two decades and has been found to allow for almost bloodless excisional cone biopsies [1] (Fig. 6.1).

The Nd:YAG laser has also been used for excisional procedures, but because it must be coupled with a sapphire tip to do incisional work, it is somewhat more costly and difficult to manipulate inside the confined space of the vagina. It is,

Fig. 6.1 The flexible quartz fiber of the KTP-532 laser is seen passing through a hand piece which allows a 30° angle at the tip. This allows the surgeon to apply the beam parallel to the skin surface for vulvar and vaginal procedures and is advantageous when performing excisional cone biopsies of the cervix

however, extremely hemostatic because of this wavelength's intrinsic coagulation of protein.

Some authors suggest that combining LEEP with additional laser treatment of the cut margins and wound bed may improve long term success [45, 46]. Microscopically guided laser vaporization or laser excisional cone may be a less aggressive, and certainly more controllable treatment modality than a traditional "cold knife cone (CKC)" and therefore, may be the choice for young women interested in preservation of fertility [47–49].

In addition to the previously mentioned complications of CKC, it may result in the removal of too much or all of the endocervical glands, resulting in cervical factor infertility and/or cervical stenosis, which precludes the passage of menstrual tissue. In the case of cervical stenosis, the CO_2 laser is the instrument of choice to vaporize the scar tissue which is occluding the canal. A higher power density is used in the range of 5,000 W/cm^2 to decrease thermal damage of the surrounding area and allow the normal tissues to grow back into place.

The use of lasers has significantly decreased the complications which have been historically encountered with the traditional cold knife cone.

Laser in the Treatment of Vaginal Disease

The treatment of vaginal dysplasia and condyloma remain challenging, regardless of treatment modalities. Since the vaginal epithelium is less than a millimeter thick, ablation has to be very superficial. Traditionally, the procedure was done in similar fashion to cervical laser vaporization, under colposcopic supervision with the micromanipulator. A 2 mm spot size is chosen at a 20–30 W power setting [8, 50]. Duane Townsend was among those establishing the technique. Because of the sharp tangential angulation of the impact beam delivered to the vaginal wall from a colposcopic delivery system, many surgeons today prefer to use a hand held device. This is incrementally better, but because of the bulky nature of the CO_2 hand piece, it is still difficult to deliver a beam at 90° to the surface. The use of a fiber-optic laser such as the KTP-532 delivered through a hand piece with an angled tip as previously described, can allow the surgeon to deliver the beam with a more even distribution of energy to the surgical site. This is done using 10 W and short exposure times to compensate for the increased penetration of this wave length into the underlying tissue. With either technique, it is very important not to overlap exposure applications in order to protect the underlying dermis.

The bulk of the available literature is from the 1980s to the mid-1990s. Uniformly, recurrence or persistence rates in the 30–50% range are reported after the first laser treatment. Even after the second and third treatment courses, 20% relapse or persist. This disease is considered multi focal in the majority of cases. In the case of VAIN III involving the vaginal cuff angles after hysterectomy, upper vaginectomy is proposed over plain laser ablation. Additional superficial lasing of the surrounding vagina is generally recommended [51–58]. The main advantage of the laser procedure in comparison to conventional surgery or the use of cytotoxic agents, is the preservation of the anatomic integrity of the vagina, even after repeated laser courses [55]. The recommended curative and safe depth to be achieved with the laser treatment is only 1.5 mm, which allows for re-epithelialization without scarring [59].

In the case of larger exophytic condyloma, the lesions are vaporized down to a level consistent with the surrounding vaginal wall before the adjacent normal appearing epithelium is treated. Because of the high recurrence rates, it is assumed that substantial areas of this normal appearing epithelium are in fact infected by HPV. In many cases of extensive disease, the correct plane of the original vaginal wall may be extremely difficult to determine. In this case, it is better to err in the direction of removing less tissue and, in some cases, to only treat part of the affected area. In many instances in which only partial vaporization is completed, the post-operative inspection reveals complete clearance of the condyloma. It is believed that these patients' immune systems are stimulated to recognize the HPV as a result of the surgery and develop an immune response to the virus resulting in clearing of the untreated lesions.

Laser in the Treatment of Vulvar Disease

CO_2 laser treatment for vulvar lesions was introduced about the same time as that of the cervix. The first reports were again by Baggish and Dorsey [60, 61]. They established the technique still in use, which employs a spot size of 2–3 mm and power settings of 15–30 W.

The goal is to confine the damage to the epidermis and upper papillary dermis; however, stacking of laser pulses by treating an area with multiple passes in rapid succession or by using a high overlap setting on a scanning device can lead to excessive thermal injury with subsequent increased risk of scarring. This untoward effect can be avoided by moving the beam in a serpentine fashion or in ever increasing concentric circles while avoiding overlap. The depth of ablation correlates directly with the cumulative amount of time x wattage, or work measured in joules, applied to a specific location. Using a power density of 800–1,000 W/cm^2 is generally considered ideal for CO_2, and should result in instantaneous boiling of the water in the epithelium, causing a vapor pocket above the dermis with elevation of the superficial layer. A power density, which is too high, results in deep vaporization into the dermis, which should be avoided. However, this effect is time sensitive and as the skill and speed of the surgeon increase, a somewhat higher power density may be employed. If the power density is too low, an ablative plateau is reached with less effective tissue ablation and accumulation of thermal injury. This effect is most likely caused by reduced tissue water content after initial desiccation, resulting in less selective absorption of energy. The avoidance of pulse stacking and incomplete removal of partially desiccated tissue is paramount to prevention of excessive thermal accumulation with any laser system. The objective of ablative laser treatment is to destroy tissue down to the papillary dermis. Limiting the depth of penetration decreases the risk for scarring and permanent pigmentary alteration. When choosing treatment parameters, the surgeon must consider factors such as the anatomic location and proximity to vital organs. To reduce the risk of excessive thermal injury, partially desiccated tissue should be removed manually with wet gauze after each laser pass to expose the underlying dermis.

This technique is very reliable when treating the non-hairy vulvar surfaces. In areas containing hair, the method must be altered in an attempt to treat intraepithelial neoplastic disease, which progresses toward the base of the follicle. In most cases this is best done by making a second pass over this tissue after the superficial epithelium has been removed. This characteristic of VIN is felt to be one of the primary causes of persistent disease in cases which have otherwise been adequately treated by laser, and is perhaps the main reason some gynecologists still advocate excision in these areas. When cosmesis is a priority, the laser is still preferable, and the patient must be informed that she must commit to close follow-up and the possibility that further treatment may be needed. Unfortunately, because of the high recurrence rates in all VIN cases, this is more or less true for all patients.

When treating condyloma, the same techniques are generally applicable, but must be modified for larger exophytic lesions. The smaller condylomata may be simply vaporized or excised, but only to the level of the skin with care being taken not to coagulate the deeper dermis. The surrounding normal appearing epithelium is then treated in the same fashion as described above to a distance of 1–2 cm from the original wart. If this is not done, recurrence rates are very high.

For the larger pedunculated lesions, several techniques may be employed to decrease bleeding, which may occur if the CO_2 laser is being used. Although the carbon dioxide laser is generally regarded as a very hemostatic instrument, it does so by thermal coagulation of vessels as the tissue is vaporized at the impact site, unlike the KTP-532 and Nd:YAG wavelengths which actually pass through water and coagulate by direct absorption in hemoglobin and protein respectively. When larger vessels are encountered, the CO_2 may cut into the wall before the more rapidly moving blood is coagulated, creating bleeding. Further attempts to seal the vessel are then hampered by the complete absorption of the energy at the surface of the emerging blood, which does not allow heat to penetrate to the vessel below. The blood must be cleaned away while pressure is applied to the vessel in order to tamponade the bleeding to allow further progress. Alternatively, pedicles may be coagulated circumferentially before attempting excision. This is more productive if the blood flow can be stopped by pressure at the base. In some cases, it is better to use a much lower power density in the range of 200–400 W/cm^2 to essentially cook the tissue initially. The wattage may be decreased or the spot size increased to accomplish the change. This can however, result in thermal spread into the dermis. In some instances, electrocautery or sutures may be needed.

The KTP-532 laser, although much less widely available, may also be used in the treatment of these diseases, and offers significant advantages once the technique is mastered. Because this wavelength is not absorbed in water, there is deeper penetration (1–2 mm) than seen with the CO_2. In order to decrease damage to the dermis, a higher power density (2,000–5,000 W/cm^2) is used with a shorter application time, resulting in a more immediate coagulation of the epidermis, and less thermal spread. The outcome is somewhat different, because the effect will be desiccation and coagulation, with little or no vaporization. The treated epidermis is then wiped away using a gauze pad. The incidence of bleeding is much lower because of the extremely high absorption of the 532-nm wavelength in hemoglobin, and the ability to move through vessel walls, which are mainly water, before cutting into them. Should bleeding be encountered, the hand piece is backed away a few centimeters, which will rapidly increase the spot size secondary to the 15° divergence of the beam from the fiber tip, resulting in a much lower power density for coagulation purposes (Fig. 6.2a, b).

The most significant advantage to this wavelength is a marked decrease in postoperative pain compared to the CO_2 laser. Significant and prolonged pain is the most common morbidity of vulvar laser treatment. Because the CO_2 has very little forward scatter, the equivalent of a second degree burn is being created, with the intact sensory nerves exposed. Although the exact mechanism is uncertain, it is postulated that the 532 nm wavelength is absorbed in these nerve endings, essentially decreasing their response to stimuli for a short time during the healing process. There does not appear to be any long term effect. The increased depth of penetration may also be beneficial in treating VIN in skin containing hair follicles, although this has not yet been substantiated.

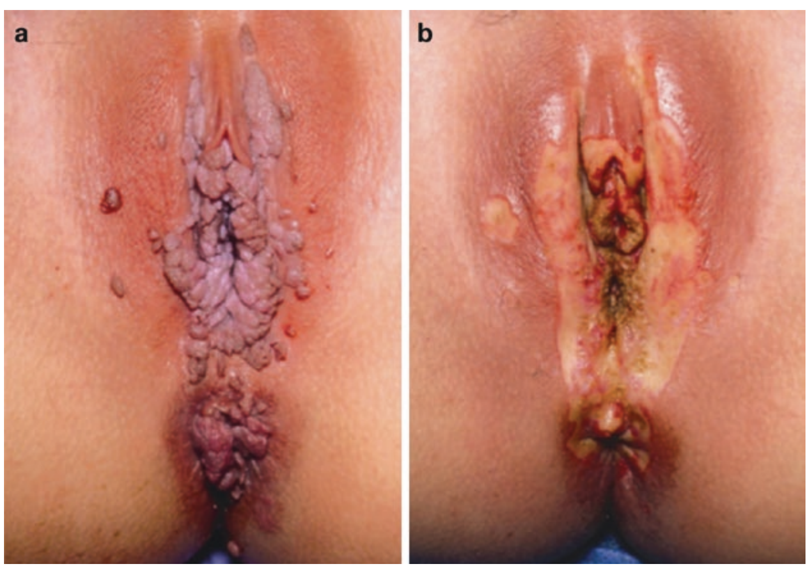

Fig. 6.2 (**a**) Patient with extensive condylomata acuminata of the vagina, vulva, and peri-anal skin. (**b**) Same patient following treatment using the KTP-532 laser. There is marked edema forming in the clitoral hood and labia minora before the entire procedure is completed. Note the absence of pitting into the dermis and the extended treatment area around all previously visible lesions

Laser therapy of vulvar intraepithelial neoplasia and condyloma results in excellent cosmetic and functional healing, but carries the risk of recurrent and persistent disease. Repeated treatments may be necessary. In light of the multifocal nature of these disease processes in the majority of patients, laser, with its ease of technique and low morbidity, is the treatment of choice, especially for younger women [7, 50, 62, 63]. For extensive VIN III, excisional laser surgery of the more suspicious areas combined with vaporization of the surrounding "normal" epithelium, provides a histologic specimen and appears to be more effective than pure vaporization [63].

Post-operative Management

The post-operative management of the lower genital tract largely centers around the treatment and prevention of pain and bleeding. Following excisional or vaporization cone biopsy of the cervix, the most common complication is delayed bleeding. This occurs as the scar falls away at 10–14 days. Because of this, the base of the excision site may be coagulated at a very low power density to further seal vessels. This is followed by placing Monsel's solution (Ferrous Sub-Sulfate) on the treated surface to decrease the risk of bleeding.

Following vaginal and vulvar procedures, the management and follow up is more complicated due to the variety of symptoms and complications encountered. The most common problem is pain following vulvar procedures. The most significant complication is that of opposing denuded surfaces of the vagina and labia scarring together. Some gynecologists have routinely coated the treated surfaces with silver sulfadiazine 1% (Silvadene) as is commonly used in severe burn patients to deter infection and stimulate tissue regeneration. The incidence of infection is extremely low after these procedures without using any type of antimicrobial compound. Because of the expense of Silvadene and assuming the depth of destruction is appropriate, the author prefers to use triamcinolone cream applied immediately after the surgery is completed. The steroid cream blocks a substantial amount of the edema and pain associated with the immediate post-operative period and physically separates the denuded tissues, preventing adhesion formation. Application of either of these medications may continue for 1–3 days if they are deemed helpful.

Because of the high incidence of significant pain following CO_2 laser vulvar procedures, these patients should routinely be discharged with substantial amounts of oral pain medication. The expectation is that the most significant discomfort will occur at 7–14 days post-operatively. It is not recommended that lidocaine ointment be used secondary to the relatively short time of pain relief it offers and because there may be significant systemic absorption and toxicity. Sitz baths are encouraged two to three times daily, using a physiologic electrolyte solution, which can be easily made by adding a salt water aquarium preparation mixture, which is available at most pet stores, to bath water. The patient is told to keep the area as dry as possible by using a hair dryer with low heat, and by avoiding underwear to keep the area exposed to air. It is also of note that Preparation H, which is marketed for the symptomatic relief of hemorrhoids, has been found anecdotally to offer significant pain relief in these cases.

These patients should have frequent post-operative exams to insure that significant scarring or adhesions are not forming and to evaluate pain control. In patients being treated for condylomata accuminata, evaluation for new lesions should also be done at each visit. These may be found very early following surgery and should be treated locally as soon as they become apparent.

Adverse Events

- Severe scarring and contracture of the vagina is a known complication.
- Attempts to treat the entire lower genital tract in an attempt to rid the area of HPV is futile and frequently results in major complications.
- The most important preventative factor is the avoidance of excessive depth of destruction.

Side Effects/Complications

Pain, bleeding, and persistence of HPV are the most common problems encountered following laser therapy of the lower genital tract, as was previously discussed. These issues are present to a greater or lesser degree in the majority of cases. The more serious complication of vaginal and vulvar scarring and contracture are much less common today than in the past, but require constant diligence and attention to detail during surgery to be avoided. During the 1980s there was a period in which it was believed that laser treatment of the skin and mucosa of the entire lower genital tract could eradicate human papilloma virus entirely. As a result of such attempts, and almost certainly coupled with an excessive depth of destruction, there were a number of cases in which the patient's vagina scarred/contracted down to a fraction of the original size. These patients generally had very severe post-operative pain and had not been examined until several weeks after their surgery. This complication can take on several different presentations. If the upper vagina scars to the contralateral side it can completely occlude the cervix from the vagina thus obstructing menstrual flow. If similar scarring occurs at the introitus, the vaginal opening may be closed to the point of precluding intercourse. In the worst case scenario, the entire length of the vagina may react similar to the skin following third degree burns with extensive fibrosis and contracture. In all of these situations, the treatment as discussed below is lengthy, usually requiring one or more plastic surgeries, and frequently does not result in a good outcome.

Prevention and Treatment of Side Effects/Complications

The most important aspect of prevention of side effects revolves around having an experienced surgeon who is meticulous about maintaining the depth of tissue damage at the level of the basement membrane. As previously alluded to, the use of inherently hemostatic wavelengths, which also tend to seal off exposed nerves such as the KTP-532, is advantageous but not widely available. The treatment of the minor side effects was previously discussed under post-operative management and must be individualized.

The prevention of the vast majority of severe complications noted above can be accomplished through education and mentoring of physicians regarding surgical technique. The concept that multiple procedures and longer term treatments are preferable to these types of complications is paramount. Despite the best efforts, these severe complications will continue to be encountered occasionally secondary to hypertrophic scarring, infection, and idiopathic responses. Treatment may be dramatically affected if the problems associated with excessive depth of tissue destruction and abnormal scarring are identified early in the post-operative course. Estrogen cream and steroids may be employed to increase epithelialization and decrease scarring. There is frequently an indication for manual dilation and the placement of vaginal obturators to counteract contracture formation. Obviously infectious processes, although rare, may be dealt with much better if identified early.

Once the scarring has matured, the effect of vaginal dilators is slow and usually very uncomfortable. Obturators are usually progressively enlarged over prolonged intervals, if possible. They are generally kept in place constantly except for cleansing. If the scarring occludes menstrual flow, or if no progress can be made using dilators, relaxing incisions and at times grafting must be considered. The overall treatment course can be protracted, and in some cases the patient must have extensive counseling to deal with a lifelong problem of dysparunia and orgasmic dysfunction.

Intrauterine and Intra-abdominal Laser Procedure

- Menorrhagia, leiomyomata, endometriosis, and pain from pelvic adhesions are leading causes of hysterectomy worldwide.
- Nd:YAG laser has been used for endometrial ablation, resection of uterine septae, and

removal/destruction of intrauterine submucosal leiomyomata for over a quarter century.
- Destruction of larger leiomyomata (3–6 cm) can be accomplished laparoscopically using laser techniques.

Endometrial Ablation

Twenty percent of women worldwide are affected by menorrhagia, a condition defined as excessive uterine bleeding [46]. More than one-third of the 700,000 hysterectomies performed yearly in the US are for symptomatic menorrhagia [64]. As previously stated, Goldrath first reported using the Nd:YAG laser for the destruction of the endometrium in 1981 [13]. Alternative treatment modalities for the permanent control of excessive uterine bleeding include several newer devices that destroy the endometrium through cautery much more rapidly than can be accomplished using a solitary laser beam. Two of these instruments freeze the tissue (CryoGen's First Option, Gynecare's Soprano). The following is a sampling of the devices that heat the tissue to achieve destruction:

- Roller ball ablation using electrocautery
- Hot water thermal balloon: Thermachoice (Gynecare, Menlo Park, CA)
- Radiofrequency thermal balloon: Vesta (Valleylab, Boulder, CO)
- Hydrothermal ablation: Genasys (Boston Scientific, Marlborough, MA)
- Bipolar three-dimensional device: Novasure (Hologic, Inc, Marlborough, MA)
- Microwave 9.2 GHz applicator: Microsulis (Hologic, Inc, Marlborough, MA)
- Bipolar Radio Frequency (RF) + Thermal Conductive Energy (Plasma) + Thermal Fluid Energy: Minerva (Minerva Surgical, Redwood City, CA)

The gold standard is generally considered to be hysteroscopically directed endometrial resection. In concordance with the Cochrane Database Review from 2013, this gold standard is being challenged by the rapid development of these new endometrial destruction devices [2]. Most of these techniques are performed blindly and are much simpler to master than hysteroscopic procedures. The expense of the equipment and competition for market share are probably confounding factors.

Despite the widespread use of the previously mentioned instruments for endometrial ablation, the Nd:YAG is still the laser of choice to resect uterine septae and in many cases, larger pedunculated and submucous leiomyomata.

- The wavelength of the Nd:YAG laser is 1,064 nm in the near infrared spectrum. Because of this, a helium-neon aiming beam, has to be incorporated. As with the argon and KTP lasers, the flexible fibers used for delivery are suitable for laparoscopic and hysteroscopic equipment. The Nd:YAG laser wavelength is less absorbed by hemoglobin rich tissue and it has a greater depth of penetration, 3–7 mm with "bare-fiber" non-contact use. Both air-cooled and water-cooled units are available. The development of sapphire and quartz tips has expanded the spectrum of application and increased the safety. Even with these advances, care must be taken not to allow the energy to scatter through the uterine wall and damage extrauterine structures.

Laser in the Treatment of Vaginal Atrophy and Relaxation

Vaginal atrophy is a common condition of postmenopausal women. Symptoms include vaginal dryness, itching, discomfort, dysuria and dyspareunia. This disorder is closely related to the dramatic decrease in ovarian estrogens due to natural or iatrogenic menopause, leading to significant changes in the structure of the vaginal mucosa, with consequent impairment of many physiological functions. Local or systemic estrogen (with or without concomitant progesterone) is a mainstay treatment option for vaginal atrophy but may cause adverse effects such as abnormal uterine bleeding or endometrial hyperplasia. Additionally, hormone therapy may be related to an increased risk of breast cancer or cardiovascular disease such as stroke or heart attack [65].

The effectiveness of vaginal or systemic estrogen therapy to alleviate vaginal dryness and improve dyspareunia has been well established [66]. More recently, microablative fractional CO_2 laser therapy has been utilized in the treatment of menopausal vaginal atrophy. Fractional CO_2 laser has been proven to determine tissue remodeling with neoformation of collagen and elastic fibers on atrophic skin [67].

Salvatore, et al., evaluated sexual function after fractional microablative CO_2 laser in women with vulvovaginal atrophy and found that laser treatment is associated with a significant improvement of sexual function and satisfaction with sexual life in postmenopausal women with symptoms of vulvovaginal atrophy [68].

In a recent study by Lee, the Erbium:YAG Laser has been successfully utilized in treating vaginal relaxation syndrome [69]. Vaginal relaxation syndrome is defined as laxity of the vaginal walls. It can result in the loss of friction and sexual satisfaction for both a woman and her partner. The most common cause of vaginal relaxation is extreme distention of the vaginal wall during childbirth. Other causes include congenital connective tissue weakness and aging. Until now, effective results for vaginal relaxation syndrome could only be achieved through aggressive surgical intervention such as anterior and posterior vaginal colporrhaphy. Outcome data from Lee's study using the Er:YAG laser showed a significant improvement in vaginal wall relaxation, including vaginal wall tightening and firming, as well as for sexual satisfaction by the patient and her partner. In addition there was significant improvement of mild-moderate stress urinary incontinence in postmenopausal women [69].

Laser Treatment of Leiomyomata

Thermal coagulation of uterine leiomyoma was first introduced in the late 1980s in Europe [70, 71]. Initially, this procedure was used as an alternative to major surgery for women interested in further childbearing. The principle of action involves taking advantage of the relatively deep penetration of the Nd:YAG and later diode laser wavelengths (up to 7 mm) whose bare fibers are inserted or drilled into the center of the leiomyoma, causing protein denaturation of the actual myoma, as well as destroying the blood supply [71–74]. Pre-treatment with GnRH may decrease the size of the leiomyomata before surgery [75, 76]. Besides bare laser fibers, bipolar needles have also been used. It takes about 50–75 punctures to coagulate a 5-cm leiomyoma [77]. Goldfarb used 50–70 W continuous power with the moving laser tip. Chapman, 1997, warned about the use of high power settings with interstitial laser because the vapor that develops during the heating has no avenue of escape and may cause burns and explosions as well as breakage of fibers. The alternative technique uses 4–8 W for photocoagulation of the leiomyoma [78].

In 2000, MRI guided percutaneous laser treatment of uterine leiomyoma was introduced [79, 80]. Shrinkage rates of 30–50% have been reported for laparoscopic and percutaneous approaches [79–81].

There are no randomized controlled trials in the published literature, which is comprised only of observational series. It can be concluded from the publications however, that these modalities are safe and well tolerated alternatives for women who desire preservation of their fertility and have fibroids less than 6 cm in diameter in challenging locations.

Nevertheless, technical problems, high costs, and unfulfilled or unrealistic expectations by physicians and patients alike hinder widespread use of this technique [82].

Laparoscopic Laser Surgery for Endometriosis and Adhesiolysis

CO_2 laser treatment has been used for the treatment of endometriosis laparoscopically since the mid-1980s [83, 84]. Especially in Europe it has been widely used. High power densities are preferred for vaporization of lesions to avoid any charring. Charring causes high temperatures in vital surrounding tissues and should be avoided under all circumstances. CO_2 laser is believed to be superior to electrocautery because of its shallow penetration [71, 83, 85]. In the case of ovarian endometriomas, excision of the capsule rather than vaporization appears to be more beneficial for long-term cure [86].

The majority of publications are case series and few comparative studies have been published. Available evidence suggests that laser treatment of endometriosis may have long-term benefits in slightly more than half of the treated women [87]. The shorter wavelength lasers (KTP, argon, and in some cases Nd:YAG) have distinct advantages over CO_2 laser in that they are delivered through 600 micron flexible quartz fibers, eliminating the cumbersome delivery arms and optic couplers necessary with CO_2 lasers. When using the visible wavelength of the KTP-532 and argon instruments, the aiming beam is the attenuated surgical beam. Because of this, they may be more accurately delivered and are more clearly visible in the abdomen than the HeNe laser that must be simultaneously superimposed on the CO_2 laser beam. These lasers do require some restraint when used directly over vital tissues because of their deeper penetration. This may be 0.3–1 mm depending on the specific tissue parameters such as pigmentation and hemoglobin content. The 4 mm depth of penetration is a much larger concern with the Nd:YAG laser, and because of this issue, it is used only for very specific laparoscopic indications. All fiber optic delivery systems do, however, have the advantage of rapid divergence of the beam from the fiber tips, which allows the power density to drop off very rapidly over a short distance, when compared to the CO_2 laser beam. The much longer CO_2 wavelength must be focused via lenses outside the body, and is therefore essentially in focus over a large depth of field, requiring the use of backstops to avoid injury of tissues distant from the surgical target [8]. KTP, to a slightly lesser extent, and argon lasers also have the advantage of extremely high absorption in hemoglobin and hemosiderin, which are typically very prevalent in lesions associated with endometriosis. They may also be used through a clear fluid medium allowing use under water and while irrigating to obtain hemostasis.

The *Cochrane Database Systematic Reviews* published a meta-analysis of randomized comparative studies involving different treatment modalities for endometriosis including laser. The limited evidence suggested that the combined surgical approach of laser ablation, adhesiolysis, and uterine nerve ablation is likely to be beneficial in alleviating pain [88].

Photodynamic Therapy

In 1984, Rettenmaier first published data on the treatment of gynecologic tumors of the vagina and vulva using photoradiation with hematoporphyrin dyes [14]. Photodynamic therapy (PDT) is a treatment modality employed to destroy a specific type of tissue. It uses a photosensitizing drug such as aminolevulinic acid (ALA) which when given, is absorbed in large quantities in the targeted cell line. These drugs exhibit very high absorption of specific wavelengths of light and once the cell is exposed to these wavelengths, it may be destroyed. The German physician Friedrich Meyer-Betz was the first to perform photodynamic therapy using porphyrins in humans in 1913. The most frequently used photosensitizer is aminolevulinic acid (ALA) which may be given systemically, but is most often applied topically as a 10–20% concentration several hours before the procedure. A light of a defined wavelength, most commonly using a laser, is directed onto these superficial lesions for treatment. The power density of the beam is below that necessary to produce tissue injury under normal conditions. ALA is absorbed into the cells and converted to protoporphyrine IX [89–92]. The affinity of porphyrins by neoplastic tissue enables treatment to be concentrated at the tumor site [93]. When exposed, the protoporphyrine absorbs the light resulting in the formation of triplet protoporphyrine IX and free oxygen radicals, which lead to cell destruction within the illuminated tissue areas [94–96]. Photodynamic therapy is well established for the treatment of Barrett's esophagus [91–97] and certain skin conditions such as psoriasis [91, 98]. PDT using topically applied ALA (trademark Levulan, Berlex/DUSA Pharmaceuticals, Inc., MA) was registered by the FDA for the treatment of actinic keratoses of the skin in 2000. There are also several case studies and series that report complete or partial response in patients treated for external anal dysplasia low and high grade [99–101]. Similar results have been reported for the treatment of dysplastic and cancerous vulvar [102–105], vaginal [106, 107] and uterine cervical [108] disease. In the treatment of vulvar intraepithelial neoplasia (VIN) the lesions are typically irradiated with 75–150 J/cm^2 of laser light at a wavelength of 635 nm (argon or KTP/YAG ion pumped dye laser) about 2–3 h after sensitizing drug application [12, 102, 109]. The treatment time varies between 10 and 40 min [106, 109]. In Europe, PDT is usually performed on the awake patient, after pretreatment with a systemic non-steroidal or narcotic pain medication or sedative. Despite this being a "cold" laser application, most patients complain about severe burning sensations at the site during the first several minutes of the treatment cycle. Following the procedure only mild burning is reported, and depending on skin complexion, a pronounced erythema is noted [109]. Photodynamic treatment has also been used for non-dysplastic vulvar conditions such as lichen sclerosis [109]. The decreased recurrence rate for VIN and condylomata following PDT is attributed to a specific immune mechanism which is stimulated by this unique procedure. It may, in part, also be secondary to the improved visibility and subsequent destruction of subclinical lesions [107]. Skinfolds, hyperkeratosis and marked pigmentation can block the illumination and lead to failure [107]. It should be noted that research is ongoing to perfect this methodology for the treatment of the intraperitoneal spread of ovarian and other malignancies by delivery of the light laparoscopically.

In summary, photodynamic therapy is a minimally invasive procedure that provides unique properties especially suited for the local treatment of superficial epithelial lesions in different organ systems, including the genital tract. There is evidence that it is well tolerated and at least as effective as other conventional modes of treatment.

Conclusion

The literature of the past decades was reviewed for outcome data and put into perspective by integrating the personal clinical experience of the authors. The result is this conclusion on the current state of the art use of lasers in gynecologic surgery.

Unchanged from the laser's introduction as a tool in gynecologic surgery, differences in penetration, absorption, and suitable delivery media for the different laser wavelengths dictate their clinical application. The use of CO_2 laser in the treatment of cervical intraepithelial lesions is well established, and indications and techniques have not changed considerably over the past 40 years. The KTP laser may also be used for this procedure and may offer some advantages in hemostasis and application, but is not widely available. Randomized controlled trials comparing the CO_2 laser to other treatment modalities are scarce. The Cochrane Systematic Review from 2013 suggests that there is no obvious superior technique. The recent literature and personal observation suggest that laser treatment appears to be less complicated by infection and bleeding and is the preferred method for young females who desire future fertility. Persistence and recurrence rates are in the 10% range and independent of clear surgical margins.

CO_2 laser ablation for vaginal intraepithelial neoplasia is also an established, as well as safe, treatment modality. Repeated treatment may be necessary, since persistent disease is not infrequent, particularly when treating multifocal disease. In case of VAIN III at the vaginal cuff after hysterectomy, upper vaginectomy appears to be the treatment of choice and is often combined with CO_2 laser ablation of surrounding vaginal tissue. CO_2 laser surgery permits treatment of vulvar condyloma and vulvar intraepithelial neoplasia with excellent cosmetic and functional results. Again, persistent and recurrent disease in the 20% range is a known problem and close follow-up and retreatment are frequently indicated. VIN III may be better treated with laser excision than pure laser vaporization. Other benign lesions of the vulva can also be treated with laser, but published data are scarce. The KTP laser offers the significant advantage of decreased pain, especially when applied to vulvar procedures.

The treatment of abnormally heavy menstrual bleeding by destruction of the endometrial lining using various techniques has been the subject of a 2013 Cochrane Systematic Database Review. Among the compared treatment modalities are also newer and modified laser techniques. The conclusion of the reviewers is that outcomes and complication profiles of newer techniques compare favorably with the gold standard of endometrial resection via the hysteroscope. The majority of new destruction techniques are performed in a blind fashion.

CO_2 laser is also the dominant laser type used with laparoscopy for ablation of endometriotic implants, although the KTP laser offers several advantages because of its preferential absorption in hemoglobin and hemosiderin, and ease of application. Recurrence rates are known to be as high as 50%. With endometriomas, excision of the capsule appears to be more beneficial than simple coagulation or vaporization. Myoma coagulation or myolysis with Nd:YAG laser through the laparoscope or hysteroscope is a relatively recent addition to the armamentarium of the gynecologic surgeon. Even MRI guided percutaneous approaches have been described. In addition, MRI guided high intensity focused ultrasound (HIFU) is an alternative to laser therapy for fibroid myolysis.

Laser is a well-accepted treatment modality among patients and physicians. Disadvantages are the high cost involved and the sophistication of equipment and maintenance. Decreasing expenses, increasing safety and ease of application will further support the use of laser in gynecology.

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7 Laser/Light Applications in General Surgery

Raymond J. Lanzafame

Abstract

Lasers and light source technologies can be applied to a wide variety of open and laparoscopic surgeries, as well as other procedures encountered by general surgeons and other medical professionals. The ability to produce highly precise and controllable effects on tissues, and the potential to facilitate complex dissection make these devices a welcome addition to the armamentarium of the surgeon, who is skilled in their use. Each laser wavelength has a characteristic effect on tissue. The combination of the laser tissue interaction, the selection of the appropriate delivery systems and laser parameters determines the ultimate effects of laser use on the conduct and outcomes of surgery. This chapter reviews the array of laser technologies available for operative surgical and therapeutic use and discusses the relative merits and disadvantages of each.

Keywords

Surgery · General surgery · Laparoscopy Minimally invasive surgery · LLLT (Low level laser therapy) · Argon laser · CO_2 laser Diode laser · KTP laser · Holmium laser Thulium laser · Surgical instrumentation Surgical technique · Wound · Antimicrobial therapy · Photobiomodulation · Laser physics Safety · Complications and complication prevention · Lithotripsy · Tissue effects Optical fibers · Optical waveguides

Outline

- Lasers and light source technologies can be applied to a wide variety of open and laparoscopic procedures in general surgery and other disciplines.
- The ability to produce highly precise and controllable effects on tissues, and the potential to facilitate complex dissection make these devices a welcome addition to the armamentarium of the surgeon.
- Each laser wavelength has a characteristic effect on tissue and it is the combination of the laser tissue interaction and the selection of the appropriate delivery systems and laser parameters that determine the ultimate effects of laser use during surgery.
- This chapter will review the array of laser technologies available for surgical use and will discuss the relative merits and disadvantages of each.

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K. Nouri (ed.), *Lasers in Dermatology and Medicine*, https://doi.org/10.1007/978-3-319-76220-3_7

Introduction

Summary Box: Introduction

- A wide variety of lasers and light-based sources are available for use in both open and minimally invasive surgical procedures.
- Proper selection of wavelength, delivery devices, and the use of appropriate surgical technique provides several advantages in the care of the surgical patient.
- Proper use can reduce blood loss, decrease postoperative discomfort, reduce the chance of wound infection, decrease the spread of some cancers, minimize the extent of surgery in selected circumstances, and result in better wound healing, when these technologies are used appropriately by a skilled and properly trained surgeon.
- The general surgeon encounters a wide and varied array of clinical conditions and operative scenarios in daily practice.
- Many different surgical skills and modalities are required to achieve acceptable outcomes for the patient.
- There are oftentimes several treatment options and surgical procedures that are equally efficacious for a particular disease process.
- Any surgical procedure can be performed using lasers.
- General surgeons can use a wide variety of laser wavelengths and laser delivery systems to cut, coagulate, vaporize or remove tissue. However, few general surgeons use these devices currently.
- The majority of "laser surgeries" actually use the laser device in place of other instruments to accomplish a standard procedure.
- Lasers are interchangeable to some degree, assuming that the proper delivery device and laser parameters are selected.

Lasers have occupied the fancy of the lay public, scientists and clinicians alike. These technologies have been applied to a wide variety of open and laparoscopic procedures in a variety of disciplines including general surgery [1–85]. The ability to produce highly precise and controllable effects on tissues, improved hemostasis, easy adaptability to fiberoptic and minimally invasive delivery systems, and the potential to facilitate complex dissection make these devices a welcome addition to the armamentarium of the surgeon, who is skilled in their use.

The general surgeon encounters a wide and varied array of clinical conditions and operative scenarios in daily practice. Many different surgical skills and modalities are required to achieve acceptable outcomes for the patient. There are often several treatment options and surgical procedures that are equally efficacious to manage a particular disease process. One need only consider the options available to treat breast cancer as an example. Surgeons often differ as to what particular instruments are the most useful during the conduct of specific technical aspects of surgical procedures. While the motto of the Stanley Tool Corporation, (Bridgeport, CT) "The right tool for the right job" is apropos; surgeons will differ in their definition of "the right tool". Such decisions are often based on preference, experience and comfortability with the technology rather than necessity. Any surgical procedure can be performed using lasers. However, there are no general surgical procedures for which the laser is *sine qua non*.

