Comparison of Laser Ablation Using Multidirectional and Forward-Firing Fiber in Human Thyroid Gland: Experimental Study

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Sponsorships or competing interests that may be relevant to content are disclosed at the end of this article.

Abstract

The aim of this study is to evaluate the differences between forward-firing and multidirectional lasers and to evaluate the effects of exposure times and power on laser ablation of thyroid tissue. This is an experimental, ex vivo study. The experiments were conducted on 3 thyroid glands using 2 power levels (3 and 5 W) and exposure times (3 and 5 minutes) with forward-firing and multidirectional lasers. The length and width of the demarcated zone were measured to assess the size of thermal effect. NADPH staining was performed to determine tissue viability. Thermal transformation caused by the forward-firing laser produced oval necrotic zones, whereas thermal transformation caused by the multidirectional-firing laser produced clear round necrotic zones, which clearly demarcated in both hematoxylin and eosin staining and NADH staining.

Keywords
forward-firing fiber, laser ablation, multidirectional fiber, thyroid gland

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Most thyroid cancers are papillary thyroid cancer, which have been associated with excellent prognoses. However, surgery may be risky for patients for whom general anesthesia is not viable due to old age or a severe underlying disease. Accordingly, nonsurgical therapy such as cryoablation, radiofrequency ablation, ethanol injection, and laser ablation have been introduced.¹-³ A previous study has suggested that laser-based procedures are effective in treating large benign thyroid nodules by a significant volume reduction (40%–80%).⁴ Downside of laser have so far been that forward-firing lasers are less effective at removing round tumors. Thyroid glands are located adjacent to the major structures, meaning complications due to the thermal effect can have more devastating consequences. In this respect, our group has developed a multidirectional laser fiber that produces circumferential thermal effects and makes up for the downfalls of the forward-firing laser. The aim of this study is to evaluate the differences between forward-firing and multidirectional lasers and to evaluate the effects of exposure times and power on laser ablation of thyroid tissue using a multidirectional laser fiber developed by our group.

Materials and Methods

This study was approved by Kyungpook National University Hospital Institutional Review Board. Specimens were normal human thyroid glands, and the experiment was performed ex vivo with 3 cases under each condition. A forward-firing system (600 μm-wide, 980-nm wavelength laser beam) using a conventional optical fiber tip and a multidirectional firing system with a conical distal tip of the fiber were prepared (Figure 1).

However, irradiation at power levels >7.5 W and exposure times >10 minutes resulted in extensive necrosis and carbonization. Accordingly, our group limited the settings to 2 power levels (3 and 5 W) and two exposure times (3 and 5 minutes). Following laser ablation, the length and width of the demarcated zone were measured by a pathologist to assess the size of the thermal effect on the tissue. Lastly, NADPH staining was performed through enzyme assessment of irreversible cell damage. With the forward-firing laser, the total volume of the necrosis was derived based on...
The ellipsoid volume formula, where \( a \) is length and \( b \) is width:

\[
V = \frac{\pi a b^2}{6}.
\]

With the multidirectional-firing laser, the total volume of the necrosis was derived using the spherical volume formula:

\[
V = \frac{4}{3} \pi r^3.
\]

**Results**

Thermal transformation caused by the forward-firing laser produced oval necrotic zones, whereas thermal transformation caused by the multidirectional-firing laser produced clear round necrotic zones. In both cases, thermal transformation produced 3 visibly distinct zones: carbonization zone (zone 1, necrosis due to direct laser exposure) and coagulation zone (zone 2, thermal transformation [damage] surrounding the necrotic cavity). Zones 1, 2, and 3 were clearly demarcated in both hematoxylin and eosin staining and NADH staining (Figure 2). It was also possible to observe that cells in zone 1 were completely destroyed due to carbonization, and cells in zone 2 were clearly dead in comparison to cells in zone 3.

The means of these results confirm an increase in the lesion width with an increase in power and exposure time (Figure 3a). The length of the lesions also increased with an increase in power and exposure time but not to the same degree (Figure 3b).

With the multidirectional-firing laser fiber system, the parameters of the lesion did not change greatly with the increase in power and exposure time, which can be attributed to the fact that the multidirectional-firing laser fiber system’s tip is at an angle as to direct the laser sideways. Comparison of the aspect ratios (width/length) of thyroid tissue zones reveals that the aspect ratio of the carbonized zones produced by the multidirectional-firing laser and forward-firing laser is 0.6 and 0.4, respectively; the multidirectional laser is closer to 1, which in turn indicates thermal transformation that is rounder in shape.

**Discussion**

Nonsurgical methods of treating thyroid nodules are technically feasible under local anesthesia; require minimal surgical access, resulting in little scarring and superior aesthetic results; and reduce major surgical complications. Sung et al concluded that percutaneous ethanol injection has proven to be particularly effective at treating cystic nodules but has little effect on solid nodules. Papini et al suggested that laser ablation was a good effective option for treating benign solid thyroid nodules. However, most conventional laser fibers are capable of unidirectional firing only. This means it is difficult to irradiate the entire lesion evenly and to estimate the extent and size of the necrosis, and multiple needle punctures are needed for ablation of a large-sized nodule. Forward laser ablation in the thyroid gland made it easy to damage surrounding major structures.

In this study, our group was able to confirm that with the forward-firing laser, the size of thermal degradation and necrotic tissue increased along with an increase in power levels and exposure times in a bullet-like oval pattern. With the multidirectional laser, on the other hand, the thermal transformation pattern grew in size and became more spherical, indicating that use of this multidirectional laser fiber in clinical applications can enable accurate estimation of the volume of the thermal transformation zone and that it is possible to develop standard indices for various power levels.
levels and exposure time combinations by measuring the degrees of coagulation and necrosis. Furthermore, development of said standard indices will make it possible to completely ablate the tumor without special monitoring, with little complications due to collateral thermal damage, and it will allow the surgeon to estimate the volume and achieve precise coagulation necrosis. We plan future studies to evaluate the effect of ex vivo laser ablation on thyroid benign nodules and cancer with multidirectional laser after thyroidectomy.

Conclusion
The forward-firing laser produced an oval-shaped thermal transformation pattern, and the multidirectional laser produced a nearly spherical one on human thyroid tissue.

Author Contributions
Ho Yong Park, wrote article; Hyang Hee Choi, collected data; Jung Ju Lee, collected data; Seung Ook Hwang, analyzed data; Jin Hyang Jung, analyzed data; Ik-Bu Sohn, designed study, revised article; Ho Lee, designed study, revised article; Wan Wook Kim, designed study, revised article.

Disclosures
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