Cadaver Study

The Extent of Tissue Damage in the Epidural Space by Ho / YAG Laser During Epiduroscopic Laser Neural Decompression

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Disclaimer: This work was supported by The Catholic University of Korea Daejeon St. Mary's Hospital, Clinical research institute, grant funded by The Catholic University of Korea Daejeon St. Mary's Hospital (CMCDJ-P-2014-016).

Manuscript received: 01-06-2015
Revised manuscript received: 04-01-2015
Accepted for publication: 04-27-2015

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Background: Lasers have recently become very useful for epiduroscopy. As the use of lasers increases, the potential for unwanted complications with direct application of laser energy to nerve tissue has also increased. Even using the lowest laser power to test for nerve stimulation, there are still risks of laser ablation. However, there are no studies investigating tissue damage from laser procedures in the epidural space.

Objective: This is a study on the risks of Ho/YAG laser usage during epiduroscopy.

Study Design: Observatory cadaver study.

Setting: Department of anatomy and clinical research institute at the University Hospital.

Methods: We used 5 cadavers for this study. After removing the dura and nerve root from the spinal column, laser energy from a Ho/YAG laser was applied directly to the dura and nerve root as well as in the virtual epidural space, which mimicked the conditions of epiduroscopy with the dura folded. Tissue destruction at all laser ablation sites was observed with the naked eye as well as with a microscope. Specimens were collected from each site of laser exposure, fixed in 10% neutral formalin, and dyed with H/E staining.

Results: Tissue destruction was observed in all laser ablation sites, regardless of the length of exposure and the power of the laser beam.

Limitations: A cadaver is not exactly the same as a living human because dura characteristics change and tissue damage can be influenced by dura thickness according to the spinal level.

Conclusion: Even with low power and short duration, a laser can destroy tissue if the laser beam makes direct contact with the tissue.

Key words: Epiduroscopic laser neural decompression, epiduroscopy, Ho/YAG laser, laser damage, neural decompression, dura histology

Pain Physician 2016; 19:E209-E214

It has become more popular to use lasers in medical fields such as ophthalmology, dermatology, dentistry, and musculoskeletal medicine because of the inherent characteristics of less pain and discomfort during interventional procedures with lasers. Since Choy et al (1) first reported positive outcomes for laser discectomy in 1992, lasers have been used widely for spinal pain. Tobita et al (2) reported that ultrafine flexible fiberscopes were a helpful tool for the diagnosis of spinal canal diseases. With development of the technology and technique, epiduroscopy has become a very useful tool not only for the diagnosis of epidural pathologies that even magnetic resonance imaging (MRI) cannot detect, but also for targeted medication delivered directly to the pathologic site (3-4). Epiduroscopic laser neural decompression (ELND)

