Laser Therapy of Dentin Hypersensitivity

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Abstract: Dentin hypersensitivity is the symptom that is often encountered in the clinic, and may be caused by incorrect tooth brushing, gingival recession, inappropriate diet, and other factors. It is generally accepted that the sensation of pain is associated with patent dentinal tubules not covered by the smear layer or the calcified dentin terminating on the root surface. Stimulus transmission across dentin in hypersensitive teeth may be mediated by a hydrodynamic mechanism. Some authors report that lasers may provide reliable and reproducible treatments in the dental field including the therapy of dentin hypersensitivity. Lasers have been shown to fulfill the requirements of Grossman's criteria by being nonirritating to the pulp. Lasers used for the treatment of dentin hypersensitivity are divided into two groups: low power output lasers (He-Ne and GaAlAs) and middle power output lasers (Nd:YAG, CO2, Er:YAG, GaAlAs, and Er,Cr:YSGG). In this paper, some kinds of laser devises used for treating dentin hypersensitivity, and the mechanism and assessment on the pain reduction by lasers are described. The effectiveness ranged from 5.2% to 100%, which was dependent on the indications, the laser type, the parameters used and the laser techniques. The mechanism involved in laser treatment of dentin hypersensitivity is not always clear. In general, treatment efficacy of dentin hypersensitivity using lasers is higher than other methods, but it is less effective in severe cases. To select the best treatment of dentin hypersensitivity, it is necessary to first consider the severity of dentin hypersensitivity before laser use.

Keywords: dentin hypersensitivity, mechanism, pain reduction, He-Ne laser, GaAlAs laser, Nd:YAG laser, CO_2 laser, Er:YAG laser, Er,Cr:YSGG laser.

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Dentin hypersensitivity is the symptom that is often encountered in the clinic, and characterized by short, sharp pain arising from exposed dentin in response to stimuli typically thermal, evaporative, tactile, osmotic or chemical, and which cannot be ascribed to any other form of dental defect or pathology.[1] Dentin hypersensitivity can arise through incorrect tooth brushing, gingival recession, inappropriate diet, and because of other factors.[2-4] It is claimed that 14.3% of all patients have some degree of sensitivity,[2] and a range of therapies has been devised to alleviate this condition.[5,6] The sensation of pain is generally accepted to be associated with patent dentinal tubules not covered by smear layer terminating on the root surface. Stimulus transmission across dentin in hypersensitive teeth may be mediated by a hydrodynamic mechanism.[7-9] Grossman[10] suggested a number of requirements for treatment of this condition; these still hold true today. Therapy should be nonirritating to the pulp, relatively painless on application, easily carried out, rapid in action, effective for a long period, without staining effects, and consistently effective. To date, most of the therapies have failed to satisfy one or more of these criteria, but some authors report that lasers may now provide reliable and reproducible treatment.[11-13]

Since the ruby laser was developed by Maiman,[14] researchers have investigated laser applications in dentistry. Laser is a device which transforms light of various frequencies into a chromatic radiation in the visible, infrared, and ultraviolet regions with all the waves in phase, capable of mobilizing immense heat and power when focused at close range. The word

Fig 1 Cervical dentin hypersensitivity with slight pain (+).

Fig 2 Histopathological findings of cervical dentin hypersensitivity.

"LASER" is an acronym derived from Light Amplification by the Stimulated Emission of Radiation. Stern and Sognnaes[15] and Goldman et al[16] were the first to investigate the potential uses of the ruby laser in dentistry. They began their laser studies on hard dental tissues by investigating the possible use of a ruby laser to reduce subsurface demineralization. They found a reduction in permeability to acid demineralization of enamel after laser irradiation. After initial experiments with the ruby laser, clinicians began using other lasers, such as argon (Ar), carbon dioxide (CO_2), neodymium:yttrium-aluminum-garnet (Nd:YAG), and erbium (Er):YAG lasers. The first laser use for the treatment of dentin hypersensitivity was reported by Matsumoto et al[11] using Nd:YAG laser in 1985. Since then, many papers on laser applications for dentin hypersensitivity treatment have been published,[17-21] with growing interest in this topic in the last 20 years. Nevertheless, acceptance of this technology by clinicians has remained limited, perhaps partly due to the fact that this technology blurs the border between technical, biological, and dental research. Moreover, the mechanisms involved remain multiple and unclear, leading to questions regarding reproducibility and safety of this technique. Many of the lasers investigated in this context can induce significant thermal effects, if laser parameters are inadequately controlled, giving rise to concerns regarding thermal damage to temperature-sensitive dental pulp tissues.

This article describes the current and possible future clinical indications, laser devices, assessment methods, and mechanisms in the field of the laser treatment of dentin hypersensitivity.

PAIN MECHANISM OF DENTIN HYPERSENSITIVITY

Hydrodynamic theory

It is generally accepted that the sensation of pain is associated with patent dentinal tubules terminating on the root surface and not covered by the enamel or the smear layer. Stimulus transmission across dentin in hypersensitive teeth may be mediated by a hydrodynamic mechanism, with a rapid movement of fluid within the dentinal tubules. Analysis of human dentinal fluid suggested that the fluid is extracellular. The wall of the dentinal tubule was found to be considerably more mineralized than the rest of the dentin. Interestingly, odontoblast processes were seen only in the tubules near the pulp. Pain would appear to be produced by the rapid displacement of the tubular contents at the pulpodentinal border as opposed to the slow outward fluid flow which seems to occur normally. It is assummed that rapid flow in the pulpal part of the dentinal tubule can be expected to result in deformation, not only of the cellular processes but also of nerve fibers which might be present in the dentinal tubules or adjacent pulp.[2,7,8,22]

The morphological investigations on the surface of the cervical dentin of hypersensitive teeth and histopathological findings of the pulp have been already reported[23-26] and the hypersensitive dentin sites and areas were confirmed (Figs 1 to 6).

