LASER IN DENTISTRY

Yoon Ho, Oh
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1960 first laser which emitted a deep red-colored beam from a ruby crystal.
In the 1970s and 1980s, turned to other devices, such as CO$_2$ and neodymium YAG (Nd:YAG), which were thought to have better interaction with dental hard tissues.
The medical community in the mid to late 1970s had begun to incorporate lasers for soft-tissue procedures.
At the same time, oral surgeons added laser technology in the early 1980s.
Component of Human Tooth

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**Fig. 4.27.** Cross-section of a human tooth
Component of Human Tooth

- Hardest substance of the human body.
- Made of 95% hydroxyapatite, 4% water, 1% organic matter.
- Hydroxyapatite: mineralized compound $\text{Ca}_{10}(\text{PO}_4)_6(\text{OH})_2$, consists of tiny crystallites (4 um : 6 um in diameter).
- Intruded by impurities: $\text{Cl}^-, \text{F}^-, \text{Na}^+, \text{K}^+, \text{Mg}^{2+}$
Component of Human Tooth

- Much softer.
- Only 70% hydroxyapatite, 10% water, 20% organic matter. (mainly collagen fibers)
- Consists of small tubuli (few mm in length, 100 nm : 3um in diameter) : growth of the tooth.
Component of Human Tooth

- Contains the supplying blood vessels, nerve fibers, different types of cells. (odontoblasts, fibroblasts)
- Odontoblasts: in charge of producing the dentin.
- Fibroblasts: stability and regulation mechanisms.
- Connected to peripheral blood vessels by root canal.
- The tooth is embedded into soft tissue. (gingiva)
  → Protected from bacteria attack.
Tooth Decay or Dental Caries

By cariogeneous nourishment and insufficient oral hygiene

Microorganisms multiply at the tooth

Form a layer of *plaque*

Lactic and acetic acid are produced

Reducing the pH down ~ approximately 3.5

\[ Ca_{10}(PO_4)_6(OH)_2 + 8H^+ \leftrightarrow 10Ca^{2+} + 6HPO_4^{2-} + 2H_2O \]
Tooth Decay or Dental Caries

• Firstly, enamel can be demineralized within few days only.
  \[\rightarrow\text{the hard enamel becomes very porous and permeable.}\]
  (Fig 4.28).

• Then, the dentin is demineralized.
  \[\rightarrow\text{Microorganisms infect the pulp induces several pain.}\]
Tooth Decay or Dental Caries

• Remove all infected substance and refill the tooth with suitable alloys (amalgam), gold, ceramics or composites.

• The removal of infected substance

  - Usually performed by conventional mechanical drills.
    - Induce vibration, Sudden increase in temperature.
  - These drills call additional pain driven by very sensitive tooth nerves.
Tooth Decay or Dental Caries

• **The removal of infected substance with laser**
  - Avoid the vibrations since it is contactless technique.
  - Thermal side effects are not always eliminated when using laser (Figs. 4.29a-b).
    → Negligible only when using ultrashort pulses.

**Advantages**
- Pain relief.
- Conditioning of dental substance
  → Additional protection by sealing the tooth.
  → The occurrence of caries can be significantly delayed.
- More precise and improved control procedure of caries removal
  → Could minimize the amount of healthy substance to be removed (Figs. 3.51a-b).
  → Indications for expensive dental crowns or bridges are effectively reduced.
Tooth Decay or Dental Caries

- The removal of infected substance with laser

Fig. 4.29. (a) Mean temperatures in the pulp during exposure to a CW CO\textsubscript{2} laser (power: 5 W) without and with air cooling, respectively. (b) Mean temperatures in the pulp during exposure to a CW Nd:YAG laser (power: 4 W) without and with air cooling, respectively. Data according to Fronsten and Koert (1992)

Fig. 3.51. (a) Spectrum of plasma on healthy tooth substance induced by a Nd:YLF laser (pulse duration: 30 ps, pulse energy: 500 μJ). Lines of neutral calcium (Ca), singly ionized calcium (Ca\textsuperscript{+}), and neutral sodium (Na) are seen. The signal at 525.5 nm partly originates from calcium and from second harmonic generation (SHG) of the laser beam. (b) Spectrum of laser-induced plasma on various tooth substance. Due to the process of demineralization, the intensity of all mineral lines is reduced. Data according to Niemz (1994a)
Laser Type in Dentistry

• Classified by wavelength
  - Soft lasers: Compact, low wavelength
  - Hard lasers: Surgical, high wavelength

• Classified by the type of active / lasing medium used

- ArF excimer, KrF excimer, XeCl excimer, Argon ion,
- Nd: YAG, Er: YAG, CO₂

Figure 2: A portion of the electromagnetic spectrum showing dental laser wavelengths being used for treatment
Laser Type in Dentistry

• Laser Delivery Systems

**FIGURE 2-10** • An assembled fiberoptic delivery system consisting of the bare fiber, a handpiece, and a disposable tip.

