

Study on Rehardening of Demineralized Dentin with Resin-modified Pulp-capping Agents Containing MTA

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Abstract

Purpose: Based on the concept of minimal intervention (MI), temporary indirect pulp capping (IPC) is used to preserve the deep parts of dentin adjacent to the pulp and avoid pulp exposure when caries advances deep into the dentin close to the dental pulp. The purpose of this study was to measure the Knoop hardness of softened dentin applied with cured bodies of resin-modified pulp-capping agents containing MTA at 1 month and 3 months postoperatively.

Methods: We measured the hardness on the side of the enamel of dentin samples with Cariotester, and used those with enamel side hardness of around 60 KNH as healthy dentin samples. We decalcified the healthy samples according to the method of Matsuda et al., and used those whose hardness decreased to around 20 KNH as softened dentin samples. As pulp-capping agents, we applied TMR-MTA cement (TMR) and NEX MTA cement (NEX), which are conventional MTA cements, and TheraCal LC (TCL) and Super MTA Paste (SMP), which are resin-modified pulp-capping agents containing MTA, on softened dentin samples and coated each with base cement to use them as the pulp-capping samples. We measured the Knoop hardness of the softened dentin after storing the prepared pulp-capping samples in a container at 100% humidity for 1 month and 3 months. We prepared three samples for each condition, and subjected the obtained values to statistical analysis using repeated measure analysis of variance and Tukey's test ($p < 0.05$).

Results: After application of pulp-capping agents, the Knoop hardness was 32.8 ± 2.7 KNH after 1 month and 33.2 ± 0.4 KNH after 3 months in the TMR group. The hardness values improved significantly after 1 month and 3 months compared to the softened dentin samples, but were significantly lower than those of the healthy samples. In the NEX group, the hardness was 41.1 ± 2.3 KNH after 1 month and 41.6 ± 4.0 KNH after 3 months. The hardness values improved significantly after 1 month and 3 months compared to the softened dentin samples, but were significantly lower than those of the healthy samples. In the TCL group, the hardness was 20.1 ± 0.5 KNH after 1 month and 27.7 ± 4.4 KNH after 3 months. There was no significant difference in hardness after 1 month or 3 months compared to the softened dentin samples, and the values were significantly lower than those of the healthy samples. In the SMP group, the hardness was 56.5 ± 5.9 KNH after 1 month and 62.0 ± 2.5 KNH after 3 months. The hardness improved significantly after 1 month and 3 months compared to the softened dentin samples. Compared to the healthy samples, hardness improved to a level where there was no significant difference both after 1 month and 3 months. The results of this experiment showed that application of resin-modified pulp-capping agents containing MTA on softened dentin induced recalcification and hardened the softened dentin.

Conclusion: It was concluded that the application of chemical-cured type resin-modified pulp-capping agents containing MTA improved the hardness of the softened dentin to a level that was not significantly different from that of healthy dentin after 1 month and 3 months.

Key words: Knoop hardness, resin modified pulp-capping agent, MTA, remineralization

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Introduction

As a result of advances in pathological research on carious dentin and dramatic improvements in adhesion and restoration methods, the concept of minimal intervention (MI) to preserve as much healthy dentin as possible and minimize invasion has become widespread in caries treatment in recent years. However, there are many cases in which pulp exposure will occur if the infected dentin is removed entirely as caries reaches deep into the dentin and is adjacent to the pulp, and in which pulp extirpation is inevitable¹⁾. In such cases, it is recommended to use atraumatic indirect pulp capping (IPC), in which sterilization and recalcification of the infected dentin that is left and formation of tertiary dentin (reparative dentin) are facilitated to preserve the pulp, while intentionally leaving the infected dentin adjacent to the dental pulp and applying carboxylate cement containing calcium hydroxide preparation or tannin-fluoride preparation in order to avoid pulp extirpation even in adhesive restoration²⁾.