Changes of pain perception threshold of the tooth

The pulp irritation may be induced by caries or even hypersensitivity of the nervous system. The pain per-

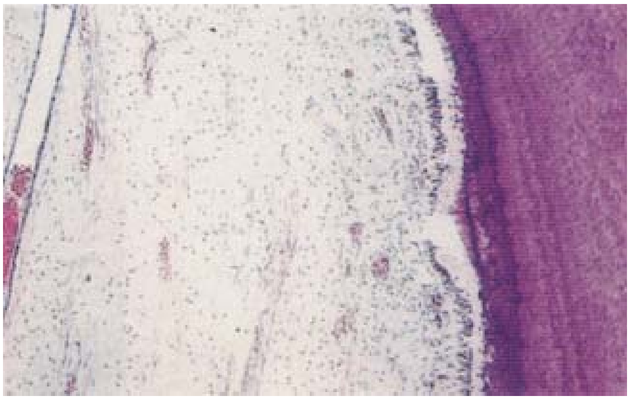

Fig 3 Changes of odontoblastic layers of cervical area.

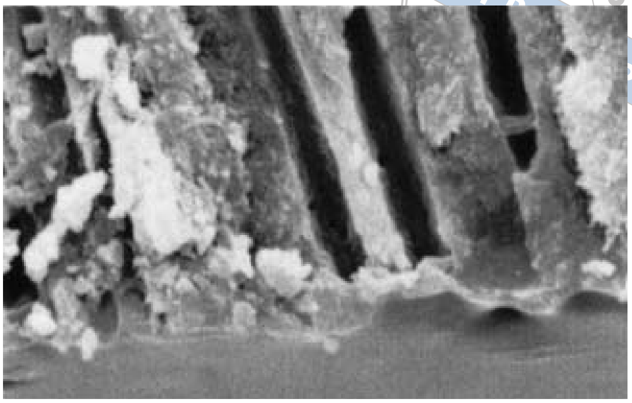

Fig 4 Empty dentinal tubules of hypersensitive surface area.

ception is not controlled in the teeth, but the central neurons. The peripheral nerve endings of teeth stimulate or irritate the central neurons depending on the diseases of pulp or periodontal tissue. It is said that the winding up phenomenon in the central neuron is easily caused by weak, prolonged irritation such as the pain from cervical dentin hypersensitivity.

DIAGNOSIS OF DENTIN HYPERSENSITIVITY

More than 90% of hypersensitive surfaces are at the cervical margin on the buccal or labial aspects of the teeth. Lesion localization occurs by exposure of dentin, either by loss of enamel or by gingival recession. Ginvival recession is the more important of these two factors.[22] However, not all exposed dentin is sensitive. Dentin hypersensitivity occurs when the smear layer or tubular plugs are removed, which opens the outer ends of the dentinal tubules.

Dentin hypersensitivity is a painful but otherwise harmless reaction to external thermal, tactile, electric, chemical and osmotic stimuli to dentin of teeth with viable pulps. Usually the pain is short lived, lasting from seconds to minutes after provocation.[4] If the pulp is inflamed, hypersensitivity is more easily provoked, more severe, and of longer duration.

To determine the sensitivity, an air blast, water spray, or a dental sharp explorer are applied. Using a blast or water spray from a fully depressed air or water syringe, the sensitivity is recorded before and up to several weeks after the treatment. A dental explorer is also used for the diagnosis of dentin hypersensitivity as one of the tactile tests. Difficulties involved in tactile stimulation include accurately scratching the surface using the same force and direction in the same previously tested location.[5]

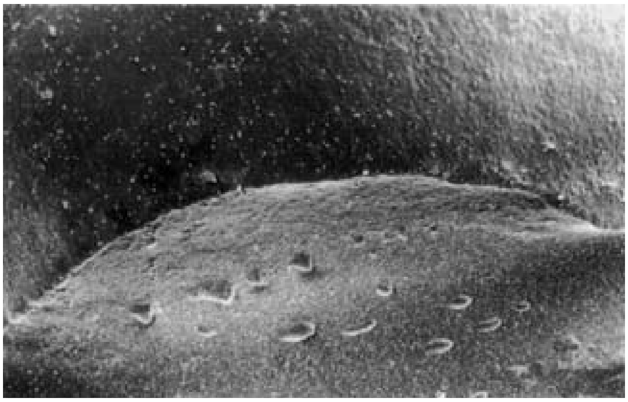

Fig 5 SEM-replica findings of surface of dentin hypersensitivity.

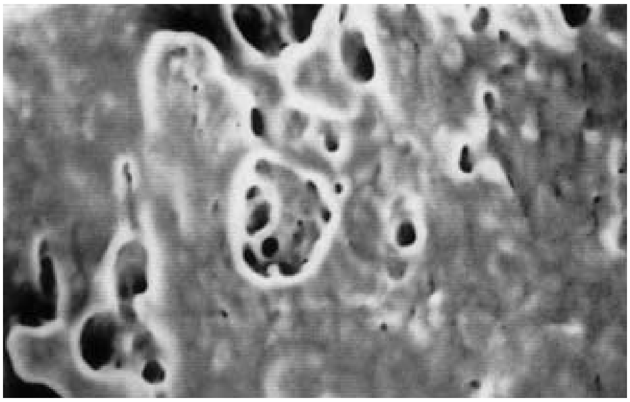

Fig 6 SEM findings of dentin hypersensitivity spots and area.

ASSESSMENT OF THE DEGREE OF DENTIN HYPERSENSITIVITY

The sensitivity was rated on a 4-point scale, which was a modification of the method of Matsumoto et al:[12] 0: no discomfort, 1: mild discomfort, 2: moderate but tolerable pain upon the stimulus application, and 3: severe and intolerable pain during and persisting after the stimulus application.