General surgeons can potentially use a wide variety of laser wavelengths and laser delivery systems to cut, coagulate, vaporize or remove tissue. The majority of "laser surgeries" actually use the laser device in place of other tools such as scalpels, electrosurgical units, cryosurgery probes or ultrasonic devices to accomplish the technical steps of a standard procedure like mastectomy or cholecystectomy [2–57]. Lasers can reduce blood loss, decrease postoperative discomfort, reduce the chance of wound infection, decrease the spread of some cancers, minimize the extent of surgery in selected circumstances, and result in better wound healing, if they are used appropriately by a skilled and properly trained surgeon. They are useful in both open and laparoscopic procedures. Lasers are used in both contact and non-contact modes depending on the wavelength and the particular clinical application. These devices are interchangeable to some degree, assuming that the proper delivery device and laser parameters are selected. However, the visible light and Nd:YAG lasers should not be used for skin incisions, since they are less efficient than the carbon dioxide laser and result in excessive thermocoagulation of the wound edges.

Laparoscopic cholecystectomy can be credited with fueling a revolution in surgical thinking and application. Surgeons initially had an intense interest in lasers and laser technology for use during laparoscopic cholecystectomy [3, 4, 9, 16–19, 21–28]. Nearly 80% of all cholecystectomies performed in the United States during 1992 were performed laparoscopically, with only 4% being performed with laser technology. Lap chole accounts for approximately 96% of cholecystectomies performed in the United States today [86] with less than 1% being performed using laser technology.

The initial enthusiasm and interest in the use of lasers in minimally invasive surgery from the general surgeon's perspective can be traced to the work of Reddick, Schultz, Saye and McKernan [20, 22–26]. The majority of general surgeons rapidly abandoned using "the laser" as they grappled with mastering new techniques and procedures with unfamiliar instruments and skills which they had never seen or used previously.

This chapter will review the array of laser technologies available for surgical use and will discuss the relative merits and disadvantages of each.

Lasers Versus Other Technologies

Summary Box: Lasers Versus Other Technologies

- Advantages of other technologies
  - Electrosurgical devices are much more familiar and ubiquitous in the operating room.
  - Capital equipment expenditures are more modest for many of these devices and <u>some</u> of the disposables used with them.
  - These devices are "faster" since the surgeon is much more conversant with the technology and its appropriate application.
  - The main advantages of electrosurgical devices are their ubiquity in the operating room and the fact that no additional training or safety considerations need be implemented.
  - These factors, when coupled with the average surgeon's comfortability with using them, make them the technology of choice for many surgeons.
- Disadvantages of electrosurgical devices
  - The main disadvantages of electrosurgical devices rest on the relative imprecision of the delivery of energy to the desired target.
  - The build-up of char and debris on the electrode surface can result in the delivery of energy to areas adjacent to the desired target rather than to the target itself.
  - Electrosurgical devices work poorly in the presence of blood, edema and irrigating solutions.
  - The majority of insulated laparoscopic hand instruments have relatively large exposed electrode surfaces. A large electrode may result in damage to adjacent structures.

  - Capacitance coupling can occur with monopolar devices.
  - The tips of bipolar or harmonic scalpel devices can become hot during use and can damage tissues contacted after use.
- Advantages of laser technology
  - Proponents of laser technology list the high degree of precision possible with these devices and the ability to control the tissue effect at the desired target as being their main advantages.
- Disadvantages of laser technology
  - The acquisition expense of laser machinery and accessories in addition to an increased operative time are cited as the main disadvantages of lasers.
  - Additional training and attention to safety are necessary.

Electrosurgical devices are much more familiar and ubiquitous in the operating room, "less expensive" from perspective of capital equipment expenditures and for some disposables, and are "faster" since the surgeon is much more conversant with the technology and its appropriate application. Other alternatives including bipolar cautery and the harmonic scalpel are popular alternatives to both monopolar cautery and lasers. The skills required to use these technologies are also more easily acquired since they are part of the daily routine of the surgeon. No additional training or safety considerations are necessary when these devices are in use. These factors, when coupled with the average surgeon's comfortability with using them, make this the technology of choice for many surgeons [2–13, 16–21, 28].

Both monopolar and bipolar instruments are available for open and laparoscopic use. The majority of laparoscopic instrumentation is insulated to permit its use with electrosurgical devices. The main disadvantages of electrosurgical devices rest on the relative imprecision of the delivery of energy to the desired target. Build-up of char and debris on the electrode surface can result in the delivery of energy to areas adjacent to the desired target rather than to the target itself. These devices work poorly in the presence of blood, edema and irrigating solutions. The majority of insulated laparoscopic hand instruments have relatively large exposed electrode surfaces. A large electrode may result in damage to adjacent structures, particularly in close spaces. Capacitance coupling is also a potential problem. Bipolar devices and harmonic scalpels avoid the issues of stray current injuries. However, the instrument tips become hot during use and can damage tissues if they come in contact with them after use.

An array of laser technology is available for use during laparoscopy for incisional purposes. Currently, the CO_2, holmium, thulium, KTP, Nd: YAG, and high power diode laser technology are available for use in soft tissue applications. Laser technology is also available for lithotripsy. We will discuss each of these wavelengths and technologies in some detail below. Several points bear mention prior to the consideration of specific technologies.

Proponents of laser technology list the high degree of precision possible with these devices and the ability to control the tissue effect at the desired target as being the main advantages of these devices [3–6, 9, 10, 16–34]. Opponents often cite the acquisition expense of laser machinery and accessories in addition to an increased operative time as the main disadvantages of lasers in general. Although these issues are often raised, few recognize that the "cost" of a technology is not necessarily correlated with the actual price of the technology and that the price has little to do with the charge or the reimbursement. It must be understood that the net or global effect of a technology may be to lower the total cost of an illness when one considers factors such as the length of hospitalization, the degree and length of disability and the ability of the patient to return to normal productivity [87].

Surgical "speed" evolves and improves and the "length of the procedure" declines after the "learning curve" and once the surgeon becomes experienced and facile with the techniques and the technology used to accomplish a procedure. A laser may be used for only a small portion of a procedure and several other factors also impact the operative time.

The surgeon should have a complete working understanding of lasers, their delivery systems and their tissue effects prior to attempting to apply them to laparoscopic or other procedures. The surgeon should attend specific hands-on laser training programs if laser education and the opportunity to use these devices during the course of an approved residency training program were not available or if the surgeon is not familiar with a particular device or delivery system. Clearly, the house officer is in the ideal position to acquire the intellectual and manual skills necessary to use lasers and other technologies properly if this opportunity is provided as a part of the residency training program. Postgraduate continuing medical education programs are useful for those who did not have formal training elsewhere. It is imperative that the surgeon continue to develop these newly acquired skills in an ongoing, graded fashion. This requires the gradual incorporation of laser technology into clinical practice by tackling the simpler procedures and tasks first, followed by more difficult problems later, after the surgeon has developed a sense of comfortability with the technology. One should have a working understanding of the limits and advantages of lasers in one's own hands. The surgeon must be aware that all lasers and delivery systems are not alike and that attention to the selection of the proper wavelength, the proper delivery system and the proper laser parameters are central to achieving the desired clinical endpoint given the appropriate technical expertise.

The above point cannot be neglected by the surgeon. The selection of a laser device, delivery system or any other instrument during the course of a procedure is critical to the conduct and outcome of that procedure. The selection of instrumentation for procedures involves a number of variables. However, the preference of the surgeon is a major determinant in this process. Preference depends on availability, skill, judgment, experience and the sense that a particular tool "feels right" or "works well" for a particular task. One needs only to examine the back table during an operative procedure to realize that several alternatives exist for the surgeon's execution of a particular task.

Laser Characteristics/General Considerations

> **Summary Box: Preoperative Management**
> - Adequate preoperative patient evaluation and education
> - Oral antibiotic prophylaxis as indicated

Several different laser wavelengths and laser delivery systems are available for use during surgery [2–57]. Each laser wavelength has a characteristic effect on tissue and it is the combination of the laser tissue interaction and the selection of the appropriate delivery systems and laser parameters that determine the ultimate effects of laser use during surgery. This presumes that the surgeon has the appropriate skill and technique. Thus, it is possible to precisely select and control the degree of tissue injury during surgery.

The ability to achieve the desired effect on the target tissue is also dependent on the surgeon's understanding about the relationship between Power Density (PD) and the laser tissue interaction. Power Density represents a concentration function and is defined as:

$$\text{PD} = \text{Power} / \pi r^2 = W / \text{cm}^2$$

The power is the selected output power of the laser given in Watts and r represents the radius of the beam's spot. It can be seen that given this relationship, the spot size or beam diameter has a significant influence on the Power Density relative to a given power output of a laser. Power Density is synonymous with Irradiance (I). The length of exposure of a target tissue to the laser energy is the Energy Density or Fluence that is measured in Joules per centimeter squared and which is defined as follows:

$$\text{Fluence} = \left(\text{Power} / \pi r^2\right) * \left(\text{time in seconds}\right)$$
$$= \text{W s} / \text{cm}^2 = \text{J} / \text{cm}^2$$

The surgeon generally endeavors to use the highest power density that can be safely controlled, thereby minimizing the duration of the exposure and unwanted tissue injury by conductive heating of the tissue during contact with the laser beam.

The primary end result of the laser tissue interaction produces the classical histology of injury. The center of the wound is the zone of ablation, where tissue is vaporized or removed given a sufficiently high power density. This is followed by a zone of irreversible injury or necrosis, which is followed by a zone of reversible injury. Minimizing the duration of laser exposure will optimize the tissue effects for most applications by reducing conductive thermal injury to the tissues adjacent to the area of exposure to the laser beam.

Laser Use in Minimally Invasive Surgery

Summary Box: Laser Use in Minimally Invasive Surgery

- These devices can provide substantial convenience and time savings for the surgeon by enhancing precision, control, and hemostasis, while decreasing the need for instrument swapping.
- Virtually all laser wavelengths have found some utility in laparoscopic procedures.
- The KTP, holmium, thulium and Nd: YAG lasers are the most versatile and are the least intrusive on endoscopic visualization.
- The surgeon should have a thorough understanding of the procedure to be performed as well as the laser device, its delivery systems and safety considerations.
- Practice and continued use of these devices will lead to improved outcomes.
- Lasers are being used in urology, gynecology and otolaryngology but are rarely being used by general surgeons.

We will first discuss laser utilization in laparoscopic and endoscopic surgery. The types of laser technology available for laparoendoscopic use are listed in Table 7.1. We will describe these laser wavelengths in more detail and consider the applications and shortfalls for each. Specific laser parameters for open surgery are presented in Tables 7.2, 7.3, and 7.4. The reader may find it useful to refer to this information as a rough guide for laparoendoscopic applications as well.

Laser utilization offers several advantages during operative laparoscopy. These devices can provide substantial convenience and time savings for the surgeon by enhancing precision, control, and hemostasis, while decreasing the need for instrument swapping. Dissection and hemostasis in areas of inflammation and scar can be facilitated and the potential for stray energy damage, which is a known hazard of electrosurgery, can be minimized. Although virtually all laser wavelengths have found some utility in laparoscopic procedures, the KTP, holmium, thulium, and Nd:YAG laser are the most versatile [3–7, 9–12, 14, 16–28, 30–33].

All of the fiber capable lasers can be used under water or saline irrigation and are effective in cases with edema. These properties provide substantial advantages over monopolar electrosurgical devices. However, the surgeon must understand the laser tissue interaction for the particular wavelength and delivery system chosen in order to minimize the potential for iatrogenic injury.

CO_2 Laser

Summary Box: CO_2 Laser

- CO_2 lasers have been used extensively for gynecologic laparoscopic applications but have been rarely utilized for other minimally invasive surgical procedures.
- This wavelength is intensely absorbed by cellular water.
- The CO_2 laser wavelength is carried via hollow tubes, waveguides and mirrors.
- Small diameter flexible waveguides have been developed for clinical use.
- The focusing cube and waveguide systems require a direct line of sight or the use of angled mirrors.

Table 7.1 Lasers applied for laparoscopic use and their properties

Laser	λ	Power max	Absorption chromophore	Tissue necrosis
CO_2	10,600 nm	150 W	Water	200 μ to 0.5 mm
Holmium	2100 nm	180 W	Water	300 μ to 2 mm
Thulium	1900–2100 nm	180 W	Water	300 μ to 2 mm
Argon	488, 514 nm	30 W	Pigment, hemoglobin	300 μ to 4 mm
KTP	532 nm	180 W	Pigment, hemoglobin	400 μ to 4 mm
Nd:YAG	1064 nm	120 W	Pigment, proteins	200 μ to 2 cm
Dye	508–690 nm	20 W	Pigment	300 μ to 1 mm
Diode	905 nm	30 W	Pigment, proteins	500 μ to 1 mm

Table 7.2 Parameters for use of the CO_2 laser without a waveguide

Tissue type/tasks	Power	Spot diameter
Skin incision	15–25–40 W continuous (CW)	0.2 mm
Subcutaneous tissue/fat incision	60 W CW[a]	0.2–0.4 mm
Dissection of breast tissue/creation of flaps	60 W CW[a]	0.2–0.4 mm
Muscle incision/transection	60–80 W CW	0.4 mm
Dissection clavipectoral fascia	40–60 W[b] CW	0.4 mm
Axillary dissection[c]	40–60 W[b] CW	0.4 mm
Laser sterilization[d]	40 W CW	10–20 mm
Tissue vaporization/ablation[e]	15–100 W CW or pulsed	0.2–20 mm

Wavelength: 10,600 nm, Mode: TEMoo, Handpiece: 125 mm lens[f] (0.2 mm spot diameter)

[a]Using settings higher than 60 W CW increase the likelihood of causing a flash fire due to ignition of aerosolized fat in the plume

[b]Use powers no greater that 40 W until you become proficient and are comfortable with the higher powers. However, 60 W is more efficient and hemostatic

[c]This procedure requires the use of an optical backstop such as the Köcher bronchocele sound, which permits precise dissection without damaging adjacent or underlying structures

[d]Laser sterilization is accomplished by defocusing the laser and gently heating the wound surface. The tissue should be heated just to the point of dessication and slight shrinkage of the wound. Blanching and charring of the wound is indicative of excessive irreversible damage to the wound

[e]Vaporization or ablation of tissues is most efficient when a high power density is used with a large spot diameter. This permits the surgeon to cover a large area expeditiously

[f]The 125 mm lens is the most convenient for use for most applications. The 50 mm lens with a spot diameter of 0.09 mm achieves the same power density with 25% of the wattage. For example, the 10 W with a 50 mm lens in-focus produces the same power density as 40 W with a 125 mm lens in-focus. However, the 50 mm lens is more cumbersome and difficult to use for non-cutaneous applications

Table 7.3 Parameters for the KTP laser

Wavelength:[a]	532 mm
Output:	1–180 W[b]
Delivery system:	Fiberoptic, 0.2 mm, 0.3 mm, 0.4 mm, 0.6 mm diameter fibers. Microstat® probes are formed to an appropriate configuration for the desired task
Incision:[c]	10–20 W continuous wave or pulsed
Coagulation:	1–20 W continuous wave or pulsed
Vaporization/ablation:[d]	10–20 W continuous wave or pulsed

[a]This wavelength is also produced by KDP and LBO laser devices which are used in urology

[b]Higher energies can be used in aqueous environments, but open and laparoscopic procedures generally do not require settings above 20 W CW. High power applications are generally reserved for TULIP, VLAP and other urologic procedures. Currently produced KTP laser systems produce 5 W outputs

[c]The KTP laser is used with the cleaved fiber in direct contact with the tissue for most uses. Near-contact use is analogous to defocusing the laser beam. Skin incisions are usually not made with the KTP laser because of the extent of lateral tissue damage (burn). However, some users do prefer to make incisions in the anoderm with the laser. Blackened instruments and optical backstops are helpful

[d]Vaporization is best accomplished by using the fiber in a defocused position. Pulsing the laser or using continuous wave mode for brief intervals reduces the likelihood of flaming and burning of the fiber tip. If fiber burnout does occur, the fiber is easily recleaved and the cladding is stripped, making it again ready for use. Urologic applications utilize very high power outputs to achieve vaporization of prostate in an aqueous environment

Table 7.4 Parameters for use of the Nd:YAG laser

Delivery system	Incision	Coagulation	Vaporization/ablation
Lens[a]	NR[b]	20–120 W	20–120 W
Polished fiber[c]	NR[b]	20–120 W	20–120 W
Sculpted fiber[d]	5–35 W	5–35 W	NR[b]
Cleaved bare fiber[e]	10–55 W	20–120 W	20–120 W

Wavelength: 1064 nm, Output: 1–120 W, Delivery Systems: Fiberoptic, usually with 0.4 mm or 0.6 mm fibers; varies with type of application and terminal delivery system apparatus. Common delivery systems are: Lens or polished fiber, sculpted fiber, or cleaved bare fiber

[a]The lens system was one of the first applications of the Nd:YAG laser. The laser energy cuts poorly due to extensive forward and back scattering in tissue. The main applications of the lens system was for coagulation or for tissue vaporization

[b]Not recommended

[c]Polished fiber applications are mainly for endoscopic coagulation or vaporization techniques. It is poor for making incisions

[d]These fibers are said to transmit 81% of laser energy when held in contact with tissue. They produce effects that are similar to sapphire tips on tissue but the surgeon can increase incisional speed and effect with increasing power input

[e]Cleaved fibers (bare fibers) can be used for cutting, coagulation or vaporization. This mode of delivering of YAG energy is extremely dangerous if optical backstops are not used due to the 10° angle of divergence of energy from an optical fiber and due to the extreme forward and backscatter of YAG energy in biological tissues

CO_2 lasers have been used extensively for various gynecologic laparoscopic applications, and have seen increased use in otolaryngology more recently, but have been rarely utilized for laparoscopic cholecystectomy and other minimally invasive surgical procedures in general surgery [6, 7, 9, 10, 19]. The energy of the CO_2 laser (wavelength = 10,600 nm) is in the far-infrared portion of the electromagnetic spectrum. This wavelength is intensely absorbed by cellular water. This property results in "superficial" injury to tissues and enables the sealing of blood vessels and lymphatics that are up to 0.5–1.0 mm diameter. The potential for inadvertent injury to deeper structures is minimal. The zone of necrosis is approximately 100–300 μ, when the CO_2 laser is used at appropriate fluences in a cutting mode. The result most closely resembles the histology of an incision created by the scalpel. This wavelength is absorbed independently of the color of the tissue. Thus, the clinical effect seen in soft tissues is relative to the water content of the target tissue. The local infiltration of tissue with saline or anesthetic solutions will protect or insulate them from injury by the laser beam until the fluid has been vaporized. This laser is the most efficient modality available for ablation or vaporization of large volumes of tissue such as tumor nodules or endometriomas.

The CO_2 laser wavelength is carried via hollow tubes, waveguides and mirrors. Flexible fiberoptics have been recently developed for clinical use. The Omniguide® fiber is a flexible chalcogenide glass waveguide that has been utilized for otolaryngological and neurosurgical procedures. The potential exists for broader clinical use, including various general surgical procedures.

The laparoscopic use of this wavelength is possible with the use of a focusing cube and an operative laparoscope or with a variety of waveguides designed for multi-puncture laparoscopic applications. The focusing cube permits the use of the CO_2 laser in a free beam mode for cutting, vaporization and coagulation of tissue. The focusing cube also is capable of transmitting an aiming beam. This feature makes it easier for the surgeon to direct the laser energy to the desired target. A variety of procedures such as myomectomy, partial oophorectomy, resection and ablation of endometriomas, adhesiolysis, and even cholecystectomy have been accomplished successfully with this delivery system. Cholecystectomy requires a McKernan-type approach. The successful use of this approach requires knowledge and facility with the operative laparoscope and the surgeon's ability to visualize the desired target and maneuver a micromanipulator or joy stick. The surgeon can alter the tissue effect by focusing or defocusing the laser beam as well as varying the laser wattage selected. This configuration is rarely used today, if at all, given the availability of numerous less-cumbersome alternatives.

Laser waveguides are hollow tubes with mirror-like surfaces which reflect the CO_2 wavelength. Waveguides are available in both rigid and flexible versions and can be used to achieve a spot size (i.e. burn or incision) which is in the range of 0.8–2.2 mm. However, laser waveguides, particularly those capable of carrying high powers are increasingly difficult to obtain today. As a general principle, the waveguide is used in a non contact fashion, particularly since tissue contact can obstruct the waveguide and liquid can be drawn into the waveguide by capillary action. The resultant of these events is the irreversible destruction of the waveguide.

The successful use of this laser for dissection and hemostasis requires that the surgeon be facile and expert with the laser as this will affect the ability to dissect tissues and achieve an adequate degree of hemostasis. Both the focusing cube and rigid waveguide systems require a direct line of sight or the use of angled mirrors. This further complicates the maneuverability of these devices more so than fiber capable lasers and conventional instruments. However, the Omniguide® overcomes some of the problems associated with free beam and rigid waveguides due to its small diameter and flexibility which more emulates a true fiber.

The typical carbon dioxide laser configurations require flowing gas to cool the system and to prevent vaporized tissue plume from being thrown into the delivery device. The most frequently used purge gases are argon and carbon dioxide. High CO_2 gas flow rates can actually absorb the laser energy and reduce its efficiency (i.e. the transmission of energy from the laser to the tissue). Therefore, lower flow rates (i.e. 1 L/min.) are suggested. Some laser systems are equipped with a nitrogen purge gas system. The surgeon should NOT use nitrogen during laparoscopy as its absorption from the peritoneum can cause "the bends".

The optimal use of the CO_2 laser for laparoscopic or open use is achieved when the beam is oriented perpendicular to the desired target. Hemostasis is enhanced by tissue compression, the use of epinephrine containing local anesthetic solutions and the ability of the operator to recognize the presence of a vessel <u>prior</u> to its division. Under these conditions, the surgeon defocuses the laser (i.e. moves the handpiece, waveguide or operating laparoscope farther away from the target) and then applies short bursts of energy to the vessel in the area to be divided. This maneuver heats and coagulates the vessel, thereby enabling its division by the focused beam. The surgeon should use the highest power setting with which he/she is comfortable as this will enable more efficient cutting, better hemostasis and less thermal injury to the wound edges by minimizing conductive and radiative heat loss into the wound. Intermittent evacuation of the vaporized tissue plume or the use of a re-circulating filtration system assure a clear field of view and prevents absorption of toxic products of combustion by the patient. This problem is identical in magnitude and toxicity to vaporized tissue plume created by <u>any</u> electrosurgical, thermal or laser source. Similarly the "smoke" should not be vented into the operating room as it should be considered hazardous for OR personnel. OSHA/NIOSH has written regulations which require that OR staff be protected from vaporized tissue plume regardless of its source [1, 52, 56, 57].

Argon Laser

Summary Box: Argon Laser

- The argon laser was once used extensively for gynecologic laparoscopic procedures. However, it is rarely available or used today.
- One of the main drawbacks of the argon laser was the camera/eye safety filter which must block the six wavelengths produced by the laser. These filters were a deep orange color and absorb 30–60% of the visible spectrum, resulting in color distortion of the image.
- Visible light wavelengths can be passed through water, enabling the argon laser to be used in aqueous environments such as the bladder and in the presence of irrigating fluids.
- White or lightly colored tissue could not be cut efficiently and could not be vaporized (ablated) unless they were first painted with India ink, indigo carmine dye or another exogenous chromophore.

The argon laser was once used extensively for gynecologic laparoscopic procedures [10, 11, 16–21, 26]. The argon laser is seldom used or available today. This laser produces light in the visible portion of the spectrum. This laser actually produces six lines (wavelengths). However, the majority of the laser output is in the blue-green spectrum (wavelengths = 488, 514 nm). This energy is intensely absorbed by hemoglobin and melanin although other exogenous chromophores will absorb these wavelengths efficiently. Visible light wavelengths can be passed through water, enabling the argon laser to be used in aqueous environments such as the bladder, during hysteroscopy, arthroscopy and in the presence of irrigating fluids as is routinely encountered during abdominal and pelvic procedures. This property enabled the surgeon to photocoagulate a bleeding area while irrigating to locate the source of the bleeding. Both free-beam and conventional fiberoptic applications were utilized during operative laparoscopy.

Argon laser light penetrates and scatters in tissues. The resultant damage can be as much as 6 mm depending upon the tissue exposed. When used in an incisional mode, the speed of incision and the degree of hemostasis were adequate. Blood vessels on the order of 2 mm diameter could be divided and coagulated with this wavelength. Although some authors reported successful hemostasis with vessels as large as 3–4 mm diameter, delayed re-bleeding could occur. The etiology of the delayed bleeding was necrosis of photocoagulated tissue and resultant tissue slough. This condition also occurs after use of the Nd: YAG laser in a free beam mode on similar tissues.

The contact or fiber optic method was more easily mastered than the free beam approach since the surgeon has direct tactile feedback from the tissue. The speed of incision and the degree of hemostasis are adequate and the more selective absorption of the wavelength in hemoglobin enabled the surgeon to photocoagulate vessels prior to their division by bringing the fiber away from the tissue surface. This maneuver is similar to defocusing the free beam. The defocused mode was used to vaporize endometriomas.

Since these wavelengths are color dependent, white or lightly colored tissue such as meniscus and tumor implants could not be cut efficiently or be vaporized (ablated) unless they were first painted with India ink, indigo carmine dye or another exogenous chromophore. A droplet of blood placed on the surface was sometimes also used for this purpose. Blackened or ebonized instruments and the use of optical backstops are required to prevent beam reflection and iatrogenic injury.

One of the main drawbacks of the laparoscopic use of the argon laser was the camera/eye safety filter. The eye and camera filters must block the six wavelengths produced by the laser. These filters were usually a deep orange color and absorbed 30–60% of the visible spectrum. As a result, the color balance of the image was distorted. Many laser systems used intermittent shutter mechanisms to place the filter in the visual field only while the laser was actually being fired.

Nd: YAG Laser

Summary Box: Nd: YAG Laser

- This wavelength is carried via conventional fiberoptics and, like visible light lasers; the energy will be transmitted through water.
- The energy can be applied to tissues with a wide array of delivery systems but is most commonly used with cleaved bare fibers.
- The energy of the Nd: YAG laser is intensely absorbed by tissue protein and chromophores and is highly scattered in tissue. These properties result in deep penetration of the energy and much greater damage below the tissue than can be appreciated at the surface.
- Use of the bare fiber for dissection has been practiced safely by surgeons having a detailed understanding of anatomy and by orienting the fiber in a plane which is tangential to the line of incision to limit the forward scattering of the energy into the tissues.
- The YAG wavelength is a poor ablating wavelength, particularly when compared to the CO_2, KTP or holmium wavelengths whose rates of ablation are significantly faster.

The neodymium YAG laser produces near infrared light at a wavelength of 1064 nm. This wavelength is carried via conventional fiberoptics and, like visible light lasers; the energy will be transmitted through water. The energy can be applied to tissues with a wide array of delivery systems [3, 5, 6, 10–12, 16–21, 26–28]. The energy of the Nd: YAG laser is intensely absorbed by tissue protein and chromophores and is highly scattered in tissue. These properties result in deep penetration of the energy and much greater damage below the tissue than can be appreciated at the surface. This makes non-contact applications of the Nd: YAG laser extremely dangerous unless the surgeon has a thorough understanding of the laser-tissue interaction and orients the beam in a direction which would reduce the likelihood of damaging nearby structures. The Nd: YAG laser is a poor cutting instrument when it is used in a non contact mode. The development of sapphire tips and sculpted fiber technologies facilitated use of this laser in contact with tissue. Free-beam type applications can result in damage to as much as 1–2 cm of liver tissue and the photocoagulation of vessels up to 4 mm in diameter.

Sapphire tip technology created a combined thermal and optical interaction with tissue. Much of the Nd: YAG energy is absorbed by the sapphire or fiber tip and converted to heat. The result is to produce optically driven cautery [16–20]. The temperature of the tip can be tightly regulated for some applications. These instruments improved the cutting ability of the laser, but the tissue damage and the extent of coagulation are reduced dramatically. The histology of these devices is quite similar to the results produced by electrosurgical devices. Since their main tissue interaction is thermal cautery, the rate of incision and the degree of hemostasis was significantly reduced when these devices were used in the presence of irrigating fluids or in the aqueous environment of the bladder or joint space. Sapphire tip technology is seldom used today due to issues with their use and since other, less expensive alternatives are available.

Sculpted fibers were developed with many of the same properties as the sapphire tip, but without the liability of the tip remaining hot for an appreciable period of time after lasing has ceased and with less fragility of the tip. Some types of sculpted fibers transmitted a sufficient quantity of laser energy to permit the coagulation of bleeders by using the fiber in a non contact mode. Sculpted fibers were a good compromise for many laparoscopic applications. Surgery with sapphire tips and sculpted fibers is facilitated by using them at an oblique angle relative to the plane of dissection. This technique enhances hemostasis by taking advantage of the heated mass of sapphire (or fiber tip), which coagulates the tissues prior to their division by the much hotter tip portion.

Use of the bare fiber for dissection has been practiced safely by experienced surgeons. However, the surgeon must have an intimate understanding of anatomy and should orient the fiber in a plane which is tangential to the line of incision to limit the forward scattering of the energy into the tissues. The use of ebonized instruments and optical backstops are mandatory.

Hemostasis with the YAG laser is best accomplished by using the laser in a defocused mode and delivering short bursts of energy to the area and its immediate periphery. It is generally better to deliver a few pulses and then wait for a few minutes to observe the area rather than attempting to lase continuously as the latter practice will increase tissue damage unnecessarily and may actually result in the vaporization of the clot and re-bleeding.

The Nd: YAG laser has been used for the vaporization (ablation) of tumors [16, 47, 53, 56, 57]. Typically, the surgeon will orient the beam parallel to the long axis of hollow viscera to avoid iatrogenic injury or perforation. Most of these procedures were performed in stages over multiple treatment sessions. The tumor is treated, allowed to slough, and then is treated as needed in subsequent sessions after debridement or natural sloughing of the photocoagulated tissue. The YAG wavelength is actually a poor ablating wavelength, particularly when compared to the CO_2, KTP or holmium wavelengths, whose rates of ablation are significantly faster. Lightly colored tissues require substantially more energy to initiate tissue ablation. Ablation does not proceed until an area becomes desiccated and/or carbonized. The carbon then absorbs the laser energy and "catalyzes" the ablation of the subjacent tissue. Painting the tissue with India ink, Methylene blue, blood or other chromophores makes the process much more efficient and safer by dramatically reducing the total amount of energy required to photoablate a given volume of tissue.

KTP Laser

Summary Box: KTP Laser

- The KTP laser is a frequency-doubled YAG laser which produces pure lime green light at a wavelength of 532 nm.
- The KTP wavelength is intensely absorbed by hemoglobin and melanin. Its absorption by hemoglobin is quite efficient as it is very near the hemoglobin absorption peak at 540 nm.
- This wavelength is easily transmitted through water and is carried via conventional fiberoptics.
- The KTP laser is capable of incision, coagulation and vaporization of tissue. This wavelength is much more efficient than the Nd: YAG laser as regards cutting and vaporization functions.

The KTP laser is a frequency-doubled YAG laser which produces pure lime green light at a wavelength of 532 nm. The 532 nm wavelength is also available using crystals other than potassium-titanyl-phosphate. These include KDP (potassium dihydrogen phosphate) and LBO (lithium triborate) which are commonly used for the so-called Greenlight® and other urologic laser devices. The KTP wavelength is intensely absorbed by hemoglobin and melanin. Its absorption by hemoglobin is quite efficient as it is very near the hemoglobin absorption peak at 540 nm. This wavelength is easily transmitted through water and is carried via conventional fiberoptics. Typically, a cleaved and stripped bare fiber is used with a suction-irrigation instrument. Free-beam applications are possible with a micromanipulator or Microslad® which is more commonly used in otolaryngology and in microsurgical applications.

The KTP laser is capable of incision, coagulation and vaporization of tissue [10, 12, 15–17, 19–25]. This wavelength is much more efficient than the argon laser for these functions and surpasses the Nd: YAG laser as regards cutting and vaporization functions. These properties make this laser quite versatile for laparoscopic procedures. Vessels of up to 2 mm diameter are easily coagulated. The hemoglobin selectivity of this wavelength enables the surgeon to defocus the beam (i.e. move the fiber away from the tissue surface) and preferentially coagulate a vessel prior to its division. Bleeders such as those encountered in the gallbladder bed during cholecystectomy are dealt with by irrigating the area with saline, using the laser in a defocused mode and delivering short bursts of energy.

As with the argon and Nd:YAG lasers, the KTP laser requires eye safety filters, camera filters, and optical backstops along with ebonized instruments to prevent damage from stray light or beam reflection hazards. Since the KTP laser produces a single line of visible light, interference filters are available. Interference filters protect the camera and the eyes from injury by blocking the transmission of the 532 and 1064 nm wavelengths. This causes little if any color distortion since the CCD camera and monitor are easily adjusted to compensate for the filtered color. The tip of the bare optical fiber is the portion emitting laser energy and is therefore the part which incises and/or coagulates the tissue. The surgeon positions the fiber either perpendicularly or obliquely relative to the plane of dissection in order to use his technology most efficiently. Despite its versatility and utility, only a few remanufactured systems are available today. The wavelength is available as 5 W devices that are primarily intended for dermatologic use.

A high power KTP laser system capable of delivering 80 W to tissue was developed for laser ablation of the prostate [14, 15, 22]. Further developments using KDP and LBO crystals have made systems capable of 180 W outputs available in the form of systems configured for urologic applications. The laser energy is applied through the use of side-firing fibers. This produces an effect similar to a traditional TURP, with significantly reduced perioperative bleeding and with shorter operative times relative to its counterpart.

Holmium and Thulium Lasers

Summary Box: Holmium and Thulium Lasers

- The holmium laser produces infrared light at a wavelength of 2100 nm and is intensely absorbed by water. The thulium laser produces wavelengths between 1900 and 2100 nm and is available for surgical use.
- The highly efficient absorption of this wavelength by water permits cutting and ablation of bone and cartilage.
- This wavelength can be used in an aqueous environment due to the development of a cavitation bubble between the fiber and the tissue.
- The laser output is pulsed and high fluences may produce significant splattering and sputtering of tissue from the target area. This can coat the laparoscope and obscure the view.
- This laser is the most efficient wavelength for meniscectomy and percutaneous laser disc decompression (PLDD), other neurosurgical applications, and lithotripsy of urinary calculi. It is rarely used by general surgeons.

Both the holmium laser (Ho:YAG) and the thulium laser (THC:YAG) produce infrared light at a wavelength of 2100 nm. This wavelength is intensely absorbed by water. This mid-infrared laser wavelength can be carried via conventional fiberoptics unlike the CO_2 wavelength. The fiber is usually encased in a metallic sheath for single puncture use or for use in combination with a suction-irrigation probe. This delivery system is quite durable and tends to be "self-cleaning". Bare fiber delivery systems are also widely available for use [16, 17, 19, 20].

The highly efficient absorption of this wavelength by water permits cutting and ablation of bone and cartilage. Despite its water absorption, this laser can be used in an aqueous environment due to the development of a cavitation bubble between the fiber and the tissue. This "Moses effect" transmits the laser energy to the tissue. Current systems can achieve outputs of up to 180 W. The laser output is pulsed and high fluences may produce significant splattering and sputtering of tissue from the target area. This can coat the laparoscope and obscure the view. This problem can be minimized by selecting an appropriate power output and repetition rate as well as viewing the surgical site at a slightly greater distance than one would normally use with other modalities.

The incisional and ablative speed of this laser is somewhat slower than many of the other wavelengths available for laparoscopic use, particularly at lower fluences. However, this is offset by the ease of use and durability of the fiberoptics. The zone of coagulation is similar to that seen with electrosurgical devices and sculpted fibers. This laser is the most efficient wavelength for meniscectomy and percutaneous laser disc decompression (PLDD), and lithotripsy of urinary calculi. It is also being applied to other neurosurgical applications. It is rarely used by general surgeons for the most part.

