



Title	Effects of heating on mechanical properties of human dentin
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Citation	大阪大学, 2008, 博士論文
Version Type	
URL	<a href="https://hdl.handle.net/11094/49250">https://hdl.handle.net/11094/49250</a>
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学 位 記 番 号	第 2 1 9 3 2 号
学 位 授 与 年 月 日	平成 20 年 3 月 25 日
学 位 授 与 の 要 件	学位規則第 4 条第 1 項該当 歯学研究科分子病態口腔科学専攻
学 位 論 文 名	Effects of heating on mechanical properties of human dentin (加熱がヒト象牙質の機械的性質に及ぼす影響)
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### 論 文 内 容 の 要 旨

#### 目的

Tooth fracture is a serious problem that clinicians face in their everyday practice. It has been demonstrated to be the most frequent reason for tooth loss in patients following an adequate plaque control program. Better understanding of the fracture mechanisms in different environmental conditions is needed to address the problem properly. Microstructure and the tubular orientations appear to play an important role for the strength of dentin. The anisotropic behavior of dentin was proven under static loading, but the relationship with hydration and dehydration has not yet been fully investigated. In addition, since the flexural strength of Type I collagen, the major organic component of dentin, has been known to increase with heating, it is worth considering when hypothesizing that human dentin can be strengthened by heating.

The objectives of this study were to investigate the effects of dehydration and heating on the various mechanical properties of human dentin by focusing on tubule orientations.

#### 方法ならび成績

Beam-shaped specimens were prepared from human third molars to investigate their various mechanical properties. Dentinal tubule orientations, which are important factors for investigating the mechanical strength of dentin were organized to run in three different orientations as follows : transverse (tubules run parallel to the loading surface along its length) ; in-plane longitudinal (tubules run parallel to the loading surface and perpendicular to its length) and anti-plane longitudinal (tubules run perpendicular to the loading surface). The environmental conditions for testing its mechanical properties were : wet (stored in HBSS at 4°C) ; dry (desiccated for 7 consecutive days at ambient temperature and humidity <20%) and heat (heated in an oven at temperatures in the range of 70 to 170°C).

The flexural fracture testing was performed by using a universal testing machine until complete fracture occurred. Among the transverse specimens, the flexural strengths were significantly different between the

groups in the three environmental conditions. The flexural strength in the heated group was found to have increased from  $81 \pm 10$  MPa to  $211 \pm 36$  MPa, when compared to their initial wet condition. The transverse specimens under wet conditions showed significantly lower flexural strength ( $81 \pm 10$  MPa) when compared to the in-plane longitudinal ( $187 \pm 14$  MPa) and anti-plane longitudinal groups ( $143 \pm 21$  MPa). Between the transverse group and the other two orientations groups, there was anisotropy under wet and dry conditions, which disappeared after heating. After heating, specimens in all the tubule orientation groups required higher energy to fracture. The most pronounced increase was again in the transverse groups : from  $1.7 \pm 0.6 \times 10^4$  J/mm<sup>2</sup> under wet conditions to  $8.6 \pm 3.5 \times 10^4$  J/mm<sup>2</sup> after heating. The SEM pictures revealed smooth fractured surfaces in the transverse orientation under wet condition, but after heating the entire surfaces were rough with many irregularities and signs of “pulling” in the peritubular cuffs. The Young’s moduli were calculated using the data from the flexural fracture testing. They were found to be within the range of 10 to 11 GPa and they did not change significantly regardless of dehydration or heating.

For the stress intensity analyses, pre-notched specimens were subjected to a cycling loading using an electromagnetic micro-material testing machine. Then, the stress intensity factors were calculated from the fracture strength and the ratio of the pre-notched area to the catastrophically fractured area, obtained after fracturing the specimens. They were also significantly increased by heating and this was true for all the tubule orientation specimens, with the transverse groups showing a marked increase from  $1.41 \pm 0.25$  MPa  $\sqrt{\text{m}}$  under wet condition to  $2.39 \pm 0.32$  MPa  $\sqrt{\text{m}}$  after heating. Among the different orientation groups, there was no significant difference found between the wet and dry conditions.

The fracture endurance strength, which was defined as a stress amplitude at which specimens survived cyclic loading up to  $1.5 \times 10^6$  cycles was compared between wet and heated specimens. The repetitive loading test showed an increase of the endurance strength from 15 to 33 MPa by heating in the transverse groups, while the in-plane longitudinal orientation groups did not show any significant changes between wet and heated specimens. The numbers of the dentinal tubules, counted using the SEM pictures at x2000 magnification were plotted against the flexural strength. With the increase of the number of tubules, a decrease in the flexural strength was found under wet conditions. This tendency was completely reversed after heating.

To identify the most effective heating condition for strengthening human dentin, different temperatures and time exposures to heat were tested and their effects on the flexural strength and linear shrinkage for transverse specimens were evaluated. Judging from the increased flexural strengths and stable linear shrinkage, we can assert that the heating at 110°C for 10 min or heating at 140°C for 0 min are the most favorable conditions to strengthen dentin. Re-hydration of the specimens in HBSS after the heating at 110°C for 10 min or at 140°C for 0 min reverted the strength to that of the initial wet condition after three and seven days, respectively. However, heating up to 140°C, followed by an UV irradiation for 15 min helped to retain 66% of the flexural strength even after seven days of re-hydration, and also showed a residual shrinkage of  $0.08 \pm 0.02\%$ .

## 総括

The results in the present study demonstrated that heating of human dentin increased its various mechanical strength, while desiccation did not show significant effect in improving the mechanical properties. The transverse tubule orientation was the most susceptible to heating. It was noteworthy that the heat treatment did not make dentin brittle, since the Young’s moduli were unchanged for all environmental conditions and tubule orientations.

Heating at 140°C without time exposure increased the flexural strength almost threefold when compared to the initial wet condition, while the most optimal temperature and time duration for clinical use appeared to be 110°C for 10 min. The strengthening effect by heating, however was completely reversible upon re-hydration.

UV irradiation for 15 min following heating at 140°C was found to retain approximately 2/3 of the strengthening effect by heating after the seven days re-hydration.

The findings from this study are potentially applicable in a clinical situation, where teeth undergoing endodontic treatment could possibly be strengthened by heating.

#### 論文審査の結果の要旨

本研究は、乾燥および加熱がヒト象牙質の機械的性質におよぼす影響を、象牙細管の走行方向に着目して多面的に解析したものである。

その結果、象牙質は 110°C、10 分の加熱によって、曲げ強さが最大 3 倍に増加することが明らかになった。さらに、加熱直後に紫外線照射を加えることによって、水中に再浸漬した場合でも、加熱による強化効果の 66%が保持されることが示された。

以上の研究成果は、象牙質の物性に関する新たな知見を加え、歯を強化する治療法の開発につながるものであり、本研究は博士（歯学）の学位授与に値するものと認める。