ASSESSMENT OF PAIN REDUCTION BY LASER TREATEMNT

The pain reduction by laser treatment is classified as follows: excellent: the score of 3 or 2 was changed to 0; good: the score of 3 was changed to 1 or 2, 2 changed to 1, or 1 changed to 0; ineffective: the degree of pain was unchanged, or returned to the same degree as that before treatment after once improved; worse: pain became stronger after the laser irradiation.[12] However, the evaluation of treatments for dentin hypersensitivity is extremely difficult regardless of the methods or materials employed. In estimating improvement for hypersensitive teeth, investigations are handicapped by an inability to objectively observe patient response and are dependent upon the patient's interpretation, which is, in turn, subject to suggestion.[5]

INDICATIONS FOR LASER TREATMENT

The best indication for laser treatment is cervical dentin hypersensitivity. Dentin hypersensitivity with or without dental caries can be observed. A sensitivity score of 1 or 2 is suitable for laser treatment, and dentin hypersensitivity of noninfected pulpitis (congestion of dental pulp, partial serous pulpitis) is one of the indications for laser treatment. When dental caries proceeds and the toxin enters the dental pulp tissue through dentinal tubules but bacteria have not yet invaded the dental pulp tissue, inflammation is induced and the pain perception threshold decreases. The dentin hypersensitivity after cavity preparation (exception of infected dental pulp, eg, suppurative pulpitis) is also one of the indications. There are two causes; one is due to the removal of enamel, and the other is physical damage by heat and vibration during cavity preparation. The exposure of root surface by the periodontal disease or dental trauma also is one of the causes of dentin hypersensitivity.

TREATMENT METHODS AND MECHANISM OF PAIN REDUCTION OF DENTIN HYPERSENSITIVITY

Topical application on the surface of a dentin-hypersensitive tooth with some substances has been performed.[5,6,22] These include 25% strontium chloride ($SrCl_2$), 38% diamine silver fluoride solution (38% $Ag(NH_3)_2F$) (Fig 7), 1% to 2% sodium fluoride (NaF) solution, 8% zinc chloride ($ZnCl_2$) solution (Fig 8), 10% paraformaldehyde paste, etc. In the cases of dentin hypersensitivity after removing caries or cavity preparation, indirect capping with zinc oxide eugenol (EZ) or calcium hydroxide material is performed. Sometimes, treatment with composite resin materials and metal inlays or crowns is conducted to reduce dentin hypersensitivity. Iontophoresis is also effective for reducing the dentin hypersensitivity. This treatment is performed with the electric device for iontophoresis and a 2% NaF solution for 1 min at 1 mA, or 8% $ZnCl_2$ solution for 1 min at 1-2 mA. The pain-reducing mechanism of these treatments is based on the physical sealing of dentinal tubules. On the other hand, the laser treatment of dentin hypersensitivity controls pain both locally and centrally. Commonly used laser devices include low power-output devices such as helium-neon (He-Ne) (6 mW) and gallium-aluminum-arsenium (GaAlAs) (semiconductor) laser (30-100 mW), and intermediate power-output devices (0.3-10 W) such as Nd:YAG, CO_2, and Er:YAG lasers etc. The diagnosis is very difficult, but in cases where the crown dental pulp is infected, vital pulp amputation must be performed. This, rather than several laser treatments, decreases pain. Of course, in the case of the dentin hypersensitivity with spontaneous percussive pain, all pulp tissue must be extirpated.

LASER TREATMENT OF DENTIN HYPERSENSITIVITY

1. Low power-output laser treatment

Low power-output laser therapy has been utilized in humans since the early 1970s. Initially, this form of energy delivery was used to support wound healing.[27-29] Subsequently, in the 1980s, the benefit of low output-delivery systems as an anti-inflammatory tool was described.[30,31] Then, it was demonstrated that low power-output laser therapy stimulates nerve cells in a clinical environment.[32-34]

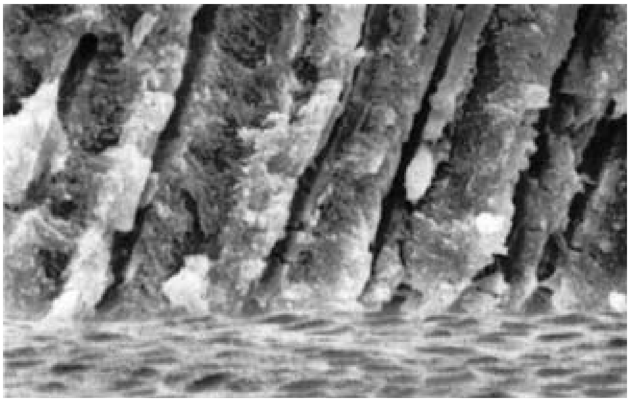

Fig 7 SEM finding after applying the diamine silver fluoride solution.

Fig 8 SEM finding after iontophoresis with 8% $ZnCl_2$.

He-Ne laser

(1) Indications: Mild cervical dentin hypersensitivity (score 1) is only one indication. In the cases of moderate or severe dentin hypersensitivity (score 2 or 3), the effects cannot be expected.

(2) Parameters: 6 mW and 5 Hz or continuous wave (CW) mode for 2 to 5 minutes.

(3) Technique: The laser tip has to be placed as close as possible to the tooth surface in noncontact mode. The irradiation is applied to the same tooth surface without scanning. The examination of change of dentin hypersensitivity is carried out every 30 minutes until the dentin hypersensitivity decreases.

Clinical case presentation of pain reduction of dentin hypersensitivity with He-Ne laser irradiation.

A 43-year-old male visited our dental hospital for the treatment of dentin hypersensitivity of the lower left canine. As the result of the examination, the degree of dentin hypersensitivity was mild (score 1). The laser treatment was carried out at 6 mW for 3 min. Laser irradiation was performed at a distance of 3 cm from the tooth surface (Figs 9 and 10). The degree of dentin hypersensitivity decreased from mild (score 1) to no pain (score 0). There was no recurrence after 2 months.

Clinical assessment: Table 1 shows the laser parameters used for the He-Ne laser, and their treatment effectiveness. The first use of He-Ne laser for the treatment of dentin hypersensitivity was reported by Senda et al,[35] and later by several other investigators.[36-41] They initially used only a power output of 6 mW for the treatment of hypersensitivity. Irradiation modes were pulsed (5 Hz only) or CW mode. Treatment effectiveness rate ranged from 5.2% to 100%. The mechanism involved is mostly unknown. According to physiological experiments, He-Ne laser irradiation does not effect peripheral Ad- or C-fiber nociceptors,[34] but does effect electrical activity (action potential), which in the healthy nerve increased by 33% following a single transcutaneous irradiation.[32,33] This was found to be a long-lasting effect, inducing an increase in the size of nerve action potential for more than 8 months after cessation of irradiation.[32] He-Ne laser irradiation at 6 mW does not affect the enamel or dentin surface morphologically, but a small fraction of the laser energy is transmitted through enamel or dentin to reach the pulp tissue.[42] With low power-output lasers, there is no danger of causing skin burns or damaging cells.[43]

GaAlAs laser

(1) Indications: Mild cervical dentin hypersensitivity (score 1) is only one indication. In the cases of moderate or severe dentin hypersensitivity (scores2 or 3), it is ineffective.