A recent development has been the availability of thulium laser technology for use with the DaVinci® Surgical Robotic System (Intuitive Surgical, Sunnyvale, CA). The so-called RevoLix® (LISA Laser USA, Pleasanton, CA). The robotic platform is fitted with a flexible introducer that is capable of accepting up to a 5F diameter fiber. The system is currently being marketed to gynecologists. However, the platform is certainly capable of much broader use in minimally invasive surgery.

Diode Laser Technology

Summary Box: Diode Laser Technology

- The promise of these systems is their compact size, easy portability and the potential for lower capital and maintenance costs.
- The typical wavelengths are carried by conventional fiber optics and are most frequently applied with sculpted or bare fiber technology.

High powered diode laser systems are becoming available for clinical use [19, 20]. The promise of these systems is their compact size, easy portability and the potential for lower capital and maintenance costs. The Diomed® laser (Diomed Inc., The Woodland TX) was the first such unit approved for surgical use. This laser produced near-infrared light at 805 nm. The wavelength could be carried by conventional fiber optics. While this manufacturer filed for bankruptcy in 2008, it is likely that other diode laser devices will become available in the future.

Lithotripsy Devices

Summary Box: Lithotripsy Devices

- Laser and non laser based technologies have both been applied for laparoscopic common duct exploration and lithotripsy as well as for use in the urinary tract.
- A variety of wavelengths including: pulsed dye lasers, alexandrite, and holmium laser have been used for lithotripsy.
- These lasers generate photoacoustic shock waves at the surface of the calculus at the point of the laser's impact that jackhammers and disintegrates the stone into small particles which can be flushed from the duct.

The surgeon had a limited number of options as regards management of the patient with choledocholithiasis during the early years of laparoscopic cholecystectomy. As surgeons became more facile with minimally invasive surgical techniques and as smaller diameter fiberscopes and glidewires became available, it became possible to perform common duct exploration and stone extraction laparoscopically.

Stone extraction with baskets and forceps proceeds in a manner that is similar to that of open common duct exploration. However, these procedures can be difficult in the presence of large stones or stones which have become impacted at the ampulla. These patients can be successfully managed with a variety of lithotripsy techniques. Laser and non laser based technologies have both been applied for laparoscopic common duct exploration and lithotripsy [4, 19, 20].

Laser based lithotripsy devices are available for laparoscopic and ureteroscopic use. A variety of wavelengths have been tested including: pulsed dye lasers, alexandrite, holmium and excimer lasers. Of these, holmium laser devices are available for clinical use at the present time. These lasers generate photoacoustic shock waves at the surface of the calculus at the point of the laser's impact. This jackhammers and disintegrates the stone into small particles which can be flushed from the duct. A cleaved fiber is placed in contact with the stone and a cavitation bubble develops as the laser is fired. Absorption of laser energy at the proper fluence and duty cycle causes the bubble to vibrate and fragment the stone. These devices are quite simple to use. They can be applied under direct vision with a fiberscope, or they can be placed percutaneously or threaded into the common bile duct or ureter "blindly". A characteristic cracking or snapping sound is audible as the stone is contacted and as fragmentation occurs. Matching of the wavelengths and the relatively low fluences required for this photoacoustic effort enables destruction of the calculus without damage to the tissues of the common duct or ureter. Holmium laser units are more frequently used since they are typically found in the urology department and are generally simpler to operate and maintain than the other alternatives.

Practical Tips for Laser Use in Minimally Invasive Surgery

Summary Box: Practical Tips for Laser Use in Minimally Invasive Surgery

- The surgeon should have an intimate understanding of the details of the procedure as well as the laser technology and delivery systems selected for use.
- Learn the procedure and become comfortable with it after having successfully accomplishing it using so-called "conventional" devices prior to attempting it with laser technologies.
- The surgeon should practice with the laser devices as much as possible prior to using them clinically.
- A thorough understanding of tissue effects and the ability to assemble and troubleshoot the instrumentation is critical.
- It is helpful to work with the instrumentation in a pelvic trainer and then gradually introduce laser technology into clinical procedures.
- The operative port should be positioned such that the laser fiber can easily reach the intended surgical site end on. This is particularly important for direct fiber systems.
- Sculpted fibers cut and coagulate optimally when they can be dragged obliquely across the tissues rather than using them end-on.
- The rate of movement of the fiber should be deliberately slow enough to allow the tissue to be cut through completely prior to advancing the fiber. The fiber should not be visibly bowed.

We have considered the various laser technologies and delivery systems available for laparoscopic use. This section will discuss various practical tips to optimize the clinical results from these devices.

It must again be emphasized that the surgeon should have an intimate understanding of the details of the procedure as well as the laser technology and delivery systems selected for use. It is preferable to learn the procedure and become comfortable with it after having successfully accomplishing it using so-called "conventional" devices prior to attempting it with laser technologies. The surgeon should practice with the laser devices as much as possible prior to using them clinically. A thorough understanding of tissue effects and the ability to assemble and troubleshoot the instrumentation is critical [12, 13, 17, 19–21, 28, 32]. It is helpful to work with the instrumentation in a pelvic trainer and then gradually introduce laser technology into clinical procedures.

Trocar placement should be well-thought and should be based on the needs of the procedure as well as the habitus of the patient. As a general principle, the operative port should be positioned such that the laser fiber (and other instruments) can easily reach the intended surgical site end on. This is particularly important for direct fiber systems such as bare fibers for KTP, holmium or waveguides for CO_2 lasers. Sculpted fibers cut and coagulate optimally when they can be dragged obliquely across the tissues rather than using them end-on. Therefore the trocar placement may need to be modified for the specific laser and delivery system which is to be utilized.

The assistant surgeon should provide steady countertraction in order to distract the line of incision, facilitate exposure and optimize the efficiency and efficacy of laser use. The tissues should be incised in fluid, complete strokes as this too will increase the efficiency of the dissection and enable the dissection to proceed with better hemostasis. Staccato and repetitive passage of the laser fiber over the same area tends to produce a more irregular incision and frequently causes bleeding as vessels become injured at multiple points in the irregular wound.

Typically the fiber capable lasers are applied by placing the fiber into a suction-irrigation cannula. The fiber should be positioned such that it is easily visualized and such that the proposed line of incision is not obstructed by the suction irrigator. An optimal distance is often 1–2 cm for fiber extension. This permits visualization and maneuverability of the fiber and the surgical site without causing the fiber to be too floppy as a result of having too much fiber length protruding from the suction irrigator. It is also critical that the fiber be retracted completely within the instrument when the instrument is being removed or inserted into the abdomen (or other site). This maneuver prevents fiber breakage or iatrogenic injury. The foot pedal for the laser and the electrosurgical device should be within easy reach while the monitor is viewed and the instrumentation is manipulated. Ideally, the surgeon should only have access to one pedal at one time in order to prevent inadvertent triggering of the wrong device.

Several devices are available which bend or angulate the bare fiber and thereby permit the surgeon to optimize the position of the fiber relative to the topography of the dissection. Again, the fiber should be permitted to enhance visualization and minimize fiber breakage.

The surgeon should learn to use a light touch when using laser fibers. The rate of movement of the fiber should be deliberately slow enough to allow the tissue to be cut through completely prior to advancing the fiber. The fiber should not be visibly bowed as this indicates undue pressure or too deep a placement of the fiber into the wound. These conditions reduce efficiency and increase the likelihood of fiber breakage.

Sculpted fibers should be used in a similar fashion to the method suggested for bare fibers. However, the tip or probe should be oriented more obliquely or tangential to the line of incision. This optimizes the coagulative effect of the laser and facilitates the dissection.

Laser Injury and Its Prevention During Laparoscopic Surgery

Summary Box: Laser Injury and Its Prevention During Laparoscopic Surgery

- The surgeon should understand and implement safety procedures as recommended by the ANSI Standard (ANSI Z136.3_2011) and other appropriate regulatory bodies to prevent injury to patients and personnel.
- The use of ebonized surfaces is helpful in the case of visible light and near infrared lasers.
- Instruments will become hot as they are absorbing the laser's energy. Therefore, inadvertent contact with adjacent structures must be carefully avoided to prevent secondary burns.
- Accidental injuries from inadvertent activation of the laser foot pedal can be avoided by placing only a single foot pedal in the surgeon's proximity and by placing the laser in stand-by mode when it is not in use.
- Any site of stray burn or contact with a heated instrument should be inspected carefully and should be handled as if it were a frank perforation. This is particularly important when using the Nd: YAG laser.
- The patient that has symptoms beyond those expected for the procedure, or the patient with ileus or "doing poorly" postoperatively should be suspected of having an iatrogenic injury and should be managed accordingly.

We have discussed the various wavelengths available for use during minimally invasive procedures and have considered some of the techniques to prevent injury. The surgeon would do well to understand and implement safety procedures as recommended by the ANSI Standard (ANSI Z136.3-2011) and other appropriate regulatory bodies [1, 52]. Implementation of these guidelines will prevent injury to patients and personnel.

The primary risk of injury during laparoscopy is to the patient's intraabdominal and pelvic structures due to the closed nature of the surgery and the proximity of adjacent structures [2, 3, 8, 12–14, 19–21, 28, 29, 33]. Several methods have been developed to minimize the risk of potential injuries due to reflection of energy from the surface of surgical instruments. These methods are designed to scatter the beam or absorb the incident laser energy. It should be remembered that the CO_2 laser wavelength is color independent. Therefore, ebonized surfaces are not helpful in this case. Instruments should have brushed beaded or sand-blasted surfaces. Titanium is preferable as a back stop material. The use of ebonized surfaces is helpful in the case of visible light and near infrared lasers. However, the surgeon must remember that these instruments will become hot as they are absorbing the laser's energy. Therefore, inadvertent contact with adjacent structures must be carefully avoided to prevent secondary burns.

The surgeon should orient the laser fiber and beam such that the possibility of past-pointing is avoided. This too can result in damage to nearby structures, particularly if backstops are not in use during the dissection. Accidental injuries from inadvertent activation of the laser foot pedal can also occur. These potential problems are best avoided by placing only a single foot pedal in the surgeon's proximity and by placing the laser in stand-by mode when it is not in use.

The bowel and bladder should always be checked for perforation injuries or potential burns, particularly after extensive dissections or vaporizational procedures. Such a practice is prudent irrespective of the technology that has been used during the conduct of the case. Several strategies have been used including filling the area with irrigation fluid, insufflating the bowel with air, and/or the instillation of betadine, methylene blue, indigo carmine or other dyes and observing the tissue for any leaks or staining. Leaks or suspected areas of injury should be oversewn or closed using good surgical technique.

Any site of stray burn or contact with a heated instrument should be inspected carefully and should be handled as if it were a frank perforation. This is particularly important when using the Nd: YAG laser since the degree of damage is grossly underestimated by visualization of the surface.

As should be the case with any minimally invasive procedure, the patient that has symptoms beyond those expected for the procedure, or the patient with ileus or "doing poorly" postoperatively should be suspected of having an iatrogenic injury and should be managed accordingly.

Summary

We have discussed the tissue effects and delivery systems available for laser utilization during minimally invasive surgical procedures. These versatile devices have many justifiable uses during surgery. The surgeon should have a thorough understanding of the procedure to be performed as well as the laser device, its delivery systems and safety considerations. Practice and continued use of these devices will lead to improved outcomes.

Laser Use in Open Surgical Procedures

Summary Box: Laser Use in Open Surgical Procedures

- Lasers are also applicable to open surgical procedures.
- Common surgical uses have included wound debridement and ulcer excision, breast surgery, cholecystectomy, hernia repair, bowel resection, hemorrhoidectomy, solid organ surgery, and treatment of pilonidal cysts.
- It is preferable to consider <u>how</u> best to utilize lasers rather than <u>whether</u> to use a laser for a particular procedure.
- Many different laser wavelengths and delivery systems are useful and interchangeable for most surgical applications. Certain applications will require a specific wavelength or delivery system.

Lasers are also applicable to open surgical procedures. Common surgical uses at one time included wound debridement and ulcer excision, breast surgery, cholecystectomy, hernia repair, bowel resection, hemorrhoidectomy, solid organ surgery, and treatment of pilonidal cysts [16, 34–58]. Lasers are used on a routine basis by a minority of general surgeons today.

The majority of them use lasers for wound debridements and special cases. The carbon dioxide laser remains a surgical mainstay for these applications.

Like all surgical instruments, there are some uses for which lasers are indispensable and other uses where their merit is relative. Electrocautery and lasers enable the surgeon to incise tissues, obtain hemostasis and dissect with a single instrument. Unlike electrocautery, these devices enable the vaporization or ablation of large volumes of tissues (e.g. tumors) and permit the sterilization of contaminated wounds (e.g. decubitus ulcer) without the transmission of thermal or electrical energy to distant sites via neurovascular routes.

It is preferable to consider how best to utilize lasers rather than whether to use a laser for a particular procedure. As with any new technique or deviation from the routine, the use of the laser may result in an increase in operative time initially, but repeated use usually results in streamlining the procedure and reduction in operative time as the user become more comfortable and experienced.

It is helpful to have an assistant who is familiar with the laser(s). The lack of proper assistance might prove disastrous. When possible, the surgeon and surgical assistants should work together frequently and should practice with their hospital's equipment prior to attempting a major procedure for the first time. These practice sessions can be accomplished in the laboratory or after hours. Meat, fruit and vegetables provide sufficient material for the surgical team to familiarize themselves with the technology. Practice, when coupled with an adequate understanding of what a particular laser wavelength and delivery system is capable of accomplishing, enables the surgeon to select the appropriate laser (if any) for a given procedure.

The experienced laser surgeon will soon recognize that many different laser wavelengths and delivery systems are useful and interchangeable for most operations. However, certain applications will require a specific wavelength or delivery system.

Laser Parameters for Open Surgery

Summary Box: Laser Parameters for Open Surgery

- Surgery will proceed more efficiently and with less thermal damage to adjacent tissues when the surgeon uses the maximum power density (irradiance) that he/she is able to control comfortably.
- Guidelines are presented for parameters typically useful when using lasers for open surgical procedures.

Let us begin our discussion of "how" to use lasers optimally with some suggested guidelines for use of the CO_2, KTP and Nd: YAG lasers. The reader should recognize that the tables, which follow, represent a series of parameters, which we have found to be the most useful. They are not intended to be absolute, but are intended to be suggestions, which should be tailored for the individual procedure to be performed. Modification of the suggested parameters should be based on the skill and experience of the surgeon. It should be noted that surgery will proceed more efficiently and with less thermal damage to adjacent tissues when the surgeon uses the maximum power density (fluence) that he/she is able to control comfortably.

Table 7.2 presents guidelines for the CO_2 laser. Parameters for the KTP laser are presented in Table 7.3. Table 7.4 lists suggested guidelines for the use of the Nd: YAG laser.

Preparation of the Operative Site and Surgical Retractors

Summary Box: Preparation of the Operative Site and Surgical Retractors

- Some special considerations are in order when lasers are used during surgery.
- Wound scrubs and paints should be aqueous or non-flammable.
- Draping and gown materials should be flame retardant or non-flammable.

- The wound itself should be surrounded with moistened towels or sponges, or should have gel lubricants layered around the wound, particularly when one first begins using lasers.
- Retractors may be wrapped with wet gauze or stockingette material if a significant risk of beam reflection exists.
- One must maintain constant vigilance when using lasers.
- The procedure must be conducted with a continuous awareness of the three-dimensional topography and anatomy of the operative site.
- Adjacent structures should be protected at all times to prevent inadvertent injury.
- Appropriate optical backstops for the particular laser in use should be employed whenever possible.

Some special considerations are in order when use of the laser is contemplated [1, 41, 52]. Wound scrubs and paints should be aqueous or non-flammable. It is an excellent practice to ensure that no surgical prep solution is allowed to puddle or collect on or around the patient. Draping and gown materials should be flame retardant or non-flammable. Cooling blankets must not contain alcohol or other flammable coolants.

The wound itself should be surrounded with moistened towels or sponges, particularly when one first begins using a laser. This reduces the possibility of fire. Alternatives include the use of gel lubricants, which can be placed in layers around the wound. Recently, sheets of gel wound protectant have become available for use. This material can be trimmed to conform to the surgical site. It adheres and provides wound protection without the inconvenience of a wet field. However, it must be remembered that clear or transparent gels and materials will not prevent transmission of visible light and some infrared wavelengths. Inadvertent exposure can occur in these areas if care is not taken to avoid stray beams in these seemingly protected areas.

Many so-called laser retractors, which feature blackened or ebonized surfaces, are available. Such specialized instruments may be helpful when working in confined spaces, particularly when one is using visible light l and near infrared lasers. These instruments do not absorb the longer far infrared wavelength of the CO_2 laser. Instruments with a beaded or matte surface or those with special coatings are required to prevent significant reflection of the CO_2 laser beam. For the most part, these specialized instruments are unnecessary. Retractors may be wrapped with wet gauze or stockingette material if a significant risk of beam reflection exists. Plastic and acrylic retractors are also useful and inexpensive [37, 41]. However, extreme caution must be exercised to avoid striking them with the laser beam, as they will melt or burn and can cause injury to the patient.

Acrylic blocks are serviceable as inexpensive, but effective retractors. Quarter-inch (6 mm) acrylic sheet material can be cut into 8 × 15 × 0.6 cm sections, packaged and presterilized for use. They can be resterilized or may be discarded after a single use and are quite inexpensive [37, 41]. These retractors facilitate the application of steady traction on the wound, making incision and dissection more efficient. Wide malleable retractors may be wrapped with a moistened Miculicz pad or stockingette material as an alternative to the acrylic blocks. These retractors have the advantage of being capable of being formed, which facilitates their use in deeper wounds.

One must maintain constant vigilance when using lasers. The procedure must be conducted with a continuous awareness of the three-dimensional topography and anatomy of the operative site. Adjacent structures should be protected at all times to prevent inadvertent injury. Moistened Miculicz pads or towels are used to pack the wound and adjacent areas. Appropriate optical backstops for the particular laser in use should be employed whenever possible. Examples of these include the Köcher bronchocele sound, glass rods, titanium rods, and saline.

Practical Tips for Laser Use

Summary Box: Practical Tips for Laser Use

- All lasers function most efficiently when appropriate power densities (irradiances) are used in conjunction with proper technique.
- Tissue should be held under constant tension to distract the tissues, thereby exposing the plane of dissection and maintaining good exposure.
- Cutting should be done in a single pass of the laser, with care being taken to avoid rapid, back and forth type motions, which create multiple planes of dissection and undue bleeding.
- Liquefied fat should be aspirated or blotted.
- "Water is your friend" is important when using the CO_2 laser. Delicate dissection around nerves, tendons, vessels and other structures can be accomplished safely by infiltrating local anesthetic or saline into the tissue plane below the intended target.
- A similar technique is useful when using the KTP and Nd: YAG lasers. These wavelengths are easily transmitted through water. An opaque optical backstop should be used.

All lasers will function most efficiently when appropriate power densities (irradiances) are used in conjunction with proper technique. Tissue should be held under constant tension to distract the tissues, thereby exposing the plane of dissection and maintaining good exposure. This requires about twice the amount of "pull" or force, as that is required for conventional surgical techniques.

Cutting should be done in a single pass of the laser, with care being taken to avoid rapid, back and forth type motions, which create multiple planes of dissection and undue bleeding. The full thickness of tissue to be cut should be incised by advancing the beam (i.e. your hand) slowly along the proposed line of incision.

Liquefied fat should be aspirated or blotted. This prevents flash flaming of the liquefied fat (in the case of the CO_2 laser), reduces the transmission of thermal energy to the tissues and permits more efficient incision by enabling more direct interaction between the laser and the tissues to be incised.

The concept that "water is your friend" is important when using the CO_2 laser. Delicate dissection around nerves, tendons, vessels and other structures can be accomplished safely by infiltrating local anesthetic or saline into the tissue plane below the intended target. This forms a natural barrier to penetration by the laser beam until or unless the surgeon vaporizes this layer. This principle may be coupled with the use of solutions containing epinephrine to enhance the hemostatic effect of the laser by promoting local vasoconstriction. This technique is useful when performing hemorrhoidectomy. The varix is ligated proximally (i.e. crown ligature) and the tissue is infiltrated with 0.25% Bupivacaine with epinephrine. This maneuver separates the varix from the sphincter muscles, produces vasoconstriction, and prevents the inadvertent sectioning of the sphincter. A similar technique is useful when performing hemorrhoidectomy with the KTP and Nd: YAG lasers. However, these wavelengths are easily transmitted through water or saline. Therefore, an opaque optical backstop should be used. The surgeon should also recognize that absorption of laser energy by the backstop can heat these instruments and result in thermal damage if they are used carelessly or for prolonged periods without stopping to permit them to cool.

Practical Considerations

Summary Box: Practical Considerations

- The CO_2 laser is useful for the incision, excision and vaporization of tissues.
  – The surgeon should generally select the minimum spot size and the highest fluence that can be managed safely.

- A 125 mm handpiece is the most commonly used delivery device for free-hand application.
- The main advantages of electrosurgical devices are the ubiquity of them in the operating room and the fact that no additional training or safety considerations need be implemented.
- It is important to divide tissues completely in a V-shaped plane in order to achieve the maximum speed and efficiency.
- Generally, these devices should be used at 25–40 W for skin incisions and 60 W for incision of fat, muscles and other tissues.
- Liquefied fat should be aspirated to increase efficiency and present flash fires due to the diesel effect.

- The Nd: YAG laser is capable of photocoagulating as much as 2 cm tissue when applied in a free-beam mode, with much of the photothermal coagulation occurring 4 mm beneath the target surface.
  - A sculpted fiber results in much of the laser energy being absorbed at the tip of the instrument. This produces zones of coagulation similar to these seen with electrosurgical devices or with use of the KTP/532 laser. These delivery devices are used at 10–25 W outputs.
  - Bare fiber applications for solid organ surgeries are more efficient at energies of 50–60 W.
  - Tumor ablation is generally performed at energies of 40–100 W. The surface needs to be desiccated or carbonized in order to provide a nidus for the ablation to begin, particularly if the lesion is not deeply pigmented.
- The KTP laser is a versatile tool for both open and laparoscopic procedures.
  - It cuts, vaporizes and coagulates tissues efficiently, with a zone of injury that is intermediate between a CO_2 laser and electrosurgical unit used in coagulation mode.
  - KTP laser incision is efficient over power outputs between 8 and 25 W.
  - The fiber capable lasers are easier to learn to use since the surgeon is able to maintain tactile feedback as the fibers contact the tissues.
  - These lasers should generally not be used for skin incision and are best used on tissues deep to the dermis.
- Pulsed dye lasers are used for the management of common duct stones and for the fragmentation of renal and ureteral calculi.

A CO2 laser is useful for the incision, excision and vaporization (ablation) of tissues [34–44, 53, 55, 57]. The surgeon should generally select the minimum spot size and the highest power density (irradiance) that can be managed safely. This increases the efficiency and speed of the procedure and enhances hemostasis. A 125 mm handpiece is the most commonly used delivery device for free-hand application. Using the beam in focus will produce optimal results for skin incisions and fine dissection of tissues. Defocusing the beam permits greater transfer of heat to the underlying tissues and improves hemostasis during the division of muscular and parenchymatous organ tissues. Tissues should be maintained under constant traction to facilitate the dissection and the surgeon should maintain a relatively slow, steady hand speed. It is also important to divide tissues completely in a V-shaped plane in order to achieve the maximum speed and efficiency. Generally, these devices should be used at 25–40 W for skin incisions and 60 W for incision of fat, muscles and other tissues. It is generally helpful to use not more than 60 W for soft tissue incision since the laser is more difficult to control and since the potential for a flash fire in the wound due to aerosolization of liquefied fat exists. Liquefied fat should be aspirated to increase efficiency and present flash fires due to the diesel effect. CO_2 lasers capable of generating outputs greater that 60 W can be used for effective and efficient ablation of bulky lesions and expeditious debridements of large areas.

CO_2 laser waveguides are available for both open and laparoscopic use. Flexible waveguides are more practical and are typically used at outputs of 30 W or less. They are available with some laser systems, including models marketed for dental office use. These delivery systems are not practical for skin incisions but have been used for numerous other applications. The Omniguide® system is generally used at 15–20 W or less.

The CO_2 laser sterilizes as it cuts and vaporizes tissues in a non-touch fashion. It is useful for wound debridements and in situations where decreasing or eliminating wound contamination is desirable. Use of this laser in either a freehand mode or with scanners facilitates hemostasis during surface debridements such as in cases of burn wound care or management of decubitus ulcers. Recent developments with erbium laser delivery systems may make the Er: YAG laser an attractive alternative for these procedures in the future, although these devices are more common in dermatology, dental, and plastic surgical applications.

The Nd: YAG laser is capable of photocoagulating as much as 2 cm tissue when applied in a free-beam mode, with much of the photothermal coagulation occurring 4 mm beneath the target surface [34, 47, 53–57]. This occurs due to forward and back scattering of light in the tissue. Using a sculpted fiber results in much of the laser energy being absorbed at the tip of the instrument (delivery device). This produces zones of coagulation similar to these seen with electrosurgical devices or with use of the KTP/532 laser. Laser procedures are generally performed at 10–25 W when using sculpted fibers. However, bare fiber applications for solid organ surgeries are more efficient at energies of 50–60 W. Tumor ablation is generally performed at energies of 40–100 W. The surface of the lesion needs to be desiccated or carbonized in order to provide a nidus for the ablation to begin, particularly if the lesion is not deeply pigmented. The surface can be “doped” by applying a droplet of blood, India ink, methylene blue or another chromophore to start the ablation process by enabling surface absorption of the YAG laser energy.

The KTP laser is a versatile tool for both open and laparoscopic procedures [16, 54, 56, 57]. This wavelength is intensely absorbed by hemoglobin, myoglobin and melanin and the laser is capable of both contact and noncontact use. It cuts, vaporizes and coagulates tissues efficiently, with a zone of injury that is intermediate between a CO_2 laser and electrosurgical unit used in coagulation mode. KTP laser incision is most efficient using power outputs between 8 and 25 W.

Generally speaking, the fiber capable lasers are easier to learn to use initially, since the surgeon is able to maintain tactile feedback as the fibers contact the tissues. These lasers should generally not be used for skin incision and are best used on tissues deep to the dermis. The power densities, and hence speed of action of KTP, holmium and thulium lasers may be increased by using smaller fibers if desired. Sculpted fibers behave most like optically-driven cautery with cutting speed and efficiency reaching a plateau once the tip is heated. The surgeon should remember that these tips can remain quite hot for several seconds after the beam is deactivated. Iatrogenic injury or adherence to the wound can occur at this time if careless tissue contact occurs.

Holmium, Thulium and Pulsed Dye lasers have also been used for the management of common duct stones at the time of cholecystectomy or during perioperative ERCP. These laser systems are also quite helpful in the fragmentation of renal and ureteral calculi [4, 16, 56, 57].

Lasers have been useful in the palliation of obstructing esophageal, bronchial and colonic lesions both with and without photosensitizing agents such as Photofrin®. Most of these procedures are performed using flexible or rigid endoscopes. Both laser and other light sources are used for these applications [34, 47, 50, 57].

Some surgeons reserve lasers for special procedures such as tumor resections including, non-anatomic resection of liver metastasis, procedures on patients with bleeding disorders, and in the treatment of infected or contaminated wounds. These versatile instruments can provide many advantages and are a useful addition to the armamentarium of the surgeon, who is conversant with their tissue effects and delivery systems. However, it is unlikely that lasers will replace scalpels, electrosurgical devices and other "standard" instruments. Some procedures such as laparoscopic herniorrhaphy and many parts of "laser surgeries" are better performed without one. Nonetheless, surgeons would do well to become comfortable with laser technology and use it is clinical practice. Beginners will achieve better results and improved outcomes by graded use of these devices on simple procedures initially and tackling more complex procedures as operative experience increases.

The CO_2 laser represents an excellent modality for surgery of the breast [34–36, 41, 47, 48, 55, 57]. The laser permits the precise creation of flaps with significant reduction in operative blood loss, postoperative drainage, and postoperative seroma formation. Both the volume and duration of postoperative drainage is significantly reduced in patients treated with the laser. These factors can be used to advantage particularly in the case of immediate reconstruction wherein postoperative seroma formation could predispose the patient to wound infection. Experimental studies have demonstrated that the laser results in a tenfold reduction in local recurrence as compared to scalpel or cautery treatment particularly when laser excision is combined with sterilization of the wound. This suggests that the CO_2 laser should be the modality of choice for the surgical treatment of carcinoma of the breast.

Axillary dissection may be accomplished successfully with the YAG, KTP, or CO_2 lasers. The use of optical backstops is helpful in preventing iatrogenic injury when using lasers for this purpose. Laser use permits the precise definition of anatomic structures as a result of enhanced hemostasis and clear definition of the planes of dissection. Experimental evidence suggests that lasers are useful in reducing the likelihood of tumor implantation at the time of surgery and may reduce local recurrence in human breast carcinoma [35, 36, 39, 41–43, 48, 55, 57]. It is noteworthy that lasers seal blood vessels and lymphatics and therefore reduce the volume and duration of postoperative drainage.

The YAG laser permits precise bloodless dissection in surgery of the head and neck, using a sculpted fiber in these dissections. Other laser wavelengths such as the CO_2 laser and KTP laser also have been used quite successfully. However, these systems require the use of optical backstops and an expert understanding of the laser's capability and the surgical anatomy.

Hemorrhoidectomy may be accomplished with a variety of laser wavelengths and techniques. The use of lasers has been documented to reduce the perioperative morbidity of surgical hemorrhoidectomy. Significant reductions in the incidence of urinary retention and delayed bleeding are noted. In addition, the patients generally resume their normal activity in approximately one half the time required by their conventionally treated counterparts. The incidence of post-hemorrhoidectomy strictures is greatly reduced [41, 48, 53, 57].

Lasers are quite useful for herniorrhaphy and are particularly useful for recurrent hernia repair. Hemostasis is excellent and scar tissue from previous repairs can be divided easily. The majority of hernioplasties are performed with local anesthesia and conscious sedation. Laser use permits excellent hemostasis without the use of electrocautery. This is particularly advantageous because the patient may find electrocoagulation to be painful due to conduction of electrical current along neurovascular bundles and away from the wound site, despite an adequate local block. Additional advantages are significant reduction in postoperative edema, ecchymosis, and discomfort. Patients resume normal activities much sooner than their conventionally treated counterparts.

Lasers are quite helpful in the performance of procedures under local anesthesia. Patient comfort is enhanced during the performance of the procedure as well as postoperatively. A clear, dry operative field is obtained and the procedure is accomplished more rapidly since less time is spent in obtaining hemostasis. A variety of wavelengths can be used interchangeably in the performance of herniorrhaphy. Postoperative discomfort is reduced due to the reduction in edema and induration of laser wounds.

The CO_2 laser is extremely effective in the ablation of large volumes of tissue. This is particularly useful in the case of local recurrence of carcinoma. Some large tumors may be quite vascular. Hemostasis may be enhanced by the use of epinephrine containing local anesthetics injected at the periphery of the lesion. Another approach is the combined use of free beam YAG laser energy as a means of coagulating the tumor mass followed by its immediate ablation with the CO_2 laser.

Photobiomodulation

Summary Box: Photobiomodulation

- Low Level Laser (Light) Therapy (LLLT) is currently being used to treat various conditions based on the principles of photobiomodulation (PBM).
- These therapies are based on the observation that photostimulatory effects are generally observed at fluences between 1 and 10 J/cm^2, while photoinhibitory effects are typically observed at higher fluences.
- Light sources including lasers, light emitting diodes, superluminous diodes, and other noncoherent sources are employed both clinically and experimentally. The most effective wavelengths appear to be clustered in the red and near infrared portions of the electromagnetic spectrum.
- LLLT (PBMT) using blue light wavelengths has been recently used as an antimicrobial agent and has found some success in the management of chronic wounds.

Low Level Laser Therapy (LLLT) is currently being used to treat various conditions based on the principles of photobiomodulation (PBM) [58–72, 88]. Several in vitro and in vivo studies have demonstrated that LLLT (PBMT) has a significant influence on a variety of cellular functions and clinical conditions [56–81, 88]. However, other studies have concluded that LLLT had little or no effect on treatment outcomes [63].

The traditional application of photobiomodulation in clinical and experimental models is based on the observation that photostimulatory effects are generally observed at fluences between 1 and 10 J/cm^2, while photoinhibitory effects are typically observed at higher fluences. Treatments are generally administered on a daily or every other day basis, and usually three to four times per week [58]. Several different light sources including lasers, light emitting diodes, superluminous diodes, and other noncoherent sources are employed both clinically and experimentally. The most effective wavelengths appear to be clustered in the red and near infrared portions of the electromagnetic spectrum.

Work from several investigators has demonstrated that photobiomodulation influences a variety of biological processes, including the acceleration of wound healing [69, 71, 77, 79, 80], increased mitochondrial respiration and adenosine triphosphate (ATP) synthesis [66, 68, 70, 75, 76], cell proliferation [67–69, 74, 81], enhancement and promotion of skeletal muscle regeneration following injury [70] and a variety of other effects. Photobiomodulation enhances collagen synthesis in the wound area, thereby increasing wound tensile strength [71]. Stimulation of cell proliferation results from an increase in mitochondrial respiration and ATP synthesis [66, 72–74].

Work from our laboratory has demonstrated that in vitro cell proliferation and metabolism can be influenced by varying the dose frequency or treatment interval [80, 85]. Our results suggested that a unique dose frequency regime may exist for tissues and cell lines and that the determination of that treatment paradigm is necessary in order to achieve maximal stimulation of cellular metabolism and proliferation. The data also demonstrated that the use of other treatment regimes results in bioinhibition, despite the delivery of the same total energy [80]. We found that two treatments per day were more effective than once daily therapy in some cases. Therefore, the empiric use of a single treatment per day dosing frequency as a treatment strategy for all cell lines and tissues might explain why conflicting results demonstrating both positive and negative effects have been published and why the efficacy of LLLT (PBMT) remains controversial. Long exposures using 670 nm light at low intensities were ineffective in accelerating wound healing in an experimental pressure ulcer model [85]. This finding, in conjunction with data from other studies indicates that a certain threshold must be reached, although it is unknown whether delivering the light in a pulsed fashion with higher peak powers but the same time course would yield the same results. Our experimental findings demonstrate that identification of the proper treatment parameters for the particular cell line or tissue is crucial to achieve photobiostimulation. Work from several laboratories has demonstrated that certain wavelengths of light are bactericidal when used alone or in combination with other chromophores [88–94]. Blue light, between 405 and 470 nm has been shown to be particularly useful as an antimicrobial agent. Bacterial density and the mode of treatment can significantly affect the outcomes achieved [89, 93, 94]. These strategies have been successfully applied clinically [89, 94]. Blue light photoirradiation might one day play a role in routine wound management and should be considered for use in the management of chronic wounds.

LLLT (PBMT) holds great promise for the treatment of both acute and chronic wounds. It is likely that improved delivery devices and treatment paradigms will be available in the near future.

Conclusion

This chapter has presented a synopsis of the applications of lasers and light sources in general surgery. A wide variety of wavelengths and delivery systems can be applied in both routine and complex surgical procedures. Lasers and light sources can yield improved outcomes and allow the surgeon to work more efficiently, given proper selection of wavelength, delivery systems, laser parameters and the use of appropriate technique. The appropriately trained and skilled surgeon, who is conversant with the anatomy and technical details of the procedure at hand will find these devices a welcome addition to the surgical armamentarium.

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8 Laser Applications in Urology

Viacheslav Iremashvili and Robert Marcovich

Abstract

- Summary of laser-tissue interactions in urology.
- Holmium:YAG laser lithotripsy for calculi.
- Laser treatment of benign prostatic enlargement.
- Laser incision of urethral and ureteral strictures.
- Other laser applications in urology for treatment of penile carcinoma, partial nephrectomy, etc.

Keywords

Nephrolithiasis · Renal stone · Ureteral stone Laser lithotripsy · Holmium laser Benign prostatic hyperplasia Laser prostate ablation Laser prostate enucleation

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Introduction

- Laser energy has become the most commonly used modality for treatment of urinary tract calculi and is increasingly being used for soft tissue applications such as prostate ablation.