**FIGURE 2-13** • Variety of handpieces available with most CO₂ laser systems offer a variety of spot sizes and focal distances.

**FIGURE 2-14** • Fiber diameters for Nd:YAG and diode lasers, yielding different spot sizes.

**2-16** • Nd:YAG fiber entering periodontal pocket.
Laser Type in Dentistry

• **Argon lasers**
  - Argon gas that is energized by a high-current electrical discharge, delivered in CW and gated pulsed mode.
    - 2 wavelengths: 488 nm in blue color, and 514 nm in green color.
    - Poor absorption for enamel and dentin: using this laser for cutting and sculpting gingival tissues because there is minimal interaction by poor absorption, no damage is generated to the tooth surface during those procedures.

• **Diode lasers (800-980 nm)**
  - Solid medium laser, manufactured from semiconductor crystals using some combination of aluminum or indium, gallium, and arsenic.
    - Highly absorbed by pigmented tissue and are deeply penetrating, not as rapid as with the argon laser.
    - Poorly absorbed by tooth structure. Thus, soft tissue surgery can be safely performed to enamel dentin and cementum.
  - Used for cutting and coagulating gingiva and mucosa and for sulcular debridement.
Laser Type in Dentistry

• **Nd-YAG lasers**
  - Used to remove incipient enamel caries
  - Has the greatest depth of penetration, tissues under the surface are exposed to laser energy.
    - Risk of unwanted damage, especially in the underlying bone or the dental pulp.
    - Pulpal damage (denaturation and disruption of neuronal tissue) associated with a decrease in pulpal function.

• **The erbium family**
  - Erbium, chromium:YSGG (2780 nm), Erbium:YAG (2940 nm)
  - Caries removal and tooth preparation are easily accomplished by above lasers.
  - Er:YAG laser produces clean, sharp margins in enamel and dentin since it has negligible depth of energy penetration.
    - Less likely to provoke discomfort or pain, without significant cracking.
  - Er,Cr:YSGG laser produces a rough surface in enamel and dentin without significant cracking.
  - Disadvantages of the Er,Cr:YSGG laser involve the etching results.
CO₂ lasers

- A gas active medium laser that incorporates a sealed tubes containing a gaseous mixture with CO₂ molecules
- The light energy, whose wavelength is 10,600 nm.
- Can easily cut and coagulate soft tissue providing a clear operating field and a shallow depth of penetration into tissue.
- Disadvantages: Delaying in wound healing.
This method is verified by five independent existing tests

- **Scanning electron microscopy**: A type of electron microscope that produces images of a sample by scanning it with a focused beam of electrons.

- **Dye penetration tests**: A low-cost inspection method used to locate surface-breaking defects in all non-porous materials.

- **Hardness tests**

- **Histology**: The study of the microscopic anatomy of cells and tissues of plants and animals.

- **Polarized microscopy**: An optical microscopy techniques involving polarized light.
Laser Treatment of Hard Tooth Substance

- **Scanning Electron Microscopy (SEM)**
  - Below figures show the ability of a picosecond Nd:YLF laser to produce extremely precise tetragonal cavities in teeth.
  - Created by distributing 1mJ laser pulses onto 40 lines over the tooth surface with 400 lasered spots per line, dimensions $1 \times 1\, \text{mm}^2$ and a depth $400\, \mu\text{m}$.
  - Repeating this procedure 10 times for healthy one (left) and once for cavity one (right).
  - Indicates that the ablation rate of demineralized enamel is about ten times higher than that of healthy enamel.

→ The Nd:YLF laser provides a caries-selective ablation.

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**Fig. 4.31.** (a) Cavity in healthy enamel achieved with 100,000 pulses from a Nd:YLF laser (pulse duration: 30 ps, pulse energy: 1 mJ). (b) Cavity in carious enamel achieved with 10,000 pulses from a Nd:YLF laser (pulse duration: 30 ps, pulse energy: 1 mJ)
Laser Treatment of Hard Tooth Substance

• **Scanning Electron Microscopy (SEM)**
  – Below figures show the cavity wall and bottom.
  – The cavity wall is extremely steep and is characterized by a sealed glass-like structure.
    → Great significance for the prevention of further decay.
  – The roughness of the cavity bottom is of the order of 10~20 μm.
    → Thus facilitates the adhesion of most filling materials.