(2) Parameters: A power output of 30 to 100 mW is used, and the wavelength is between 660 and 900 nm. The irradiation time is from 30 s to 5 min.

(3) Technique: The laser tip has to be placed as close as possible to the tooth surface in noncontact mode. Irradiation is applied to the same tooth surface without scanning for several minutes. The examination of change in dentin hypersensitivity is carried out every 30 minutes until dentin hypersensitivity decreases. It is thought that the stimulation of the acupuncture points by laser irradiation is also useful.[44]

Table 1 Laser parameters and treatment effectiveness of He-Ne laser (wavelength 632.8 nm)

Investigators	Irradiation parameters	Effectiveness
Senda et al (1985)[35]	6 mW, 5 Hz or CW for 2 - 3 min	84%
Matsumoto et al (1986)[36]	6 mW, 5 Hz for 1 - 3 min	90%
Gomi et al (1986)[37]	6 mW, 5 Hz for 3 min	100%
Kanamura et al (1986)[38]	6 mW, 5 Hz for 3 min	90%
Wilder-Smith (1988)[39]	6 mW, 5 Hz for 2.5 min for 3 days	5.2 - 17.5%
Matsumoto et al (1988)[40]	6 mW, CW for 0.5 - 3 min	90%
Mezawa et al (1992)[41]	6 mW, CW for 5 min	55%

Fig 9 He-Ne laser device.

Fig 10 Application of He-Ne laser to the hypersensitive tooth.

Clinical case presentation:
A 34-year-old female visited our dental hospital for the treatment of dentin hypersensitivity of the upper right first premolar. Initial dentin hypersensitivity was mild (score 1). The treatment with 830 nm wavelength GaAlAs laser was carried out at 30 mW and CW mode for 2 min (Figs 11 and 12). Laser irradiation was performed as close as possible to the tooth surface in noncontact mode. The degree of dentin hypersensitivity decreased from mild (score 1) to no pain (score 0). As there was recurrence after 3 months, the same treatment was performed again. Subsequently, there was no recurrence after 4 months.

Clinical assessment: GaAlAs (diode) lasers were initially restricted to GaAs systems. In their early stages of development, GaAs systems were difficult to run for long periods in a CW mode because of the propensity of the chip to overheat. However, by 1979, experiments using a new diode were looking very promising. This new chip, which used wafer-thin crystals of GaAlAs, could produce a variety of wavelengths from 720 to 904 nm, all within the infrared spectrum. It could also generate a continuous wave with no likelihood of overheating. Mainly four wavelengths (780, 790, 830, and 900 nm) of GaAlAs laser have been used for the treatment of dentin hypersensitivity.

Table 2 shows the laser parameters used for the GaAlAs laser at 780 nm and their treatment effectiveness. The first use of this laser for the treatment of dentin hypersensitivity was reported by Matsumoto et al,[12] then consecutively by some other investigators.[44-49] A power output of 30 mW was used for the treatment. Irradiation mode was CW, and irradiation time ranged from 0.5 to 3 min. Treatment effectiveness ranged from 85% to 100%. Table 3 shows the laser parameters used for the GaAlAs laser at 790 nm and their treatment effectiveness.[50,51] A power output of 30 mW was used for the treatment, and irradiation mode was CW. Irradiation time was 3 min. Treatment effectiveness rate ranged from 60% to 70%. Table 4 shows the laser parameters used for the GaAlAs laser at 830 nm and their treatment effectiveness. The first

Table 2 Laser parameters and treatment effectiveness of GaAlAs laser (wavelength 780 nm)

Investigators	Irradiation parameters	Effectiveness
Matsumoto et al (1985)[12]	30 mW, CW for 0.5 - 2.5 min	100%
Matsumoto et al (1985)[44]	30 mW, CW for 0.5 - 3 min	85%
Ebihara et al (1988)[45]	30 mW, CW for 1 - 2 min	58.5%
Furuoka et al (1988)[46]	30 mW, CW for 0.5 - 3 min	92%
Kawakami et al (1989)[47]	30 mW, CW for 0.5 - 3 min	95%
Sato et al (1989)[48]	30 mW, CW for 0.5 - 3 min	88.8%
Hoji (1990)[49]	30 mW, CW for 0.5 - 3 min	83.6%

Fig 11 Use of GaAlAs diode laser at 30 mW of CW mode.

Fig 12 Cervically hypersensitive tooth with mild pain (grade 1).

use of this laser for the treatment of dentin hypersensitivity was reported by Matsumoto et al,[52] and later by others.[41,53-59] Power output ranged from 20 to 60 mW, and irradiation mode was CW. Irradiation time ranged from 0.5 to 3 min. Treatment effectiveness rate was dependent on the output power, and ranged from 30% to 100%. Table 5 shows the laser parameters used for the GaAlAs laser at 900 nm and its treatment effectiveness. Treatment effectiveness ranged from 73.3% to 100%.[60] The effectiveness of the other GaAlAs laser of 660 or 670 nm wavelength was also reported.[59,61,62] Treatment effectiveness ranged up to 89%. The 660 nm red diode laser was more effective than the 830 nm infrared laser and a higher level of desensitization was observed.[59]

Mechanism of pain reduction by lasers:
It is postulated that this type of low power output laser mediates an analgesic effect related to depressed nerve transmission. According to physiological experiments using the GaAlAs laser at 830 nm, this effect is caused by blocking the depolarization of C-fiber afferents.[63,64] GaAlAs laser emissions at 904 nm have an analgesic effect on the cat tongue although the mechanism remains unclear.[65] GaAlAs laser irradiation at a maximum power of 60 mW does not affect the enamel or dentin surface morphologically, but a small fraction of the laser energy at 830 nm wavelength is transmitted through enamel or dentin to reach the pulp tissue (Fig 13).[66]

2. Middle power-output laser treatment

Nd:YAG laser

(1) Indications: The cases from mild to severe dentin hypersensitivity (score 1 to 3) are indications, but bacterially infected dental pulp is a contraindication.