Meanwhile, it has been reported that mineral trioxide aggregate (MTA)³⁾, which is used in direct pulp capping, provides excellent sealing property and biocompatibility⁴⁾ with relatively low probability of causing inflammatory reactions, and it is considered that favorable therapeutic effects can be expected, including early induction of the formation of new dentin bridges with regular dentinal tubule-like structures^{5,6)} even though MTA is strongly basic⁷⁾. A characteristic of these cements is that they provide sustained release of mineral ions such as calcium ions and hydroxide ions when they come into contact with moisture⁸⁾. In addition, it has been discovered that calcium phosphate precipitates including apatite crystals form on the material surface through their reaction with calcium ions under an environment in which phosphate ions are also present⁹⁻¹²⁾, and it is considered that this phenomenon explains the favorable biocompatibility and sealing properties of these materials¹³⁾. MTA has therefore attracted attention as an excellent direct pulp-capping agent to replace the conventional calcium hydroxide preparation^{14,15)}, and its use in direct pulp capping was approved under the Pharmaceutical Affairs Law in April 2007. However, there are several disadvantages of MTA, including operability during filling, long curing

period and high price^{5,16)}. To resolve these issues, resin-modified pulp-capping agents containing MTA, which are calcium silicate and Portland cement, the main components of MTA, added with resin monomers, have been developed in recent years¹⁷⁻²⁰⁾.

We hypothesized that IPC of various resin-modified pulp-capping agents containing MTA was beneficial for remineralization of dentin. The purpose of this study was to measure the Knoop hardness of softened dentin applied with cured bodies of resin-modified pulp-capping agents containing MTA at 1 month and 3 months postoperatively.

Materials and methods

1. Experiment samples

As test subject teeth, we used human molars that had been extracted at the Department of Dental Surgery, Osaka Dental University Hospital and stored in a freezer at -40°C . We defrosted the human molars under running water immediately before use, observed the occlusal surface of each tooth with the naked eye, and excluded any teeth with caries, white spots, coloring or cracks.

This study was conducted with the approval of the Medical Ethics Committee, Graduate School of Dentistry, Osaka Dental University (Approval No. 111093, April 6, 2020).

2. Experiment methods

1) Preparation of samples

We prepared the samples for this study according to the method of Matsuda et al²¹⁾. We extracted the pulp by cutting the root of the human molar at a position 3 mm toward the root apex from the anatomical cervical line, and cut the dental enamel and the root dentin with a model trimmer perpendicular to the tooth axis direction. We ground the side of the enamel and the side of the pulp cavity of the exposed dentin with waterproof abrasive paper of #1000 to prepare a dentin sample of 10 mm diameter and 2 mm thickness. We prepared only one dentin sample from one tooth. We measured the hardness of the side of the enamel in each dentin sample with Cariotester (SUK-971, SaneiME), and used those samples with hardness of around 60 KNH as healthy dentin samples (hereafter referred to as "healthy samples"). We made 24 healthy samples to be used for preparing the softened dentin samples (3 sam-

Table 1 Materials

Brand	Code	Component	Manufacturer	Lot No.
TMR-MTA Cement	TMR	Powder : Calcium carbonate, Silicon dioxide, Aluminum oxide, Zirconia Liquid : Purified water	YAMAKIN	1041809
NEX MTA Cement	NEX	Powder : Calcium oxide, Bismuth oxide, Silicon dioxide, Aluminum oxide Liquid : Purified water	GC	1808031
TheraCal LC	TCL	Light-curable paste : Calcium oxide, Silicon dioxide, Aluminium oxide, Barium zirconate, Strontium glass, Polyethylene glycol dimethacrylate Bis-GMA, Photo initiator	Bisco	1800007022
Super MTA Paste	SMP	Chemically-curable paste : Portland cement, Zirconium dioxide, Hydroxypropyl methacrylate Catalyst : TBBO, n-Hexane, Ethanol	Sun Medical	TV5
Base Cement	BC	Powder : Fluoroalumino silicate glass Liquid : Acrylic acid-Tricarboxylic acid copolymer solution, Tartaric acid	SHOFU	Powder : 011621 Liquid : 031620

ples for each group×4 materials×2 storage periods).