![SEM images of cavity wall and bottom](image)

*Fig. 4.32. (a) Cavity wall in healthy enamel achieved with a Nd:YLF laser (pulse duration: 30 ps, pulse energy: 1 mJ). (b) Cavity bottom in healthy enamel achieved with a Nd:YLF laser (pulse duration: 30 ps, pulse energy: 1 mJ)*
Laser Treatment of Hard Tooth Substance

• **Scanning Electron Microscopy (SEM)**
  – Below figures show more evident scanning ablation when using fewer pulses to produce a shallow cavity.
  – Left: A circular ablation pattern with 2500 pulses.
  – Right: The effect of a conventional drill on the cavity wall.
  
  → Deep grooves and crumbled edges are clearly visible.

Fig. 4.33. (a) Cavity in carious enamel achieved with 2500 pulses from a Nd:YLF laser (pulse duration: 30 ps, pulse energy: 1 mJ). (b) Cavity wall achieved with a conventional diamond drill.
Laser Treatment of Hard Tooth Substance

• **Dye penetration tests**
  – Below figure(right) shows the results of dye penetration tests after exposure to a picosecond Nd:YLF laser.
  – Laser-induced fissures typically remained below 20 μm.
  – Same order as fissure depths obtained with the mechanical drill.
  – Potential cause of extremely small dye penetration…
    → The sealing effect by the steep cavity.

![Diagram showing dye penetration tests](image)

**Fig. 4.30.** Results of dye penetration tests for three different solid-state lasers and the mechanical drill. Listed are the maximum penetration depths inside the enamel of human teeth. Pulse durations: 250 μs (Ho:YAG), 90 μs (Er:YAG), and 30 ps (Nd:YLF). Data according to Niemz (1993b)
Laser Treatment of Hard Tooth Substance

• **Hardness tests**
  
  – One obvious test for the potential influence of shock waves is the measurement of hardness of a tooth before and after laser exposure.
  
  – The hardness is defined as 
    
    $$ H_v = 1.8544 \frac{K}{D^2} $$
    
    With $K = 5.0 \times 10^4$ (N), $D$ is the impact of a diamond tip cut at an angle of 136 degree.
  
  – Softer material $\rightarrow$ deeper impact of the diamond tip $\rightarrow$ larger impact diameter.
  
  – Below table shows the results of hardness tests after exposure to picosecond Nd:YLF pulses.
    
    $\rightarrow$ No significant alteration in hardness is observed in exposed and unexposed.
    
    $\rightarrow$ Dentin appears much softer due to its lower content of hydroxyapatite.

<table>
<thead>
<tr>
<th></th>
<th>$D$ (mm)</th>
<th>$H_v$ (N/mm$^2$)</th>
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</thead>
<tbody>
<tr>
<td>Exposed enamel</td>
<td>5.9</td>
<td>2660</td>
</tr>
<tr>
<td>Unexposed enamel</td>
<td>5.8</td>
<td>2760</td>
</tr>
<tr>
<td>Unexposed dentin</td>
<td>11.5</td>
<td>700</td>
</tr>
</tbody>
</table>
• **Histology**
  
  – Important for new therapeutic technique to check response of the tissue.
  – The survival of cells
  – Its sections enable specific statements concerning the condition of cells due to highly sophisticated staining techniques.
  – Below figure shows the dentin-pulp junction of a human tooth.
  – 1 X 1mm² area exposed to 16000 pulses from a Nd:YLF laser.
  – Along the junction, several odontoblasts are clearly visible.
  – They have not intruded into dentin and have a similar appearance as unexposed teeth.
  – Potential shock waves do not have a detectable impact on the pulp.

![Histologic section of a human tooth after exposure to 16000 pulses from a Nd:YLF laser (pulse duration: 30 ps, pulse energy: 500 μJ, bar: 50 μm).](image)
Laser Treatment of Hard Tooth Substance

- **Polarized microscopy**
  - Tool for detecting alterations in optical density which might arise from the exposure to shock waves.
  - Below figure shows the enamel-dentin junction of a human tooth.
  - Located underneath a 1 X 1mm² area exposed to 16000 pulses from a Nd:YLF laser.
  - Top and bottom parts: dentin tubuli and enamel prisms
  - Different optical densities of two different color (blue and yellow)

(b) Polarized microscopy of a human tooth slice after exposure to 16000 pulses from the same laser (bar: 50 μm). The junction of dentin (*top*) and enamel (*bottom*) is shown which was located next to the application site.
Further thought

- Base on results of the above tests followings can be concluded.
- To cope with conventional mechanical drills, a ten times higher ablation efficiency would be desirable.
- Can be achieved by increasing both the pulse energy and repetition rate.
  → Then, the Nd:YLF picosecond laser might represent a considerable alternative in the preparation of hard tooth substances.
- One very important issue: Temperature increase inside the pulp with dental laser systems.
  → Over 5°C increment, thermal side effects might occur.