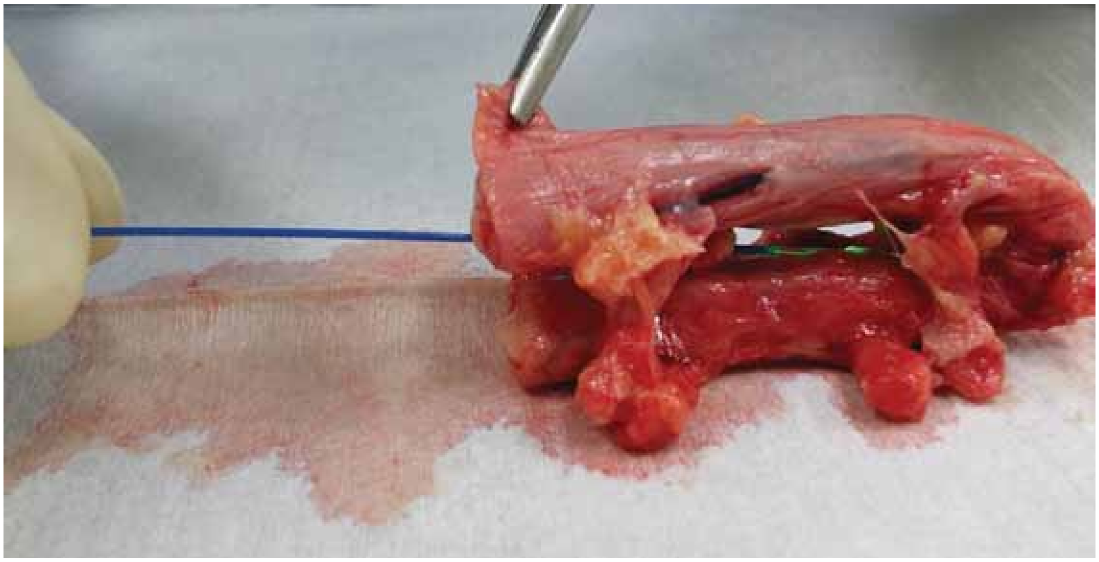

Fig. 1. Image showing the virtual epidural space with laser.

for patients with low back pain and/or leg pain was performed recently with laser ablation to remove the pathology in the epidural space (5,6).

As the use of lasers increases in the medical field, however, reports of complications and side effects from unwanted tissue destruction have also increased. In ELND specifically, there have been some reports of complications related to laser use (7,8). The extent of tissue damage differs according to the total amount of energy and the wave length of the laser (9). Physicians who use lasers in their clinics must be cautious to avoid unwanted damage from the laser. The Holmium/Yttrium-Aluminum-Garnet (Ho/YAG) laser can be used as an option to reduce laser risks during epiduroscopic laser procedures as it has a wavelength of 2.1 μm (8,10), which invades tissue by less than 0.5 mm. Even with the Ho/YAG laser, there are still risks from laser ablation as even the small dose used for stimulation testing can cause damage to the patient.

Although there are several studies evaluating the effectiveness of ELNDs (5,11), there are none investigating the degree of tissue destruction in the epidural space from lasers. The aim of this study was to evaluate the extent of tissue damage due to laser usage during ELND.

Methods

Five cadavers that had not undergone spinal surgery were enrolled in the study in accordance with the university policy for handling cadavers. Posterior laminectomy was performed on each cadaver from T1 to the sacral hiatus to expose the dura and nerve root. After removal of the dura, nerve root, and spinal cord from the spinal column, we directed pulses from a Ho/YAG laser (VersaPlus p20, Lumenis, USA), which had an inner diameter of 0.55 mm, an outer diameter of 0.78 mm, and a pulse type of 5 – 15 Hz, perpendicular to the dura and nerve root. Furthermore, to create a virtual epidural space similar to the space in which ELND is performed, the dorsal dura was folded towards the ventral dura and laser energy was delivered parallel to the 2 layers of the ventral dura (Fig. 1). The dura was exposed for one second (D1), 2 seconds (D2), and 3 seconds (D5) to a laser 5 joules strong, and for 3 seconds to a laser 10 joules strong (D10). The nerve root was exposed for one second (R1), 2 seconds (R2), and 3 seconds (R3) to a laser 2.5 joules strong, and for 3 seconds to a laser 5 joules strong (R5). The virtual epidural space was exposed for 3 seconds to laser doses of 5 joules (E5) and 10 joules (E10).

Lesion sizes from the laser ablations were observed with the naked eye and measured with a ruler. Specimens were obtained from each laser exposure site – 15 x 15 mm frames from the dura and 15 mm lengths from the nerve root – as well as from the laser-unexposed sites to compare the tissue damage. Immediately after resection of the specimen from the dura and nerve

