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Review

Recommendation on the use of protective eyewear in endourological laser procedures

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Objectives

This work examines the current evidence available regarding the risks of eye injury in endourology laser environments with the aim of providing a consensus recommendation on the appropriate use of protective eyewear.

Methods

A working group was set up consisting of urological surgeons and laser protection advisors. A literature review was conducted to identify articles relevant to endourology practice and the commonly used lasers, and these were reviewed by the working group. Searches of the medical device fault/reporting databases were also undertaken. A consensus was developed and shared with stakeholders.

Results

No reports of eye injuries from Ho:YAG, Tm:YAG, or Thulium Fibre Lasers (TFLs) were identified, although reports of skin burns and equipment-related fires were found. Available evidence suggests that ocular risks in endourology from these lasers are minimal and limited to rare cases of reversible corneal damage. Protective eyewear can further reduce this risk. However, Lasers with wavelengths below 1400 nm pose significant ocular risks, including blindness.

Conclusion

Personnel working in an endourology environment using Ho:YAG, Tm:YAG, or TFLs face minimal ocular risks when adhering to established safety procedures, and laser-specific eyewear may not always be essential. This requires an understanding of the hazards and risks and is in accordance with the recommendations herein, which should form the basis for relevant local rules. Protective eyewear remains critical when using visible and near-infrared lasers due to the heightened associated ocular risks.

Keywords

laser safety, holmium, Ho:YAG, thulium, thulium fibre laser, TFL, eyewear, personal protective equipment, ergonomics

Introduction

Urology lasers are used to treat a variety of conditions, including BPH, bladder cancer, and kidney stones. While these lasers are very effective, they can also pose a risk to staff members who are not properly trained and who do not take the necessary precautions.

The most serious hazard to staff associated with urology lasers is eye injury. Laser beams have the potential to cause damage to the cornea, retina, and optic nerve. This risk can be eliminated with appropriate use of protective eyewear. However, the use of protective eyewear has some disadvantages, including obstruction of vision, distraction and discomfort, as well as the potential for cross contamination between multiple users of the same set of eyewear. Due to these disadvantages, along with the perception that some endourological procedures carry a low risk of ocular injury, the application of safety measures currently varies among organisations and individuals in the UK.

This joint publication has been produced by associations representing urological surgeons and laser protection advisors working in the UK, to help employers carry out pragmatic and robust risk assessments that ensure a safe working environment during endourological laser procedures. It is intended to help decide, based upon current evidence available in the scientific literature, when laser safety eyewear is required and where the balance of risks may allow the operating surgeon to work safely without laser safety eyewear.

Methods and Results

A PubMed literature search was carried out (T.L.). Results were excluded if they did not include any reference to eye injuries or associated ocular risks in the clinical environment. A search for 'urology laser eye' returned 40 results, which were refined to 11. A second PubMed search for 'urology fibre break', returned 19 results, of which three were suitable to be analysed in detail, and a further PubMed search for 'cornea laser damage threshold' from 1980 onwards returned 64 results, of which three were relevant to corneal damage caused by 1900–2100-nm lasers. At the time of writing, there are a small number of publications in the scientific literature that aim to help quantify the risks of ocular exposure to laser radiation from urological lasers.

Once non-relevant literature had been excluded, the remaining studies were reviewed in full by the working group and the findings condensed into the discussion and recommendations below. The results and findings from these papers are summarised in Appendix S1 [1–18].

Databases such as Manufacturer and User Facility Device Experience (MAUDE; fda.gov) and the Global Medical Device Nomenclature (GMDN) database, which record problems and incidents relating to medical devices, were also reviewed. From the evidence reviewed we found the following:

- There was direct evidence of eye injuries caused by neodymium:Yttrium-Aluminium-Garnet (Nd:YAG), frequency-doubled Nd:YAG (potassium titanyl phosphate [KTP]), and diode lasers (Appendix S1). These lasers pose a risk to the retina and therefore can potentially cause injuries, including loss of sight.
- There was no direct evidence of eye injuries for holmium: YAG (Ho:YAG) lasers, thulium YAG (Tm:YAG) lasers or thulium fibre lasers (TFLs).
- Three publications which provided *in vitro* evidence of superficial eye damage caused by Ho:YAG lasers and TFLs; this only occurred at significantly shorter distances than reported nominal ocular hazard distances (NOHDs).
- Prescription eyewear was found to provide some protection to the eyes, although no study has investigated the wide range of prescription eyewear available and whether all types afford the same levels of protection.

Discussion

All organisations in the UK are required by law to protect staff and the public from exposure to potentially harmful laser radiation. Risk assessments must be conducted by a competent person with experience and knowledge of the risks associated with laser radiation (e.g., a laser protection advisor) and legal limits, termed exposure limit values, are included in legislation [19].

The Health and Safety Executive recommends a hierarchy of risk control, in which personal protective equipment is the last option and the least effective means of protecting staff. Within the clinical environment, other means of controlling the risk are usually not able to reduce the risk adequately, therefore, laser safety eyewear is widely recommended to protect patients and employees. However, the use of laser safety eyewear during endourological laser procedures can have a detrimental effect on the vision and comfort of the surgeon, increasing the probability of errors and poor clinical outcomes, as well as reducing operating efficiency and ergonomic functions.