Fig. 4.28. Increase in temperature in a distance of 1 mm from cavities achieved with a Nd:YLF laser (pulse duration: 30 ps, pulse energy: 1 mJ, repetition rate: 1 kHz). Unpublished data
Laser Treatment of Soft Dental Tissue

• **CO\textsubscript{2} laser**: used to treat malignant, premalignant, and benign lesions of the oral mucosa, useful for small mucosal lesions.
  – Advantage is that there is no need to suture the wound, since small blood vessels are coagulated and bleeding is stopped.
  – Wound healing: occurs in 2 weeks, reepithelialization is done after 4-6 weeks.

• When treating soft tissue lesion inside the mouth, surgeon has a choice of two techniques: Excision or vaporization.
  – Excision: Preferable, provides histologic evidence of its complete removal and confirmation of the preceding diagnosis.
  – Vaporization: A risk always remains that not all altered tissue is eliminated.
Laser Treatment of Soft Dental Tissue

• Soft Tissue Gingivoplasty, using an Er:YAG Laser (2940-nm)
  ➢ Er:YAG : Decreased healing time with minimal patient discomfort.
  ➢ Being able to be utilized for soft tissue ablation and osseous recontouring for biologic width maintenance.

Figure 2: Preoperative full smile
Figure 6: Preoperative target length
Figure 8: Initial laser ablation of tissue
Figure 10: Initial frenum revision
Figure 16: Immediate postoperative view with osseous contouring finished.
Figure 22: One-year postoperative view of the full smile
Laser Treatment of Soft Dental Tissue

• Gummy Smile correction by laser
Laser in Endodontics

- Endodontics is concerned with the treatment of infections of the root canal.
- The treatment of infections of the root canal, arise from:
  - Breakthrough of decay into the pulp.
  - The plaque accumulation beneath the gingiva and bacterial attacks.
- Method: must sterilize both pulp and root => create the death of tooth
  - ArF excimer laser creates very clean surfaces of the root canal.
Laser Treatment of Filling Materials

- In dental practice, not only tooth substance needs to be ablated but also old fillings have to be removed.
- Removal of metallic fillings → infrared lasers can not be used.
- Amalgam should never be ablated with lasers at all.
  → When amalgam has melted with laser, a significant amount of mercury can be released.
  → Extremely toxic.

Fig. 4.40. (a) Removal of amalgam with a Nd:YLF laser (pulse duration: 39 ps, pulse energy: 0.5 mJ). (b) Removal of amalgam with an Er:YAG laser (pulse duration: 90 ps, pulse energy: 100 mJ)
Laser Treatment of Filling Materials

- Laser-welding of dental bridges and dentures
  - Advantages compared to conventional soldering
    - Higher resistance against corrosion.
    - The ability to weld different metals.
    - The ability to weld coated alloys.
    - Lower heat load.
    - Higher reproducibility.

*Fig. 4.41.* Tear thresholds of laser-welded and soldered dental alloys (KCM: cobalt-based alloy, NCA: nickel-based alloy, Sipal: silver-palladium-based alloy). Data according to Dobberstein et al. (1991)
Applications

- **Er:YAG LASER assisted treatment of fractured teeth**
  - In ablating superficial dentin, laser can prepare the surfaces of the fractured teeth and the fragments so that they could be bonded together.
  - Effects: Reduces bacteria, attaches the fragments with composite filling material.

![Image of patient with three fractured teeth, with fragments displayed separately.](image)

Figure 1: The patient with three fractured frontal teeth, with the fragments displayed separately.

![Image of completed dentin modification. Laser was used in contact mode.](image)

Figure 2: Completed dentin modification. Laser was used in contact mode.

![Image of dentin ablation completed. Laser was used in noncontact mode.](image)

Figure 3: Dentin ablation completed. Laser was used in noncontact mode.

![Image of immediate postoperative view of restorations.](image)

Figure 4: Immediate postoperative view of restorations.
Applications

• Er:YAG LASER to prepare teeth for veneer placement
  – Preparations for veneers were completed with a bur, the laser was used to produce craters to increase the surface area for adhesion.

