Effects of Holmium(HO)-YAG Laser Irradiation on Rabbit Lumbar Discs

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Summary: To study the effect of laser irradiation on normal lumbar discs, a 2100 nm Holmium (HO)-YAG laser irradiation was applied to the 83 lumbar discs of 23 adult rabbits. The extent of disc vaporization, the temperature changes in the surrounding tissues, and changes in the radiograph and MRI findings were assessed after laser irradiation. When laser irradiation was delivered to the discs, the disc weight decreased linearly with the increase in total laser energy, indicating steady vaporization of disc material. The temperature was highest at the site of the guide needle. Laser irradiation was delivered at 0.5 J/pulse or 1.4 J/pulse X5 pulses/sec to the intervertebral discs, and radiographs and T2-weighted MRI of the irradiated discs were investigated at 1, 4, and at 12 weeks after irradiation. At 1 week after irradiation at 0.5 and 1.4 J/pulse, the radiographs showed a decrease in the disc height. At 12 weeks after irradiation at 0.5 J/pulse, the disc height had restored to normal, while the decrease was persistent after irradiation at 1.4 J/pulse. At 1 week after irradiation, MRI showed a decrease in the signal intensity of discs treated at 0.5 J/pulse, but the decrease was recovered at 12 weeks. After irradiation at 1.4 J/pulse, the decrease in signal intensity was also recovered by 12 weeks, but the recovery was less than the recovery after treatment at 0.5 J/pulse. Laser irradiation is applicable for the treatment of intervertebral discs, but it is necessary to select the optimal operating conditions. It may also be necessary to change the power of irradiation according to the pathological condition of the disc being treated.

Key words laser irradiation, Holmium-YAG laser, lumbar intervertebral disc, experimental study, radiograph, magnetic resonance imaging

INTRODUCTION

In 1969, Smith [1] developed chemonucleolysis, in which chymopapain is injected into an intervertebral disc, for treatment of lumbar disc herniation that was refractory to conservative therapy. Since then, various disc therapies have been developed as therapeutical therapy between open surgery and conservative therapy. In recent times, laser discectomy has been developed as a moderately invasive therapy. In 1984, Grooper [2] reported his experience with a CO2 laser for anterior cervical discectomy in dog. In 1991, Choy [3,4] studied the effects of laser irradiation at various wavelengths for the treatment of lumbar disc herniation. Yonezawa et al. [5] reported the clinical usefulness of the Neodymium(Nd)-YAG laser in 1991, and this was supported by Siebert [6] in 1993. It is generally considered necessary for a new therapy to undergo detailed experimental evaluation before it is applied clinically. However, laser discectomy was applied clinically before it had been adequately investigated in animal studies, despite the fact that the extent of disc vaporization varies depending on irradiation conditions even at the same wavelength. The 2100 nm Holmium(HO)-YAG laser, which is easily absorbed in water, has been reported to be useful for disc therapy. We have also used the HO-YAG laser for clinical treatment of lumbar disc herniation. However, it is not adequate to rely solely on the information supplied by the manufacturer or
the results of the few experiments that have been done. We therefore conducted experiments in rabbit to assess the effects of the 2100 nm HO-YAG laser on intervertebral discs. In the first experiment, we investigated the effects of HO-YAG laser irradiation on normal lumbar discs.

MATERIALS AND METHODS

For this experiment, we used 83 discs, at the levels between L3-4 and L6-7 in 23 adult white Japanese rabbits weighing 3-4 kg. Ketamine hydrochloride and pentobarbital sodium were infused intravenously for general anesthesia. Each rabbit was fixed in the prone position on an operating bed, and an 18-G needle was inserted extraperitoneally into the intervertebral disc under fluoroscopic control. A 400 μm fiber was introduced through the guide needle and laser irradiation was applied to the nucleus pulposus. The HO-YAG laser (COHERENT, Palo Alto, CA) delivered pulse irradiation at a wavelength of 2100 nm (0.5-2.0 J per pulse at a rate of 5-20 pulses/sec). In a preliminary experiment, the laser was used to irradiated 16 discs of 4 rabbits, employing various combinations of power and pulse interval to confirm that laser irradiation caused disc vaporization.