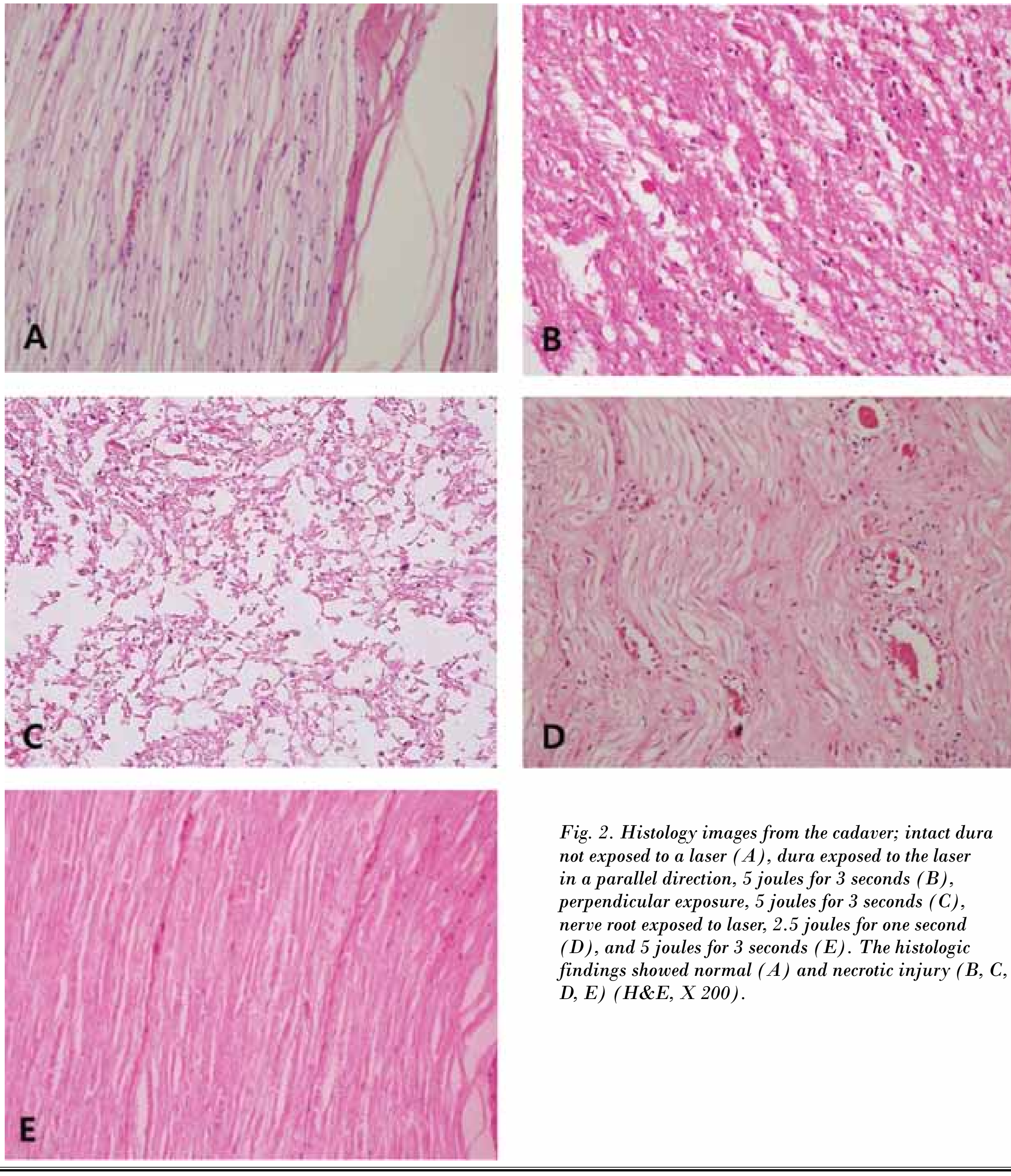

Fig. 2. Histology images from the cadaver; intact dura not exposed to a laser (A), dura exposed to the laser in a parallel direction, 5 joules for 3 seconds (B), perpendicular exposure, 5 joules for 3 seconds (C), nerve root exposed to laser, 2.5 joules for one second (D), and 5 joules for 3 seconds (E). The histologic findings showed normal (A) and necrotic injury (B, C, D, E) (H&E, X 200).

roots, all specimens were fixed in 10% neutral formalin to preserve the cells and were embedded in paraffin. The specimens were cut 0.5 mm thick and H/E staining was performed for microscopic examination. We evaluated the amount of tissue destruction from each laser ablation.