2) Preparation of softened dentin

To decalcify the healthy samples, we used lactic acid (Kishida), which is one of the major organic acids generated by cariogenic bacteria. According to the method of Matsuda et al^[21], we soaked the side of the enamel of a healthy sample in 50 ml of 20 mmol/l lactic acid solution, and let it stand for 10 hours while conducting suction at 0.01 MPa from the side of the pulp cavity using an aspirator (MDA-006, ULVAC). After rinsing the healthy sample well with distilled water, we measured the hardness of the side of the enamel with Cariotester, and used the samples whose hardness decreased to around 20 KNH as softened dentin samples. We made 24 softened dentin samples for preparing the pulp-capping samples

3) Preparation of pulp-capping samples

Table 1 lists the pulp-capping agents and cements that were used in the experiment to prepare the pulp-capping samples. As pulp-capping agents, we used TMR-MTA Cement (YAMAKIN, hereafter “TMR”) and NEX MTA Cement (GC, hereafter “NEX”) which are conventional mineral trioxide aggregate (MTA) cements, and TheraCal LC (Bisco, hereafter “TCL”) and Super MTA Paste (Sun Medical, hereafter “SMP”)

as the resin-modified pulp-capping agents containing MTA. We left the TMR, NEX, or SMP agent standing to cure inside a rubber mold after mixing according to the manufacturer’s instructions, and left the TCL agent inside a rubber mold, and cured it by irradiating light for 40 seconds each from two directions. Then we shaped each into a disc with 3 mm diameter and 2 mm thickness, placed it in a storage box at 100% relative humidity and stored it for 24 hours in an incubator at 37°C to prepare the pulp-capping agent disc. We placed each disc on the surface of the decalcified part in a softened dentin sample, and coated it with a Base Cement (SHOFU, hereafter “BC”) to use it as the pulp-capping sample. We stored the pulp-capping samples in distilled water inside an incubator at 37°C for 1 month or 3 months, respectively, after BC curing. We made 24 pulp-capping samples (12 stored for 1 month and 12 stored for 3 months).

4) Hardness measurement

To examine the temporal changes in hardness caused by the application of a pulp-capping agent, we measured the hardness of the healthy dentin, softened dentin, and dentin 1 month and 3 months after pulp capping with Cariotester. We specified the measurement range to be within 3 mm diameter from the center of

Table 2 Knoop hardness of dentin in each condition after 1 month and 3 months

	TMR	NEX	TCL	SMP
Sound dentin	62.4 (1.8)	63.6 (0.7)	61.6 (2.1)	62.8 (2.1) ^c
Demineralized dentin	21.8 (2.2)	20.1 (1.1)	20.4 (2.7) ^a	23.0 (2.6)
1M	32.8 (2.7)	41.1 (2.3)	20.1 (0.5) ^a	56.5 (5.9) ^c
Sound dentin	63.2 (0.7)	60.8 (2.8)	63.2 (1.4)	62.8 (1.2) ^d
Demineralized dentin	23.7 (0.8)	23.9 (1.1)	21.5 (1.0) ^b	22.0 (0.6)
3M	33.2 (0.4)	41.6 (4.0)	27.7 (4.4) ^b	62.0 (2.5) ^d

The unit Knoop hardness of dentin in each condition. () means SD of Knoop hardness. The number of samples was three for each condition. In each group, values with the same superscript letters are not significantly different ($p>0.05$).

the enamel side of a healthy sample and within 3 mm diameter from the center of the decalcified part of a softened dentin sample. For pulp-capping samples at 1 month or 3 months after pulp capping, we specified the measurement range to be within 3 mm diameter from the center of the part applied with pulp-capping agent after removing the BC and pulp-capping agent disc from the pulp-capping sample which had been stored for the specified period while trying not to touch the part to which the pulp-capping agent had been applied. We took measurements at five points per sample, and used the mean value of the five points as the hardness of the sample; three samples were used for each condition.

3. Observation of SEM images

To observe the surface of the pulp-capping sample after hardness measurement, we fixed the sample according to the general method, conducted alcohol-based dehydration, then freeze-dried the sample using a t-butyl alcohol freeze dryer (VFD21S, VD). Then we conducted Os deposition using an osmium coater (HPC-20, VD), and observed the SEM images using a field emission-type scanning electron microscope (S-4800, Hitachi). We also observed the surfaces of the healthy samples and softened dentin samples in a similar fashion.

4. Statistical processing

We subjected the measurement values obtained from each sample to statistical analysis using repeated measure analysis of variance and Tukey's test ($p<0.05$).