Development of medical lasers has had a revolutionary impact on the treatment of urologic disease. The two most common urological conditions treated with laser devices are urolithiasis and benign prostatic hypertrophy (BPH), and the most widely used lasers in urology are currently the holmium:YAG (Ho:YAG) for lithotripsy and BPH and the potassium-titanyl-phosphate (KTP) for BPH. Table 8.1 lists a number of current clinical applications of lasers in urology.

In addition to refinement in laser equipment, advances in fiberoptic and digital endoscopes as well as in optical fiber technology have also

Table 8.1 Clinical uses of lasers in urology

Lithotripsy of renal, ureteral, and bladder calculi
Ablation/enucleation of benign prostate
Incision of ureteral and urethral strictures
Ablation of superficial bladder and ureteral carcinomas
Ablation of penile lesions
Incision of ureteroceles
Ablation of urethral hair post urethroplasty or hypospadias repair
Excision of renal tumors (partial nephrectomy)
Focal ablation of prostate cancer

© Springer International Publishing AG, part of Springer Nature 2018
K. Nouri (ed.), *Lasers in Dermatology and Medicine*, https://doi.org/10.1007/978-3-319-76220-3_8

provided significant impetus for dissemination of laser techniques into community practice and made minimally invasive outpatient surgery for stones and BPH the rule rather than the exception.

Various mechanisms exist for the interaction of laser energy with a target, be it soft tissue or stone. In urological applications, the photothermal mechanism dominates and is responsible for ablation, incision, and coagulation of tissue. A photothermal mechanism has also been postulated to be of primary importance for Ho:YAG lithotripsy [1]. The photothermal effect of lasers is responsible for the so-called "vaporization" of benign enlarged prostate glands but can also be used to incise through large portions of the prostate in what is termed "enucleation". Laser energy can also vaporize or resect bladder carcinoma, and incise strictures of the urethra and ureter. Tissue "welding" is another application in development which utilizes a photothermal mechanism. Photodynamic therapy (PDT) for treatment of bladder and prostate cancer is an example of a photochemical laser-tissue interaction.

In this chapter we present state of the art information on laser use in urology, focusing on the two most important applications, treatment of calculi and BPH. We will also discuss available data on other uses of lasers in the field of urology and briefly delineate the future directions of research.

Laser Lithotripsy

Introduction

- Due to its efficacy and safety, the Holmium:YAG laser is in widespread clinical use for fragmenting stones throughout the urinary tract.

Development of laser lithotripsy began in the 1960s. The first laser to be used on urinary stones was the ruby laser [2] which worked by heating the stone surface to the point at which the stone melted. Due to its mechanism of action, the ruby laser was impossible to use in vivo and, therefore, never achieved clinical application. The introduction of pulsed dye lasers, namely the coumarin laser, led to the first clinical use of laser energy for lithotripsy in the 1980s [3].

The coumarin laser represented a major advancement in the treatment of urinary stones because the device was able to fragment stones of nearly any composition and small fibers could be used for energy delivery. While very high success rates were reported initially, the coumarin laser had significant disadvantages. It was prohibitively expensive and required unwieldy ocular protection as well as subsequent disposal of the toxic dye.

The Holmium:Yttrium-Aluminum-Garnet (Ho:YAG) laser has multiple advantages and has effectively replaced the pulsed dye laser, becoming the most commonly used device for lithotripsy. Compared to pulsed dye lasers, the Ho:YAG is more compact, less expensive to operate, and more reliable. It fragments stones by both generating shock waves (photomechanical) and by heating the stone surface (photothermal). The latter mechanism is by far the most important for calculus fragmentation [1]. Despite generation of heat and shockwaves, the excellent safety margin of the Ho:YAG is another major advantage. Since its wavelength of 2100 nm is highly absorbed by water, it penetrates tissue to a depth of less than 0.5 mm and can be confidently applied even in the tight confines of the ureter and renal pelvis [4].

Indications and Contraindications

Indications

- Urinary stones less than 2.0 cm in diameter

Contraindications

- Untreated bacteriuria or clinical evidence of urinary tract infection

The Holmium:YAG laser effectively fragments stones located in any part of the urinary tract, regardless of composition. Although any size stone can be treated with laser lithotripsy, the stone burden (size and number of stones) is the major factor determining whether laser lithotripsy is the best choice for a given patient. Stone burden affects treatment efficacy and large stones of the upper tract (kidneys and ureters) may not be amenable to ureteroscopic Ho:YAG laser lithotripsy (URSLL). Ureteral and renal calculi less than 2 cm can be approached with either URSLL [5] or extracorporeal shockwave lithotripsy, although comparisons of the efficacy of these two modalities is beyond the scope of this chapter. The effectiveness of URSLL for large stones is reduced due to limitations of the size of stone fragments that can be extracted through the ureter, as well as impaired visualization caused by stone dust and debris generated during fragmentation of large stones in the renal pelvis. In patients with sizable stone burdens, percutaneous nephrolithotomy using larger diameter rigid ultrasonic and pneumatic devices is a preferable option, although several reports exist of multisession URSLL for stone burdens over 3 cm [5].

For treatment of bladder stones, large diameter fibers can be used through cystoscopic instrumentation so there is no particular stone size limit precluding use of the Ho:YAG laser. Essentially any bladder stone can be fragmented with the laser. As with large renal stones, extracting numerous bladder stone fragments, as well as creation of vast amounts of stone dust and debris can render the technique inefficient. Thus, for very large stone burdens in the bladder, an open surgical approach or percutaneous surgery using ultrasonic or pneumatic devices is often more efficient, but clearly more invasive.

Presence of untreated urinary tract infection is the only absolute contraindication to laser lithotripsy as such patients have significant risk of developing life-threatening urosepsis. Holmium laser lithotripsy is feasible in patients who are receiving antiplatelet or anticoagulant therapy, thus making it the modality of choice for removing stones in patients with bleeding diatheses or those who cannot safely stop anticoagulant or antiplatelet drugs [6]. Similarly, laser lithotripsy has been shown to be effective and safe in multiple other patients subpopulations including obese [7] and pregnant [8] patients as well as children [9] and those with horseshoe kidneys [10].

Technique

Fiber selection

- 550 or 1000 μm fibers for use with rigid cystoscope in bladder.
- 365 μm fiber for use with rigid ureteroscope in ureter.
- 200 μm fiber for use with flexible ureteroscope in kidney or ureter.

Energy settings

- Pulse energy, frequency, and duration are chosen based on the desired effect.

Lithotripsy strategies

- Dancing, chipping, fragmenting, and popcorn are various strategies which can be applied depending on the situation.

Choice of laser fiber is dictated by location of the stone and thus the endoscope with which one plans to treat it. Bladder stones are approached via large-bore rigid cystoscopes which can easily accommodate side-firing 550 μm fibers or end-firing 1000 μm fibers. Side-firing fibers are advantageous in cases in which the patient has a large median prostatic lobe that impedes a straight-line approach to the stone. Side-firing fibers are also very useful for prostate vaporization and therefore may be the fiber of choice when both a bladder stone and enlarged prostate are treated during the same procedure. Ureteral and renal stones are addressed via smaller bore ureteroscopes with limited diameter working channels and thus require the use of smaller fibers. The working channel of these scopes must also accommodate flow of irrigant used to distend the ureter and renal pelvis for visualization, and larger fibers tend to impair irrigant flow. Typical fiber diameters used to treat ureteral and renal stones are 200 μm and 365 μm. The smaller of these also allows for maximal scope deflection, which is a requirement for lithotripsy of stones in the lower pole of the kidney. Laser lithotripsy of lower calyceal renal stones can lead to retention of fragments in the kidney postoperatively. Displacing the stone into an upper pole calyx using a stone basket obviates the need for deflecting the scope with a laser fiber in it and also allows for a more direct line for stone fragments to clear the kidney after lithotripsy. Passage of a laser fiber through a maximally deflected ureteroscope is one of the most common causes of scope damage. Recently introduced laser fibers with rounded "ball" tips allow for unencumbered passage of the fiber through a maximally deflected scope, allowing in situ lithotripsy of lower calyceal calculi as well as protecting the integrity of the ureteroscope.

Choosing appropriate laser settings is the most critical step after fiber selection. Available settings vary with the maximum power of the laser. Ho:YAG lasers are commercially available in 20, 30, 60, 100, and 120 W machines. Twenty-watt lasers are the least expensive and also the least versatile in terms of settings. Energy settings of 20 W lasers typically range from 0.5 J to 1.5 J and pulse frequencies range from 5 Hz to 12 Hz, while on a 100 W machine the energy can be set from 0.2 J to 2.5 J and the pulse frequency from 5 Hz to 50 Hz. Application of 20 W lasers is generally limited to stone treatment, whereas lasers of 60 W and higher can be used for both lithotripsy and tissue ablation, again making the latter a more versatile tool. Interestingly, laser manufacturers have recently begun to increase the available energy and frequency settings on 20 W models, with energy range up to 3.5 J and frequency up to 20 Hz.

Choice of pulse energy and pulse frequency is dictated by the goals of treatment and stone hardness. If the overall power of the laser remains constant, settings with higher pulse energy and low frequency are significantly more efficient as shown by increased ablation volume. Thus, pulse energy is the crucial determinant of the ablation volume, while pulse frequency and total power are less important [11]. However, high pulse energy can lead to stone migration, known as retropulsion. "Dusting" a stone into fine particles which can pass spontaneously after the procedure is best accomplished with low pulse energy (e.g. 0.3 to 0.5 J) and high pulse frequency (e.g. 20 to 30 Hz), settings which yield the smallest particles and very little stone retropulsion. Fragmenting stones into pieces small enough to remove with a stone basket is achieved with higher energy and lower frequency (e.g. energy of 0.8 to 1.0 J and frequency of 8 Hz). The degree to which these two mechanisms can be applied depends to some extent on the stone composition. Soft stones, such as calcium oxalate dihydrate and uric acid, are easier to dust into fine particulate matter, whereas very hard stones such as calcium oxalate monohydrate are quite resistant to dusting and tend to break into coarse fragments. The energy required to dust harder stones cannot be effectively delivered due to resultant retropulsion of the fragment. Also, as stone pieces become smaller, a given pulse energy causes relatively more stone migration.

Pulse duration is another parameter which has recently been added as a controllable parameter in newer Ho:YAG machines. Short pulse mode has been the default parameter and some manufacturers have added the ability to choose a long pulse mode up to 1500 μs per pulse. Traxer and coworkers have shown using artificial stones that shorter pulse duration results in significantly more ablation than longer pulse durations regardless of which energy-frequency-power settings are chosen [11]. However, shorter pulse duration, as with higher pulse energy, also increases retropulsion. Long pulse mode may result in slightly less damage to the fiber's cladding and tip [11].

Preparation of a reusable laser fiber frequently includes tip cleavage with various tools and stripping of the terminal portion of the polymer coating. A recent study examined the effects of stripping the laser fiber versus leaving the laser fiber coated, and compared the difference between cleaving the fiber with specialized ceramic scissors and using simple metal scissors [12]. Results showed that fiber stripping leads to reduced ablation efficiency. Furthermore, no differences were found between metal and specialized ceramic scissors, as long as the fiber tip remained coated. These surprising findings may have significant influence on clinical practice and obviate the necessity of purchasing fiber strippers and specialized scissors.

Several techniques of laser application for stones with different mechanical characteristics have been described [13]. For soft stones, a "dancing" technique is recommended. The laser fiber is brushed back and forth across the stone surface resulting in a uniform ablation into small fragments. For harder stones a "chipping" technique is suggested. With this method the laser fiber is directed at the periphery of the stone with an intention of breaking off small (<1 mm) fragments. This is continued until the stone is small enough to be extracted with a basket. Chipped fragments are usually able to pass spontaneously. "Fragmenting" technique includes continuous firing at the center of the stone mass. This results in stone weakening along the natural cleavage planes. In some cases several holes should be bored and then connected. This method is recommended for very hard stones. Finally, the "popcorn" technique is used when multiple stones of average size are accumulated in one of the calices and chasing individual stones is inefficient. Instead, the fiber is positioned near the stone collection and the laser is fired at relatively high frequency resulting in a whirlpool-like phenomenon. Stone fragmentation is achieved by both direct laser ablation and collisions between stone fragments [13]. Table 8.2 summarizes the various approaches and gives examples of settings which can be used.

Adverse Events

- Injury to urothelial tissue and tissue perforation.
- Stone migration
- Endoscope damage

The Holmium laser has a very wide safety margin and serious complications related to laser energy are uncommon, especially in the renal collecting system. Thermal injury is more likely to occur in the ureter, especially with larger stones that are impacted within the ureteral wall, thus necessitating firing of the laser at the periphery of the stone. The most common adverse event is injury of the urothelial tissue, usually in the area adjacent to the treated stone. Since the depth of tissue penetration of the Holmium laser is less than 0.5 mm, most injuries are managed conservatively, but in relatively rare cases, a ureteral stricture may develop.

Stone retropulsion is another potential complication which can lead to incomplete stone removal. Retropulsion is due to the photomechanical effect of the laser pulse producing shockwaves which push the stone retrograde, away from the operator. Retropulsion is directly proportional to pulse energy. To prevent retropulsion and retrograde migration of ureteral stone fragments the urologist should use lower energy and higher frequency settings.

The Ho:YAG laser can cause significant damage to flexible ureteroscopes. The fiber itself can perforate the working channel of the scope if the fiber is passed through the scope when the latter is in a deflected state. Laser emission within the scope or too close to the tip of the scope will destroy the optics. Laser-related endoscope damage is a leading cause of the frequent need for, and high cost of, repair of flexible ureteroscopes.

Future Directions

- Development of smaller fibers that are more flexible and do not impede ureteroscope deflection.

Table 8.2 Lithotripsy techniques—Holmium laser

Technique	Energy-frequency combination	Example settings
Dancing	Low energy—high frequency	0.4 J × 30–40 Hz (12–16 W)
Chipping	Moderate energy—low frequency	0.8 J × 6–10 Hx (4.8–8 W)
Fragmenting	High energy—low frequency	1–1.5 J × 6–10 Hz (6–15 W)
Popcorn	High energy—high frequency	1 J × 20 Hz (20 W)

- Introduction of more efficient solid-state lasers and fibers (e.g. Erbium and Thulium lasers).
- Use of laser lithotripsy for stones larger than 2 cm.

Current and future efforts to advance laser lithotripsy focus on refining existing Holmium laser technology, extending the application of laser lithotripsy to larger stone burdens, and developing alternative lasers such as erbium:YAG and thulium. As mentioned previously, Holmium laser fibers with rounded, coated tips have recently been introduced in a 242 μm size which allow for passage of the fiber through a fully deflected flexible ureteroscope, thus facilitating in-situ lithotripsy of lower pole calculi. Further miniaturization of existing laser fibers may also improve accessibility to stones in the lower pole by allowing for improved deflection of scopes. Features which make the Holmium laser more user friendly are also being introduced, such as foot-pedal control of energy and frequency settings and feature-rich touch-screen interfaces, as well as the ability to save the preferred settings of a user, and "preset" settings for various techniques such as dusting or fragmenting. Increasing power (up to 120 W, 6 J, 80 Hz in one model) and combination with in-line suction allow for much more efficient use of lasers during percutaneous nephrolithotomy, a procedure in which laser use has been limited to deployment through flexible scopes to access smaller stones in peripheral calyces which could not be reached with more efficient rigid instrumentation. Continued refinements such as these will continue to improve efficiency of Ho:YAG lithotripsy and widen its potential application.

Two devices have been explored as potential alternatives to the Holmium laser but have not yet achieved clinical application for stone management. The erbium:YAG laser [14] has a wavelength of 2940 nm, which is better absorbed by water than that of the holmium laser's wavelength of 2120 nm. While this yields a much more efficient rate of stone fragmentation in vitro, currently available fibers are not suitable for erbium:YAG transmission in vivo. The thulium laser can be used for calculus fragmentation and in contrast can be used with standard fibers [15]. In vitro studies show more rapid stone fragmentation resulting in shorter laser and operation times for the experimental thulium laser compared to conventional holmium laser, suggesting potential clinical utility for this new technology [15].

Further innovation in endoscope design will also continue to promote the widespread use of laser lithotripsy. Development of smaller and more flexible ureteroscopes, introduction of digital optics, as well as increasing surgical experience has resulted in a gradual increase in the size of renal and ureteral stones which can be safely and efficiently managed ureteroscopically with laser lithotripsy. Although current guidelines suggest ureteroscopy for stones up to 2 cm, there is a growing body of literature describing successful treatment of even larger stones [5]. In properly selected patients this approach can result in stone-free rates up to 90% and allows one to avoid the potential increased morbidity of percutaneous surgery. Longer operative times and frequent need for repeat procedures are the main disadvantages of this management option.

Benign Prostatic Hyperplasia

Introduction

- Holmium:YAG and Potassium Titanyl Phosphate (KTP) Greenlight™ are the most commonly used lasers for treatment of BPH.
- Higher power Holmium:YAG (120 W) and Greenlight™ XPS (180 W) lasers are available for rapid treatment of BPH.

Benign prostatic hyperplasia is one of the most common conditions prevalent in aging men. While effective pharmacotherapy exists, surgical management is an excellent option for advanced cases or those refractory to medical treatment. Transurethral resection of the prostate (TURP) has been considered the gold standard procedure in such cases and has withstood the test of time, but over the past two decades Ho:YAG and KTP laser therapy for BPH have become accepted and effective alternatives.

These newer laser systems had to overcome the initially disappointing results of the first laser used for the treatment of BPH, the neodymium-doped yttrium aluminium garnet (Nd:YAG) laser. Procedures termed "visual ablation" and "interstitial coagulation" were accomplished with this device, but postoperatively patients often developed long-term dysuria and urinary retention, and the technique quickly fell out of favor [16]. Contemporary laser procedures differ significantly from these early techniques. Terminology used to describe different laser surgeries of the prostate is presented in Table 8.3. A considerable amount of experience has been accumulated with the Ho:YAG laser and Greenlight™. Two other devices—Thulium:YAG and diode lasers have shown some encouraging results, although more data is required to support their clinical use.

The two most commonly used systems for laser treatment of BPH, the GreenLight™ and the Holmium: YAG, use photothermal energy to heat intracellular fluid above the boiling point, thus vaporizing cells and either ablating or cutting through the prostate. The 532 nm wavelength of the GreenLight™ is absorbed by hemoglobin, resulting in efficient ablation of well-vascularized tissue. Penetration depth is approximately 0.8 mm, and within this zone, tissue is vaporized with a peripheral region of thermal coagulation of approximately 1–2 mm. It is important to understand that the term GreenLight™ includes several generations of devices, which differ in terms of efficiency, although safety and outcomes are thought to be comparable. The first generation of GreenLight™ KTP laser procedure [17] was termed Photoselective Vaporization of the Prostate (PVP) due to the interaction between the laser and hemoglobin within the tissue. As tissue is vaporized, a cavity is created in the prostate resulting in a wider lumen for urine flow. The original KTP laser system was introduced in 2002 and had power up to 80 W. The 120 W HPS laser system introduced in 2006 had higher maximum power output and focus of the laser beam, resulting in more rapid tissue vaporization. The most recent 180 W XPS laser system has a modified thicker inner core fiber, which in combination with increased power provides even higher ablative energy per time unit. Furthermore, fiber degradation leading to a loss in power output is no longer observed [18].

Greenlight™ laser has been compared to TURP in multiple randomized studies, most of which used the 80 W and 120 W devices. Postoperative catheterization time and hospitalization time were shorter with Greenlight™, whereas operative time was shorter with TURP [19]. These findings are similar to those for other laser-based procedures. The risk of postoperative blood transfusion and clot retention was significantly lower in patients undergoing the Greenlight™ procedure. This is expected, as the physical properties of lasers operating at 532 nm include the ability to ablate the tissue at the center of the beam area and coagulate the tissue at the outer area of the beam. This makes Greenlight™ ablation ideal for patients who are at increased risk of hemorrhagic complications, such as those on anticoagulant or antiplatelet therapy. The safety of this technique in these

Table 8.3 Terminology of laser prostate surgery [16]

Visual laser ablation	Early and largely abandoned laser technique to ablate prostate tissue by heating the tissue with a laser beam
Interstitial laser coagulation	Early and largely abandoned laser technique where laser probes were introduced into prostatic tissue to induce coagulation necrosis
Enucleation	Surgical removal of the entire adenomatous tissue of the prostate
Vaporization	Surgical removal of prostate tissue by heating above the boiling point of water
Morcellation technique	Surgical technique that uses a device to crush and remove enucleated prostate tissue
Vaporesection	Surgical removal of prostate chips by incisions with a laser that also vaporizes prostate tissue
Vapoenucleation	Surgical removal of the entire adenomatous tissue of the prostate with a laser that also vaporizes prostate tissue to some extent

patient populations has been shown in several case series [20, 21]. The incidence of other complications, such as postoperative retention, urinary tract infection, gross hematuria, urethral stricture, and bladder neck stricture, were also found to be comparable between the Greenlight™ system and TURP.

There have been several procedures developed for BPH treatment using the Holmium laser. The first was termed HoLAP (holmium laser ablation of the prostate) and was performed with lower power devices. As such, it was limited to use on small prostates. Holmium laser resection of the prostate (HoLRP) was later introduced, in which prostate tissue was incised into pieces that required subsequent removal from the bladder. However, it was not significantly advantageous compared to HoLAP in terms of speed and also was not very effective for large prostates. With higher power Holmium lasers, some practitioners have found these techniques to be more practical, but their use is still not widespread.

High wattage systems have also fostered the HoLEP (holmium laser enucleation of the prostate) technique [22]. HoLEP involves creating incisions in the prostatic lobes, carrying these incisions down to the avascular plane between the prostatic capsule and the adenoma, using the beak of the resectoscope to mechanically dissect the tissue off the capsule, and connecting the areas of incision until the lobes are freed and pushed into the bladder. This procedure is very effective for removing the median lobe as well as both lateral lobes. In addition to having a steep learning curve, it requires a high power laser as well as a tissue morcellator to cut the enucleated prostate into pieces that can be evacuated through a resectoscope sheath. Unlike HoLRP, this technique can be used on the largest of glands and in the hands of those familiar with the technique is a viable substitute to an open prostatectomy. Multiple randomized studies comparing HoLEP and TURP have consistently demonstrated that catheterization time, length of hospital stay, blood loss, and requirement for blood transfusion are more favorable for HoLEP. Nevertheless operative time is longer and postoperative dysuria is seen more frequently than with TURP [16]. The functional outcomes of HoLEP, including symptom improvement, maximum urine flow, and post-void residual volumes are at least comparable to those of TURP. Similar results have been shown in studies comparing HoLEP to open prostatectomy in patients with large prostate volumes [23]. Like the Greenlight™ laser system, the holmium laser can be safely applied to patients on anticoagulant treatment or those with bleeding diatheses [24].

HoLEP is thought to be more challenging to learn than Greenlight™. For example in a recent multicenter study of the HoLEP learning curve, three of nine participating centers abandoned the procedure due to complications. Of the remaining centers only one was able to meet the preset criteria for successful mastery of the procedure (ability to perform four consecutive successful HoLEPs out of 20 cases) [25]. All participants were surgeons experienced in TURP.

Indications and Contraindications

Indications

*Moderate to severe lower urinary tract symptoms due to BPH resistant to medical therapy.

- Complications of BPH such as urinary retention or bladder stones.

Contraindications

- Untreated bacteriuria.

Practice guidelines from the American Urological Association endorse surgical therapy for men with moderate to severe lower urinary tract symptoms due to BPH resistant to medical therapy, as well as for patients who develop sequela of this condition, such as urinary retention or bladder stones. The choice of procedure depends on multiple factors, including equipment availability and training, with electrosurgical resection (i.e. TURP and its variants) and laser surgery being the most commonly used options. The Greenlight™ and holmium lasers each have unique characteristics which make them more suited in certain cases.

The Greenlight™ vaporizes the prostate through photothermal ablation of vascular tissue, which results in vaporization of prostate tissue. The rate of tissue removal is therefore to some extent limited, and for very large glands the operative times can be prolonged. The procedure seems to yield reductions in prostate size and PSA levels of 30–44% [26], so it may be best suited to smaller to medium size glands. Nevertheless, larger glands can be treated effectively if the surgeon invests enough time in the procedure. This concern may be less relevant for the most recent generation of XPS laser system, with its significantly higher power level. Holmium laser ablation is also limited by prostate size, thus also restricting its utility to small and medium size glands. For men with large prostates, the holmium laser is more suitably applied for enucleation rather than ablation. HoLEP also requires a significant time investment and therefore does not provide a time advantage over Greenlight™. The only significant surgical contraindication to these procedures is untreated bacteriuria.

Technique

- Equipment includes laser, cystoscope with irrigation system, and side-firing fiber.
- Greenlight™ is used to vaporize obstructing prostatic tissue.
- In HoLEP the laser is used to enucleate the prostatic adenoma.
- HoLEP is technically more complex than HoLAP or Greenlight™ ablation, but yields anatomically similar results to simple prostatectomy.
- Both Ho:YAG and Greenlight™ provide excellent hemostasis.

The technique of laser ablation, whether it is done with a Greenlight™ or a holmium laser, is essentially the same. The procedures are facilitated by using a continuous flow laser cystoscope, which has a stabilizing channel to guide the fiber through the scope. The KTP fiber is a side-firing fiber while, for Holmium applications, either side-firing or end-firing fibers can be used. The former is usually preferable. The fiber is maintained so that it nearly touches the surface of the tissue and is rotated from side to side in a sweeping arc traversing about 45–90°. The scope itself is moved back and forth in small increments to target unablated tissue, in effect "spray painting" the surface. Effective vaporization is confirmed by visualizing air bubbles escaping from the tissue. The median lobe is ablated first, just as in a standard TURP, taking care to identify and preserve the ureteral orifices. Vaporization then continues past the bladder neck, and is extended towards the verumontanum, which is the distal extent of treatment. Next, the lateral lobes are addressed, continuing the incremental spray painting motion from the bladder neck to verumontanum. The goal is to reach the transverse fibers of the prostate capsule, indicating complete ablation of adenoma tissue. Hemostasis is achieved by defocusing the laser fiber, or moving it away from the surface of the tissue, thus enhancing coagulation.

Holmium laser resection and holmium laser enucleation of the prostate are somewhat more complex procedures. If a prominent median lobe is present, this structure is generally enucleated or resected first. Using the laser a groove from the bladder neck to the verumontanum is created on either side of the median lobe, and deepened to the level of the surgical capsule. The median lobe is then undermined just proximal to the verumontanum and the plane between the adenoma and capsule is developed in a retrograde fashion. The lateral lobes are then dissected at a plane between the surgical capsule and the prostate adenoma. The laser is used to incise the attachments of these two structures, and the beak of the resectoscope pushes the adenoma upward, facilitating its separation from the capsule. Next, a groove is created at the extreme anterior aspect of the prostate and joined to the previous plane of dissection. The lobe is then freed from the capsule and pushed into the bladder, morcellated, and evacuated. The same steps are repeated for the contralateral lobe. If a morcellator is not available, the prostate is not completely freed from its final attachments, and the laser is used to incise the prostate into pieces small enough to be evacuated. The final attachments can then be separated from the capsule after this step.

Adverse Events

- Bleeding
- Perforation of the prostate
- Bladder neck contracture
- Urinary incontinence

Laser prostate surgery typically results in relatively little bleeding. Hemorrhage is more likely in men with large and very vascular prostates. However, even in such cases transfusion is rarely required. Perforation of the prostate may happen when the depth of the ablation or resection is poorly controlled. Bladder neck contracture is rare, particularly with HoLEP, and if it does occur it can usually be corrected with a transurethral incision procedure. Urinary incontinence may result from damage to the urethral sphincter but is unlikely if appropriate margins of ablation are carefully maintained.

Future Directions

- Development and validation of higher power Holmium: YAG and Greenlight™ lasers.
- Novel laser sources (e.g., Thulium:YAG and Diode Laser).
- Comparative studies of different laser techniques

Currently there exist only limited data regarding the outcomes of treatment with the latest Greenlight™ 180 W XPS laser system. The key feature of this new device is the high speed of vaporization which should translate into superior tissue ablation. Indeed, in a comparative study of 120 W HPS and 180 W XPS laser vaporization of the prostate performed by one surgeon, the operating time and lasing time were significantly shorter in the XPS group [27]. Given the rather generous mean prostate volume of 79.1 cm^3 in this series, these findings suggest that the new Greenlight™ device can be used efficiently for prostates of any size. However, further studies are required to confirm this.

The Thulium:YAG laser, operating in a continuous mode at wavelengths ranging from 1940 to 2013 nm, is a relative newcomer to the arena, introduced as a would-be alternative to the holmium laser for soft tissue applications. The thulium laser utilizes a front-firing fiber and provides excellent tissue cutting and hemostasis. Unlike Holmium:YAG, the Thulium:YAG laser fiber does not pulsate, which may slightly increase its ease of use. The optical penetration of 0.2 mm results in powerful vaporization. After treatment, the prostatic bed has a slightly charred appearance, as opposed to the fluffy white appearance that remains after Ho:YAG therapy. Due to the powerful vaporization effect, procedures utilizing Thulium:YAG are best labeled vaporesection and vapoenucleation (Table 8.3), although for the latter procedure the term ThuLEP is commonly used. Currently, Thulium:YAG is mainly used for vapoenucleation and according to a large cohort study provides high efficacy and perioperative safety [28].

The Thulium:YAG has been compared to mono- and bipolar TURP in several small randomized studies with limited follow-up. Similar to other laser prostate surgery techniques, ThuLEP was associated with shorter catheterization time and hospital stay compared to TURP while functional outcomes were comparable [16]. At this time Thulium:YAG vaporesection of the prostate seems promising, but high-quality evidence is scarce and proper trials with long-term follow-up are lacking.

Modifications in diode lasers have also resulted in renewed application to BPH. Diodes are semiconductors which are able to produce monochromatic light. Light is passed through a crystal, which leads to the final wavelength. Diode laser systems are available in different wavelengths (ranging from 940 to 1470 nm) and fiber designs (side-fire and end-fire). Due to its physical properties the diode laser has significant penetration depth with deep tissue coagulation up to 6.1 mm [29]. This rim of necrotic tissue postoperatively results in sloughing and severe dysuria along with bladder neck stricture formation, as was seen with Nd:YAG visual laser ablation procedures decades ago. Attempts have been made to reduce penetration depth of diode lasers by modulating frequency, pulsation, maximum power, or fiber design. Currently there are several diode laser systems available.

In small comparative trials the outcomes of diode laser vaporization of the prostate and diode laser enucleation of the prostate were similar to those of TURP and other laser procedures, although a trend towards a higher incidence of dysuria, passing of sloughed tissue, and reoperation owing to bladder neck stricture and obstructive necrotic tissue was evident [30]. A novel end-firing fiber with a 30-degree angulation, overlain with quartz for concentrating energy at its tip, and which works only in contact mode, was compared to a side-firing fiber in a small randomized study of prostate ablation [31]. Functional outcomes were similar in both arms, but complications were more common in the side-firing group. Thus, the quartz head fiber may improve performance of diode laser vaporization and requires further study.

Comparative studies of outcomes of different laser prostatectomy techniques remain wanting, as most trials have used TURP as a control. The few available investigations have not demonstrated major differences between the commonly used laser devices. For example, a recent study compared HoLEP with GreenLight™ vaporization of the prostate (HPS 120 W) in 80 patients with large prostates (>60 cm^3) [32]. Operative time and duration of catheterization were similar in both groups, but several conversions to HoLEP or TURP were observed in the Greenlight™ group due to bleeding. With 1-year follow-up, symptomatic improvement was comparable between the groups, while changes in postvoid residual (PVR) and maximum flow rate (Q_{max}) favored HoLEP. In another study, HoLAP was compared to the Greenlight™ (80 W) in 109 patients with prostate volumes less than 60 cm^3 [33]. The operative time was shorter in the Greenlight™ group, while catheterization time and hospital stay were comparable. Significant improvements in symptoms, PVR, and Q_{max} were seen in both groups. The retreatment rate was slightly higher in the Greenlight™ group (25% vs. 19.2%). This area clearly requires further investigation.

Urethral and Ureteral Strictures

Introduction

- Urethral and ureteral strictures usually result from trauma and iatrogenic injury.
- Cold knife or electrosurgical incision and balloon dilation provide inconsistent results.
- Open surgical repair is the gold standard, but is associated with greater morbidity for ureteral strictures.
- Holmium and Thulium lasers have been used for treating strictures with some success.

Strictures of the ureter and urethra may result from injury (iatrogenic and traumatic), stones, infection, and radiation therapy. Open surgical reconstruction involving removal of the diseased segment and re-anastomosis of healthy tissues remains the most definitive type of treatment. The significant morbidity associated with open repair, particularly of ureteral strictures, provided impetus for development of minimally invasive procedures such as balloon dilation and incision using cold knife, electrocautery, and holmium laser. These techniques have met with variable success, and as more urologists receive training in urethral reconstruction, it is expected that reparative urethroplasty, which has excellent success rates, will doom incision procedures for urethral strictures. Similarly, the widespread dissemination of robotic assisted laparoscopy has provided urologists with a less invasive, but highly effective alternative to open ureteral reconstruction, possibly making endoscopic ureteral stricture incision a thing of the past.

Indications

Indications

- Short (less than 2 cm) ureteral or urethral strictures.

  Contraindications

- Ureteral or urethral strictures longer than 2 cm.

Stricture length is the most important parameter predicting treatment outcome of minimally invasive incisional treatment. Thus, patients with short strictures are the best candidates for endoscopic laser urethrotomy or ureterotomy. When the narrowing is longer than 2 cm, laser therapy is rarely effective and such patients should undergo open or laparoscopic reconstruction.

Technique

Ureteral Strictures

- Full thickness incisions with Holmium laser settings of 1–1.2 J and 10–15 Hz.
- Postoperative ureteral stenting for 4–6 weeks.

  Urethral strictures

- Incisions at 6 and 12 o'clock.
- Postoperative urethral catheterization

Laser ureterotomy is usually accomplished with a ureteroscope, but may also be performed via a percutaneous antegrade approach depending on stricture location. A safety wire guide is used to traverse the stricture. Location of the incision in the ureteral wall depends on stricture location. A computed tomography scan will provide excellent guidance on avoiding incision towards periureteral structures immediately adjacent to the site of the stricture. For example, incision should be on the posterolateral wall in patients with proximal ureteral strictures, and on the anteromedial wall for distal strictures. If the narrowing is in proximity to the iliac vessels, incision should made on the anterior wall. A full thickness incision, extending into periureteral fat and ranging several millimeters into normal appearing ureter on both the proximal and distal margins, is mandatory. Multiple passes of the laser are often necessary to achieve adequate depth. In the ureter it is very challenging to make a focal longitudinal incision, especially using a flexible ureteroscope, and great care must be taken not to thermally injure a wide sector of the ureteral circumference. Typical laser settings include energy of 1–1.2 J and rate of 10–15 Hz. A balloon catheter may be inflated across the stricture before or after the laser incision to facilitate tissue separation. Injection of radiographic contrast media through the scope should reveal extravasation at the site of incision. A ureteral stent is then positioned and remains in situ for 4–6 weeks. Success rates of up to 80% have been reported in carefully selected patients with short strictures [34].

Urethral stricture incision is performed via cystoscopy. A safety wire guide is positioned traversing the stricture into the bladder, and then the stricture is incised at the 12 o'clock position. A 6 o'clock counter-incision may be necessary if a single urethrotomy seems inadequate. Laser settings are similar to those previously described for the ureter. No studies determining optimal duration of post-procedural urethral catheterization exist. Most urologists leave a catheter for several days, which is likely inadequate given that healing occurs by scarring and in-growth of tissue from the cut edges. A meta-analysis of laser versus cold knife urethrotomy demonstrated an average success rate of 75% for the former compared to 69% for the latter [35]. There were no differences in serious complications, suggesting that use of lasers for urethrotomy is well tolerated.

Laser incision of strictures is a very safe procedure. The most significant intraoperative complication is bleeding, which can typically be managed with Foley catheter tamponade of the urethra. Avoidance of vascular structures such as the corpora cavernosa is necessary and not difficult to accomplish. During laser endoureterotomy bleeding can occur if a periureteral vessel is entered. If the vessel is small, bleeding will be self-limited. Large vessels can be avoided with appropriate choice of incision site on the ureteral wall as previously described.