Results

All tissues exposed to the laser beam were injured, regardless of the length of time for laser ablation and the power of the laser (Fig. 2). Microscopically, there were many necrotic cells in all of the tissues where the laser was applied in a parallel (Fig. 2, B) as well as perpendicular (Fig. 2, C) direction. The lowest power for the Ho/YAG laser, 2.5 joules, which was used as the test dose before laser ablation, also caused cell damage to the nerve root tissue (Fig. 2, D). It was neither possible nor meaningful to measure the diameter of the resulting lesion with the naked eye because the laser ablated tissue shrunk to the center of the laser ablation area, with a hole made by the laser beam (Fig. 3). It was also not possible to measure the diameter of the injured site on the microscopic view because the diameters of the lesion sites were much larger than the field of the microscopic view.

Discussion

ELND has been reported to be very helpful for relieving chronic back pain resulting from intervertebral disc prolapse, spinal stenosis, and failed back surgery (5,6,11). Laser usage was recently adopted for the treatment of musculoskeletal disorders, especially in endoscopic laser procedures for lower back pain.

There are various types of lasers available for laser discectomy such as the ND/YAG laser, the CO2 laser, and the Ho/YAG laser. The Nd/YAG laser penetrates tissues deeply and thus is most effective. However, it is absorbed inefficiently by water and has a greater risk of thermal damage to surrounding tissues. The CO2 laser has a high power and is readily absorbed by water, therefore, it has a low risk of thermal damage to surrounding tissues. However, the laser's applications are limited because its medium is gas (12). The Ho/YAG laser can offer exact ablation of target tissues with minimum damage to surrounding tissues and nerve roots (13). It has a wavelength of 2.1 μm, its energy is mostly absorbed by tissue water, and it penetrates tissue by 0.5 mm. When Ho/YAG laser was applied to pig spine discs, there was no temperature elevation in the annulus and around the nerve root both ipsi- and contralaterally (14). Cernavin (15) reported that a Ho/YAG laser is more suited for cutting tissue than a Nd/YAG laser. The Ho/YAG laser is also more appropriate for localization of the laser lesion in the epidural space.

Even though ELND with the Ho/YAG laser is effective for treating chronic lower back pain, there are risks of laser-related thermal damage such as transient mild motor paralysis (8). Because of their mono-chromaticity, coherency, and collimation, lasers have a high potential to cause trauma to tissues, especially when applied in a narrow space like the epidural space. Applying a laser to tissues boils the tissue water contents and denatures the tissue proteins. Laser ablation usually results in lesions with hemispherical or cone-shaped contours with third degree burn tissue surrounding second and first degree burn tissue (9). Hirohashi (12) reported that temperatures in the surrounding tissues increased with irradiation at a higher power level when a Ho/YAG laser was applied to intervertebral discs in a rabbit. There are still controversies regarding the degree of temperature increase in surrounding tissues due to laser usage