Results

1. Hardness measurement results

Table 2 shows the hardness of each sample that was measured using Cariotester.

1) Hardness of sound dentin and demineralized dentin

The mean hardness of the 24 healthy samples for preparing pulp-capping samples (3 samples \times 4 materials \times 2 conditions) was 62.6 ± 1.7 KNH, and the mean hardness of softened dentin samples was 22.1 ± 1.9 KNH. The hardness of softened dentin samples was significantly lower than that of the healthy samples ($p<0.001$).

2) Hardness of pulp-capping samples

(1) TMR group

Hardness after 1 month was 32.8 ± 2.7 KNH and after 3 months was 33.2 ± 0.4 KNH. Hardness was significantly higher both 1 month and 3 months after application than that of softened dentin samples ($p<0.05$). Hardness values after 1 month and 3 months were significantly lower than those of the healthy samples ($p<0.001$).

(2) NEX group

Hardness after 1 month was 41.1 ± 2.3 KNH and after 3 months was 41.6 ± 4.0 KNH. Hardness was significantly higher both 1 month and 3 months after application than that of softened dentin samples ($p<0.01$). Hardness values after 1 month and 3 months were significantly lower than those of the healthy samples ($p<0.001$).

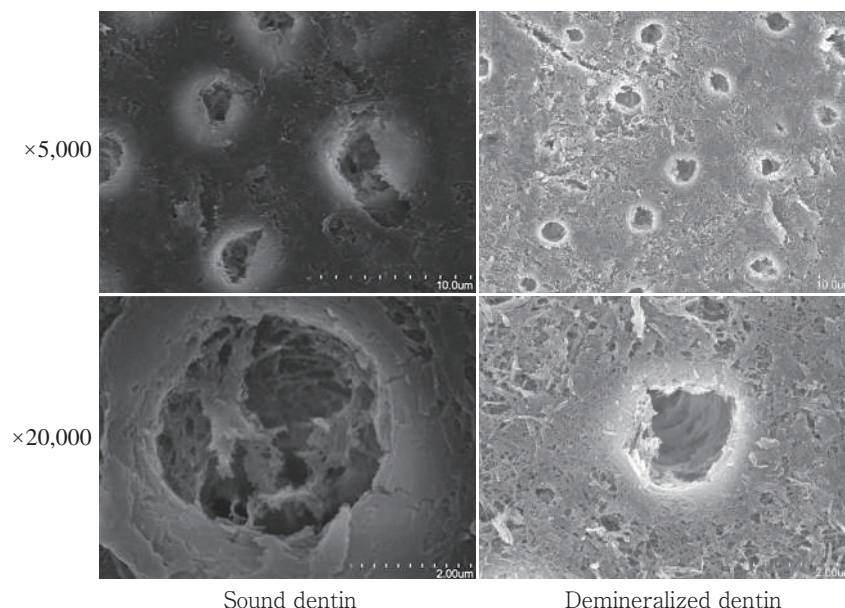


Fig. 1 SEM images of sound dentin and demineralized dentin

Left shows the results of SEM image observation for sound dentin. The surface of the sample is finely covered with crystal deposits assumed to be hydroxyapatite and so forth, and exposure of collagen fiber was not observed.

Right shows the results of SEM image observation for demineralized dentin. Collagen fibers were exposed due to decalcification by lactic acid.

(3) TCL group

Hardness after 1 month was 20.1 ± 0.5 KNH and after 3 months was 27.7 ± 4.4 KNH. Hardness did not show a significant difference from that of the softened dentin samples either 1 month or 3 months after application. Hardness values after 1 month and 3 months were significantly lower than those of the healthy samples ($p < 0.001$).

(4) SMP group

Hardness after 1 month was 56.5 ± 5.9 KNH and after 3 months was 62.0 ± 2.5 KNH. Hardness was significantly higher both 1 month and 3 months after application than that of softened dentin samples ($p < 0.01$). Hardness was also improved to a level at which there was no significant difference from that of the healthy samples both 1 month and 3 months after application ($p > 0.05$).