Other Applications of Lasers in Urology

Less common applications of lasers in urology include laser ablation of non-muscle invasive bladder tumors using holmium or KTP lasers [36], laser ablation of penile lesions including penile cancer with Nd:YAG and CO_2 devices [37], laser incision of ureteroceles [38], laser ablation of urethral hair in patients with prior urethroplasty or hypospadias repair [39], focal laser ablation for prostate cancer [40], and laser partial nephrectomy [41].

Laser partial nephrectomy holds some very interesting potential given the dramatic increase in small, asymptomatic renal masses detected with ever widespread use of axial imaging over the past two to three decades. Most such neoplasms are amenable to treatment with nephron-sparing surgery, in which only the diseased tissue and a small rim of normal kidney parenchyma are resected, either via an open or minimally invasive (laparoscopic or robotic assisted) approach. Due to the abundant vascularity of renal parenchyma, hemostasis is a major concern associated with partial nephrectomy. Traditionally, renal blood flow is interrupted during resection of the mass. This requires dissection of the renal hilum with clamping of the arterial and sometimes venous supply of the kidney and, more importantly, results in ischemia which may negatively affect kidney function. The excellent cutting and coagulation properties of many lasers suggest their potential use in partial nephrectomy to provide bloodless tumor excision while avoiding ischemia. Almost all existing laser systems have been assessed for both open and minimally invasive nephron-sparing surgery, however most of the trials were performed in small single-institution cohorts [41]. The most promising results have been seen with the thulium laser. Several groups have successfully reported successful laparoscopic partial nephrectomy without clamping of the renal vessels using this device [42, 43]. This technique clearly merits further investigation.

Conclusions

It is truly difficult to imagine contemporary urology without laser devices. The combination of both the power and precision of laser energy has promoted multiple applications in the field, especially laser lithotripsy for urinary stones and laser surgery for BPH, as well as incision, ablation, and excision of other structures and lesions. New, less expensive but more powerful, versatile and compact systems continue to be developed, creating novel opportunities for minimally invasive treatments and improving on existing applications. A typical example of this is the evolution of laser prostate surgery which accompanied the development of holmium, KTP, and thulium laser platforms, as well as the increasing power of subsequent generations of these lasers. In the future, even smaller and more efficient laser technologies, such as fiber lasers, may become available and replace current solid state devices. Applications of high-power lasers may further disseminate to other procedures requiring strong hemostatic efficacy such as laser laparoscopic partial nephrectomy, which is still in its infancy. Further innovation will no doubt promote increasing use of lasers even more dramatically for both benign and malignant genitourinary conditions.

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9 Lasers in Cardiology and Cardiothoracic Surgery

Andrew Whittaker, John Rawlins, Allyne Topaz, On Topaz, and Peter O'Kane

Abstract

History and rationale for laser in the treatment of cardiovascular diseases.

Early applications, growing expectations and the development of realistic perspectives.

Current indications and applications: coronary, peripheral, TMR, EP.

Technique of lasing and catheter technology.

Adverse outcomes.

Future potential.

Keywords

Laser · Atherectomy · Coronary intervention
Calcified coronary lesions
Coronary thrombus · Saphenous vein grafts
Coronary stents · Intracoronary imaging

Box 1: Introduction

- History and rationale for laser in the treatment of cardiovascular diseases
- Laser catheter design and technology
- Early clinical applications, growing expectations and the development of realistic perspectives
- Current cardiovascular indications and applications: coronary, peripheral, TMLR, electrophysiology
- Future potential

Introduction

Utilization of lasers in cardiovascular medicine began some two decades after the first therapeutic application of medical lasers had occurred in the field of dermatology. The 1980s heralded the introduction of lasers for the treatment of atherosclerotic vascular disease, initially exploited for the treatment of critical limb ischaemia [1]. It was the absorption properties of laser light by

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© Springer International Publishing AG, part of Springer Nature 2018
K. Nouri (ed.), *Lasers in Dermatology and Medicine*, https://doi.org/10.1007/978-3-319-76220-3_9

atherosclerotic material that created the hypothesis that laser could treat a variety of coronary and peripheral occlusions that were considered "non ideal" for standard balloon angioplasty [2]. The concept of using laser to debulk or ablate coronary atherosclerosis followed and laser gained momentum as a potential method to remove atherosclerosis and reduce the rate of vessel restenosis and occlusion that accompanied coronary balloon angioplasty [3]. Initial studies predicted that laser would render coronary bypass surgery an unnecessary operation as preliminary experience reported successful plaque removal [4–6].

Publication of several large scale successful clinical trials during early experience with laser led to a conviction that laser had established a prominent role in interventional cardiology [7, 8]. However, the application of the device in cardiac catheterization laboratories was limited by technical difficulties. The devices were very large, cumbersome to handle and necessitated lengthy warm up and calibration time. The laser catheters were also very rigid restricting their deliverability to the lesion particularly when sited more distally or within tortuous vessel segments. Lasing technique was basic with a tendency for rapid advancement of the catheters across the target lesions which did not permit adequate absorption of the laser energy within the irradiated plaque and thus did not yield the maximum ablative potential of the device.

Therefore, although initial laser experience in cardiovascular medicine was positive, limitations in laser catheter technology and an incomplete understanding of laser-tissue interaction combined with the inevitable early frequency of significant complications including abrupt vessel closure, thrombosis and vessel dissection, dampened the expansion of this therapy [9, 10]. However, despite concurrent development of coronary stents that solved some deficiencies of balloon angioplasty, there remained a desire amongst enthusiasts to develop laser in the field of coronary intervention. Refinements in catheter design permitting smaller laser generators [11] and introduction of safe lasing techniques emphasizing slow debulking and concomitant injections of saline [12, 13] led to significant improvement in clinical outcomes [14]. With better understanding of laser as a treatment modality, numerous indications were soon established for utilization within the field of cardiovascular medicine.

In contemporary percutaneous coronary intervention (PCI) practice laser is used in the cardiac catheterization suite for treatment of coronary atherosclerotic vascular disease, for peripheral vascular disease, surgically for trans-myocardial revascularization and for pacemaker/AICD lead removal in electrophysiology laboratories. There are emerging technologies utilizing laser for atrial fibrillation ablation.

How Lasers Work in Cardiovascular Medicine

Laser devices harness light of a specific wavelength to generate a unidirectional beam of high-intensity light that can be directed towards on object of interest. The wavelength of the emitted light is used to categorize the type of laser (Table 9.1). The depth of penetration of the laser is directly related to its wavelength, with laser in the ultraviolet range (shorter wavelength) having less depth of penetration, less heat production, and less unwanted tissue damage. The excimer (excited dimer) laser emits light at 308 nm with a typical absorption depth of 50 μm (Fig. 9.1). The original Nd-YAG and Argon medical lasers emitted infra-red light continuously, which resulted in excess heat production and tissue injury and inflammation, explaining the high rates of throm-

Table 9.1 Different types of laser categorized by emitted light wavelength

XeCl[a] (Excimer)	308	0.05	Protein-lipids
Nd:YAG[b]	1060	2.0	Protein-water
Dye	480	0.5	Protein
Argon	488	0.5	Protein
Ho:YAG[c]	2060	0.3	Water
Nd:YAG	1320	1.25	Water

[a]Xenon chloride
[b]Neodymium-doped yttrium aluminium garnet
[c]Holmium yttrium aluminium garnet

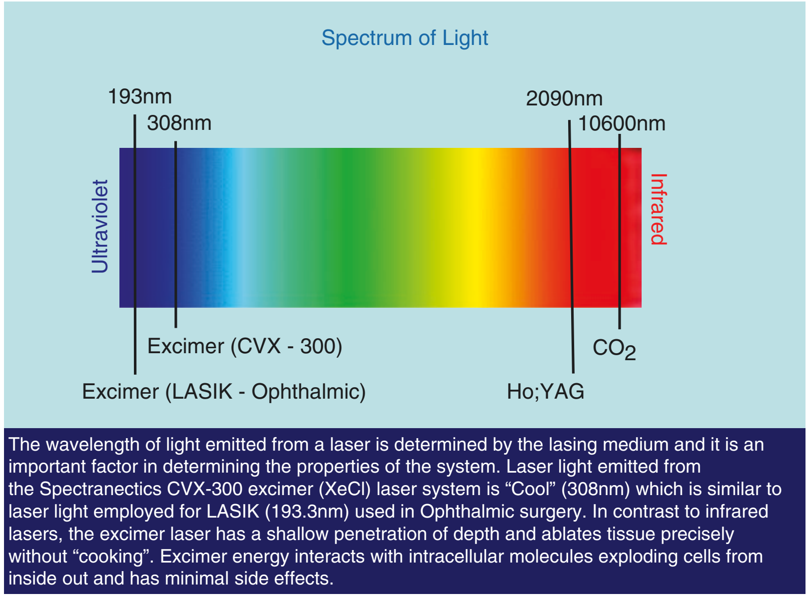

Fig. 9.1 Wavelengths of medical lasers. A figurative representation of the spectrum of light demonstrating the wavelength of light used in Excimer laser systems (308 nm for the CVX-300 used in coronary intervention) relative to that used in OCT (1300 nm—within the infra-red spectrum), and other forms of industrial Laser (Ho;YAG and CO2)

bosis and vessel damage/dissection. The newer excimer laser systems deliver the light in short bursts or 'pulses' during a period of between 5 and 10 s. This approach minimizes heat production and allows the emitted energy to disperse during the "off" period. The number of pulses generated during 1 s (known as the frequency) can be modified at the operator's discretion. Fluence refers to the amount of energy delivered in mJ/mm^2 and the frequency relates to the on/off repetition rate per second. These values are typically presented as numerical values with fluence first and frequency second e.g. 60/40.

Excimer laser tissue ablation within the cardiovascular system is mediated through three distinct mechanisms: photothermal, photochemical, and photomechanical. UV light is rapidly and effectively absorbed by intravascular tissue and thrombus, and the absorbed light breaks carbon bonds so weakening the structure of the cells (photochemical). Delivery of UV light aggravates molecular bonds, which elevates the temperature of intracellular water, eventually producing water vapour causing the cells to rupture. The generation of a vapour bubble cloud at the tip of the catheter enables controlled disruption of the atherosclerotic material (photothermal). Expansion and implosion of these vapour bubbles generates the photomechanical effect as the pressure is released from the vapour bubble, further disrupting the obstructive intravascular material as well as sweeping the freed particles downstream (photomechanical). The vast majority of the fragments released during laser atherectomy are >10 μm in diameter and are easily filtered by the reticuloendothelial system downstream which avoids microvascular obstruction and no-reflow phenomena.

Excimer Laser Equipment and General Technique

The majority of cardiovascular applications of laser utilize excimer laser technology; therefore we will focus on this modality. The only available excimer laser coronary atherectomy (ELCA) system is manufactured by Spectranetics, Inc. Colorado, USA. The excimer laser light is produced by a transportable generator that is powered by mains electricity with a standard plug suitable for each country (Fig. 9.2). There are a several catheters available in a variety of sizes that are tailored to the relevant clinical application (Fig. 9.3). The catheters are available as

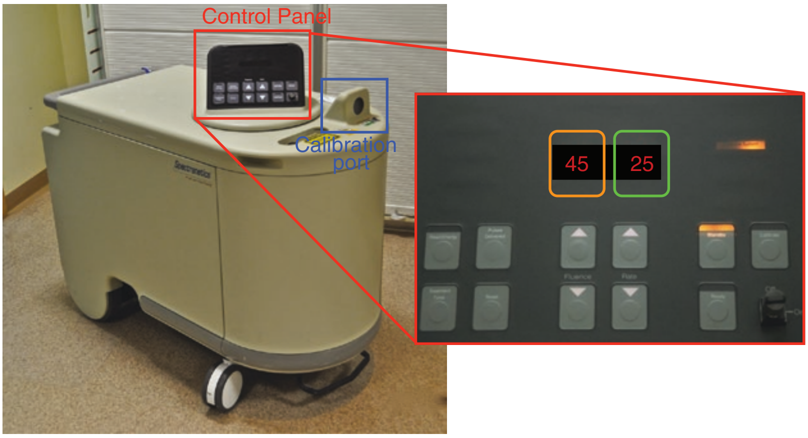

Fig. 9.2 Excimer laser generator (Spectranetics® Colorado Springs, CO, USA). The Spectranetics CVX-300 system system which is a portable unit 89 cm high, 124 cm long and 61 cm wide weighing approximately 295 kg. The system can emit laser energy from 30–80 mJ/mm² (indicated within the orange panel) with repetition rate from 25 to 80 Hz (indicated in green) and a pulse width range of 125–200 ns (nominal 135), altered via the control panel (red). Prior to introduction of the laser catheter, it should be calibrated by pointing the tip of the catheter towards the energy detector (highlighted in blue) on the CVX 300 unit itself and activating the laser by pressing the foot pedal for 5 s. The laser calibrates automatically and enters standby mode

RX	0.9mm	0.9mm X-80	1.4mm	1.7mm	1.7mm Eccentric	2.0mm	2.0mm Eccentric
Model Number	110-003	110-004	114-009	117-016	117-205	120-009	120-008
Guidewire Compatibility (in)	0.014	0.014	0.014	0.014	0.014	0.014	0.014 / 0.018
Guide Catheter Compatibility (F)	6	6	6 / 7	7	7	8	8
Minimum Vessel Diameter (mm)	1.5	2.0	2.2	2.5	2.5	3.0	3.0
Max Tip Outer Diameter (in)	0.038	0.038	0.057	0.069	0.066	0.080	0.079
Max Shaft Outer Diameter (in)	0.049	0.049	0.062	0.072	0.072	0.084	0.084
Working Length (cm)	130	130	130	130	130	130	130
Fluence (mJ / mm²)	30-60	30-80	30-60	30-60	30-60	30-60	30-60
Repetition Rate (Hz)	25-40	25-80	25-40	25-40	25-40	25-40	25-40
Laser On / Off Time (sec)	5 / 10	10 / 5	5 / 10	5 / 10	5 / 10	5 / 10	5 / 10

OTW	0.9mm	0.9mm X-80
Model Number	110-001	110-002
Guidewire Compatibility (in)	0.014	0.014
Guide Catheter Compatibility (F)	6	6
Minimum Vessel Diameter (mm)	1.5	2.0
Max Tip Outer Diameter (in)	0.038	0.038
Max Shaft Outer Diameter (in)	0.049	0.049
Working Length (cm)	130	130
Fluence (mJ / mm²)	30-60	30-80
Repetition Rate (Hz)	25-40	25-80
Laser On / Off Time (sec)	5 / 10	10 / 5

Fig. 9.3 Sizes of laser catheters commercially available for human use. Table of excimer laser catheters produced by Spectranetics® Colorado Springs, CO, USA

over-the-wire or monorail (rapid exchange) devices and laser fibre arrangement is either eccentric or concentric (Fig. 9.4), each having relevant applications. Specific catheters will be referred to in subsequent sections of this chapter. Safety is paramount and therefore prior to the excimer laser being activated all persons in the room, including the patient, MUST wear protective spectacles to minimize the risk of retinal exposure and all windows should be covered and the doors should be locked. Following this safety checklist, the laser unit is warmed up and then the selected catheter is plugged into the generator and calibrated prior to being introduced into the body. Laser catheter size selection is primarily based on (a) the severity of the lesion, (b) the reference vessel diameter, and (c) consistency of the target material [15].

In general the 0.9 mm X80 catheter is used in non-crossable, non-dilatable fibrocalcific lesions given its excellent deliverability characteristics and because this catheter can emit the most power (80 mJ/mm²) at the highest repletion rate (80 Hz) necessary for 'balloon resistant' coronary lesions.

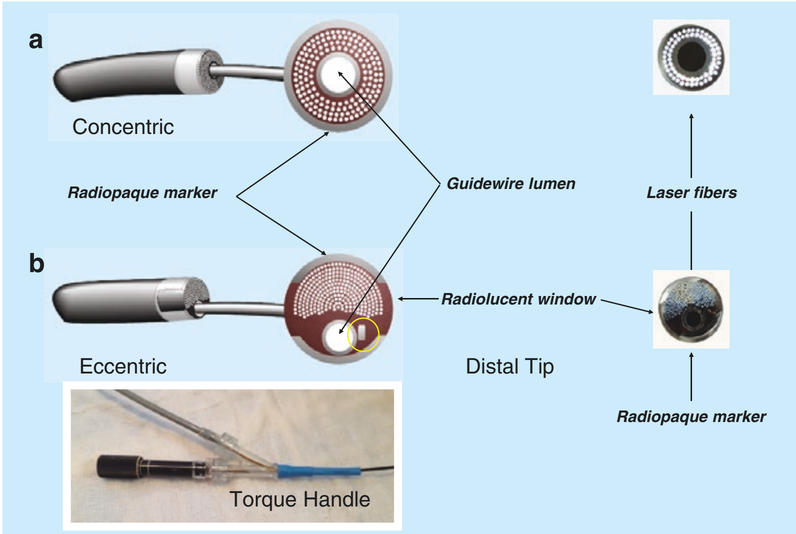

Fig. 9.4 Currently, each disposable ELCA catheter contains a bundle of very pure fused silica (synthetic quartz) fibres since ordinary glass or polymer fibres such as that used for telecommunications will not conduct UV light at useful power levels. Up to 250 individual fibres are used in each catheter with a fibre diameter of 50–140 mm. The use of these multiple fibres is preferable since it permits catheter flexibility and improves deliverability. At the distal end of the concentric catheter the fibres are potted in epoxy around a guide-wire lumen and polished to an optical finish. At the proximal end of the catheter, a laser coupler holds the fibres in a bundle to receive the laser beam. At the proximal end of the eccentric catheter (Illustrated in panel **b**i), a torque handle allows rotation of the device around the torque wire (highlighted within the yellow circle), and with catheter manipulation enabling systematic quadratic tissue ablation

The larger (1.4–2.0 mm) catheters are used in larger diameter vessels with straight segments and are therefore particularly useful when dealing with heavy intra-coronary thrombus or in the treatment of saphenous venous grafts (SVG). In some circumstances more than one catheter may be required, gradually increasing size based on the result obtained from the initial laser procedure. For intravascular applications, the laser catheter is delivered to the appropriate clinical site via a percutaneous guiding catheter and intravascular wire. In the coronary circulation the laser catheter is compatible with any standard 0.014″ guidewire which is a major advantage over alternative atherectomy systems that require a dedicated guidewire.

The guide catheter must then be flushed with 15–20 mL of normal saline to remove all contrast and blood prior to lasing. The laser catheter is positioned a few millimeters proximal to the lesion and using a foot pedal it is activated and slowly advanced forward under fluroscopic guidance. For the coronary catheters the duration of each lasing train is preset so for the standard catheters activation will automatically stop after 5 s with a 10 s rest period before the next laser train can commence. The X80 0.9 mm catheter permits 10 s activation and 5 s rest period reflecting its use in more complex lesions subsets. In contrast to the coronary catheters those used in the peripheral circulation (Turbo Elite™) do not have automatic preset timings and permit continuous laser activation with the operator determining the duration of each lasing train.

The excimer laser energy is delivered in pulses as the catheter is slowly (0.5 mm/s) advanced through the lesion. Since the depth of the excimer laser penetration is shallow (35–50 μm) the slow advancement along the target lesion provides adequate absorption of the emitted light energy into the lesion and subsequent ablation of the atherosclerotic plaque and thrombus. Upon completion of several trains of emission along antegrade laser propagation the laser catheter should perform retrograde lasing particularly in severe lesions when there is resistance for antegrade crossing. Continuous saline flushes accompany all stages of the procedure to reduce adverse augmentation of acoustic shock waves from interaction between the contrast media or blood and the laser light. Application of laser in blood or contrast media is rarely performed in certain specific situations, but should only be undertaken by experienced operators (see later sections).

Current Indications

Table 9.2 presents the current indications for use of laser in cardiovascular medicine. Careful case selection is integral to ensuring successful laser procedures. In acute coronary syndromes (ACS) or acute myocardial infarction (AMI) caused by obstructive plaque and associated thrombus, restoration of normal antegrade coronary flow is crucial for preservation of the myocardium. As the laser devices interact uniquely with plaque and thrombus, they can be successfully applied in these patients [16, 17]. An important advantage of laser PCI (both holmium:YAG [18] and excimer laser) is its safe application in patients with depressed left ventricular ejection fraction (LVEF). When the outcome of ELCA and stenting was compared in patients with depressed ejection fraction [mean LVEF = 28 ± 6%] versus those with preserved ejection fraction [LVEF = 53 ± 8%], successful debulking and thrombus removal was achieved irrespective of baseline ventricular function [19].

Table 9.2 Current indications for use of laser in cardiovascular medicine

1. Percutaneous treatment of atherosclerotic coronary artery disease
(a) Acute myocardial infarction, especially with large thrombus burden
(b) Chronic total occlusions
(c) Non-crossable or non-dilatable stenoses
(d) Degenerative saphenous vein grafts
(e) In-stent restenosis
(f) Under-expanded metallic stents
(g) Fibrotic aorto-ostial plaques
2. Cardiac electrophysiology
(a) Extraction of pacemaker and defibrillator leads
(b) Atrial fibrillation ablation
3. Cardiac surgical treatment of refractory angina
(a) Transmyocardial laser revascularization (TMLR)
4. Peripheral arterial disease
(a) Superficial femoral artery occlusions
(b) Popliteal artery occlusions
(c) Below the knee arterial occlusions
(d) Renal artery stenosis
(e) Stent restenosis

The Specific Effects of Laser on Thrombus

Thrombus is an integral factor in the pathophysiology of ACS and AMI. The presence of intracoronary thrombus is associated with an increased complication rate both during and after PCI. Laser energy interacts with two essential components of thrombus: fibrin and platelets. Pulsed wave lasers such as the mid infrared holmium: YAG and the ultraviolet excimer create acoustic shock waves that propagate along the irradiated vessel. These waves carry a dynamic pressure front toward the fibrin mesh within the thrombus. This process disrupts and breaks the fibrin fibers resulting in fibrinolysis and thereby reduces thrombus size [17]. Clinically, the excimer laser has been found to be a useful interventional tool for targeted thrombus removal strategy [18]. This laser also alters the aggregation kinetics of platelets leading to reduced platelet force development and inhibition of platelet activity. This phenomenon of platelets stunning is dose dependent and most pronounced at high fluence levels such as 60 mJ/mm^2 [19].

Contraindications

Laser coronary atherectomy can be safely performed in PCI centers without on-site cardiothoracic surgery but as with all PCI procedures, arrangements for offsite surgical cover must be in place. Other than lack of informed consent and unprotected left main disease [a relative contraindication] there are no absolute coronary contraindications to laser. As for peripheral laser applications, the presence of poor flow in a sole remaining vessel to the lower limb constitutes a contraindication.

Laser Induced Complications and Adverse Outcome

Several procedural and clinical complications can occur with either percutaneous or surgical laser application. These complications, though rare, relate almost without exception to faulty lasing techniques and mistakes in judgment by the operators [10]. Perforation, dissection, acute closure thrombosis, distal embolization and spasm have been reported. There is a clear inverse relationship between complication rate and operator volume.

> **Box 2: Key Points of Cardiovascular Lasing Technique**
>
> - Eccentric and concentric laser catheters are available with rapid exchange and over the wire systems
> - The more severe the target stenosis—the smaller the initial catheter size
> - Laser catheter should be advanced slowly, do not exceed 0.5 mm/s
> - Saline flush should be used each laser-lesion interaction to reduce augmentation of laser induced acoustic shock waves
> - Antegrade lasing should be followed by retrograde lasing along the target

Specific Coronary Clinical Applications and Lesion Subsets Suitable for Laser

Acute Coronary Syndromes and Myocardial Infarction

Patients presenting with AMI represent a medical emergency and frequently exhibit unstable hemodynamic parameters. These patients have marked activation of the clotting cascade with production of large amounts of platelet and fibrin rich thrombus within the coronary arterial vasculature. In most developed countries the recommended treatment for AMI associated with ST segment elevation on the electrocardiogram is immediate emergent PCI (Primary PCI) [20, 21] ELCA is a potentially beneficial revascularization modality given the potential for effective thrombus removal [22], promotion of fibrinolysis [23], platelet stunning effects [24], and concomitant plaque debulking [25] (Fig. 9.5).

However, randomised clinical data regarding for the use of ELCA in AMI is extremely limited. The largest study to date, The CARMEL [Cohort of Acute Revascularization of Myocardial infarction with Excimer Laser] [19] multicenter registry, enrolled 151 AMI patients from 6 centers in the USA, 1 in Canada and 1 in Germany. One in five cases involved a SVG, 13% patients presented in cardiogenic shock and large thrombus burden was present in the infarct related vessel (IRA) in 65% of the patients. Adjunctive glycoprotein IIb/IIIa inhibitor (GPI) was administered in 52% of the cases. Following ELCA, TIMI flow grade was significantly increased from 1.2 to 2.8, along with reduction in angiographic stenosis diameter from 83% to 52%. Overall a 91% procedural success rate, a 95% device success rate and a 97% angiographic success rate were reported [19]. There was a low rate (8.6%) of associated major adverse coronary events (MACE) with a 3% dissection and only 0.6% distal embolization rate encountered. There were no laser induced perforations. Mortality of those presenting in cardiogenic shock was 30%. Importantly, maximal laser effect was observed in lesions laden with a heavy thrombus burden. Separate analysis of the study's data base demonstrated maximal laser luminal gain among those patients who presented with an already established Q wave MI, an ongoing ST segment elevation and large-extensive thrombus burden in the IRA [26]. Further data has suggested that ELCA is capable of removing as much as 80% of the thrombus burden from the treated targets [27]. The first Laser AMI study is the only completed randomized trial of ELCA in acute MI and included just 27 patients. The study demonstrated safety and feasibility but was not powered to determine superiority over conventional treatments [28]. Two other small registries examining the effects of ELCA in ACS suggested a greater outcome with regards to TIMI flow and myocardial blush grade compared with manual thrombus aspiration devices [29, 30]. A second, larger Italian Laser AMI study is currently recruiting up to 194 patients treated with Primary PCI with 1:1 randomization to either ELCA or manual thrombus aspiration followed by standard PCI strategies. The primary endpoint in this study will be MACE at 6 months follow-up.

Non-crossable and Non-expansible Lesions

In contemporary PCI and with an expanding elderly patient cohort, it is not unusual to find that a coronary lesion can be crossed with a 0.014″ guidewire but either a low profile balloon fails to cross or once across the lesion fails to fully expand. ELCA can successfully be applied in this situation (Fig. 9.6). The success rate in uncrossable or undilatable stenoses is high, approaching 90%. However, when these targets are calcified, the response is less favorable to laser debulking than that of non calcified lesions [79% vs. 96%, $p < 0.05$] [31]. In the past, lasers utilizing a wide range of wavelengths encountered difficulties in recanalization of these stenoses. However, following Rentrop's invention of a high energy level excimer laser catheter [capable of producing fluence up to 80 mJ/mm^2 at 80 Hz frequency] for calcified lesions, the device was introduced to the field as the 0.9 mm X-80 catheter and improved results have been reported with this technology [32].

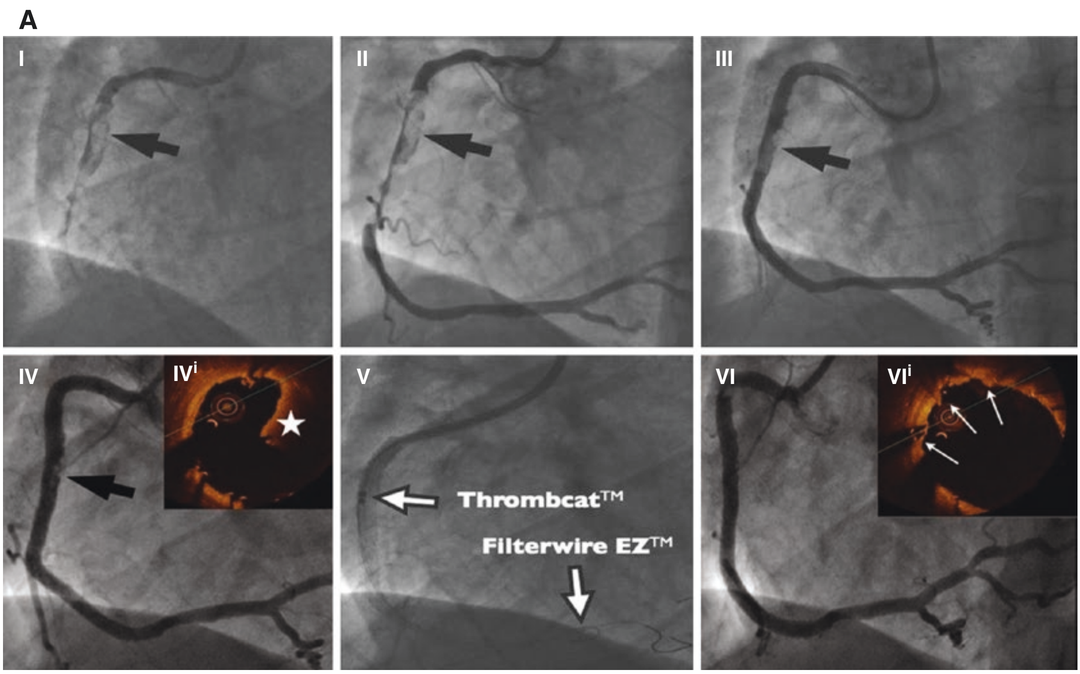

Fig. 9.5 (**A**) Series of angiographic stills that demonstrate: (I) Occluded dominant right coronary artery with a massive intracoronary thrombus (Black arrrows). (II) Establishment of TIMI 2 flow following excimer laser atherectomy. (III) Final result after treatment with three drug-eluting stents with proximal thrombus still evident (Black arrows). (IV) Evidence of proximal red thrombus remains (black arrow), shown to overly stent struts (Panel di—Star indicating residual thrombus). (V) Passage of Thromcat device over distal protection device. (VI) Final angiographic and Optical CT (panel fi) result, with almost complete thrombus resolution (white arrows showing small volume of red thrombus remains adherent to stent struts). (**B**) Contempory management of intracoronary thrombus: 25 year old male presenting with anterior STEMI. (I) Massive thrombus in the LAD, evident on OCT (II). ELCA with excellent effect to reduce thrombus burden angiographically (III), with the underlying lesion treated with an appropriately sized bioresorbable scaffold (final angiographic result—panel (IV) and (V), OCT result (VI) and (VII))

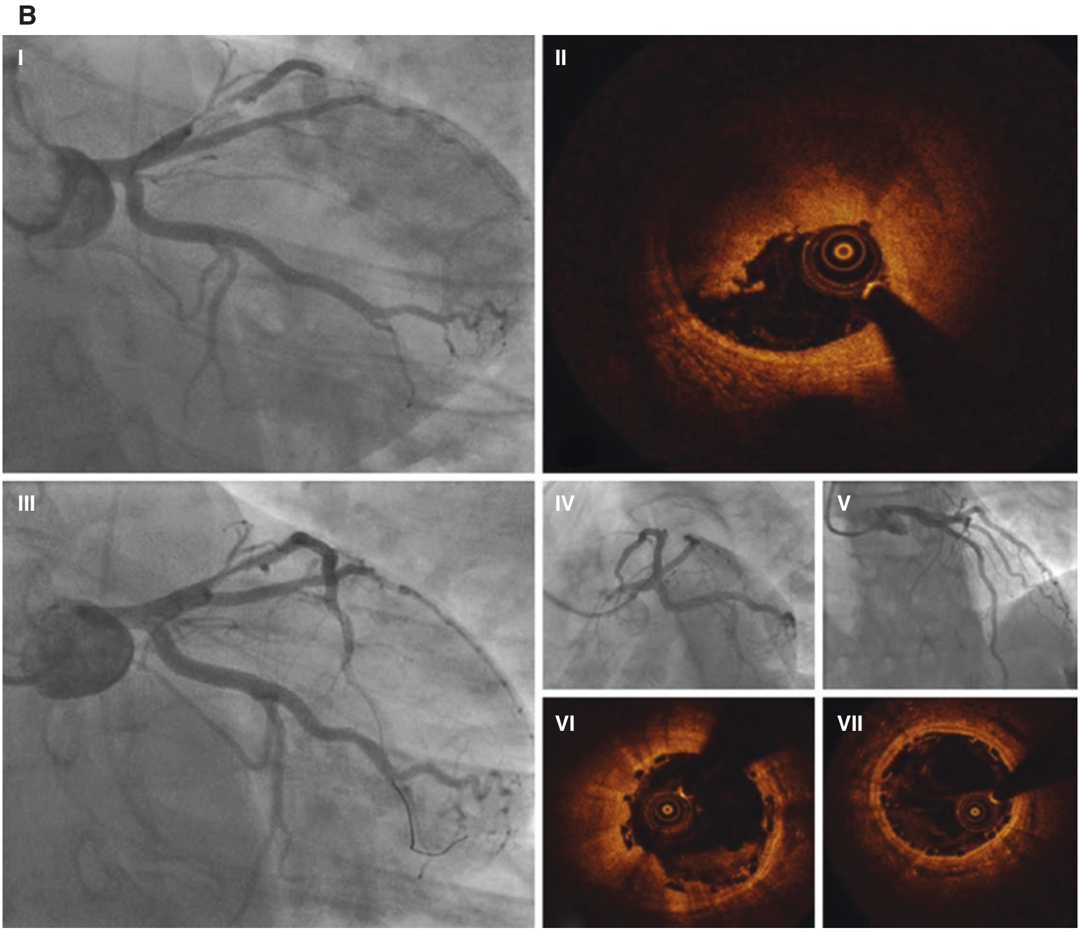

Fig. 9.5 (continued)

In this situation for the non-ELCA operator, rotational atherectomy (RA) would be considered the treatment of choice. Even for the proficient ELCA user, RA would be preferred if there was heavy calcification as it is more effective at debulking. However, this technique requires delivery of a dedicated 0.009″ guidewire which is less deliverable and may not be possible either independently or through a micro-catheter exchange system when the lesion is very stenotic. The combination of ELCA upstream to modify the lesion and create a channel through which a Rotawire™ can be delivered distally and subsequently permit RA was described by our group as Raser (Fig. 9.6). This technique is particularly effective for non-crossable, non-dilatable calcified stenosis and has been demonstrated to have a low complication rate in experienced hands [33, 34].

Chronic Total Occlusions

Chronic total occlusions (CTO) are challenging atherosclerotic stenoses that are frequently difficult to traverse with a guide wire, respond unfavorably to balloon angioplasty and resist stent deployment. There have been significant advances in CTO techniques in recent years with adoption of antegrade dissection re-entry (ADR) systems [35] and increasing utilization of retrograde approach [36]. An extensive array of equipment has been developed to support the CTO techniques and ELCA is considered amongst expert CTO operators to be very helpful within the CTO toolbox to debulk these lesions and facilitate adjunct balloon and stenting [37] (Fig. 9.7). A success rate of 86–90% for ELCA in CTO cases has been reported [38]. From a technical perspective saline is often not used at the

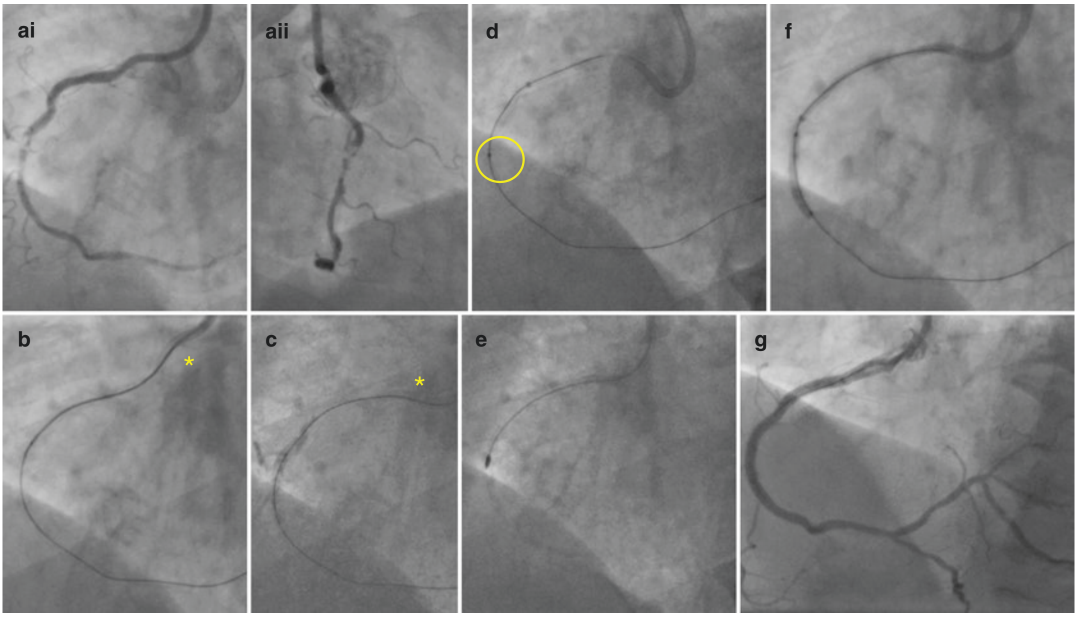

Fig. 9.6 The Uncrossable lesion. Angiographic Panel **ai** and AII demonstrate a severe complex calcific lesion in the RCA. Wire passage was challenging, requiring corsair support. Neither corsair (panel **b**) nor a low profile balloon (panel **c**) would cross the lesion, with multiple balloons bursting within the lesion (panel **d**). After further lasing, rotawire passage was possible. After extensive rotational atherectomy, balloon inflation and stent deployment was possible (panels **e** and **f**)

laser-lesion interface for CTO cases as antegrade injections are usually not desirable in case of hydraulic pressure extending sub-intimal planes leading to hematoma formation.