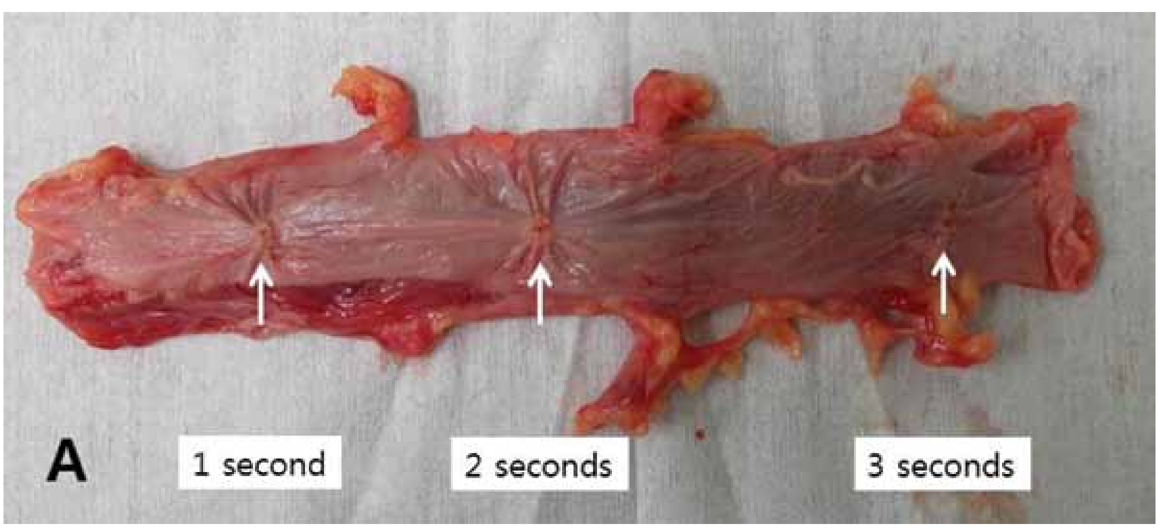

Fig. 3. *Cadaver dura exposed to the laser in a perpendicular direction, 5 jous for one, 2, and 3 seconds.*

(12,14). There have been several efforts to reduce the hazards of laser use, such as by shortening the pulse duration and the development of tissue selectivity.

We observed destroyed cells in the microscopic views of tissues to which laser beams were applied parallel as well as perpendicular to the direction of the dura. There were no significant differences in tissue damage observed histologically according to laser power and length of exposure in this study. When observed with the naked eye, the lesions appeared as holes with a diameter of 0.4 mm and swelling of one mm in diameter (Fig. 3). Based on this result, we anticipate the possibility of tissue damage from laser use in the epidural space during ELND, even if the laser is applied for only a short time with low energy. During ELND, the tissues are stimulated by laser fiber and the catheter is moved before laser ablation to avoid nerve damage. However, it is sometimes very hard to distinguish the anatomy, especially in severe epidural adhesion patients, a laser power of 2.5 joules is often used as a test dose. The nerve root was damaged when exposed to the laser at strength of 2.5 joules, despite the one second exposure period in this study. A stimulation power of 2.5 joules is not completely safe and carries a risk of unintended tissue damage. A safer option is needed for testing the stimulation of nerve tissue.

Using water concurrently during a laser ablation can reduce the tissue damage from the laser when performing an ELND. However, too much water can cause other complications by increasing pressure in the epidural space as well as intracranial pressure (7). More research on appropriate usage of lasers and water during ELND is required.

This study had some limitations. First, dura characteristics in cadavers are not exactly the same as in living humans. Second, tissue damage may be influenced by dura thickness according to the spinal level (16). We did not apply the laser at the same spinal level. Despite these limitations, we can conclude that Ho/YAG laser usage during ELND has a risk of tissue damage in the epidural space, even at the lowest laser power. We should further investigate tissue damage from the laser and better confirm the anatomical relationship before using lasers during ELND. More studies and guidelines on using lasers are required to minimize unintended tissue damage.

Acknowledgments

This work was supported by The Catholic University of Korea Daejeon St. Mary's Hospital, Clinical research institute, grant funded by The Catholic University of Korea Daejeon St. Mary's Hospital (CMCDJ-P-2014-016).

This article has not been previously published and is not currently under consideration for publication in another journal. All of authors have read and approved this article. Daehyun Jo planned this study, made the protocol, dissected the cadavers, made the slides, and wrote the original manuscript. Dong Joo Lee participated in the cadaver dissection and assisted in making the slides.

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