2. Observation of SEM images

1) Observation of sound dentin

Figure 1 (left) shows the results of SEM image observation for healthy samples. The surface of the sample is finely covered with crystal deposits assumed to be hydroxyapatite, and exposure of collagen fiber was not

observed.

2) Observation of demineralized dentin

Figure 1 (right) shows the results of SEM image observation for softened dentin samples. Collagen fibers were exposed due to decalcification by lactic acid.

3) Observation of pulp-capping samples

(1) TMR group

Figure 2 shows SEM images of the TMR group.

The intertubular dentin had become finer after 1 month due to calcification, with fine crystal deposits observed at the opening of dentinal tubules, and the intertubular dentin had become even finer after 3 months due to calcification, with fine crystal deposits at the opening of dentinal tubules.

(2) NEX group

Figure 3 shows SEM images of the NEX group.

The intertubular dentin had become finer after 1 month due to calcification, with minute crystal deposits observed, and the intertubular dentin had become even finer after 3 months due to calcification, with minute crystal deposits.

(3) TCL group

Figure 4 shows SEM images of the TCL group.

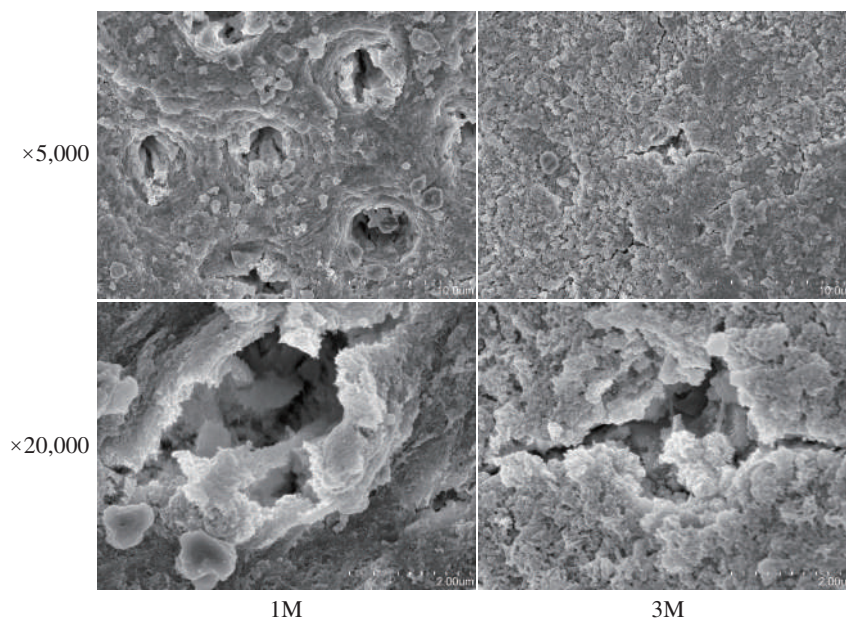


Fig. 2 SEM images of dentin applied with TMR

The intertubular dentin had become finer after 1 month due to calcification, with fine crystal deposits observed at the opening of dentinal tubules, and the intertubular dentin had become even finer after 3 months due to calcification, with fine crystal deposits at the opening of dentinal tubules.