Visible and near-infrared lasers, such as Nd:YAG, KTP and diode lasers, can be used in urology for prostate ablation and urothelial tumour ablation. However, Nd:YAG lasers are rarely used in contemporary practice. These lasers primarily target haemoglobin and use wavelengths that are relatively transparent to the anterior eye and aqueous humour, as well as to prescription spectacles and therefore the risk of damage is to the retina and optic nerve in the posterior eye. Furthermore, the eye's ability to focus visible and near-infrared radiation of <1400 nm wavelength can increase irradiance from the cornea to the retina by approximately 100 000 times, so a beam of 10 Wm^{-2} at the cornea becomes 1 MWm^{-2} at the retina [20]. In a worst-case scenario, damage to the retina or optic nerve can result in permanent loss of vision. Reported eye injuries in urological laser procedures appear to be limited to these lasers.

Longer wavelength infrared devices, such as Ho:YAG lasers, Tm:YAG lasers and TFLs, are primarily used for lithotripsy of stones, transurethral or ureteroscopic vaporisation of urothelial tumours, and enucleation or resection of the prostate. These wavelengths are absorbed by water and, in the eye, the energy is absorbed within the anterior anatomy of the eye and thus this poses a risk primarily to the cornea. Thermal damage to the cornea may result in corneal burns and abrasions, which can cause severe pain but do not appear to be associated with long-term impairment of vision [14,21]. However, we were not able to find any reported eye injuries from the endourological use of lasers emitting wavelengths >1400 nm. It should be noted that incidents of this kind are known to be underreported and thus a lack of cases in the literature does not explicitly rule out the possibility that eye injuries have occurred.

Ex vivo studies have shown that superficial damage to the eye can result from exposure to lasers at wavelengths >1400 nm at typical clinical settings, in some cases even through prescription eyewear but that such damage is not likely to cause permanent effects and will not usually cause severe complications such as irreversible loss of vision. Full thickness corneal burns can occur with prolonged direct contact, as shown in some of the animal studies reported. This can, rarely, lead to more significant loss of vision, as reported in a personal communication from an ophthalmology medical consultant. During endourology treatments the laser aperture is within the body, so the potential risk to the operating theatre personnel would be from inadvertent fibre fracture or failure to follow laser safety protocols when the fibre is outside the body.

During stone treatment, it is unusual to use energy levels > 20–30 W for kidney stones. However, for prostate treatments, the average powers may be as high as 100–150 W, potentially posing greater risk to personnel at greater distances. Appendix S2 has more detail on the calculations used to support safe working distances for these lasers.

For significant corneal injury to result from an incident relating to use of, e.g., a Ho:YAG laser for bladder or prostate surgery, a highly unlikely set of circumstances need to arise. This follows a 'Swiss cheese' model of risk, where multiple elements must align, none of which individually would lead to a risk of major injury, and where the cumulative likelihood of events is exceptionally low. In this example, for significant injury to occur the following would need to happen: the fibre breaks between its leaving the laser and entering the endoscope; the surgeon keeps activating the laser with the footswitch; the staff member operating the laser does not press the 'emergency stop' button; the laser energy from the fibre break is directed at the eye of a nearby member of staff at a relatively short distance without significant movement; and the staff member does not blink or turn away.

Each of these elements is unlikely to occur individually, and this probability can be further reduced through the following:

- adequate training in laser safety for all staff working in the laser controlled area;
- maximising the distance between any point of the fibre and the eyes of the surgeon or any other personnel, e.g., by avoiding equipment that raises the fibre to eye level;
- ensuring that there are no bends in the fibre before and during operation;
- securing the fibre using, for example, damp gauze swabs and laser port seals on the scope (such as Tuohy-Borst adaptors) to reduce the risk of fibre fracture due to excessive handling;
- Performing operations via video-endoscopes, as these do not require the laser fibre to pass close to the surgeon's eyes.

In real-world practice, the experience of any injury caused by these longer-wavelength lasers is, to our knowledge, limited to superficial hand and finger injuries caused by excess and/or inappropriate laser fibre handling. The reported incidence rate in an extensive global clinical experience is fewer than 0.1% of cases. If we apply the National Patient Safety Agency risk assessment scoring matrix to this, although the outcome of significant injury would be severe (score 4), the likelihood would remain at 1, and therefore give a total risk score of 4, which does not require any further special measures to be implemented.

The risk from Nd:YAG, KTP, and diode lasers substantiates the need for eye protection. In urology, this means that practitioners using, e.g., greenlight laser or diode lasers for transurethral laser ablation of bladder tumours must wear suitable eyewear (in respect of the laser in use) to avoid the risk of vision loss.

The risk of eye injury from Ho:YAG lasers, Tm:YAG lasers and TFLs is not zero, but due to the need for a relatively close proximity and multiple-second long exposure, it appears that the likelihood of serious injury is very low. This is supported by a lack of reported incidents worldwide despite a significant proportion of urologists not using protective eyewear and a huge volume of cases carried out globally. This is also supported anecdotally by UK experiences from several high-volume centres.