A CTO is by definition a long standing lesion that contains layers of old, well organized thrombus within calcified and fibrotic plaques. In subtotal occlusions fresh thrombus can form in the area heavily disease with near-occlusive fibrocalcific atheromatous plaque material producing acute-on-chronic occlusion. ELCA can be used successfully to modify the fresh thrombus in addition to facilitating the recanalization of the sub-total chronic occlusion [22].

Under-Expanded Stents

Under-expanded stents represent a high potential for stent thrombosis and in-stent restenosis. There are few PCI options available when confronted with these cases and in most situations where this is encountered, maximal balloon dilatation in terms of diameter and pressure have already been undertaken without success. RA although, an option, risks metal fragment embolization and stalling of the burr. In contrast ELCA is both a safe and effective therapy (Fig. 9.8). Usually the mechanism of under-expansion is fibro-calcific plaque impinging on the stent struts to obstruct full expansion during deployment. Whilst having no impact on the calcification itself, ELCA modifies the plaque behind the stent which weakens the overall resistance, thus enabling subsequent complete stent expansion [39–42]. From a technical perspective this is also an indication for delivering laser energy in contrast or blood (rather than saline) [39–42].

Instent Restenosis

In-stent restenosis (ISR) is caused by focal or diffuse neo-intimal and neo-atherosclerotic tissue growth. Laser debulking of this re-stenotic material may become a preferred treatment over simple tissue displacement by standard balloon angioplasty [43]. Mehran et al. compared excimer laser with adjunctive balloon angio-

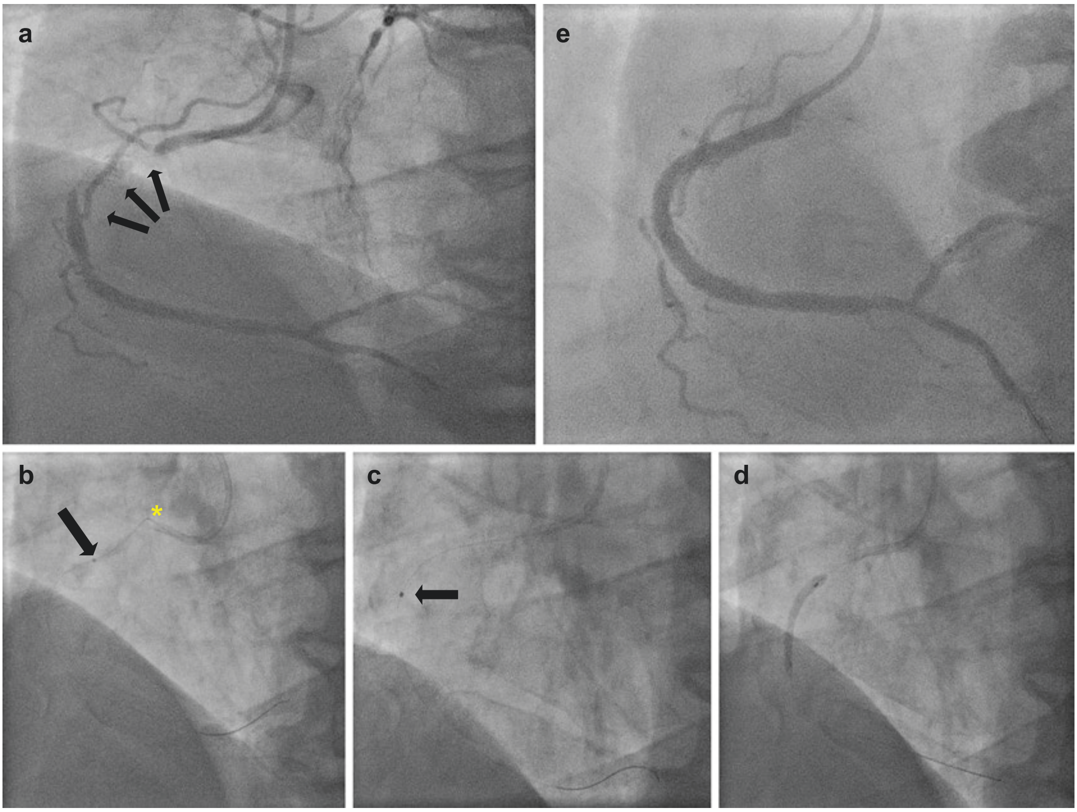

Fig. 9.7 The use of ELCA in CTO intervention. (**a**) Demonstrates the CTO in RCA which appears to be heavily calcified (arrows). (**b**) Failure to advance a low-profile 0.85 × 10 mm balloon (arrow) across the CTO resulting in 'buckling' of the guide-wire and disengagement of the guide-catheter (asterisk). (**c**) 0.9 mm X-80 ELCA catheter is used to debulk, crossing the proximal cap and establishing position within the true lumen. A 2.5 × 20 mm non-compliant balloon is used to pre-dilate the lesion (**d**) and the final result can be seen (**e**), after deployment of overlapping DES

plasty to balloon angioplasty alone and concluded that (a) no complications were associated with the use of laser, and (b) laser resulted in greater luminal gain, greater ablation of intimal hyperplasia, and a tendency toward less frequent subsequent target vessel revascularization [44]. The use of Eccentric laser catheters in treatment of diffuse in-stent restenosis may offer advantages over standard concentric equipment as they can be reorientated in increments of 90° thus providing progressive quadrantic tissue ablation [45] (Fig. 9.9).

Saphenous Vein Grafts

Occlusions in old saphenous vein grafts frequently consist of diffuse or multifocal plaques often containing thrombus. These lesions are degenerative and prone to distal embolization leading to the microvascular obstruction and the no reflow phenomenon, which is associated with adverse clinical outcomes. Despite the presence of a large thrombus burden within these vessels, a success rate of 94% was reported with both ELCA and mid-infrared holmium: YAG laser [46, 47]. The considerable capability of laser to provide safe debulking of these grafts even in the setting of AMI and in the presence of a heavy thrombus burden has been documented [29, 48]. Furthermore, the remarkably low rate of distal embolization during ELCA of degenerative bypass grafts (1–5%) precludes the need for adjunct distal protection device (DPD) in the

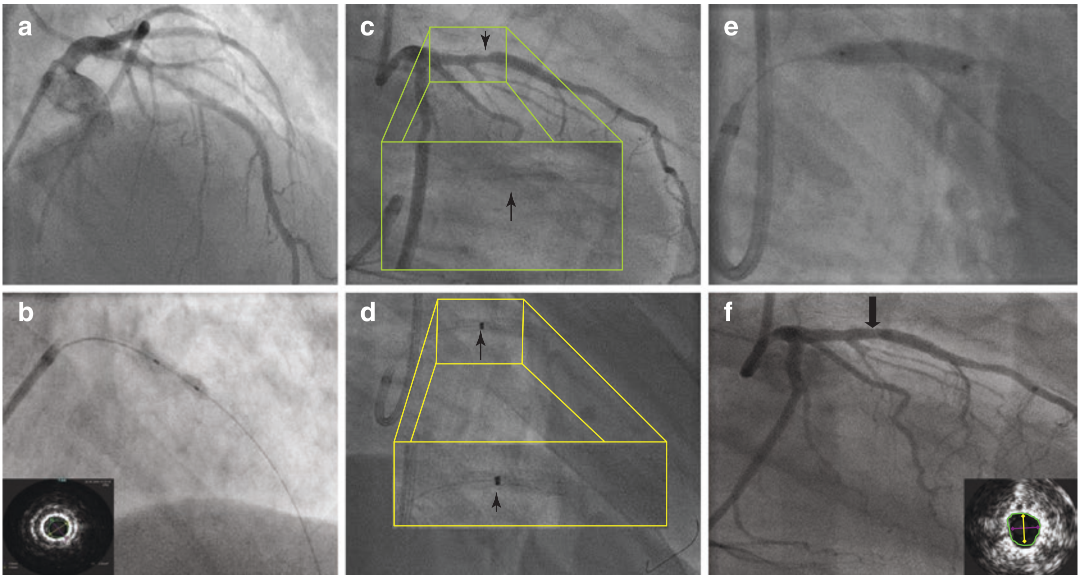

Fig. 9.8 Panel (**a**) illustrates a heavily calcified lesion in the proximal LAD. Despite extensive lesion preparation, including the use of rotational atherectomy (2 burrs), extensive use of non compliant, cutting, and double layer balloons, the lesion remains un-dilated (panel **b**, with IVUS of lesion within the inlay). A stent also failed to deploy, with an under expanded stent is visualised in the proximal LAD. (**d**) A 2.0 mm ELCA catheter is seen within the stent (arrow). The under expanded stent has been magnified in the in set (arrow head). (**e**) Successful balloon dilatation with a 4.25 x 10 mm balloon. (**f**) Final result

majority of cases where the excimer laser is used. However, when OCT has been used to visualize the effects of ELCA in SVG PCI, it is clear that there remain friable fragments that could embolise and cause no reflow [49] (Fig. 9.10). Indeed, one application of ELCA in SVG PCI is purely to create a small channel to deliver a DPD easily to complete the PCI in contrast to full debulking strategy with a larger diameter laser catheter.

Left Main Stem PCI

The role of PCI for unprotected left main coronary artery (LMCA) disease remains a hot topic of debate. Many Cardiologists agree that outcomes of PCI in ostial and mid-body LMCA disease are comparable to those with CABG, however the trial data for distal LMCA bifurcation disease somewhat favours CABG although a number of trials to report imminently look set to challenge that. A role for laser in LMCA PCI has emerged. In a series of 20 symptomatic patients with severe LMCA disease, the ELCA was used for pre-stent debulking (Fig. 9.11). Traditionally, performing a safe percutaneous intervention in the LMCA requires at least partial myocardial protection by patent bypass grafts (protected LMCA). However, in this series patent grafts were present in only 20% of cases with the majority having no distal protection or poor protection from a diseased graft. Nevertheless, successful intervention was achieved in 95% of the patients. The investigators concluded that small size laser catheters, when used with proper lasing technique and adjunct stenting can lead to successful debulking strategy in select patients with left main stenosis [50].

Aorto-Ostial Disease

These resistant atherosclerotic obstructions are usually focal, almost universally fibrotic, and often calcified. Precise laser debulking enables subsequent stenting. The success rate with laser and adjunct balloon angioplasty in two series of patients have been reported as high as 94% [51, 52], thus, far exceeding the relatively low 74–80% success rate for standard balloon angioplasty.

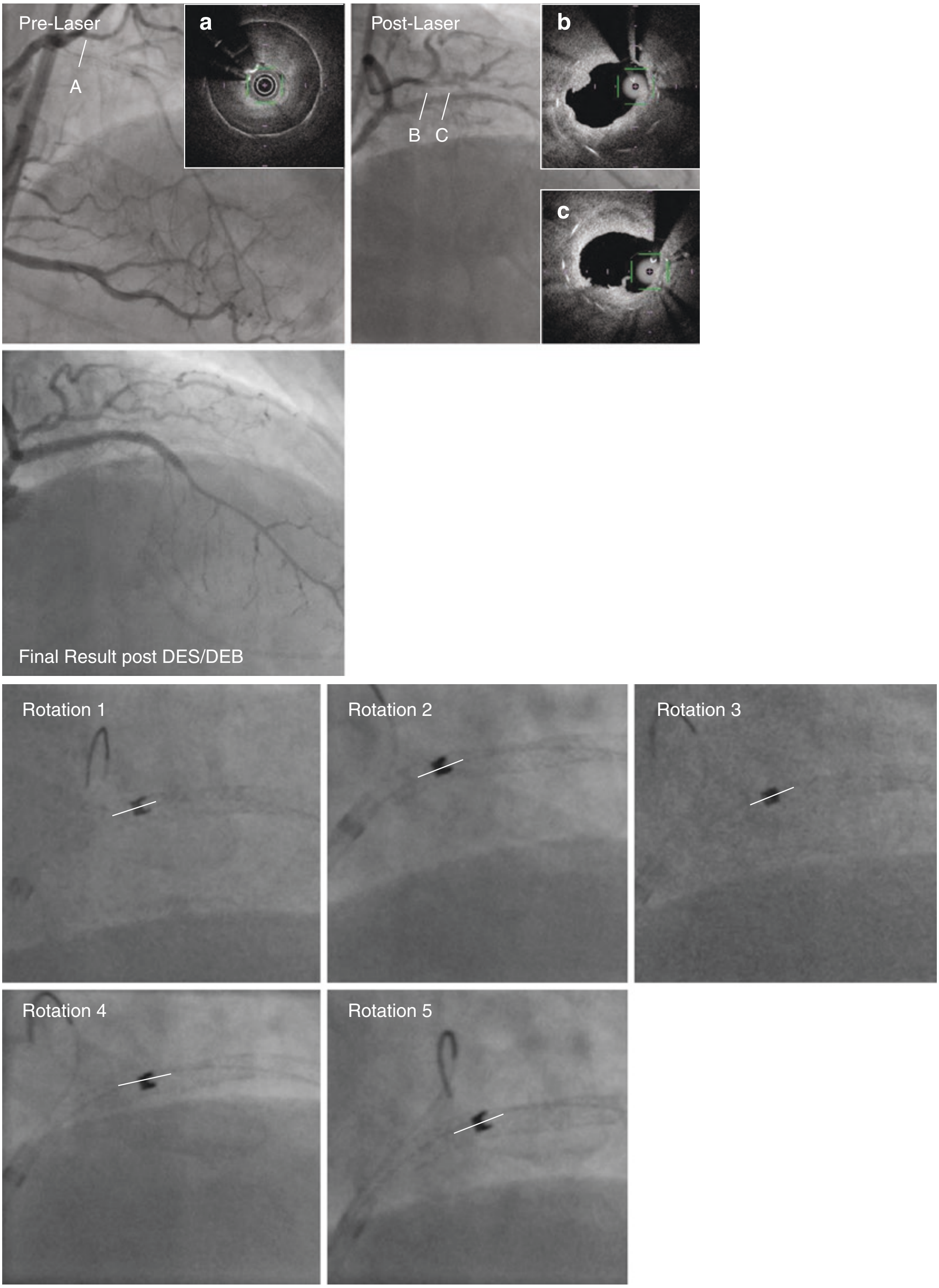

Fig. 9.9 (**a**) Severe concentric In-stent restenosis with near obliteration of the true lumen, with the appropriately sized stent clearly shown on the OFDI image. (**b**) Mid stent after passage of eccentric ELCA catheter, with evidence of tissue having been denuded from the stent surface (white circle). (**c**) Distal stent with a clear eccentric cavity having been created through tissue ablation from the ELCA catheter passage. The case is completed with a combination of new distal edge DES plus drug eluting balloons to the main LAD

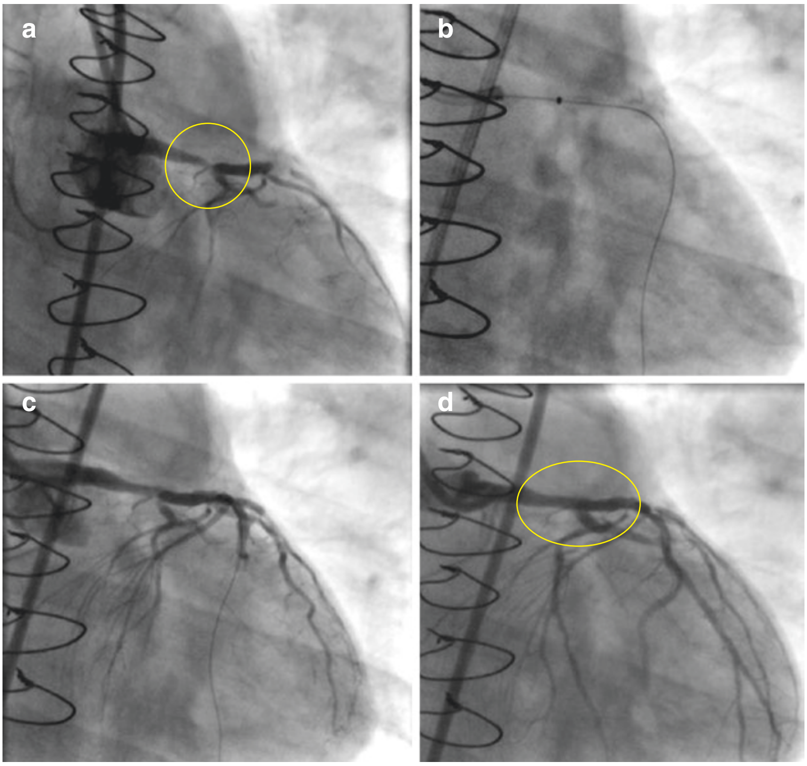

Fig. 9.10 Application of excimer laser in left main coronary artery disease in a patient with unstable angina following recent coronary artery bypass surgery, just 4 weeks prior to presentation. Two saphenous vein grafts had occluded with only the left internal mammary artery remaining patent. (**a**) The critical stenosis at the distal segment of the left main coronary artery (highlighted), with a strategy of performing PCI to the LMS bifurcation. (**b**) Activation of a 0.9 mm X-80 excimer laser [Spectranetics, Colorado Springs, CO] catheter [The radio-opaque tip highlighted and visible], successfully traversing the lesion. (**c**) Adequate recanalization post laser debulking, with maintenance of TIMI flow. (**d**) Final angiographic results post adjunct stenting: patent left main artery is present with good flow into the Circumflex artery. The patient's symptoms were completely relieved

Specific Non-coronary Clinical Applications for Laser

Trans Myocardial Laser Revascularization [TMLR]

This unique revascularization concept is based on the diversion of arterial blood flow into regions of the myocardium that do not receive adequate perfusion as a result of severe atherosclerotic coronary arterial disease. The technique predates coronary bypass grafting and coronary balloon angioplasty [53]. The aim of TMLR procedure is to create multiple 1 mm intramyocardial laser channels [TMLR] within the viable ischemic myocardium. The creation of these channels then promotes angiogenesis with growth of microvessels that provides an alternative blood supply to the treated area of myocardium [54]. The increase in microvessels significantly correlates with the expression of matrix metalloproteinases −2 and platelet-derived endothelial cell growth factor [55]. A specific indication for TMLR is the treatment of patients with refractory angina pectoris who are unable to undergo coronary bypass surgery for pain relief. TMLR has also been incorporated as an adjunct surgical treatment for those who undergo coronary bypass surgery but need further intraoperative revascularization of myocardial regions that cannot be reached with bypass grafts. The TMLR application involves application of specially designed laser catheters under direct vision or under fluo-

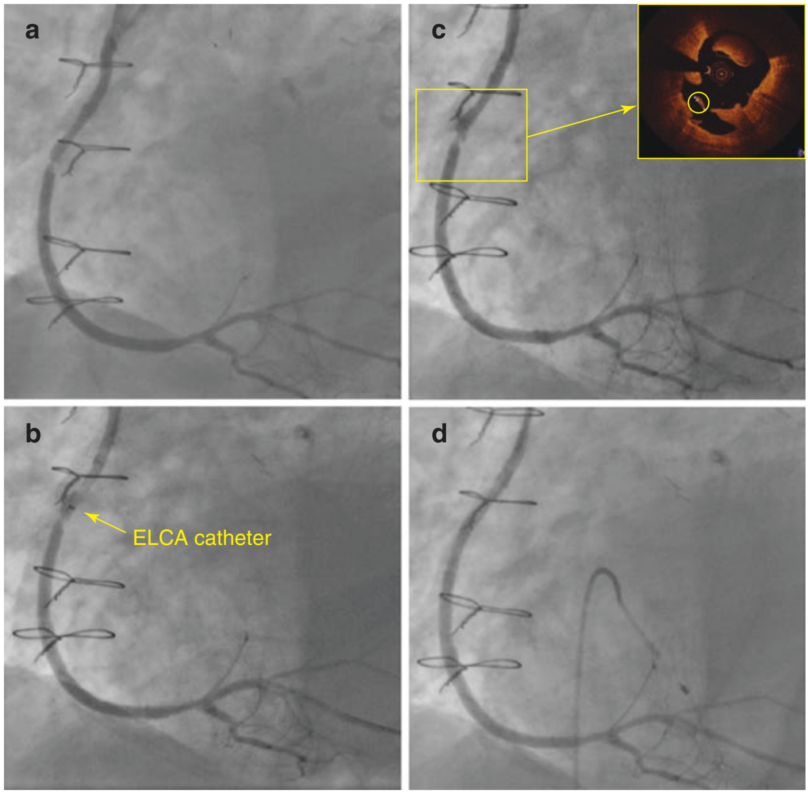

Fig. 9.11 Series of angiographic stills illustrating the role of ELCA in vein graft intervention. Panel **a** demonstrates a severe lesion in the mid SVG. Given its severity, distal protection device passage was not possible, to the lesion was treated with LECA (panel **b**). Panel **c** shows the angiographic and OCT result post ELCA. Crucially, given the soft nature of the plaque contained within SVGs, large fragments (~600 μm) are visible (yellow circle), and use of distal protection devices should be encouraged where possible to minimise any embolic complications. The case was completed with a pericardial stent (panel **d**)

roscopy guidance. These catheters are placed in direct contact against the epicardium and activated with emission of laser fluence inward toward the myocardium. Various laser sources such as CO2, excimer and holmium:YAG have been used for TMLR either surgically or percutaneously for treatment of patients with refractory angina [56]. TMLR has been shown in randomized studies to improve subjective symptoms of angina [57, 58] promote increased exercise time [59] and improve quality of life as compared with maximal medical therapy [60]. Recently it has been proposed that combining TMLR with cell therapy delivered through direct myocardial injections is a safe strategy which may act synergistically to reduce myocardial ischemia and improve functional capacity [61]. However, the precise functional mechanism of angina relief in TMLR remains unclear, and its effect is often transient in many cases [62]. One suggested punitive mechanism, that laser induced thermal damage to cardiac nerves resulting in denervation and subsequent angina relief, has been refuted [63]. Furthermore, whether TMLR results in improved cardiac function remains a controversial issue. It is a procedure that is now rarely undertaken, as both interventional revascularisaton and medical therapy for advanced intractable angina has advanced considerable since the techniques inception.

Laser for Revascularization of Heart Transplant Allograft Vasculopathy

Coronary allograft vasculopathy is a leading cause of late death in heart transplant recipients. Given the surgical complexity of repeat heart transplant, these patients are frequently not considered to be good candidates for the procedure. Hence, endovascular treatment in general, is the preferred, practical management option. However, this strategy has encountered difficulties with balloon angioplasty, directional atherectomy, and direct stenting having all been applied but with results that have been disapointing and less successful than in native vessels [64]. The application of excimer laser through low profile laser catheters appear to provide a unique advantage for revascularization in these challenging target lesions [65, 66]. As long term reduction of restenosis is not expected from the laser alone, adjunct stenting with drug eluting stents is indicated, and may offer reasonable long results.

Laser for Congenital Heart Disease

In certain congenital cardiac defects, the laser can provide means of critical revascularization. For example, the prognosis of infants with pulmonary atresia and intact ventricular septum is poor and presents a major management challenge. Mechanical penetration of the atretic pulmonary valve is an applicable option for decompression of the right ventricle to reduce critically high pressure and improve overall left ventricular function. Percutaneous excimer laser induced ablation of the atretic pulmonary valve can be accomplished safely by a "step by step" technique whereby the tip of the laser catheter is advanced before a guide wire. This recanalization then enables insertion and deployment of a peripheral balloon leading to life saving reopening of the main pulmonary artery. The laser fluence does not damage the surrounding cardiac tissue along this application [67].

Laser in Peripheral Revascularization

Peripheral atherosclerotic arterial disease is a major cause of lower extremity ischemia and limb loss. While several lasers have been investigated for peripheral revascularization [Holmium:YAG, Nd:YAG and excimer], initial experience by Isner and Rosenfield indicated that more favorable clinical results are obtained with the ultraviolet excimer laser [68]. Over the last decade, the excimer laser has gained a recognized role in the treatment of superficial femoral occlusions, popliteal artery stenoses and infra popliteal lesions. These targets cause chronic or critical limb ischemia, claudication and non-healing ulcers. The laser provides safe and efficacious lesion debulking, thrombus removal and facilitates stenting in such targets [69–71]. As for the technique of peripheral lasing Biamino and colleagues have described a gradual "step by step" approach for arterial recanalization with excimer laser. The long occlusions are reached by a guide wire and an over the wire laser catheter. The lesion is traversed by the laser catheter while the guide wire inside the catheter provides stable support. Then as the laser catheter debulks a portion of the obstructive plaque, the guide wire is advanced a few millimeters distally into the occlusion and the laser is reactivated to follow it with debulking [72]. Then the process is repeated until the entire length of the lesion is recanalized [64].

Specific Electrophysiological Clinical Applications for Laser

Device Lead Extraction

Until recently the only option for removal of intracardiac pacemaker or defibrillator leads were either by surgical procedure or traction; however both approaches carried significant risk and complications. The development and application of the excimer laser sheath technology [Spectranetics, Colorado Springs, CO] that delivers ultraviolet light has revolutionized the lead extraction procedure. The energy interacts and ablates the encasing fibrotic tissue surrounding the pacemaker or defibrillator leads making extraction of the entire lead possible without disruption of the myocardium and vascular structures. This results in a predictably high success rate and markedly low complication rate [73]. Furthermore, the excimer laser has been shown to be safe and effective in the removal of device leads associated with central venous obstruction, and in crossing device related subclavian vein occlusion where wire escalation techniques have failed without damaging the in situ lead insulation [74, 75].

AF Ablation/Pulmonary Vein Isolation

Over recent years ablative strategies for atrial fibrillation have grown hugely. These procedures have typically been performed using radiofrequency energy with electro-anatomical mapping. Recently, visually guided laser ablation (VGLA) has been developed which incorporates an endoscope, a laser and a semi-compliant balloon in a system that enables direct visualization of the left atrium and pulmonary veins and delivery of a

980 nm diode laser to isolate the pulmonary veins [76]. This technology appears to be effective with acceptable peri-procedural complications.

Future Potential

Renal Artery Interventions

Since the excimer laser effectively removes coronary and peripheral plaques, conceptually it could also be applied for renal artery stenosis. In an early experience, this technology was found safe and effective in debulking of severe-critical renal artery stenosis. The application of laser energy facilitated adjunct stenting and preserved renal integrity. Improved hypertension control and management of congestive heart failure were observed. This was accompanied by preservation of renal function [77].

Stroke

Thrombus plays a crucial role in the pathophysiology of intracranial stroke. As lasers enhance the effect of thrombolytic agents and favorably interact with thrombus and platelets they may become a unique treatment option for enhanced thrombolysis in selected acute stroke patients [78, 79].

Venous System

Based on the abovementioned description of the favorable interaction between laser light and thrombus and fibrotic tissues, conceivably, selected patients with acute or chronic venous obstructions or thrombosis will benefit from laser treatment.

Summary

Cardiovascular lasers with various wavelengths produce intense electromagnetic energy. This may be utilised in a variety of applications throughout the cardiovascular sstem. Currently, the most common application remains the ablation and removal of coronary and peripheral atherosclerotic plaques. The ultraviolet pulsed wave excimer laser [308 nanometer wavelength] is currently the only laser approved by the FDA for peripheral and coronary interventions in the context of acute and chronic ischemic syndromes. This laser has been shown to effectively debulk atherosclerotic and fibrotic plaques and remove associated thrombus burden. Within the coronary circulation, data would currently support the use of excimer laser in "uncrossable" lesions and the treatment of an under-expanded and re-stenotic stent. The holmium:YAG laser is currently approved for surgical TMLR. Careful case selection, proper utilization of the laser equipment and incorporation of a safe, efficacious lasing technique plays a crucial role in successful laser interventions.

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10 Laser/Light Applications in Neurology and Neurosurgery

Roberto Diaz, Ricardo J. Komotar, and Michael E. Ivan

Abstract

Applications of light in neurology and neurosurgery can be diagnostic or therapeutic. Neurophotonics is the science of photon interaction with neural tissue. Photodynamic therapy (PDT) has been attempted to destroy infiltrative tumor cells in tissue. Spatially modulated imaging (MI) is a newly described non-contact optical technique in the spatial domain. With this technique, both quantitative mapping of tissue optical properties within a single measurement and cross sectional optical tomography can be achieved rapidly. The ability to control the activity of a defined class of neurons has the potential to advance clinical neuromodulation.

Keywords

LITT · Laser interstitial thermal therapy
Optical Coherence Tomography
Fluorescence assisted surgery
Raman spectroscopy · CO_2 laser

- Applications of light in neurology and neurosurgery can be diagnostic or therapeutic.
- Optical Coherence Tomography (OCT) is a non-invasive imaging technique that uses the back scattering of light at different depths from tissue to generate micron scale resolution images from a single imaging plane.

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K. Nouri (ed.), *Lasers in Dermatology and Medicine*, https://doi.org/10.1007/978-3-319-76220-3_10

- Laser interstitial thermal therapy (LITT) is a method for tissue ablation that has shown promising results as a new minimally invasive method for treating brain tumors, radiation necrosis, and epileptogenic tissue.
- Photodynamic therapy (PDT) has been attempted to destroy infiltrative tumor cells in tissue.
- Raman spectroscopy involves rare photon-electron interactions in a molecule and has clinical promise in identifying CNS tumors.

Introduction

The application of lasers to the medical fields of neurology and neurosurgery is described in this chapter. We begin with an overview of laser physics in relation to the nervous system and progress to describing specific applications in neurology and neurosurgery. In general, the use of lasers in neurology and neurosurgery can be classified into the following categories: diagnostic imaging, thermal tissue ablation, photodynamic therapy, and neuromodulation. While laser technology is becoming increasingly useful in neurosurgical treatment of brain tumors, radiation necrosis, and epilepsy, its use in the treatment of non-surgical neurological disorders is still theoretical and experimental.

Laser Interaction with Brain Tissue

Laser light can interact with neural tissue in five principal modalities: absorption, phosphorescence, fluorescence, elastic scattering, and inelastic scattering. Absorption involves the effect of photon electromagnetic energy on chromophores in the tissue and conversion of that energy into heat. Phosphorescence describes the release of a photon with similar or lower energy with a delay period after the incident photon interacts with the tissue. Fluorescence involves the excitation of electrons to higher energy orbitals with electron transitions resulting in release of a photon of lower energy. Elastic scattering involves the deviation of the photon path with no change in energy. Inelastic scattering involves an increase in the wavelength (reduction in energy) of a photon after interaction with molecular components of the tissue, the magnitude of the change being determined by individual molecular components of the tissue.

Light traveling in tissue shows decay in intensity due to absorption of photons by the tissue. The intensity decays exponentially with the depth of penetration (z) at a rate determined by the absorption coefficient of the tissue (α), according to the Beer-Lambert law, $I(z) = I_{(0)}e^{-\alpha z}$. Chromophores are the light absorbing molecules in the tissue. Ultraviolet light has very short penetration due to avid absorption by organic molecules such as DNA and proteins. The principle brain chromophore for light in the visible range is hemoglobin. Near-infrared (NIR) wavelength light is used in lasers designed to generate thermal energy in brain tissue in order to permit greater penetration into tissue since water is the main chromophore for NIR light and NIR light shows less scattering than visible light in tissue. In the NIR region, the absorption spectra of water and other primary chromophores, such as lipids, and oxy and de-oxy hemoglobin are different (Fig. 10.1). The greater brain penetration of NIR light (940 nm) versus blue light (453 nm) has been confirmed experimentally in mouse brain [1]. Lipids absorb avidly in the NIR range, which suggests theoretically faster heating of white matter than grey matter may be achieved with NIR laser light given the lipid density of white matter. The absorption coefficients of astrocytoma is higher than that of normal brain, allowing for preferential deposition of light energy in these tumors [2].

The brain has intrinsic fluorescence when excited by high-energy light in the UV to green range due to high proportion of aromatic amino acids (tryptophan, tyrosine, phenylalanine), high NADH content due to energy demands, and presence of lipids and vitamins (A, K, D). Fluorescence involves the transfer of energy from a photon to a lower molecular orbital electron transition to a higher molecular orbital, and decay of the electron down to a lower energy molecular orbital releasing a photon of lower energy.

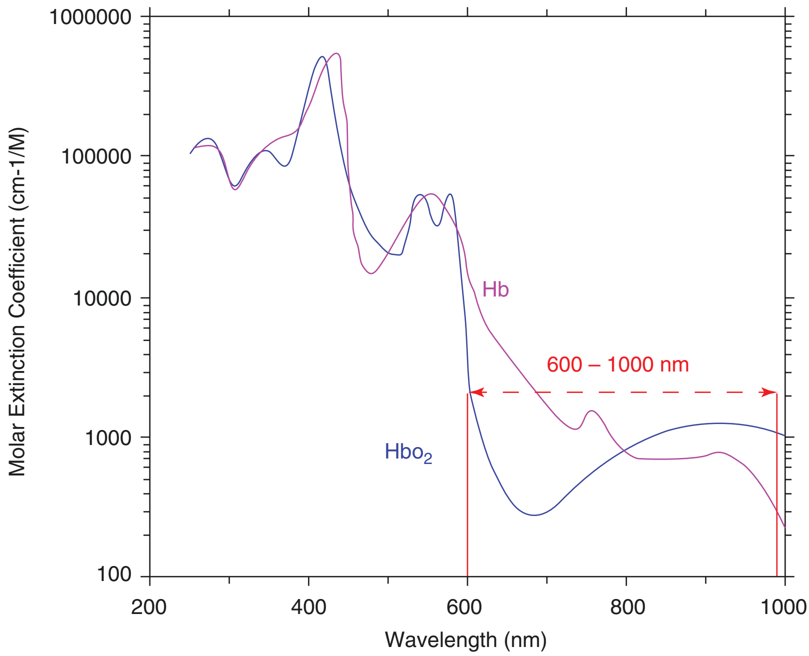

Fig. 10.1 Graph showing the molar extinction coefficients of oxy (*HbO2*) and deoxy (*Hb*) hemoglobin. Between wavelengths of 600–1000 nm the extinction coefficients of the two states of hemoglobin show low absorption with distinct spectral features. This provides a spectral window of good tissue penetrance of photons as well as allows better resolution of their individual chromophore concentrations from the Beer-Lambert Law

The process is affected by the environment of the molecule, such as pH, as well as the presence of other fluorophores with absorption maxima in the range of the emitted photons resulting in quenching. Because the microenvironment is an important determinant of brain fluorescence the emission spectra of tumor infiltrated brain and normal brain have been compared. Tumor infiltrated brain shows a shift of 10–20 nm in peak autofluorescence and the overall autoflourescence intensity can vary 15–30% [3].