(2) Parameters: Continuous or pulsed wavelength is used and the number of the pulses is from 10 to 20 Hz. A power output from 0.3 to 2 W is usually used. This type of laser irradiation can be used with or without Chinese black ink.

Table 3 Laser parameters and treatment effectiveness of GaAlAs laser (wavelength 790 nm)

Investigators	Irradiation parameters	Effectiveness
Yamaguchi et al (1990)[50]	30 mW, CW for min	60%
Kumazaki et al (1989)[51]	30 mW, CW for 3 min	69.2%

Table 4 Laser parameters and treatment effectiveness of GaAlAs laser (wavelength 830 nm)

Investigators	Irradiation parameters	Effectiveness
Matsumoto et al (1990)[52]	60 mW, CW for 0.5 - 3 min	100%
Setoguchi et al (1990)[53]	30 mW, CW for 1 min	85%
Hamachi et al (1992)[54]	40 mW, CW for 0.5 - 3 min	83.9%
Wakabayashi et al (1992)[55]	40 mW, CW for 0.5 - 3 min	97%
Mezawa et al (1992)[41]	30 mW, CW for 5 min	58%
Tachibana et al (1992)[56]	40 mW, CW for 0.5 - 3 min	92.5%
Tachibana et al (1992)[56]	20 mW, CW for 0.5 - 3 min	30%
Gerschman et al (1994)[57]	30 mW, CW for 1 min	65 - 67%
Liu & Lan (1994)[58]	40 - 100 mW, CW for 15 - 60 s	70 - 88%
Ladalardo et al (2004)[59]	35 mW, CW for 114 s	effective, but rate is unknown

Table 5 Laser parameters and treatment effectiveness of GaAlAs laser (wavelength 900 nm)

Investigators	Irradiation parameters	Effectiveness
Iida et al (1993)[60]	2.4 mW, 1.2 kHz for 2.5 min	73.3 - 100%

(3) Technique: Without Chinese black ink, the laser tip has to be held over the tooth surface at a distance of approximately 10 to 20 cm in order to avoid causing pain to the tooth. When Chinese black ink is used, the laser tip has to be kept close to the tooth or gingival surface in noncontact mode, and has to be scanned as quickly as possible over the tooth or gingival surface in order to avoid thermal damage to the tooth or gingival surface. It is thought that the stimulation of the acupuncture points is also useful.[44]

Clinical case presentations

a) Reducing dentin hypersensitivity due to wedge-shaped defect (WSD)

A 61-year-old male visited our dental hospital for the treatment of dentin hypersensitivity of the lower right premolar. The initial degree of dentin hypersensitivity was mild (score 1) (Fig 14). Laser treatment was carried out at 2 W and 20 Hz for 30 s (Fig 15). Laser irradiation was performed at a distance of approximately 10 cm from the WSD surface. The degree of dentin hypersensitivity decreased from mild (score 1) to no pain (score 0). There was no recurrence after 6 months.

b) Reducing dentin hypersensitivity on gingival surfaces

A 43-year-old female complained the dentin hypersensitivity of the lower right first molar after inserting a metal inlay. The initial degree of dentin hypersensitivity was mild (score 1) (Fig 16). The laser treatment was carried out at 2 W and 20 Hz for 60 s. The laser irradiation was performed at a distance of approximately

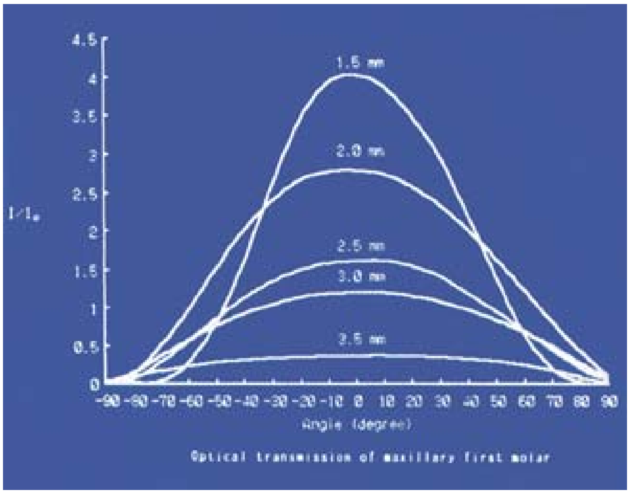

Fig 13 The transmission rate of dentin with GaAlAs laser.

Fig 14 The WSD was observed on the cervical portion

10 cm from the gingival surface near the hypersensitive tooth (Fig 17). The degree of dentin hypersensitivity decreased from mild (score 1) to no pain (score 0) (Fig 18). There was no recurrence after 3 months.

c) Reducing dentin hypersensitivity on tooth and gingival surface after applying Chinese black ink
A 52-year-old male visited our dental hospital for the treatment of the dentin hypersensitivity of the lower right premolar. Initial dentin hypersensitivity was moderate but tolerable (score 2) (Fig 19). The laser treatment was carried out at 2 W and 20 Hz for 3 s. After black ink was applied (Fig 20), laser irradiation was performed from close to the tooth and gingival surface at a distance of 2 to 3 mm from the surface (Fig 21). The degree of dentin hypersensitivity decreased from moderate but tolerable (score 2) to no pain (score 0). There was no recurrence after 2 months.

Fig 15 Application of Nd:YAG laser on the surface of WSD.

Fig 16 Dentin hypersensitivity after setting metal inlay.

Clinical assessment: Table 6 shows the laser parameters used for the Nd:YAG laser and their treatment effectiveness. The first use of this laser for the treatment of dentin hypersensitivity was reported by Matsumoto et al,[11] and later by others.[13,67-75] The power output varied and ranged from 0.3 to 10 W, but 1 or 2 W output was most common. Irradiation methods were dependent on the laser powers and varied. Treatment effectiveness ranged from 5.2% to 100%. When using Nd:YAG laser irradiation, the use of black ink as an absorption enhancer is recommended, to prevent deep penetration of the Nd:YAG laser beam through the enamel and dentin and excessive effects in the pulp.[76] According to Morioka et al,[77] the use of black ink for Nd:YAG laser irradiation is suitable to absorb the laser beam, and various effects of this laser would be considered to be enhanced by black ink. There have been some reports on the use of black ink for enhancing the

Fig 17 Laser irradiation on the ginvival surface near the hypersensitive tooth.