Prescription eyewear or leaded eyewear used for X-ray shielding ('lead glasses') reduces the risk of corneal damage from these lasers as well but does not provide the same level of protection as dedicated wavelength-specific laser safety eyewear. Operators should be fully aware of the potential risk and suitable dedicated protective eyewear must be available for those who choose to wear it.

Due to the low risk of eye damage, the mitigation possible through appropriate laser safety procedures, the training of all staff in the laser controlled area, and the potential adverse impact of wearing laser safety eyewear when performing these procedures, a surgeon using Ho:YAG lasers, Tm:YAG lasers or TFLs for endourological procedures via video-endoscopes may choose not use laser protective eyewear. This is based on an understanding of the hazards and risks and is in accordance with the recommendations outlined in this document.

Given the even lower risk for other personnel working in the laser environment and the very small amount of time (if any) that they are likely to spend within the NOHD of the fibre, other personnel may also choose not to use laser protective eyewear, based on an understanding of the risk and in accordance with the recommendations outlined in this document. Patients' eyes may be within the NOHD but can be adequately protected by being taped closed or covered with a damp cotton swab.

Based upon the current available evidence outlined in this literature survey, and supported by our own experience, we present the following recommendations:

1. All personnel working in an endourological laser environment (laser controlled area) should understand the risks associated with lasers, including the specific risk of eye damage from the laser in use.
2. Local rules must be produced by a suitably trained laser safety expert (a laser protection advisor), and may be informed by these national guidelines.
3. All laser operators, including all laser surgeons, must complete formal certificated 'Laser Safety Core of Knowledge'[1] training prior to using lasers in their practice, and must undertake certificated refresher training at least every 5 years. All other personnel working routinely within the laser controlled area need to complete formal certificated 'Laser Safety Awareness' training[2] and must also undertake certificated refresher training at least every 5 years. Other personnel working within the laser controlled area should have read and understood the local rules.
4. All personnel working in an environment where Nd:YAG, KTP, or diode endourology lasers are in operation must wear suitable wavelength-specific protective eyewear. All laser safety recommendations, including locked doors, window blinds, appropriate signage, and non-reflective surfaces, etc. should be in place whenever the laser is used. This also applies to any other lasers with a wavelength <1400 nm.
5. Personnel working in an endourology operating theatre environment where Ho:YAG lasers, Tm:YAG lasers or TFLs in the wavelength range 1940–2100 nm are in operation may work in the laser controlled area without using specific laser eye protection if the following measures are in place:
   a. treatments are performed via video-endoscopes to ensure that the fibre does not pass close to the surgeon's eyes;
   b. a discussion about laser usage is incorporated into the WHO theatre team briefing at the start of the operating list, identifying equipment needs, laser operators, and providing a reminder of basic laser safety recommendations including the NOHD;
   c. the number of personnel and the time spent within the NOHD of the laser fibre are limited. In practical terms, this is already accomplished in most theatre setups;
   d. the use of damp swabs, for example, to hold the laser fibre in place on the surgical scrub trolley to ensure against excessive bends in the fibre and to minimise handling of the fibre once connected and in use;
   e. the whole length of exposed laser fibre is kept as far below eye level as possible during the time it is in use, e.g., not looped over drip stands;
   f. regular audits are undertaken against all the recommendations listed here;
   g. any incidents or near misses relating to laser eye safety are reported widely, including to the authors of this recommendation.

[1]BMLA Core of Knowledge. Available at: https://bmla.co.uk/core-of-knowledge-syllabus/. Accessed 22 July 2024.
[2]BMLA Laser Safety Awareness. Available at: https://bmla.co.uk/resources/laser-ipl-safety-awareness/. Accessed 22 July 2024.

Disclosure of Interests

None of the authors have any relevant conflicts to disclose.

Author Contributions

T.L. undertook the initial literature reviews. All authors agreed the inclusion and exclusion criteria and reviewed the reviewed articles. T.L., J.B. and J.P. wrote and edited the manuscript. T.L. undertook the calculations in Appendix S2, with further input from J.B., S.B. and M.R. The manuscript was reviewed and comment and editorial input was provided by S.B., M.R., F.A.-J. and H.R. The corresponding authors for the respective professional groups (the British Medical Laser Association [BMLA] and BAUS) are T.L. and J.P. The Executive Committee of the BAUS Section of Endourology approved the consensus statement, and it has also been presented to the BMLA and BAUS Section of Endourology membership at annual meetings, but has not been submitted for publication elsewhere.

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Abbreviations: BMLA, British Medical Laser Association; Ho:YAG, holmium:YAG; KTP, potassium titanyl phosphate; Nd:YAG, neodymium yttrium aluminium garnet; NOHD, nominal ocular hazard distance; TFL, thulium fibre laser; Tm:YAG, thulium:YAG.

Supporting Information

Additional Supporting Information may be found in the online version of this article:

Appendix S1. Published papers and a review of their findings.

Appendix S2. Example calculations.

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