The following factors were investigated: 1) the extent of disc vaporization, 2) temperature changes in the surrounding tissues, and 3) the time course of changes in the radiograph and MRI findings of the irradiated discs.

Disc vaporization

The spine was removed from the rabbit, and the laser fiber was introduced into the discs to apply irradiation at 1.0 J/pulse ×5 pulses/sec. The weight of the special section containing 3 discs and the surrounding vertebrae was determined after each irradiation, and the loss of weight was used to calculate disc vaporization.

Temperature in the surrounding tissues

To assess the thermal penetration of the laser irradiation into the surrounding tissues, the temperature was measured at the site of guide-needle insertion, a site ventral to the disc, a site opposite to that of guide-needle insertion, and in the spinal canal. Measurements were done for 3 discs and laser irradiation was applied at 1.0 J/pulse ×5 pulses/sec.

Subsequently, to assess the effect on temperature of changes of the irradiation conditions (various power levels and various irradiation methods at the same power), laser irradiation was applied to 9 discs under the following conditions, and the temperature changes were followed at the site of the guide-needle insertion, where the greatest temperature increase had been determined previously. The following irradiation conditions were used: 0.5 J/pulse ×5 pulses/sec (2.5 watts), 0.5 J/pulse ×14 pulses/sec (7.0 watts), and 1.4 J/pulse ×5 pulses/sec (7.0 watts).

Imaging investigation

Laser irradiation was performed in 12 rabbits at 0.5 J/pulse ×5 pulses/sec (2.5 watts) and 1.4 J/pulse ×5 pulses/sec (7.0 watts), and the radiographs of the lumbar spine were obtained immediately after irradiation and at 1, 4, and at 12 weeks after irradiation to assess any changes in the disc height. The height of each disc was expressed as a disc index, which was the ratio of the height of the disc space to the anterior-posterior diameter of the vertebral body. In addition, T2-weighted sagittal MR images of the irradiated discs were examined in 4 of the above 12 rabbits at 1, 4, and at 12 weeks after irradiation to investigate changes in signal intensity in the discs, using an MRT 50A/II instrument (0.5 tesla, Toshiba Med. Tokyo, Japan) and a 20-cm round target coil.

RESULTS

Disc vaporization

The disc weight decreased almost linearly with the increase in the total energy applied in all the discs investigated, indicating the steady vaporization of disc material by laser irradiation (Fig. 1).

![Fig. 1. Correlation between degree of disc vaporization and energy of laser irradiation. The weight of the irradiated discs decreased almost linearly with the increase in total irradiation energy (kilojoules).](image-url)
Temperature of the surrounding tissues

The temperature of the surrounding tissues increased with an increase in total energy applied in all 3 discs irradiated. The greatest increase in temperature was 10.2 degrees centigrade (p < 0.01) observed

Fig. 2a. Changes in temperature in the surrounding tissue. The temperature in the surrounding tissue increased with the increase in total irradiation energy (kJ). It was highest (10.2 °C) at the site of the guide-needle insertion, followed by 5.8 °C at the site ventral to the disc. The increase in temperature was only 3.6 °C at the site opposite to that of guide-needle insertion, and only 3.0 °C in the spinal canal.

Fig. 2b. Changes in temperature at the site of the guide-needle insertion depending on irradiation conditions. The temperature only increased slightly at the site of the guide-needle insertion when the disc was irradiated at 0.5 J/pulse × 5 pulses/sec (2.5 watts). In contrast, when the disc was irradiated at 0.5 J/pulse × 14 pulses/sec (7.0 watts) or at 1.4 J/pulse × 5 pulses/sec (7.0 watts), the temperature increased significantly at the guide-needle site (p < 0.01). When compared on an equal wattage basis, the higher the joule level then the greater the rise in temperature (p < 0.01).

Fig. 3a. Radiographs of the lumbar spine after laser irradiation. The radiographs of a disc irradiated at 0.5 J/pulse × 5 pulses/sec showed disc space narrowing at 1 week after irradiation, but the decrease in disc height was recovered slightly at 12 weeks after.