Fig 18 No change on the tissue.

Fig 19 Cervical dentin hypersensitivity with the moderate degree.

Fig 20 The Chinese black ink was painted on the surface.

Fig 21 The laser was irradiated on the tooth and gingival surface.

Fig 22 Mild dentin hypersensitivity of the cervical portion of upper canine.

Table 6 Laser parameters and treatment effectiveness of Nd:YAG laser (wavelength 1.064 μm)

Investigators	Irradiation parameters	Effectiveness
Matsumoto et al (1985)[11]	10 W, for 0.1 sec, 5 times	100%
Renton-Harper & Midda (1992)[13]	100 mJ/pulse, 10 Hz	90%
Gelskey et al (1993)[67]	30 - 100 mJ/pulse, 10 Hz	58 - 61%
Kawada et al (1996)[68]	2 W for 1 sec, 20 times	74.8 - 85.7%
Lan & Liu (1996)[69]	30 mJ/pulse, 10 Hz for 2 min	65 - 72%
Gutknecht et al (1997)[70]	0.3 - 1.0 W, 10 Hz for 30 - 90 sec	83 - 93%
Yonaga et al (1999)[71]	2 W, 20 Hz for 0.5 - 60 sec	75.5 - 95.6%
Kobayashi et al (1999)[72]	1.5 W, 15 Hz for 1 min	51.5 - 95.8%
Ciaramicoli et al (2003)[73]	1 W, 25 Hz for 30 sec	almost 100%
Kumar & Mehta (2005)[74]	30 mJ/pulse, 10 Hz for 2 min	66%
Birang et al (2006)[75]	1 W, 15 Hz for 60 sec, 2 times	effective, but rate is unknown

effects of Nd:YAG laser irradiation to treat dentin hypersensitivity,[67,71,72] and indeed treatment effectiveness using black ink was better than without it.[71]

The mechanism of Nd:YAG laser effects on dentin hypersensitivity is thought to be the laser-induced occlusion or narrowing of dentinal tubules[69,71,78] as well as direct nerve analgesia.[79] In hypersensitive dentin, most dentinal tubules appear open when visualized by scanning electron microscopy.[23,24] There is a significant, high correlation between open dentinal tubules and dentin hypersensitivity.[25] Nd:YAG and CO_2 lasers effectively cause occlusion of dentinal tubules. Laser energy at 1064 nm is transmitted through dentin,80 producing thermally mediated effects on microcirculation,[81] and pulpal analgesia via its nerve system.[79] He-Ne laser irradiation has no effect on intradental nerve excitability, but Nd:YAG laser can depress intradental nerve responses to dentin stimulation.[82] A variety of theories have been put forward as to how the laser produces its analgesic effect. It has been hypothesized that the laser energy interferes with the sodium pump mechanism, changes the cell membrane permeability and/or temporarily alters the endings of the sensory axons.[83] Irradiation by semiconductor laser has a suppressive effect by blocking the depolarization of very slowly conducting C-fiber afferents only, but it was reported that the blocking of not only C-fibers, but also rapidly conducting Aß-fibers is performed by Nd:YAG laser irradiation.[84] The sealing depth achieved by Nd:YAG laser irradiation at 30 mJ/pulse and 10 Hz on dentinal tubules is usually measured to be less than 4 μm,[85] but it is dependent on the irradiation parameters.

CO_2 Laser

(1) Indications: Mild to severe dentin hypersensitivity (score 1 to 3); bacterially infected dental pulp is a contraindication.

(2) Parameters: As the parameters, 1 to 2 W with CW or pulse mode can be recommended. Sometimes an air blast should be used for preventing the tooth pain induced with the laser irradiation.

(3) Technique: The laser tip has to be kept on the tooth or gingival surface at a distance of 10 to 20 cm and has to be scanned as quickly as possible on the tooth or gingival surface in order to avoid thermal damage to the tooth or gingival surface. To check the laser's effect, sensitivity to an air blast is noted every 5 s.

Clinical case presentation:

a) Pain reduction on the gingival surface via laser

A 46-year-old female visited our dental hospital for the treatment of dentin hypersensitivity of the upper right canine. The initial dentin hypersensitivity was mild (score 1) (Fig 22). Laser treatment was carried out at 1 W and CW mode for 5 s. Laser irradiation was performed at the distance of approximately 10 cm from the gingival surface (Fig 23). The degree of dentin hypersensitivity decreased from mild (score 1) to no pain (score 0) (Fig 24). There was no recurrence after one month.

Fig 23 Application of CO_2 laser of 1 W for 5 s at the distance of 10 cm from the tooth surface.

Fig 24 The surface of lased portion on the gingival surface showed white spots.

Fig 25 The cervical dentin hypersensitivity of the canine.

Fig 26 Laser application to the acupuncture point of the earlobe with CO2 laser with 1 W for 20 s.

b) Pain reduction by laser at an acupuncture point
A 43-year-old male visited our dental hospital for the treatment of dentin hypersensitivity of the lower right canine. The initial degree of dentin hypersensitivity was mild (score 1) (Fig 25). Laser treatment was carried out at 1 W and CW for 20 s. Irradiation was performed at the distance of approximately 15 cm from the earlobe which is one of acupuncture points related to tooth pain (Fig 26). The degree of dentin hypersensitivity decreased from mild (score 1) to no pain (score 0). There was no recurrence after 4 months.

Clinical assessment: Table 7 shows the laser parameters used for the CO_2 laser and their treatment effectiveness. The first use of this laser for the treatment of dentin hypersensitivity was reported by Moritz et al,[86] and later by other investigators.[87,88] Output powers of 0.5 and 1 W and the CW mode were used. Irradiation time ranged from 0.5 to 5 s, and irradiation was repeated 5-10 times. Treatment effectiveness ranged from 59.8% to 100%. CO_2 laser effects on dentin hypersensitivity are due to the occlusion or narrowing of dentinal tubules.[89] There have been no reports on nerve analgesia by CO_2 laser irradiation. Using the CO_2 laser at moderate energy densities, mainly sealing of dentinal tubules is achieved, as well as a reduction of permeability.90 CO_2 laser irradiation may also cause dentinal desiccation, yielding temporary clinical relief of dentinal hypersensitivity.[91] The sealing depth achieved by CO_2 laser irradiation at 0.3 W for 0.1 s on dentinal tubules is usually measured to be 2 to 8 µm.[92]

Er:YAG Laser
(1) Indications: This laser device is suitable for caries treatment but endodontic and periodontic applications have also been studied. The cases of mild and moderate degree dentin hypersensitivity (score 1 and 2) are indications.