Figure 8: The final preparations after using the laser and burs

Figure 9: Immediate postoperative view showing final restorations
Applications

- **Er:YAG LASER** assisted treatment of an enamel defect

  Figure 11: Preoperative view of enamel defect in tooth #7

  Figure 13: View of preparation after bur use and acid etching

  Figure 14: Immediate postoperative view of the restoration
Applications

- Dental implant laser surgery assisted by CO$_2$ laser
Advantages

• No need of drill
• Less blood loss, Less pain
• Reduce post-operative edema
• Early healing and rapid regeneration
• Reduce post sensitivity in restorations
• Sterilization of treatment site → No infection
Lasers can't be used:
- In filling cavities located between teeth.
- For cavities around old fillings and large cavities (crown).
- In removing defective crowns or silver fillings.
- For preparing teeth for bridges.

Laser → more expensive than other methods.
In considering the biologic effects of laser light on dental tissue, there are many factors to consider.

- Wavelength of the laser.
- The energy density.
- The pulse duration of the laser radiation.
- The properties of the tissue interacting with the light.

Based on above criteria, lasers in dentistry can be used in two big different type of tissue.

- Soft lasers: CO$_2$ lasers CW mode, Argon lasers, Diode lasers and Nd:YAG Lasers.
- Hard lasers: CO$_2$ lasers pulsed mode and Erium family.
Additional Explanation

Figure 1: Approximate absorption curves of different dental compounds by various wavelengths of dental lasers.
• The reason of categorization of hard lasers
  – Absorption coefficient for hemoglobin is low.
    → Not good for hematosis of soft tissues.
  – Have high absorption coefficients for water and hydroxyapatite.

• The reason of categorization of soft lasers
  1) Argon, Diode, Nd:YAG lasers
    – Absorption coefficient for hemoglobin is high.
      → Good for hematosis of soft tissues.
    – Even the absorption coefficients for water and hydroxyapatite are lower than those of hard lasers, soft tissues have higher numbers of water contents.
      → Lower hardness, relatively lower coefficients are applicable.

  2) CO₂ lasers CW mode
    – Have high absorption coefficients for water and hydroxyapatite.
    – Have shallow penetration depth with long wavelength.
    – Because of long pulse duration, low peak power and constraint in delivery technology in CW mode, this laser can not be used in hard tissue.
      → Carbonization and crazing of tooth can be generated.
• Few examples of pulse duration sets.

1) Nd:YAG lasers
   – PreioLase® MVP-7™ Digital TruePulse™.
   – Seven operator-selectable pulse durations
   – From 100 to 650 μs.

2) Erbium family

<table>
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<tr>
<th>PULSE MODE</th>
<th>PULSE DURATION</th>
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<tr>
<td>Er:YAG (Fidelis Plus III)</td>
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<tr>
<td>SSP</td>
<td>80 µs</td>
</tr>
<tr>
<td>VSP</td>
<td>150 µs</td>
</tr>
<tr>
<td>SP</td>
<td>200 µs</td>
</tr>
<tr>
<td>LP</td>
<td>500 µs</td>
</tr>
<tr>
<td>VLP</td>
<td>800 µs</td>
</tr>
<tr>
<td>Cr,Er:YSGG (Waterlase MD)</td>
<td></td>
</tr>
<tr>
<td>H</td>
<td>600 µs</td>
</tr>
<tr>
<td>S</td>
<td>1200 µs</td>
</tr>
</tbody>
</table>
Tooth decay is led by infected substrate.

Infected substrate can be removed by mechanical drill and laser.

Laser in dentistry can be used in both soft tissue and hard tissue with different wavelength.

ex) ArF excimer, KrF excimer, XeCl excimer, Argon ion, Nd: YAG, Er: YAG, CO₂

Above lasers can be categorized into 5 types.

Argon lasers, Diode lasers, Nd:YAG lasers, The erbium family, CO₂ lasers.

These can be verified with following tests.

- Scanning electron microscopy, Dye penetration tests, Hardness tests, Histology, Polarized microscopy.
• Diode lasers, Nd:YAG lasers and CO₂ lasers (CW mode) can be used for soft tissues.

• Er:YAG lasers, Er, Cr:YSGG lasers and CO₂ lasers (Pulsed mode) can be used for both tissues.

• Argon lasers can be used for endodontics.
  
ex) ArF excimer laser create very clean surfaces of the root canal.

• To remove old fillings in tooth and to make dental-bridges, laser also can be used.

• Applications
  
  – Er:YAG LASER assisted treatment of fractured teeth.
  – Er:YAG LASER to prepare teeth for veneer placement.
  – Er:YAG LASER assisted treatment of an enamel defect.
  – Dental implant laser surgery assisted by CO₂ laser.
References


Thank You 😊

Q & A