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at the site of the guide-needle insertion, followed by 5.8 degrees centigrade at the site ventral to the disc (p<0.05). The increase in temperature of 3.6 degrees

Fig. 3b. Disc index. The disc index was significantly lower at 2 weeks after irradiation at 1.4 J/pulse, compared to that of untreated discs. In contrast, there were no significant differences in disc index between the discs irradiated at 0.5 J/pulse and the untreated discs throughout the 12 weeks of post-irradiation follow-up. When the discs were compared at 12 weeks after irradiation, the disc index was significantly lower after treatment at 1.4 J/pulse than at 0.5 J/pulse.

at the opposite site to the guide-needle insertion, and the increase in only 3.0 degrees centigrade in the spinal canal were each not significant (Fig. 2a). The temperature at the guide-needle insertion showed a modest change under irradiation conditions of 0.5 J/pulse×5 pulses/sec (2.5 watts) (p<0.001), while the temperature was increased greatly after irradiation at 0.5 J/pulse×14 pulses/sec (7.0 watts) and after irradiation at 1.4 J/pulse×5 pulses/sec (7.0 watts). When the combination of laser energy and pulse frequency was varied while maintaining the same power output (watts=joule/pulse×pulse/sec), the temperature was increased more by irradiation at a higher energy level (kilojoules) (p<0.01) (Fig. 2b).

Changes in imaging findings

Radiographs: The radiographs of discs irradiated at 0.5 J/pulse×5 pulses/sec showed narrowing in the disc space at 1 week after irradiation, but this reduction in disc height was slightly recovered at 12 weeks after irradiation (Fig. 3a). When the discs were irradiated at 1.4 J/pulse×5 pulses/sec, the reduction in disc height persisted at 12 weeks after irradiation. When the results from irradiation at 0.5 and 1.4 J/pulse were compared using the disc index, the reduction in disc height caused by 1.4 J/pulse was significantly greater than that caused by 0.5 J/pulse at 2 weeks after irradiation (p<0.01). Following

Fig. 3c. Findings on the magnetic resonance image after laser irradiation. The T2-weighted sagittal MRI showed a decrease in the signal intensity of a disc irradiated at 0.5 J/pulse×5 pulses/sec at 1 week after irradiation, although the decrease in signal intensity has recovered at 12 weeks after irradiation.
irradiation at 0.5 J/pulse, the reduction in disc height was not significant throughout the 12 weeks of observation. However, irradiation at 1.4 J/pulse caused a significantly greater reduction in height than irradiation at 0.5 J/pulse at 12 weeks after irradiation (p <0.01) (Fig. 3b).

T2-weighted MRI: Laser irradiation at 0.5 J/pulse × 5 pulses/sec caused the signal intensity of the disc to decrease at 1 week after, but the decrease in signal intensity was recovered at 12 weeks (Fig. 3c). Irradiation at 1.4 J/pulse × 5 pulses/sec also caused the signal intensity of the disc to decrease at 1 week after irradiation. Although the signal intensity of the irradiated disc was recovered at 12 weeks after irradiation, the signal intensity was lower than that at 12 weeks after irradiation with 0.5 J/pulse × 5 pulses/sec.

DISCUSSION

For treatment of lumbar disc herniation, intradiscal injection therapy was introduced initially with chymopapain. Various agents have now been developed for this therapeutic approach, and the clinical usefulness of this therapeutical method has been established. Low invasiveness is the main advantage of chemonucleolysis. However, since the agents used for chemonucleolysis are proteolytic enzymes, this therapy is associated with a risk of anaphylactic shock [7]. In this context, percutaneous nucleotomy, which was developed by Hijiikata [8] is a safer therapy since no drugs are used. However, the instrument of disc excision is limited because of the linear direction of insertion. The disadvantages of these methods are overcome by laser disc therapy. The instrument of laser can be flexible and treatment can be performed under real-time scopic guidance.