Table 7 Laser parameters and treatment effectiveness of CO_2 laser (wavelength 10.6 µm)

Investigators	Irradiation parameters	Effectiveness
Moritz et al (1996)[86]	0.5 W, CW for 5 s, 6 times	59.8 - 98.6%
Zhang et al (1998)[87]	1 W, CW for 0.5 s, 5 - 10 times	50 - 100%
Moritz et al (1998)[88]	0.5 W, CW for 5 s, 6 times	94.5 - 96.5%

Fig 27 Dentin hypersensitivity of moderate pain.

Fig 28 Laser treatment with Er:YAG laser at 1 W and 10Hz.

(2) Parameters: The parameters of Er:YAG laser irradiation for reducing pain from dentin hypersensitivity are 1 W and 10-12 Hz for less than 60 s. The distance from the tooth surface to the laser tip has to be kept at more than 10 cm for preventing the damage to the tooth and gingival surface.

(3) Technique: Laser can be applied with and without water spray. We recommend the mode without water spray. The laser tip has to be quickly scanned across the tooth or ginvival surface to prevent laser damage on the tooth or gingival surface.

Clinical case presentation

a) Pain reduction without water spray.

A 39-year-old female visited our dental hospital for the treatment of the dentin hypersensitivity of the lower right premolar teeth (Fig 27). Initial dentin hypersensitivity was moderate but tolerable (score 2). Laser treatment was carried out at 1 W and 10 Hz for 10 s without water spray (Fig 28). Laser irradiation was applied at a distance of approximately 10 cm from the tooth surface. The degree of dentin hypersensitivity decreased from moderate but tolerable (score 2) to no pain (score 0). There was no recurrence after three months (Fig 29).

Fig 29 The tooth surface is not changed.

b) Cavity preparation after Er:YAG laser-induced pain reduction

A 45-year-old male visited our dental hospital for the caries treatment of the lower right second premolar teeth. Initial dentin hypersensitivity was mild (score 1). Laser treatment was carried out at 1 W, 10 Hz for 5 s without water spray (Fig 30). Laser irradiation was performed at a distance of approximately 10 cm from

Fig 30 Caries and hypersensitivity of first premolar.

Fig 32 Caries removal by Er:YAG laser.

the tooth surface (Fig 31). The degree of dentin hypersensitivity decreased from mild (score 1) to no pain (score 0). Cavity preparation was performed at 2 W and 20 Hz for 30 s without pain (Fig 32). After that, a composite resin restoration was placed by the conventional techniques (Figs 33 and 34).

Clinical assessment: Table 8 shows the laser parameters used for the Er:YAG laser and their treatment effectiveness. The first use of this laser for the treatment of dentin hypersensitivity was reported by Schwarz et al,[93] then by other investigators.[75] The power output was varied and ranged from 80 to 100 mJ/pulse, but total irradiation time of 2 min was common. Treatment is effective, but the rate is unknown. However, Nd:YAG laser is more effective than Er:YAG laser.[75]

GaAlAs laser (middle output power)

(1) Indications: Mild and moderate dentin hypersensitivity (score 1 and 2) are indications.

(2) Parameters: The laser devices of 3 W with the wavelength of 810 nm (Osada, Tokyo, Japan) and 0.5-20 W with the wavelength of 805 nm (Panasonic, Osaka, Japan) are sold now. The 3 W power output device is a CW laser device, and the 0.5-20 W power output device is CW or pulsed mode, with a pulse width range from 0.003 to 0.2 s. As the guide beam, a semiconductor laser of the 635 nm wavelength and 1 mW power is used.

(3) Technique: In order to prevent thermal damage to the dental pulp by lasers, the laser tip is kept more than 5 cm from the tooth surface. Furthermore, when the patient feels pain, the laser tip has to be scanned quickly over the tooth surface. Sometimes, the air spray is also used for preventing a temperature rise on the surface during laser irradiation.

Clinical case presentation:

A 39-year-old female complained of dentin hypersensitivity of the upper right second premolar. Initial dentin hypersensitivity was mild (score 1). Laser treatment was carried out at 2 W and 10 Hz for 5 s. Laser irradiation was performed as close to the tooth surface as possible. The degree of dentin hypersensitivity decreased from mild (score 1) to no pain (score 0). There was no recurrence after 4 months.

Clinical assessment: According to our tentative clinical treatment with this laser device, the effect of the pain reduction is almost the same as of the pulsed Nd:YAG laser.

Table 8 Laser parameters and treatment effectiveness of Er:YAG laser (wavelength 2.64 µm)

Investigators	Irradiation parameters	Effectiveness
Schwarz et al (2002)[93]	80 mJ/pulse, 3 Hz for 2 min	effective, but rate is unknown
Birang et al (2006)[75]	100 mJ/pulse, 3 Hz for 60 s, 2 times	effective, but rate is unknown

Fig 31 Pain reduction by laser before caries removal.

Fig 33 Exposure of marginal gingiva.

Er,Cr:YSGG laser

This laser device was also developed for caries treatment, but endodontic and periodontic application has also been studied. There are no full research papers on the pain reduction in dentin hypersensitivity by Er,Cr:YSGG laser, except for clinical case reports. With regard to the indications, parameters, techniques, and clinical assessment, it seems to be almost same as those of Er:YAG laser due to the similar wavelength.