Laser light scattering by brain tissue has become a useful tool in the laboratory to assess the physiological properties of brain tissue. The scattering properties of different brain regions differ, so that photostimulation with light requires specific understanding of the optical properties of the target region in order to use adequate light intensity to achieve effects at a distance from the light source [1]. Measurement of light scattering can give important information about the functional status of brain tissue. Changes in neuronal membrane potential result in alterations in the light scattering, which can be used to monitor neuronal function in real-time [4]. This enables experimentation to determine the effects of integrated neuronal circuits, alterations in membrane ion channel composition, or testing new drugs to alter neuronal excitability in a contact free manner compared to standard patch clamping. Changes in membrane potential can also be recorded using specialized laser microscopy technique involving second harmonic generation from the membrane surface. This type of imaging has been used to characterize membrane potential dynamics in cultured hippocampal neurons [5]. The changes in scattering of light associated with spreading depolarization in brain can be used to assess brain function in pathological states such as trauma, subarachnoid hemorrhage, and ischemia. Increase in scattering at 500 and 584 nm and decrease at 800 nm was found to occur in synchrony with cortical spreading depression in rats [6].

Recently inelastic scattering of laser light has been used to evaluate surgical specimens obtained during brain tumor surgery or to determine the transition from brain densely infiltrated with tumor from that less densely infiltrated. Inelastic scattering involves the absorption and emission of light by a molecule resulting in bond vibrations that generate a unique spectral emission pattern based on the identity of that molecule and therefore the molecular composition of a tissue

[7]. These electronic transitions may be stimulated or alternatively enhanced by electromagnetic interactions of molecules with the surface of roughened metals or metallic nanoparticles.

Neurodiagnostic Application of LASER Light

Optical Coherence Tomography

Optical Coherence Tomography (OCT) is a noninvasive imaging technique that uses the back scattering of light at different depths from tissue to generate micron scale resolution images from a single imaging plane. By using scattering signal from a defined depth to generate the image, optical sections through the tissue can be imaged. This allows visualization of tissue microstructure without the need for fixation or use of a contrast agent or dyes. However, due to the limits of light penetration, the depth of imaging is small (200–300 μm), compared to other imaging tools such as ultrasound. It is structurally based on the Michelson's interferometer [8] (see Fig. 10.2). Brain structures that show high intrinsic optical contrast are myelinated fiber tracts and blood vessels [9]. OCT has been proposed as a potential guidance tool for deep brain stimulation, permitting the identification of blood vessels to avoid injury [9]. Because of the lack of contrast in OCT, tumor infiltrated brain cannot be distinguished from normal brain. Thus, OCT for pathologic analysis of low-grade gliomas is not effective [10]. When the tissue architecture changes due to tumor growth and associated changes such as the case of necrosis, microvascular proliferation, and high cell density in glioblastoma, OCT may detect these changes as a function of their effects on tissue optical contrast. The advantages of using OCT for tissue evaluation at the time of surgery it that the tissue sample does not require preparation and image acquisition is rapid [10]. OCT does not replace histological assessment, but can serve as a rapid technique to identify changes at the resection margin or identify tissue that should be sent for histologic assessment. Similarly to its use in assessment of tissue architecture in tumors, OCT can be used for imaging of the luminal wall in the assessment of cerebral aneurysms [11]. This technology provides a more detailed assessment of aneurysm healing after coil embolization than can be provided with standard angiography; however the application in current clinical practice is still under investigation.

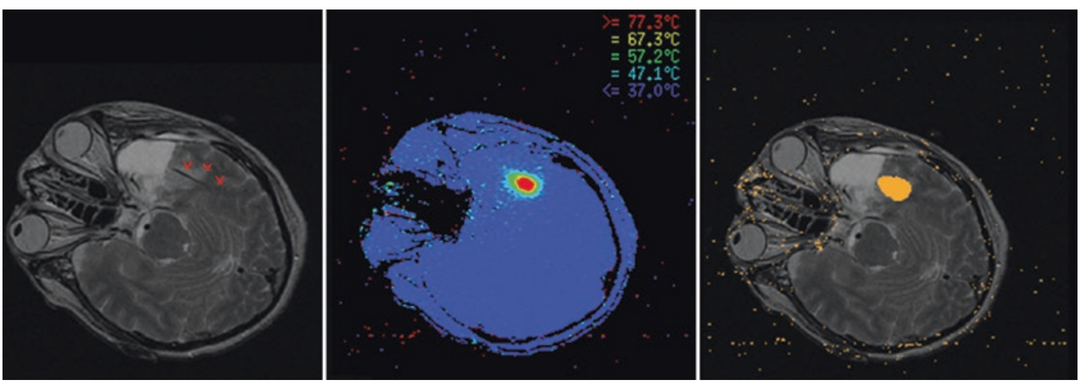

Fig. 10.2 Schematic diagram of a high speed, high resolution spectral domain OCT system which reconstructs vessel structure image. The system is constructed along the lines of a Michelson interferometer. Eighty percent of the incident power is coupled into sample arm while 20% is fed into a reference arm by a 1 × 2 fiber coupler. The reference power is attenuated by an adjustable neutral density attenuator for maximum sensitivity. Two circulators are used in both reference and sample arms to redirect the backreflected light to the second 2 × 2 fiber coupler (50/50 split ratio) for balanced detection. The signal collected by a photodetector is digitized with an analog-digital acquisition card and transferred to a computer for processing

Neurotherapeutic Applications of LASER and Light

Laser light can be used a tool to ablate or anneal tissue based on the transfer of photon energy to heat within tissue and the ability to select a specific wavelength and tune the laser power, beam width, and pulse characteristics.

Pediatric Applications

Spinal lipomas involving the conus and cauda equina are challenging surgical lesions. The intimate association with the spinal cord and nerve roots requires accurate and minimal manipulation to avoid neurological injury during debulking and untethering. The CO_2 laser, invented by Kumar Patel at Bell labs in 1964, has become an important surgical laser due to its efficiency and capacity to function as a continuous wave laser. The light generated by the CO_2 laser is in the infra-red range and readily absorbed by water and lipid molecules in tissue. McLone and Naidich decribed the advantages of the CO_2 laser in the treatment of spinal lipomas as shortening operation time, reducing blood loss, and reducing the degree of manipulation of the spinal cord and nerve roots [12]. A flexible CO_2 laser system was recently used to achieve subtotal to near-total resection of eight conus lipomas without causing new neurological deficit [13]. The CO_2 laser can be used for the cutting and cauterization of intramedullary tumors with minimal energy dispersion to adjacent tissue as described for an intramedullary dermoid tumor in a 11 month old child [14].

Cerebrovascular Applications

Laser Assisted Vascular Anastomosis

Laser assisted vascular anastomosis was first performed by Yahr and colleagues in the mid 1960s [15]. While early studies described an increased risk of aneurysm formation with laser anastomosis compared to suture anastomosis [16, 17], more recent use of an excimer (ultraviolet light) laser system has resulted in high patency rates with no increased complication rate in cerebral vascular bypass. Excimer laser assisted non-occlusive anastomosis (ELANA) has been used for bypass in the treatment of large or giant aneurysms of the internal carotid artery or middle cerebral artery [18, 19]. The use of ELANA for bypass of large caliber cerebral vessels has also been reported in the treatment of ischemia and tumors [20]. This technology works by creating a window in the recipient vessel wall and welding the donor blood vessel to the recipient vessel wall without occlusion of flow in the recipient vessel.

Neuro-Oncologic Applications

Extra-Axial Intracranial Tumors

Similar to the use of the CO_2 laser in spinal lipomas, to reduce neural tissue manipulation while permitting precision tumor destruction, the CO_2 laser can be used for the resection of meningiomas [21, 22]. The Nd:YAG laser has been combined with the CO_2 laser in order to take advantage of the hemostatic action of Nd:YAG in meningiomas [23]. In a large series of meningiomas operated with laser versus conventional techniques, patients with eloquent region tumors operated with the laser showed better outcomes [24]. Use of laser-assisted resection of meningioma may enhance the ability to resect difficult to reach meningiomas and increase the extent of resection [25, 26]. Vaporization and shrinkage of meningiomas with a safety margin beyond 2 mm of the laser-tissue interface can be achieved with the 2-μm thulium laser [27, 28]. This laser allows removal of tumor while maintaining hemostasis and visualization due to its coagulation ability.

Vestibular Schwannomas

Vestibular schwannomas commonly arise in the superior vestibular nerve just proximal to Scarpa's ganglia and are intimately related to the cochlear nerve and the facial nerve. Due to the close relationship of these cranial nerves to the tumor and the small working space for tumor resection through a retrosigmoid or middle cranial fossa approach, use of laser for tumor precision vaporization while maintaining hemostasis in these tumors is appealing to the surgeon. The flexible CO_2 laser has been used in the middle cranial fossa approach to vestibular schwannoma with similar cranial nerve function results to conventional resection [29]. Eiras et al. compared CO_2 laser excision of giant vestibular schwannomas versus conventional surgery finding that facial nerve function was better in laser treated patients, although the duration of surgery was longer [30].

Fluorescence Assisted Surgery

A growing body of evidence has associated extent of resection with increased survival and greater effect of adjuvant therapy in malignant gliomas [31–35]. Due to the intrinsic nature of this tumor and its invasive potential along white matter tracts and the perivascular niche, surgical resection is abound with challenges. Pre-operative MR imaging has allowed the assessment of enhancing tumor boundaries and demonstrates the invasiveness in extension of FLAIR signal along white matter tracts. Intra-operative neuronavigation using pre-operative images has enabled accurate operative planning of the surgical approach and surface mapping of tumor boundaries. However, as surgical resection is carried out the accuracy of neuronavigation for defining the enhancing tumor boundary is altered by brain shift secondary to CSF egress, tumor debulking, and gravity. In addition, distinguishing enhancing tumor margin from surrounding non-enhancing brain tissue becomes dependent on surgeon experience and assessment of tissue texture and other qualities such as color and softness, which are subjective measures. To address the challenge of intra-operative tumor delineation three different strategies have been previously employed: intra-operative MRI, ultrasound, and tumor cell labeling with 5-aminolevulenic acid (5-ALA).

Fluorescence guided glioblastoma resection using the tumor cell specific agent 5-ALA has been shown to have a benefit on extent of resection and 6 month progression free survival [36]. Adoption of 5-ALA fluorescence guided surgery in the US has been hindered by lack of FDA approval of 5-ALA for clinical use. From a technical standpoint, surgical resection using 5-ALA is affected by the requirement for low ambient light levels, blue hue to the adjacent non-tumor tissue, and black colored blood [37]. Use of 5-ALA requires the administration of 20 mg/kg orally 3 h prior to the surgical procedure and protection of the patient from light sources for 24 h after administration [38]. In the circulation 5-ALA is converted to protoporphyrin IX. It is the accumulation of violet-blue light fluorescing protoporphyrin IX that allows demarcation of glioma cells. A filter attachment is provided on the operative microscope that permits the excitation of PPIX in malignant tumor tissue with blue light ($\lambda = 400$–410 nm), which emits a red-violet light of 635 nm. Preclinical studies of 5-ALA demonstrated preferential uptake of into C6 rat glioma cells [39, 40].

Passive labeling by sodium fluorescein of regions of blood-brain barrier disruption associated with the infiltrative tumor margin is hypothesized to provide another means to delineate and resect brain tumors up to the enhancing tumor margin. This provides for real-time surgical delineation and resection of a glioblastoma, which is limited with intra-operative MRI and 3D-ultrasound. Unlike 5-ALA, which is currently not approved for clinical use in the US, fluorescein sodium has been used extensively in clinical practice for retinal angiography with a proven safety record. Fluorescein is a water-soluble dye that has been used in clinical medicine for retinal angiography and dermatofluorometry [41]. Use of intravenous fluorescein for the demarcation of parenchymal brain tumors was first reported in 1947 [42, 43]. However, use of fluorescence to guide tumor resection was not practical at that time given the lack of surgical fluorescence microscopy. In 1998, Kuriowa et al. [44] described the first microscope mounted fluorescein fluorescence excitation and emission filter system with white-light switching capability. Subsequently, Zeiss has developed a module for the xenon-light operating microscope that enables visualization of fluorescein fluorescence through the eyepieces using excitation via light yellow (λ = 560 nm), thereby facilitating microscopic tumor dissection [37, 45]. Recently, investigation of the mechanism of tumor demarcation using two animal models of glioblastoma have demonstrated that fluorescein labels regions of blood-brain barrier disruption and does not concentrate inside glioblastoma cells [46]. Thus, while fluorescein will identify enhancing tumor with high sensitivity it is not specific for glioblastoma cells. Fluorescein fluorescence allows surgical resection under a more normal hue with blood having a red color. Furthermore, it is envisioned that fluorescein would be more rapidly adopted as a tool in the surgical resection of malignant enhancing gliomas within the US given FDA approval for clinical use, allowing the off-label use of fluorescein. There have been three case series reported in the literature demonstrating significantly higher rates of gross-total resection when using fluorescein fluorescence to guide resection (80–84%) compared to white light (30–55%) [47–49]. Currently, there are no reported randomized controlled trials evaluating the use of fluorescein to enhance the extent of resection or survival in patients with malignant gliomas.

Laser Interstitial Thermal Therapy (LITT)

Given the optical properties of brain and capacity for conversion of light energy to heat in a controlled manner adjacent to a laser source, laser catheter ablation of intraparenchymal lesions and seizure foci has been developed and is currently undergoing clinical evaluation. Heat production by laser light can be monitored using MRI thermometry. Irreversible cell damage occurs between 46 and 60 °C [50]. The clinical platforms currently in use deliver light in the NIR-range (980 nm and 1064 nm). Ablation of metastatic or primary brain tumors can be achieved with placement of a catheter in the center of the mass and delivery of light energy in a time-dependent manner under MRI monitoring (Fig. 10.3). Specific neuroimaging changes occur after the ablation treatment, which have been described by Medvid et al. [51] The laser catheter tract is surrounded by a zone of coagulation

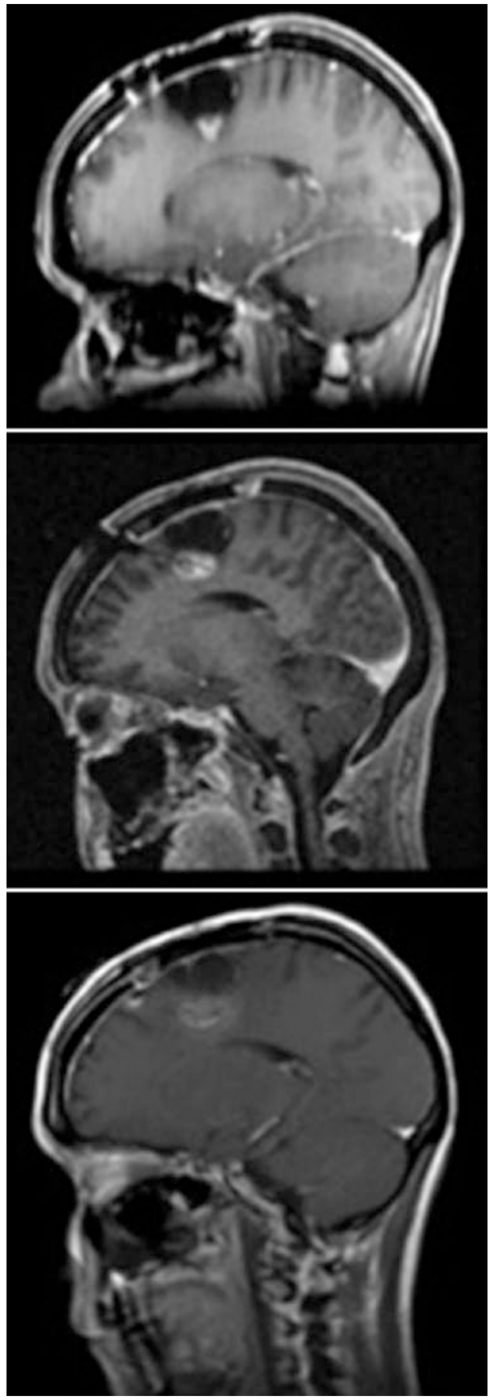

Fig. 10.3 T2 MRI demonstrating a glioblastoma recurrence abutting the prior resection cavity with a LITT catheter inserted. Red cross-haired identify areas of temperature control high temperature limits set prior to ablation (Left). MRI thermometry of the lesion, with color correlating to the lesional temperature around the catherter tip. (Center). Damage estimate after ablation of the temporal lesion (Right)

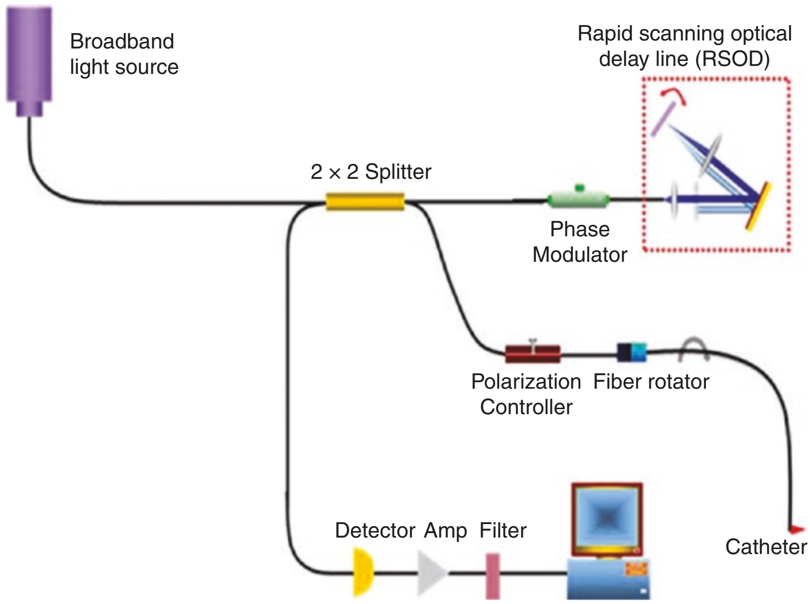

Fig. 10.4 Contrast enhanced T1-weighted MRI showing a glioblastoma recurrence in the resection cavity margin before insertion of LITT catheter (top row), immediately after LITT ablation (middle row) and 18 h after LITT ablation (lower row)

necrosis, which appears hyperintense on T1-weighted and hypointense on T2-weighted imaging at 24 h (Fig. 10.4). Concentrically adjacent to the coagulative zone is the peripheral zone, which is an area of hypointense on T1 and hyperintense on T2 due to edema. Due to disruption of the blood-brain barrier at the margin of the peripheral zone, a thin enhancing rim appears on T1-weighted contrast-enhanced images. Post-ablation edema peaks around 3–4 days and is easily managed with a 2-week steroid taper, not necessitating inpatient management. Case series reported on the treatment of recurrent gliomas demonstrate a median survival of 9.9 months after laser ablation with the majority of these patients harboring glioblastoma [52–57]. In the treatment of metastatic lesions, post-ablation median survival ranges from 4.6–19.8 months [58–60]. While the current literature includes a heterogeneous population of treated patients, it provides evidence of a safe and potentially effective use of laser ablation to disrupt lesions that are difficult to reach by standard cranial surgical routes or for which open surgery would place the patient at risk of significant neurological deficit. For gliomas it appears that the extent of tumor ablation is an important determinant of the efficacy of LITT. As such LITT for glioma treatment is primarily used today in lesions that are difficult to reach with standard procedures and for which LITT treatment is predicted to result in total or near-total thermal ablation of the tumor. The technology is in ongoing development. With the introduction of pre-operative planning software greater degrees of ablation margin planning are envisioned. Furthermore, enhanced safety will be obtained with the used of safety temperature markers and margins based on functional MRI, and diffusion tensor tractography. The use of multimodality imaging and 3-D planning of thermal tissue injury will ultimately result in more efficient and safe application of this technology.

Several advantages of LITT over traditional open craniotomy exist. First, the procedure may reduce operative time and post-operative stay for patients who are already in a fragile health state. Secondly, the procedure permits treatment of tumors that would not have been considered operable in the past and offers the opportunity for repeated treatments in multiple orientations. In addition, there is no risk of ionizing radiation damage. Because the procedure involves a single 4 mm incision and 3.2 mm drill hole, patients can be quickly transitioned to receive adjuvant radiation or chemotherapy without the need to wait for tissue healing required after a craniotomy. The indications and overall efficacy and safety of LITT for brain tumors is currently undergoing active investigation. Early studies show a similar complication rate to that of open surgery in patients with recurrent glioma (16.7% vs 11% major complication respectively) [61, 62].

Brain tissue ablation for the treatment of mesial temporal lobe epilepsy is a novel non-invasive therapeutic application of LITT. Instead of performing a craniotomy and resecting the mesial temporal structures either through a selective amygdalohippocampectomy or a complete anterior temporal lobectomy, the laser delivery catheter is placed co-axial with the long-axis of the parahippocampal gyrus in a plane below the temporal horn of the lateral ventricle. Thermal ablation of the amygdala and hippocampus in this manner offers a safe and potentially effective treatment for mesial temporal sclerosis [63, 64]. Stereotactic laser amygdalahippocampectomy could be useful where temporal lobe neocortical function needs to be preserved. For example, object recognition and naming outcomes in dominant temporal lobe procedures and famous face recognition in non-dominant temporal lobe procedures is preserved in patients with stereotactic laser amygdalahippocampectomy compared to decline seen in most patients with standard surgical procedures to treat temporal lobe epilepsy [65]. Further long-term outcome studies and neuro-cognitive assessments done in a randomized fashion in anterior temporal lobectomy versus stereotactic laser amygdalahippocampectomy are needed.

Emerging Optical Technologies

Photodynamic Therapy

Photodynamic therapy involves the activation of a light-responsive chemical process that results in cellular toxicity or the release of a cell-damaging agent. Glioblastoma accumulation of 5-ALA derived protoporphyrin IX has been tested as a photodynamic therapy agent. In a xenograft mouse model of human glioblastoma, interstitial delivery of 635 nm light after injection of 5-ALA showed induction of necrosis when delivered in a fractionated fashion at high power [66]. Human application of this technology is in early stages; however, Stummer et al. have reported a response of recurrent glioblastoma to photodynamic therapy with 633 nm laser light in a patient after administration of 5-ALA [67]. Talaporfin sodium is another photosensitizer that has been demonstrated to induce programmed necrosis in glioblastoma cells [68]. Safety data from clinical trials with Talaporfin sodium show it is well tolerated in humans [69]. Multifunctional nanoparticle platforms which can be activated by light and carry brain tumor targeting moieties such as peptides or antibodies are being designed which could be used with NIR-light or interstitial laser light sources [70, 71].

Stimulated and Surface-Enhanced Raman Spectroscopy

Raman spectroscopy involves rare photon-electron interactions in a molecule. It can be performed without the need for molecular immobilization in a discrete plane using stimulated electron transitions. A dual laser source is used to pump electrons in the molecules making up the tissue into higher energy states that show more rapid Raman inelastic scattering, allowing fast imaging. Pre-clinical studies of stimulated Raman scattering have demonstrated its use in identifying brain tissue consisting of a high tumor cell density [72]. Furthermore, application of this technology to the operative theatre using a pen-like device to probe tumor resection margins has been described [73].

Spherical and rod-shaped gold nanoparticles can be designed to have absorbance maxima in the near-infrared light wavelengths such that the particles can be heated with near-infrared (NIR) light in pulse patterns creating expansion and contraction that allows the detection of particles by their acoustic emissions (photoacoustic detection) [74, 75]. Alternatively, NIR light can be used to create a localized surface plasmon effect which allows the detection of unique Raman spectra from reporter molecules on the gold nanoparticle surface—a process known as surface enhanced Raman spectroscopy (SERS) [76, 77]. NIR-SERS capable gold nanoparticles are of particular interest in that they have recently been shown useful in imaging U87 GBM and primary brain tumour xenografts in a mouse model [78]. Structures in this size range demonstrate unique chemical properties and phenomena that are dependent on size, shape and chemical composition [79].

Summary

Laser technologies have undergone remarkable progress towards clinical application in the setting of neurological disease. In the basic science research sphere, lasers are routinely used for studying neuronal structure and function, assessment of brain microenvironment, and visualizing changes in cerebral vasculature. Clinical application of laser technology for the purposes of creating tissue damage is beginning to play a significant role in brain tumor and epilepsy surgery. Future development of laser imaging techniques for nanoparticle diagnostic and non-ablative therapeutic applications in the CNS can be envisioned. The combination of nanoparticles with light activated chemical agents may serve a role in phototherapy of brain tumors previously deemed inoperable or that have developed resistance to standard chemotherapy and radiation. Translating the basic science advances in laser technology to the clinical realm will require close collaboration between physicists, engineers, and clinicians.

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11 Clinical Laser/Light Applications in Anesthesiology Practice

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Abstract

Lasers in surgery and medicine have evolved into a specialized area with increasing use and innovative techniques requiring anesthesia providers to be familiar with the historical, technical, and procedural aspects of laser applications. Lasers applications in surgery include a variety of procedures with various laser types and specific anesthetic considerations. Currently, anesthesia providers commonly encounter use of lasers in many procedures including airway surgery, cutaneous and cosmetic surgeries, urologic, endoscopic and ophthalmology procedures. Anesthesia for procedures involving laser use in specialized patient populations such as pediatrics and obstetrics requires the anesthesia provider to be familiar with the procedure and special needs of the patient. Development of an anesthetic plan that is safe and satisfactory to the surgeon and patient necessitates knowledge of the procedure and patient characteristics. Laser applications for surgery are widespread and include excisions of dermatologic lesions, treatment of laryngeal lesions, treatment of prostatic hypertrophy, Barrett's esophagus and cataracts. Use of laser in cosmetic and cutaneous procedures is generally well tolerated with monitored anesthesia care supplemented with topical or local anesthesia. Laser use in prosthetic reduction surgery is common and often patients are elderly presenting with multiple co-morbidities influencing choice of anesthetic technique. With the use of lasers in the operating becoming more common in recent years, awareness and adherence against health hazards to both the patient and personnel are essential. Laser safety includes vigilance on the part of the anesthesia provider to prevent laser induced fires, avoid eye injury and burns, as well as, prevent electrical hazards. Procedures involving lasers and the airway represent a special challenge to the anesthesia provider including risk of airway fire, aspiration, injury, and inadequate ventilation and oxygenation. As laser technology continues to evolve in the fields of medicine and surgery benefits to the patient as it relates to anesthesia are apparent in some areas and require further study in others. Laser safety programs are required nationally in all hospitals and office based surgical facilities using lasers.

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© Springer International Publishing AG, part of Springer Nature 2018
K. Nouri (ed.), *Lasers in Dermatology and Medicine*, https://doi.org/10.1007/978-3-319-76220-3_11

Keywords

Laser applications in surgery · Laser use in the operating room · Laser use in procedural areas · Anesthesia considerations for laser use Laser use in endoscopy · Laser use in cataract surgery · Airway surgery and lasers Airway fire · Protective eyewear for laser use Laser safety checklist

Introduction

In clinical practice, lasers are used for cauterization and bloodless surgery, tumor ablation, endoscopic surgery and generally where destruction of a pathologic process within a small area is needed. Laser applications in surgery and medicine are a prime example of the value of clinical applications of basic science.

Strict adherence to safeguards against health hazards is essential to ensure safe use of any medical instrument. Laser use in medical and surgical practice requires that personnel be aware of the background principles and hazards involved.

History

Over the past 50 years, lasers applications have been in routine use in medical and surgical practice. Lasers function as a surgical tool by virtue of three basic functions:

1. Lasers behave as a light source when transmitted through optical fibers
2. Lasers can cut and cauterize deeply when focused on a point, reducing surgical trauma caused by a knife
3. Lasers can vaporize the surface of tissue [1].

Laser is an acronym for Light Amplification of Stimulated Emission of Radiation. In 1958, work was extended from microwaves to the visible light spectrum and led to the construction of the first ruby laser by Bell Telephone Laboratories. The output of early lasers was not well controlled until the technique of "Q" switching which permitted all the energy of radiation to be stored in the laser and then released in pulses. In essence, a laser beam which is defined by wavelength, duration, energy and width of spot focused optics to direct a beam to a biological target resulting in ionizing radiation in situ, mechanical shock waves and vaporization of tissues by heat. The beam acts both as a cutting scalpel and coagulates blood vessels.

Characteristics of Medical Lasers

Lasers can be generated from solids, liquids or gases (lasing medium) with resultant radiation of different wavelengths and biomedical properties. The material used to generate the laser defines depth of vaporization and damage to tissues. An energy source or "pump" is required such as a chemical reaction, a diode, flash lamp or another laser. An optical cavity or resonator contains the lasing medium and creates the laser's output beam via an interaction between reflective mirrors and the medium. Types of lasers most commonly used in surgical and medical application are summarized in Table 11.1.

Table 11.1 Types of lasers most commonly used in surgical and medical applications

Type	State	Wavelength	Color	Applications
Nd: YAG	Solid	10,640 nm	Near infrared	Cutting, coagulation, GI bleeding
CO_2	Gas	10,600 nm	Far infrared	Cutting, coagulation, laser scalpel, skin resurfacing
Argon-ion	Gas	500 nm	Blue-green	Retinal surgery, AV malformations, port wine birthmarks
Ho:YAG Holmium	Solid	2070 nm	Mild infrared	Tissue ablation, lithotripsy, endoscopic sinus surgery
Ruby	Solid	193 nm 694 nm	Ultraviolet Red	Hair removal, tattoo removal
Pulsed dye	Liquid	390–640 nm	Yellow	Birthmark removal, vascular skin lesions

Applications

Lasers have achieved many uses in medicine, especially in surgery. They can be used to excise melanomas, tumors, dermatologic scars and also for cosmetic facial enhancement [2]. Lasers are well suited for treatment of laryngeal epithelial diseases such as dysplasia and papillomatosis [3]. Carbon dioxide lasers have been used successfully in the treatment of anogenital warts in children [4]. Retinopathy of prematurity is amenable to diode laser therapy [5]. Other applications involve prostatic surgery, retinal detachment and laser assisted cataract surgery, and in-utero fetoscopic laser coagulation of placental vascular anastomosis in fetal twin-to-twin transfusion syndrome [6]. Diagnostic uses include the application of laser spectroscopy to microanalytic techniques, Papanicolau smears, immunofluorescent techniques and laser endomicroscopy.

Laser Surgery Involving the Airway

Indications and Contraindications

Summary Box

- Nd-YAG lasers may be used for debulking of tumors of the trachea, main-stem bronchi and upper airway by transmitting energy via fiberoptic cable through the suction port of a fiberoptic bronchoscope
- Procedures in and around the vocal cords and oropharynx may require the precision of the CO_2 laser
- Patients with underlying cardiopulmonary disease may be unable to tolerate desaturation, hypoxemia, and hypercarbia associated with low concentrations of oxygen and interruptions in ventilation during laser surgery of the airway

There are many types of lasers, each with specific indications. Neodymium-doped yttrium aluminum gradient (Nd-YAG) laser is the most powerful laser. YAG lasers have a tenfold shorter wavelength (1065–1320 nm) than CO_2 lasers (10,600 nm) and therefore have much better tissue penetration between 2–6 mm. YAG is used for tissue debulking, particularly in the trachea, main-stem bronchi, and upper airway. The energy may be transmitted through a fiberoptic cable placed down the suction port of a fiberoptic bronchoscope. The Nd-YAG laser can be used in "contact mode" to treat a tumor mass. Alternatively, the CO_2 laser has very little tissue penetration and can be used where great precision is needed. One advantage of the CO_2 laser in airway surgery is that the beam is absorbed by water, so minimal heat is dispersed to surrounding tissues. The CO_2 laser is primarily used for procedures in the oropharynx and in and around the vocal cords. The helium-neon laser (He-Ne) produces an intense red light and can be used for aiming the CO_2 and Nd-YAG lasers. It has a very low power and poses no danger to OR personnel or the patient [7].

Because lasers are capable of igniting airway fires, use of high concentrations of oxygen and nitrous oxide is dangerous. Some patients with cardiopulmonary disease may not tolerate low concentrations of oxygen (at or just above room air) resulting in desaturation and hypoxemia. In addition, interruptions in ventilation frequently result in hypercarbia and may induce arrhythmias. Prior to induction of anesthesia and surgery, a thorough history and physical helps to identify patients who are at risk for complications during laser surgery of the airway and associated manipulations of oxygenation and ventilation.

Techniques

Summary Box

- Patients with pathologic conditions involving the airway (i.e. mediastinal

masses, tracheal stenosis) may be difficult to ventilate and/or intubate during induction of anesthesia
- Co-morbidities such as chronic obstructive pulmonary disease and coronary artery disease are present in many patients presenting for laser surgery of the airway and should be medically optimized pre-operatively
- Airway management for laser surgery of the larynx includes endotracheal intubation, intermittent apneic ventilation, and jet ventilation
- Short-acting opioids such as remifentanil or alfentanil in combination with a sedative-hypnotic (i.e. propofol) typically provide adequate depth of anesthesia for laser surgery of the airway and rapid emergence at the conclusion of surgery
- Post-operative pain control can generally be achieved with shorter acting opioids such as fentanyl and titrated to pain relief

Pre-operative Management

Pre-operative management of patients requiring laser surgery for masses or tumors of the trachea, main-stem bronchi and upper airway involves careful attention to airway management. Airway compromise should be anticipated and a clear backup plan devised before the induction of general anesthesia. Patients with lesions in the mediastinum may be difficult to ventilate and/or intubate. Stridor suggests existing narrowing of the airway which may also compromise airway management. Inspiratory stridor indicates a supraglottic lesion, whereas, expiratory stridor suggests subglottic narrowing. Communication with the surgeon and careful planning are imperative during induction of anesthesia in this patient population. Furthermore, many patients presenting for laser surgery for lesions involving the airway are elderly and have a history of tobacco use. A history of chronic obstructive pulmonary disease suggests a need for a chest X-ray to rule out active pulmonary processes. Prior to induction, wheezing should be treated with bronchodilators. Coronary artery disease should be suspected in those at risk (age > 65 years, male, family history, tobacco use, high cholesterol, hypertension, diabetes mellitus, obesity, and sedentary lifestyle.) Adrenergic response to airway manipulation should be anticipated and treated with beta blockade to decrease the risk of myocardial ischemia [8].

Description of Technique

Laser surgery of the vocal cords requires the cords be immobile during laser firing. Adequate muscle relaxation is therefore important. The CO_2 laser is generally used because of its ability to precisely vaporize tissue. The Nd:YAG laser coagulates deeper lesions and is used for tumor debulking. Airway management for laser surgery of the larynx includes endotracheal intubation, intermittent apneic technique, and jet ventilation.

Endotracheal intubation with a small-diameter endotracheal tube (5.0–6.0 mm) or microlaryngeal tube allows for visualization of the larynx. The lowest possible FiO_2 (less than or equal to 0.3 or 0.4) while maintaining adequate oxygenation should be used. Nitrous oxide and a high FiO_2 support combustion and should be avoided. Other precautions to prevent airway fires include filling the cuff with methylene blue or normal saline and using a special laser endotracheal tube such as a Mallinkrodt Laser-Flex or Xomed Laser Shield. Polyvinyl chloride, red rubber and silicone rubber endotracheal tubes are non-reflective, but combustible. Metal endotracheal tubes are combustion resistant, but transfer heat and reflect laser. It should be noted that laser endotracheal tubes do not provide 100% protection for all laser types.

Intermittent apnea and jet ventilation are techniques used during airway surgery. Intermittent apnea allows intermittent tracheal extubation after a period of hyperventilation. The laser may be used during the time the patient is extubated for approximately 1–5 min prior to desaturation. A pulse oximeter must be accurate and always available. A disadvantage of this technique includes increased risk of airway edema and trauma. Jet ventilation allows for ventilation without an endotracheal tube such in treatment of some supraglottic and subglottic lesions. A ventilating laryngoscope is commonly used for supraglottic lesions. The jet flow should be aligned with the trachea and complete exhalation should be allowed prior to the next jet ventilation. By triggering the jet between laser firing, the vocal cords remain immobile. Complete muscle relaxation is essential with use of jet ventilation. Complications of jet ventilation include pneumothorax, barotrauma, and gastric distension.