Laser discectomy

Laser light is absorbed by tissue and the tissue is evaporated by the thermal effect. In 1986, Ascher and Choy [3,4] described the fundamental procedure of Nd-YAG laser irradiation for vaporization of the nucleus pulposus and reported that the symptoms of nerve root compression in lumbar disc herniation were relieved by the obtained decrease in intradiscal pressure as a result of a decrease in the water content of the nucleus pulposus. In 1991, Choy [3] studied the effects of the Nd laser, erbium laser, argon laser, CO2 laser, HO-YAG laser, and Excimer laser at various wavelengths and reported that the Nd-YAG laser penetrated the tissues most deeply and thus was most effective. Siebert [6] also reported similar findings in 1993. However, the Nd-YAG laser is inefficiently absorbed by water despite the high power of the irradiation [9] and since it increases the temperature of the surrounding tissue, it may damage this tissue. The CO2 laser has a high power and is readily absorbed by water [9], but there are restrictions on its use because it is a gas laser. A proto-type HO-YAG laser was developed in 1989, but it was not considered to be efficient because of poor penetration and low power levels. However, since this laser is readily absorbed by water [9], it has advantages for the treatment of intervertebral discs. In the present experiment, it was possible to vaporize the disc by laser treatment, and the weight of the disc decreased in proportion to the amount of laser irradiation, as also reported by other investigators. The changes in the temperature of the surrounding tissue observed in the present experiment was far smaller than that reported by Sherk et al. [10,11] for the Nd-YAG laser, demonstrating the safety of this HO-YAG laser treatment for the surrounding tissue. However, the position of the laser discectomy has not yet been established compared with other intradiscal therapies for lumbar disc disorders, and further investigations appear to be necessary to allow selection of optimal wavelength [12].

Changes in the disc after HO-YAG laser irradiation

The radiographs obtained after laser irradiation showed clear narrowing in the disc space even at 1 week after irradiation. At 12 weeks after irradiation, the disc height had increased again slightly following treatment at 0.5 J/pulse, while the disc height did not recover after treatment at 1.4 J/pulse. The disc index was significantly lower in discs treated at 1.4 J/pulse than in untreated discs at 2 weeks after irradiation (p<0.01). In contrast, the disc index of the discs irradiated at 0.5 J/pulse was not significantly different from that of untreated discs throughout the follow-up period. The disc index at 12 weeks after irradiation at 1.4 J/pulse was also significantly lower than that after irradiation at 0.5 J/pulse (p<0.01), so there was a difference in the changes of the disc according to the irradiation conditions, and the diminishment of disc space was maintained after irradiation at 1.4 J/pulse. It appears that regeneration occurred when discs were irradiated at only 0.5 J/pulse, while the effect of laser irradiation was prolonged when discs were irradiated at 1.4 J/pulse. Regarding the changes of chymopapain-treated discs, Bradford [13,14] reported that the disc space became narrower after chymopapain injection, but this was
reversed after about 3 months. In the present experiment, the T2-weighted MRI of discs irradiated at 0.5 J/pulse showed a decrease in the signal intensity at 1 week after irradiation, reflecting the decreased water content in the disc. However, at 12 weeks after irradiation, the decrease in signal intensity on MRI was recovered, suggesting restoration of the water content. The decrease in signal intensity persisted after 12 weeks in the discs irradiated at 1.4 J/pulse, indicating the long-term effect of laser absorption at this dosage. Based on these results, HO-YAG laser irradiation at 0.5 J/pulse allows disc vaporization, but the effect is less persistent when compared with irradiation at 1.4 J/pulse. However, since the temperature in the surrounding tissues was increased more by irradiation at a higher power level, it may be dangerous to concentrate on pursuing efficiency in vaporization by using a higher level of power if damage to the surrounding tissue is taken into consideration. Therefore, taking the vaporization effect and the thermal effect on the surrounding tissues into consideration, it is desirable to perform laser irradiation of intervertebral discs at 1.4 J/pulse for the core of the intervertebral disc and at 0.5 J/pulse for the rim of the disc.

CONCLUSION

HO-YAG laser irradiation was applied to normal intervertebral discs in rabbit. Based on the changes on the radiographs and MRI signal intensity, HO-YAG laser irradiation may be effective for the treatment of herniated lumbar discs, although it is necessary to select appropriate irradiation conditions according to the extent and degree of degeneration of the affected disc in consideration of the thermal effect on the surrounding tissues and the difference in the extent of vaporization.

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