COMBINATION OF LASER TREATMENT WITH MEDICATIONS

There have been some reports on combined use of laser irradiation with chemical agents such as sodium fluoride[58,74] and stannous fluoride.[86,88] The combined use of the GaAlAs laser (830 nm wavelength) with fluoridation enhances treatment effectiveness by more than 20% over that of laser treatment only.[58] The combination of Nd:YAG laser and 5% sodium fluoride varnish seems to show an impressive efficacy, when compared to either treatment alone.[74] In an in vitro study, most dentinal tubule orifices were occluded after treatment by Nd:YAG laser irradiation followed by topical sodium fluoride,[94] and fluoride-containing dentin desensitizer combined with Nd:YAG laser irradiation increases the duration of its effect.[95]

EFFECTS OF LASER IRRADIATION TO DENTAL PULP TISSUE

In the use of laser in vivo, thermal effects on pulpal tissues are of concern. Compared to other lasers, the Nd:YAG laser beam penetrates deeply through

Fig 34 After resin filling.

dentin,[80] bone, and non-pigmented soft tissues.[96] Irradiation causing temperature rises exceeding the threshold of pulpal tolerance will cause thermal injury to the pulp. Previous studies have demonstrated that healthy pulp tissue is not injured thermally if the laser equipment is used at correct parameters so that any temperature rise within the pulp remains below 5°C.[97]

Pulpal effects of the laser devices previously discussed have been investigated. The GaAlAs laser at a wavelength of 780 nm, and a power output of 30 mW for 3 min caused no thermal or other damage to pulp tissues in monkeys.[26] According to an in vitro thermometric study, GaAlAs laser irradiation at the parameters of 30 mW (CW) at 780 nm wavelength, 60 mW (CW) at 830 nm wavelength, and 10 W (pulsed) at 900 nm wavelength do not cause significant intrapulpal temperature rises.[98] Pulpal disruption did occur in laser-treated specimens with remaining dentin thickness of less than 1 mm, while pulps of intact and prepared

Fig 35 High power GaAlAs diode laser of 20 W output power.

Fig 36 Applying the laser tip to the cervical surface.

teeth with remaining dentin thickness exceeding 1 mm were the same as controls, and no significant pulpal disruption was observed after laser exposures up to 240 J (2 W, 20 Hz for 2 min) using the Nd:YAG laser.[99] After exposure to the Nd:YAG laser, no histologically measurable response was observed using a power of 50 mJ/pulse at 10 Hz for 30 s (total energy: 15 J) in rats.[100] However, treatment effects must be well controlled when using black ink as absorption enhancer. It was reported that irradiation at 2 W and 20 Hz for 10 s induced pulpal temperature rises of 13.4°C through 2 mm of remaining dentin thickness.[101] Using the CO_2 laser, no damage was reported after pulpal exposure to 3 W of power for 2 s in the CW mode in monkeys and dogs.[102] With the CO_2 laser, the enamel and dentin surfaces reach very high temperatures, but only low temperatures are measured in the pulp chamber.[76] At parameters of 0.5 or 1 W an intrapulpal temperature rise below 1°C was measured.[103] This is related to the very high absorption and low penetration of light at this wavelength in hard dental tissues. Laser Doppler examination revealed no change in pulpal blood flow due to laser treatment. All patients showed absolutely identical perfusion indices immediately before and after CO_2 laser treatment at 0.5 W in the CW mode for 5 s twice with 20 s intervals as well as 1 week after treatment.[86]

CONSIDERATIONS REGARDING LASER TREATMENT FOR DENTIN HYPERSENSITIVITY

The possibility of a placebo effect must be taken into account, especially as patient reports were positive immediately after laser treatment, whereas normally one would expect the cumulative effect of any therapy to provide a gradual improvement from visit to visit. A strong placebo effect is commonly described in clinical dentin hypersensitivity trials. This effect consists of a complex mixture of physiological and psychological interactions, depending considerably on the doctor-patient relationship, with both parties needing to believe that the treatment is valuable and desiring to obtain relief of symptoms. Investigators have described patients obtaining relief without any treatment due to the placebo effect. This is thought to vary from 20% to 60% in dentin hypersensitivity clinical trials.[104]

Recurrence of hypersensitivity varied with each laser and treatment protocol and depended on the irradiation methods and time after treatment. The recurrence rate of hypersensitivity after He-Ne laser treatment has been reported to range from 7.4% to 66.0%, that of the GaAlAs laser (830 nm wavelength) from 6.0% to 75.0%, Nd:YAG up to 34.0%, and CO_2 laser up to 50.0%. The mechanism of recurrence is unknown. As laser effects are considered to be due to the effects of sealing of dentinal tubules, nerve analgesia or placebo effect. The sealing effect is considered to be lasting, whereas nerve analgesia or a placebo effect is not.

In the treatment of dentinal hypersensitivity, irradiation of the cervical region is the most common and effective, followed by the apical region.[44] Other areas of laser irradiation for cervical dentin hypersensitivity treatment stimulate the nerve fibers related to the symptomatic region and acupuncture of sites such as M. adductor pollicis (Goukoku) and lobulus auriculae.[44] Treatment effectiveness is dependent on the area irradiated.

Although there are many methods of clinically assessing dentin hypersensitivity, most investigators use either a sharp explorer or a blast of cold air to measure sensitivity. These are the oldest and most frequently used methods.[5] However, the evaluation of treatments for dentin hypersensitivity is extremely difficult regardless of the methods or materials employed. In estimating treatment effects in hypersensitive teeth, investigations are handicapped by an inability to observe patient response objectively and are dependent upon the patient's interpretation, which is, in turn, subject to suggestion. A visual analog scale (VAS) test, which has been useful and popular in the fields of internal medicine and psychology, is considered to be good for objective judgement,[105] and this is effective for evaluation of human dental pain.[106] As another method, a double-blind testing protocol is useful for evaluation of dentin hypersensitivity.[45,50,51]

CONCLUSION

With the development of thinner, more flexible, and durable laser fibers, laser applications in dentistry will increase. Since laser devices are still relatively costly, access to them is limited. To date, six kinds of lasers have been used for the treatment of dentin hypersensitivity, but other lasers have potential for this application. Ideally, the laser of the future will have the ability to produce a multitude of wavelengths and pulse widths, each specific to a particular application. The mechanisms involved in laser treatment of dentin hypersensitivity is relatively unknown. These require clarification to optimize safe and effective treatment. Once this knowledge is established, the potential for developing lasers for the treatment of hypersensitivity can be fully explored and realized.

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