Standard induction techniques may be used depending on the co-morbidities of the patient (i.e. rapid sequence intubation for those at risk for aspiration.) In general, minimal post-operative discomfort implies decreased need for narcotics intra-operatively. Short-acting opioids such as remifentanil (0.1–0.25 mcg/kg/min) or alfentanil (0.25–0.1 mcg/kg/min) may be used in combination with propofol (100–150 mcg/kg/min) to maintain adequate anesthetic depth while allowing for rapid emergence. As previously mentioned, adequate neuromuscular blockade is especially important in surgery involving the vocal cords.

In most cases, full recovery of airway reflexes should be obtained prior to extubation. In special circumstances, such as vocal cord surgery, the surgeon may request a smooth emergence involving deep extubation. In either case, gastric decompression prior to extubation is prudent, especially following the use of jet ventilation.

1. A recent study of 60 patients with early vocal cord cancer were randomly assigned to receive either laser surgery or external beam radiation. Voice quality was diminished more in the laser group suggesting a careful consideration of patient-related factors in the treatment choice [9]. Another study compared CO_2 lasers versus traditional scalpel excision of oral leukoplakia and determined that CO_2 lasers allowed reduced scarring but postoperative pain and swelling were similar in each group [10].

Post-operative Management

Use of short acting opioids such as intravenous fentanyl (25–50 mcg) as needed for pain control in the post-operative is usually adequate. Depending on the nature and invasiveness of the surgical procedure, longer acting narcotics such as morphine or dilaudid may be necessary to make the patient comfortable.

With the use of jet ventilation, there is risk of pneumothorax and barotrauma. If suspected, a chest X-ray should be obtained to rule out pneumothorax.

Low level laser application has been used successfully at the end of surgery to reduce pain after tonsillectomy in adults. Analgesic consumption was reduced ($p = 0.01$) [11].

Adverse Events

Summary Box

- Factors contributing to the risk of airway fire during laser surgery include energy level of the laser, the gas environment of the airway, and the type of endotracheal tube
- A safe gas mixture of 25–30% oxygen and avoidance of nitrous oxide decreases the risk of airway fire during laser surgery
- Laser-resistant endotracheal tubes are designed to prevent fires associated with laser use
- The anesthesiologist and all members of the operating room team should remain vigilant in recognizing the early signs of airway fire (i.e. unexpected flash, flame, smoke, odors, discolorations of the breathing circuit)
- In the event of an airway fire, the endotracheal tube should be removed immediately and the flow of gases stopped followed by removal of burning materials and saline or water poured into the airway

The most serious complication of laser airway surgery is fire. The prevention of airway fires involving laser use begins with communication amongst the anesthesiologist, surgeon, and all members of the operating room team. Airway fire may occur when an endotracheal tube is ignited. If ignited, oxygen and nitrous oxide support combustion and can result in a blow-torch effect within the endotracheal tube causing severe injury to the trachea, lungs and surrounding tissue. Endotracheal tubes made of polyvinyl chloride, silicone, and red rubber are highly combustible. Precautions should be taken to minimize the risk of an oxygen rich environment that would support ignition and combustion. To prevent fires associated with endotracheal tubes and laser use, laser-resistant endotracheal tubes have been developed. Wrapping the endotracheal tube with reflective tape still imposes a hazard in that kinking of the tube may occur, gaps may be present, and non-laser resistant tape may be inadvertently used. It is best to use an endotracheal tube that is designed to be resistant to a specific laser that may be used in surgery (e.g. CO_2, Nd:YAG, Ar, Er:YAG, KTP). The tracheal cuff of the laser tube should be filled with saline and colored with an indicator dye such as methylene blue to alert the surgeon if he contacts the endotracheal tube. To minimize the risk of ignition, a safe gas mixture during laser surgery involving the airway is oxygen/air or oxygen/helium to achieve an oxygen concentration 25–30% or minimal oxygen concentration required to avoid hypoxia. Surgical drapes should be arranged to reduce the accumulation of oxidizers under the drapes. Gauze and sponges should be moistened prior to use near an ignition source. Allow sufficient drying time for flammable skin prepping solutions. The energy level of the laser is controlled by the surgeon and activation of the laser should be preceded by adequate notice. Safe use of laser in airway surgery includes intermittent and noncontinous mode at moderate power (10–15 W) In addition, allowing time for heat dispersal and packing of adjacent tissues with moist gauze helps reduce the risk of airway fire [12]. Precautions to minimize the risk of airway fire are summarized in Table 11.2.

The anesthesiologist and members of the operating room team must be vigilant in recognizing the early warning signs of fire. Examples include unexpected flash, flame, smoke or heat, unusual sounds or odors, discoloration of the drapes or breathing circuit. See table for steps in managing an airway fire. Airway fire protocol for fires of the airway or breathing circuit are summarized in Table 11.3.

Table 11.2 Precautions to minimize the risk of airway fire [12]

1.	Intubate with a laser resistant endotracheal tube resistant to the specific type of laser to be used
2.	Fill the endotracheal tube cuff with saline or an indicator dye such as methylene blue
3.	Request the surgeon to give adequate notice prior to activating the laser
4.	Reduce the concentration of oxygen to the minimum avoiding hypoxia
5.	Discontinue use of nitrous oxide
6.	Wait a few minutes after reducing the oxygen concentration before allowing laser activation

Table 11.3 Airway fire protocol for fires of the airway or breathing circuit [12]

1.	Remove the endotracheal tube
2.	Stop the flow of all gases
3.	Remove flammable and burning materials from the airway
4.	Pour saline or water into the patient's airway

Anesthesia for Cutaneous and Cosmetic Laser Surgery

Indications and Contraindications

Summary Box

- Cosmetic laser surgery is frequently used to minimize the signs of aging in areas such as periorbital and perioral creases
- Laser skin resurfacing can successfully treat superficial scars related to acne and trauma, wrinkles, pigment changes and pre-cancerous lesions
- Removal of port wine stains

Laser skin resurfacing is used to treat a variety of skin conditions including acne scars, traumatic scars, and pre-cancerous lesions such as actinic keratosis. Cosmetic laser surgery utilizes a controlled burn to the facial skin to reduce the signs of aging, especially in the periorbital and perioral creases where previous cosmetic techniques were lacking. Fractional CO_2 laser resurfacing has been shown to have continued efficacy for up to 5 years [13]. Many cosmetic procedures utilizing lasers are perfomed in an office-based setting under local or topical anesthesia sometimes with monitored anesthesia care. Therefore, patients with pre-existing medical conditions preventing safe administration of sedation and/or anesthesia should probably undergo elective procedures in a hospital setting rather than an office-based environment [12].

Birthmarks caused by malformations of blood vessels in the skin are frequently treated by lasers. These marks manifest in infancy as a flat red mark that may be extensive and cover an entire limb or face. Left untreated they become dark and finally purple and thick. Early and repeated laser therapy (at 3 month intervals) can markedly reduce the degree of disfigurement [14]. Pulsed dye lasers are most frequently used. For babies, general anesthesia is required. Attention should be paid to the Safe Tots study as repeated anesthetic exposures are indicated. After the age of about 9 years, local anesthesia with lidocaine patch or EMLA cream may be used and applied about 1 h pre procedure. However, if the lesion is large, treatment may have to be staged to avoid the risk of local anesthetic systemic toxicity [15].

Techniques

> **Summary Box**
> - Topical and/or local anesthesia supplemented with intravenous sedation generally provides adequate anesthesia for facial laser resurfacing
> - Pain control post procedure is usually managed well with oral analgesics

Pre-operative Management

Full face laser resurfacing is painful and can be stressful on the patient. Local anesthesia is often inadequate and must be supplemented with intravenous sedation, regional nerve blocks, topical anesthetics, and/or general anesthesia. Patients presenting with chronic medical problems such as hypertension, cardiovascular and/or pulmonary disease should be medically optimized prior to elective procedures.

Description of Technique

Usually, CO_2 or erbium:yag lasers are used for laser skin resurfacing. Anesthetic technique should be chosen keeping in mind that a tremendous amount of heat is delivered to the skin surface resulting in a deep thermal injury and pain [16]. Patient comfort during laser skin resurfacing can also be amplified by the additional use of a cooling device applied to the skin. Despite these measures, oral sedation with a benzodiazepine, regional nerve blockade with infiltrative anesthesia, or intravenous anesthesia is often necessary during ablative laser procedures to achieve substantial pain relief [17]. Combinations of the intravenous sedation (e.g. propofol, ketamine, midazolam, opioids) with topical anesthesia (e.g. EMLA cream-eutectic mixture of local anesthetics) have been successful for laser skin resurfacing in the ambulatory setting [18].

Post-operative Management

Patients undergoing full face laser resurfacing receive potent narcotics in a short time and should have adequate recovery time prior to discharge. Oral analgesics are generally adequate for management of pain following the procedure. Post operative nausea and vomiting should be treated with anti-emetics (e.g. ondansetron).

Adverse Events

> **Summary Box**
> - Laser-specific eyewear for the patient and operating room personnel are

necessary to provide protection from ocular hazards during cosmetic laser surgery
- A smoke evacuation system is used to remove carbon particles, DNA, microils, and toxic fumes from the operating room environment

Ocular hazards require laser-specific eyewear for the patient and operating room personnel. Protection from fire and reflectivity hazards includes use of non-combustible drapes without pockets that might accumulate oxidizing agents, moist draping, water basin and having a fire extinguisher available. Alcohol based solutions to clean the skin should be avoided. Also, oxygen sources and metal or reflective materials should be avoided. Fire-resistant endotracheal tubes decrease the possibility of tube breach or ignition. Furthermore, release of carbon particles, DNA, microils, and toxic fumes accompany laser destruction of cells. Utilizing a smoke evacuation system 2 cm from the plume and wearing high-filtration masks protect the patient and medical personnel [8].

Anesthesia for Urologic Procedures Involving Laser Use

Indications and Contraindications

Summary Box
- Laser techniques for resection of the prostate allow for minimal use of irrigating solutions compared to classic transurethral resection of the prostate
- Holmium laser enucleation and photoselective laser vaporization of the prostate are the leaders in laser treatments of benign prostatic hypertrophy.

Historically, the gold standard of treatment of benign prosthetic hypertrophy has been transurethral resection of the prostate. Advances in laser techniques for resection of the prostate have several proposed advantages over traditional transurethral resection. Classic transurethral resection of the prostate for patients with benign prostatic hypertrophy involves use of large amounts of irrigating solutions (i.e. glycine) predisposing the patient to “TURP syndrome.” Traditional spinal anesthesia for classic transurethral resection of the prostate allows the anesthesiologist to monitor for mental status changes associated with electrolyte abnormalities due to absorption of large amounts of irrigating fluids. Modern equipment (bipolar resectoscope) allows for safe operation with normal saline irrigation. Surgical alternatives to TURP offer further advantages. These include decrease blood loss, inpatient hospitalization and fluid absorption. Surgical alternatives to TURP utilizing laser include transurethral vaporization of the prostate, photoselective vaporization of the prostate and holmium laser enucleation [18]. Two types of lasers have been used in photoselective vaporization of the prostate, KTP (potassium titanyle phosphate) laser and LBO (lithium triborate) laser. An alternative to the KTP laser, LBO offers improved vaporization speed.

Techniques

Summary Box
- Patients undergoing TURP (transurethral urethral of the prostate) are often elderly with co-existing cardiovascular and pulmonary disease
- New laser technology using less irrigation fluid reduces the incidence of systemic complications associated with TURP syndrome
- Photoselective laser vaporization (PVP) and holmium laser enucleation have the potential to become valid alternatives to both open prostatectomy and TURP

Pre-operative Management

Most patients presenting for TURP have obstructive symptoms and are elderly. Co-morbidities increase risk of cardiovascular and pulmonary complications in the peri-operative period. Preexisting medical problems including coronary artery disease, peripheral vascular disease, cerebrovascular disease, chronic obstructive pulmonary disease, and renal impairment should be medically optimized in the preoperative period [12].

Description of Technique

Holmium laser technique decreases the amount of irrigation solution required and avoids the osmotic complications associated with absorption of large quantities of glycine, mannitol, and sorbitol [18, 19]. By virtually eliminating the risk of TURP syndrome, the anesthesiologist may choose among several anesthetic techniques (e.g. general, neuroaxial, local and monitored anesthesia care) and tailor the anesthetic plan to an individual patient's needs.

In PVP, the prostate tissue is vaporized from the inside to its outer layers. Both Holmium laser and PVP technology allows for an almost bloodless procedure, fewer blood transfusions, and less absorption of the irrigant [18].

Post-operative Management

In addition to electrolyte abnormalities and fluid overload, patients undergoing classic transurethral resection of the prostate under spinal anesthesia may encounter urinary retention due to blockade of the parasympathetic fibers that control detrusor contraction and bladder neck relaxation. Development of new laser technology using less irrigation fluid reduces incidence of systemic complications associated with TURP syndrome and thus the need for treatment of these complications.

Adverse Events

Summary Box

- Longer procedure times are associated with use of the Holmium and PVP lasers requiring longer durations of anesthesia
- As with most new technologies and procedures, PVP and Holmium lasers for prostate surgery are associated with a learning curve and acquisition of skills by the surgeon

Both the Holmium laser and KTP laser have longer procedure times requiring the patient to be anesthetized for a longer time period [19]. While current evidence supports the Holmium laser prostate surgery offers favorable and durable outcomes for any prostate size, it is slow to gain acceptance and is the most technically advanced form of laser prostate surgery. PVP has achieved a higher level of acceptance. Long term results of high quality studies of PVP are pending [18, 19].

Anesthesia for Endoscopic Procedures Involving Laser Use

Indications and Contraindications

Summary Box

- Laser ablation and Argon plasma coagulation are two techniques that may be used to treat esophageal obstruction and dysphagia due to advanced tumor growth
- Confocal laser endomicroscopy (CLE) is an emerging endoscopic technique that allows for real-time very high magnification and resolution images of the gastrointestinal mucosa

Endoscopic laser procedures may be used for treatment of esophageal cancer. Laser use ranges from treatment of very early stage cancers of cancer to prevention of developing cancer by treating Barrett's esophagus. Symptoms such as dysphagia and odynophagia caused by advanced cancer growth can be treated by with laser ablation and Argon plasma coagulation. Current potential applications of confocal laser endomicroscopy (CLE) include surveillance and treatment of Barrett's esophagus, diagnosis of indeterminate biliary strictures, and follow-up of colonic lesions after resection [20]. CLE utilizes a low power laser with subsequent detection of light fluorescence reflected through a pinhole in the same focal plane. CLE systems include dedicated endoscopes with integrated CLE systems or through-the-scope probes. An emerging technology, CLE has potential to significantly reduce the number of biopsies taken and reduce the need for removal of non-neoplastic colon polyps in certain patient populations [20].

Technique

Summary Box

- Procedural sedation for gastrointestinal endoscopic procedures ranges from minimal sedation to general anesthesia
- Patient-related factors (i.e. age, obesity, co-morbidities) and procedure-related factors (i.e. level of difficulty, degree of sedation) determine the type of anesthesia best suited for gastrointestinal endoscopic procedures

Pre-operative Management

All patients undergoing anesthesia for endoscopic gastrointestinal procedures require a pre-anesthesia assessment history and physical to identify potential risk factors that increase risk of adverse outcome. Patients with significant cardiac and pulmonary disease, obesity, advanced age and anemia are at increased risk for hypoxemia and cardiopulmonary complications due to sedation-related hypoxemia [21]. Except in cases of emergency, the American Society of Anesthesiologists (ASA) pre-operative fasting guidelines apply (i.e. minimum of 2 h following clear liquid ingestion and 6 h following a light meal.)

Description of Technique

In developing the anesthetic plan, both patient and procedure-related factors should be considered. From a procedural standpoint, degree of difficulty and level of sedation required are two considerations. Other factors to consider include the experience level of the gastroenterologist for a certain procedure, patient movement concerns and anticipated duration of the procedure. Special patient considerations include: patients with a history of prior difficulty with procedural sedation, benzodiazepine, opioid or heavy alcohol use; these patients may exhibit poor procedural tolerance and require deeper sedation or general anesthesia. Patients at increased risk for adverse outcomes should medically optimized. Patients with obstructive sleep apnea (OSA) may require general anesthesia with a secure airway rather than deep sedation without a secure airway, particularly in procedures that mechanically compromise the airway [22]. Often, adequate monitored anesthesia care (MAC) can be accomplished with a combination of a propofol drip (titrated to desired sedation level) and a low dose of a short acting benzodiazepine such as midazolam. Supplemental oxygen and standard monitoring including hemodynamic monitoring, electrocardiography, capnography, and pulse oximetry should be used during administration of anesthesia. Topical administration of lidocaine, tetracaine or benzocaine to suppress the gag reflex may decrease the amount of intravenous sedation required for upper gastrointestinal procedures, but may increase risk of aspiration. Methemoglobinemia associated with topical benzocaine, although rare, should be considered as a potential complication.

Post-operative Management

Patients undergoing laser assisted endoscopic gastrointestinal procedures require adequate monitoring and recovery time from anesthesia. Risks of cardiopulmonary complications from sedation continue after the procedure has concluded. Lack of stimulation coupled with active sedative drugs increase risk of respiratory depression. Reversal agents such as naloxone (opioid antagonist) and flumazenil (benzodiazepine antagonist) may be used to treat hypoxemia and hypoventilation not responsive to stimulation and supplemental oxygen. It is recommended that patients receiving reversal agents be monitored for signs of re-sedation for at least 90 min. Nausea and vomiting may be treated with antiemetics such as ondansetron.

Adverse Events

Summary Box

- Cardiopulmonary complications such as hypoxemia, cardiac arrhythmias and aspiration may occur during anesthesia for endoscopic laser gastrointestinal procedures
- Risks associated with topical local anesthesia (lidocaine, tetracaine, benzocaine) include aspiration risk and methemoglobinemia
- Intravenous fluorescein is used in CLE to obtain high-resolution confocal images of the surface epithelium and lamina propria

Cardiopulmonary complications are among the most frequent and serious complications that occur during sedation and/or anesthesia for endoscopic gastrointestinal procedures. Adverse events from over-sedation include airway obstruction, hypoxemia, hypoventilation and hypotension. Arrhythmias, vasovagal episodes and aspiration may occur as well. There is an association between increasing ASA scores and the frequency with which these cardiopulmonary complications occur [23]. Identifying patients at increased risk for complications, vigilant monitoring of vital signs and responsiveness are imperative to avoiding adverse events. Topical administration of lidocaine, tetracaine or benzocaine to suppress the gag reflex may decrease the amount of intravenous sedation required for upper gastrointestinal procedures, but may increase risk of aspiration. Methemoglobinemia associated with topical benzocaine, although rare, should be considered as a potential complication when considering its use [24]. Fluorescein, a fluorescent contrast agent, is commonly used for CLE. It is administered intravenously (2.5–10 ml of 10% fluorescein) immediately before imaging. After administration, high resolution confocal images can be obtained in the area of interest within 30 s. Adverse events associated with fluorescein use are mild and include nausea and vomiting, transient hypotension, mild epigastric pain and diffuse rash. Although rare, more serious adverse events associated with fluorescein include anaphylaxis, myocardial infarction, shock and seizures [20].

Future Directions

Summary Box

- Needle volumetric laser endomicroscopy allows for in vivo imaging on a micron scale
- Dual-axis CLE, a novel imaging system not yet FDA approved, has potential to allow for deep in vivo imaging of tissue on a micron scale and may have applications in detecting early colorectal cancer

Related and future systems in the field of endomicroscopy are expanding to include systems such as needle volumetric lasers and dual-axis CLE. Currently FDA approved, application of needle volumetric laser endomicroscopy includes imaging and detection of both surface and subsquamous dysplasia (full resolution scans in 90 s at a depth of 3 mm) in Barrett's esophagus and laser marking for targeted therapy [20]. Dual-axis CLE overcomes the constraints of single-axis system and allows greater depth and wider field-of-view images than conventional CLE. A promising application for dual-axis confocal micorendoscopy includes early detection of colorectal cancer by allowing for in vivo visualization of anatomical and functional colorectal pathology [25].

Anesthesia for Laser-Assisted Cataract Surgery

Indications and Contraindications

Summary Box

- Femtosecond lasers (FSL) replace a microkeratome, which is a mechanical tool, to create a more precise corneal flap
- Femtosecond lasers are thought to be more accurate than microkeratomes and cause less surrounding collateral damage [26]

Femtosecond lasers have been used safely and successfully since 2001. Purported benefits of femtosecond lasers for cataract surgery include better precision and accuracy of capsulotomy formation, lens fragmentation and softening, and better limbal relaxing incisions. FSL may also reduce the risk of endophthalmitis and induced astigmatism compared to traditional Nd:YAG lasers. In contrast to Nd:YAG lasers, FSL cuts through the target using photodisruption in which infrared light can penetrate nonopaque structures. This generates free electrons which collapse to form microcavitation bubbles. These bubbles are smaller than those produced by Nd:YAG's and thus allow for less collateral damage to adjacent tissues. Studies on cadaver eyes have shown that the FSL produces more consistent and stable incisions compared to using a scalpel. Limbic Relaxing incisions made with FSL can reduce the amount of astigmatism present which can improve post-operative uncorrected visual acuity. As with any new procedure there is a learning curve and complications may actually increase in the near term. Patients with dense cataracts may be at greater risk of capsular rupture [26].

Techniques

Summary Box

- Topical anesthesia or local anesthesia is usually sufficient for FSL cataract surgery [26]
- Intravenous sedation may be used to supplement the aforementioned anesthetic technique

Pre-operative Management

FSL cataract surgery as well as any involving the eye can elicit a high level of anxiety. These patients should be treated with small doses of benzodiazepines preoperatively since they will often have to be able to follow instructions during the procedure. Patients with extreme anxiety that cannot be controlled with anxiolytics may require general anesthesia.

Description of Technique

Lasers used for cataract surgery usually do not illicit much pain during the procedure. Use of tetracaine eye drops is normally sufficient to blunt any discomfort, but this can be supplemented with a retrobulbar block. Injection using 2% lidocaine or 0.5% bupivacaine into the retrobulbar space produces akinesia of the extraocular muscles by blocking cranial nerves II, III, and VI. Local ocular complications include damage to the optic nerve and perforation of the globe with hematoma and possible blindness. There can also be systemic complications such as local anesthetic toxicity, brainstem anesthesia from local anesthetic entering the cerebral spinal fluid, and stimulation of the oculocardiac reflex resulting in bradycardia.

Post-operative Management

Typically there is minimal postoperative pain following surgery. Narcotics are rarely necessary and any discomfort can be treated with acetaminophen or ibuprofen. Postoperative nausea should be treated with antiemetics such as ondansetron.

Adverse Events

Ultrashort laser pulses such as with FSL have extremely high peak powers. Even scattered radiation may possess severe risks to the unprotected eye. FSL uses a wavelength of approximately 1053 nm. In the wavelength range of 400–1400 nm, light passes through the cornea and the lens of the eye and is focused onto the retina and can cause thermal damage. Laser goggles are the most important devices for the protection of the eyes against laser radiation. Ion-doped glass filters in goggles protect against laser radiation from short-pulse FSL laser systems. Ocular damage can happen at different eye regions such as the retina or the lens and the extent of the damage is determined by the laser irradiance, wavelength, exposure duration, and beam size. Since some eye injuries, such as laser retinal burns, may be painless and the damaging beam sometimes invisible, maximal care should be taken to provide protection for all persons in the operating room including the anesthesia provider who may be what he or she considers a safe distance away. A triangular laser warning sign should be placed at all entrances to the procedural areas where lasers are in use (Fig. 11.1) [27].

Fig. 11.1 A triangular laser warning sign should be placed at all entrances to the procedural areas where lasers are in use [27]

Future Directions

- Advantages of FSL include more reproducible astigmatic incision, better primary incisions and decreased risk of endophlalmitis with laser use
- Expensive technology and cost effectiveness analyses have yet to definitively show FSL to be favorable to current technology [28]

The initial cost of purchasing one of the several FSL systems on the market is $350,000–$500,000. In addition, there is a time cost. It takes longer to perform cataract surgery with an FSL compared to traditional phacoemulsification cataract surgery. Additionally, FSL limitations include patients with very small pupils. Also, surgeons have expressed concern over possible loss of their manual skills if they exclusively use the laser technique. However, superior technology historically trumps cost so the adoption of FSL for cataract surgery may be inevitable.

Anesthesia for Laser Use in Special Patient Populations

Pediatrics

Indications and Contraindications

Summary Box

- Lasers are used for a wide variety of procedures in the pediatric population

including removal of laryngeal papillomatosis and anogenital warts
- Diode laser therapy is used in treatment of retinopathy of prematurity

Lasers are frequently used in certain types of procedures and surgeries involving pediatric patients. Lasers have been successfully used for removal of anogenital warts, laryngeal papillomatosis, and excision of port wine stains. Diode laser therapy for retinopathy is another indication for laser use in the pediatric patient.

Techniques

Summary Box
- Pre-operative fasting guidelines apply in the healthy pediatric patient for elective laser surgery
- Pre-medication with oral midazolam in patients older than 1 year helps with anxiety prior to induction of anesthesia
- General anesthesia combined with local anesthetic filtration is commonly used for laser surgery in pediatric patient
- Post-operative pain control can be difficult to assess and treat; parental presence in the recovery phase often helps comfort the pediatric patient

Pre-operative Management

Factors such as age, weight, and existing medical conditions deserve special consideration in formulating the anesthetic plan prior to surgery. Regarding pre-operative fasting, standard guidelines apply for pediatric patients presenting for elective laser surgery [29]. These guidelines are summarized in Table 11.4.

Pre-medication is generally not necessary for patients under 1 year of age. Beyond 1 year up to 10 years, oral midazolam 0.5 mg/kg to a maximum of 15 mg provides adequate anxiolysis.

Table 11.4 Fasting guidelines for pediatric patients

Type of food	Minimum fasting period	Example
Clear liquids	2 h	Water, clear juices (no pulp), pedialyte, plain jello
Breast milk	4 h	
Infant formula	6 h	
Non-human milk	6 h	
Light meal	6 h	Solid foods (not including fatty or fried foods); amount and type of food may require 8 h

Recommendations vary somewhat and are for healthy pediatric patients without increased risk of aspiration or decreased gastric emptying [30]

Description of Technique

The anesthetic plan is determined by the procedure, the requirement to stay immobile, the age of the patient, any preexisting conditions and any special needs of the patient.

Many surgeons prefer to work with pediatric patients under general anesthesia, while others prefer conscious sedation when possible. General anesthetic techniques provide many advantages such as immobility, and variables such as $PaCO_2$, blood pressure, and intracranial pressure are more easily controlled to optimize operative conditions. Combined techniques utilizing general anesthesia with local anesthetic infiltration are commonly employed. Remifentanil and fentanyl have commonly been used during conscious sedation. They may be administered by bolus or infusion techniques. Propofol infusion is also appropriate.

Post-operative Management

Pain assessment in the pediatric patient can sometimes be challenging due to their inability to communicate effectively with the care giver. Irritability and crying may be attributed to other causes other than pain. Therefore, given the invasiveness and extent of the surgery one must rely on clinical judgment on administration of pain medications. As the pediatric patient regains consciousness, it is generally helpful to have the parents at the bedside. Common pediatric post-operative analgesics include liquid acetaminophen or ibuprofen. Ondansetron is an anti-emetic used in children to treat nausea and vomiting.

Adverse Events

> **Summary Box**
> - Complications during laser surrey are mainly related to underlying conditions of the patient
> - Laryngospasm in pediatric patients should be anticipated on induction and emergence of anesthesia
> - Edema as a result of airway surgery may pre-empted by administration of dexamethasone

As with any anesthetic, complications may occur. During laser surgery, problems are related mainly to the underlying condition. Procedures are usually short, especially dermatologic conditions. Laryngospasm is common in pediatric patients during induction and emergence from general anesthesia. Manipulation of the airway during laser surgery for papillomatosis requires adequate depth of anesthesia and muscle relaxation to minimize the incidence of laryngospasm and hypoxemia during surgery. Prior to extubation, pharyngeal suctioning and an awake, spontaneously breathing patient moving all extremities helps to avoid laryngospasm. Also, some advocate deep extubation in the spontaneously breathing patient prior to the return of airway reflexes. If larygnospasm occurs, treatment includes continuous positive pressure ventilation with 100% oxygen. Failure to resolve and resultant hypoxia should be treated with succinylcholine 0.1–0.5 mg/kg IV followed by positive pressure ventilation and possible re-intubation. Bradycardia associated with succinylcholine administration can be avoided by administering atropine 0.01–0.02 mg/kg IV prior to succinylcholine administration.

Airway edema resulting from surgery may be preempted by administering dexamethasone 0.25–0.5 mg/kg IV. Post intubation croup may be treated with inhaled nebulized racemic epinephrine 0.25–0.5 ml of 2.25% solution in 2.5 ml of normal saline.

Obstetrics and Gynecology

Indications and Contraindications

> **Summary Box**
> - Conization of the cervix and diagnoses of Papanicolau smears are applications of lasers in gynecology
> - Laser ablation of placental vessels is a treatment for severe twin-twin transfusion syndrome (FTTS)

In gynecology, laser applications include diagnostic spectroscopy for Papanicolau smears and conization of the cervix for cervical dysplasia. In obstetrics, an innovative use of laser has been developed for in utero coagulation of placental vascular anastomosis in the twin-to-twin transfusion syndrome.

Techniques

> **Summary Box**
> - In general, patients presenting for gynecological procedures involving laser use are young and healthy
> - Pregnant women beyond 18 weeks gestation presenting for laser surgery are at increased risk for aspiration
> - Local anesthesia with monitored anesthesia care is usually sufficient for laser conization of the cervix

- Compared to general anesthesia or total intravenous anesthesia, moderate sedation with local anesthetic results in less hemodynamic fluctuations and intraamniotic bleeding during fetoscopic laser surgery

Pre-operative Management

Patients presenting for gynecologic procedures such as Papanicolau smears and conization of the cervix are generally young and healthy. History and physical guides the need for anything other than routine lab tests. In the pregnant woman presenting for any surgery, effects of anesthetic agents on the fetus especially in the first trimester should be considered, although no particular anesthetic technique or agent has proven to be teratogenic in humans. If greater than 18 weeks gestation, precautions to decrease the risk of aspiration are indicated [8].

Description of Technique

Gynecological procedures such as laser conization of the cervix for cervical dysplasia may be performed under local anesthesia with monitored anesthesia care. Generally, there is less blood loss, but a longer operative time compared to using a scapel [8].

Many centers that perform fetoscopic laser coagulation treatment of FTTS utilize neuraxial (spinal, epidural, or combined spinal-epidural) anesthesia [30]. An alternative to neuraxial anesthesia, are use of local anesthesia with maternal sedation. Maternal-fetal hemodynamic fluctuations and intra-amniotic bleeding can be greater when general or total intravenous anesthesia is used [31]. Use of tocolytic agents may also interfere with hemostasis. Therefore, local anesthesia with some moderate sedation or local anesthesia alone may be preferable [32].

Post-operative Management

Laser conization of the cervix under local anesthesia results in minimal discomfort for most women post-operatively. Oral analgesics such as acetaminophen or ketorolac are acceptable choices. Post operative nausea and vomiting can be treated with anti-emetics such as reglan or ondansetron. Monitoring for post operative bleeding is appropriate.

In the parturient following fetoscopic laser coagulation, management in the post-operative period involves monitoring mother for bleeding and pre-term labor. Tocolytic agents may be needed after consultation with an obstetrician.

Adverse Events

Summary Box

- Peroneal nerve injury is a complication of the lithotomy position manifested by foot drop and loss of sensation over the dorsum of the foot
- Monitoring for pre-term labor and bleeding in the parturient post-operatively is imperative and may involve consultation of an obstetrician

A complication following gynecological and obstetrical procedures involving laser is peroneal nerve injury secondary to the lithotomy position manifested by foot drop and loss of sensation over the dorsum of the foot. Vigilance during positioning and during the surgery is the best ways to prevent this injury. Post operative nausea and vomiting should be anticipated and prophylaxis given prior to emergence in those at risk [8]. Bleeding and premature labor are risks of surgery in the parturient, particularly involving in utero procedures. Involvement of the obstetrician in the peri-operative care of these patients is important.

Future Directions of Laser Applications and Anesthesia

Further clinical research in the field of laser applications will have implications on anesthesia as laser technology evolves. Proposed novel uses for laser in surgery and medicine are innovative and widespread. Research into infrared laser treatment of injured peripheral nerves and use of lasers as a source an energy source for renal denervation as a treatment for renal artery hypertension are ongoing and optimistic [33, 34]. In humans, laser-induced thermotherapy for high-grade glioma is a promising minimally invasive surgical option that results in reduced operative time, decreased blood loss and shorter hospital stays [35].

Other studies have considered the efficacy of auricular acupuncture with laser for reduction of post operative pain with promising but early results [36].

Decreased pain was also found in patients who had undergone tibal fracture surgery and received laser therapy at the end of the procedure [37].

Special Considerations

Hazards and Laser Safety in the OR

The properties of laser light make it an effective tool in the operating room, but those same properties make it dangerous more so than conventional light of the same source. Laser light is coherent and collimated, meaning there is minimal loss of power with distance from the source. Direct and reflected laser beams are potentially very dangerous. Injury to eyes, as well as burns and ignition are the principle dangers inherent to lasers [32]. Development of a laser safety program is a national requirement for all hospitals and for office based surgical facilities using lasers. The laser can ignite any combustible material and thus is a fire hazard. Any tissue that the laser focuses is vaporized, whether diseased or healthy. Also, contact with the laser, like all radiation, should be avoided. There is no known acceptable of safe dose. There may be biological effects from scattered or reflected radiation.

Laser safety checklists are designed to guide perioperative personnel to provide a safe environment for both themselves and their patients when using laser technology (see Table 11.5).

Table 11.5 Laser safety checklist

Preoperative
• Laser warning signs and alarm lights at all entrances to procedure room
• Inspection of electrical cords integrity
• Appropriate protective eyewear available at all entrances to procedure room
• Respiratory protection available (i.e. N95 fit tested mask)
• Cover all windows as appropriate for laser in use
• Laser self-test and calibrated per manufacturer recommendations
• Tracer light axis of the visible tracer and laser beam should be aligned prior to use
• Smoke evacuator operational
• Fire extinguisher checked and in procedure room
Inraoperative
• Flammable prep solutions allowed to dry before laser use
• Appropriate properly fitting (fit the forehead and enclose the globe) protective eyewear inspected and worn by all personnel and patient
• Basin with water at procedure site
• Wet towels, drapes, sponges at procedure site
• Laser foot pedal only accessible when laser is in use
• Non-reflective, dull or matte finished instruments are used near laser site
• Laser on standby when not in use
• Use minimal oxygen concentration while maintaining patient's oxygen saturation
• Laser resistant endotracheal tubes and cuffs inflated with saline or dye
Postoperative
• Laser key returned to secure storage at end of procedure
• Clean and store laser, smoker evacuator and accessories
• Clean and inspect protective eyewear for damage and scratches

Conclusion

With advancements in the field of laser technology, applications of lasers in medicine and surgery have become widespread and common place. Innovations in clinical uses of laser for surgical and procedural intervention in many fields such as otolaryngology, dermatology, urology, gastroenterology, ophthalmology, obstetrics and gynecology, and pediatric surgery have demanded a familiarity with laser technology and safety by the anesthesiologist. In some cases, previously invasive surgeries with major blood loss have now become meticulous and mostly bloodless procedures with the use of laser. In other cases, surgeries that in the past required general anesthesia or total intravenous anesthesia are currently performed under monitored anesthesia care with local anesthesia.

Patient populations undergoing laser surgery range from the fetus in utero to the elderly. Therefore, the anesthesiologist must be cognizant of many variables such as age, underlying medical conditions, and potential complications that may arise in the peri-operative period for the many procedures or surgeries involving laser use.

New directions in laser applications involving surgery and medicine continue to evolve; many of these impacting the anesthesia experience. It is incumbent on the anesthesiologist to realize the benefits to the patient of increasing use of lasers in surgery. Furthermore, he or she must stay abreast of current developments in laser technology as it applies to the field of anesthesiology.

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K. Nouri (ed.), *Lasers in Dermatology and Medicine*, https://doi.org/10.1007/978-3-319-76220-3

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