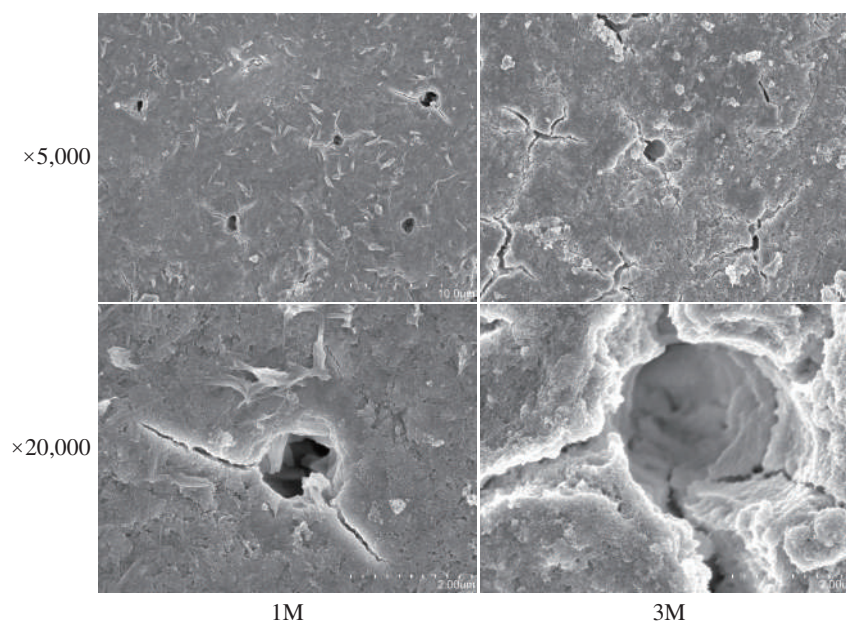


Fig. 3 SEM images of dentin applied with NEX

The intertubular dentin had become finer after 1 month due to calcification, with minute crystal deposits observed, and the intertubular dentin had become even finer after 3 months due to calcification, with minute crystal deposits.

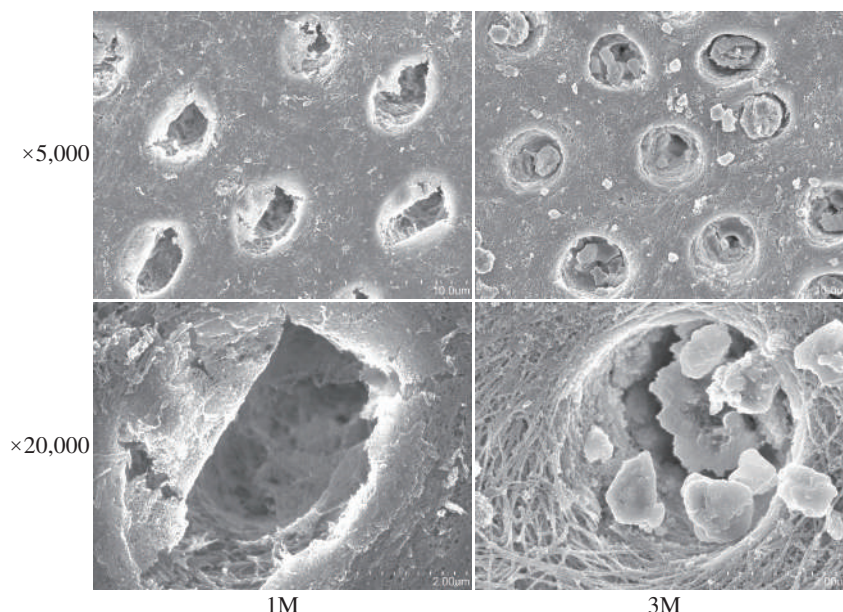


Fig. 4 SEM images of dentin applied with TCL

The intertubular dentin had become finer after 1 month due to calcification, with granular crystal deposits observed. On the other hand, the intertubular dentin had become coarser after 3 months than 1 month after application due to decalcification, with exposure of collagen fiber observed in peritubular dentin.

The intertubular dentin had become finer after 1 month due to calcification, with granular crystal deposits observed. On the other hand, the intertubular dentin had become coarser after 3 months than 1 month after application due to decalcification, with exposure of collagen fiber observed in peritubular dentin.

(4) SMP group

Figure 5 shows SEM images of the SMP group.

The intertubular dentin had become finer after 1 month due to calcification, with minute crystal deposits observed, and the intertubular dentin had become even finer after 3 months due to calcification, with minute crystal deposits.

Discussion

It is considered that the application of biofunctional materials that provide sustained release of various ions would be effective for the recalcification of carious dentin that is left in IPC. The application of carboxylate cement containing calcium hydroxide preparation or tannin-fluoride preparation²¹⁻²⁶⁾, calcium phosphate²⁷⁾, bioactive glass²⁸⁾, and surface pre-reacted glass ionomer (S-PRG) filler^{29,30)} has been examined by various meth-

ods, including hardness, X-ray, bacteriological and histopathological methods. In addition, mineral trioxide aggregate (MTA) is Portland cement modified for use in dental applications^{13,31)}, and has been applied in various treatments including direct pulp capping, retrograde filling of root canal, root perforation sealing, and root canal filling (apexification, apical plug, etc.)³²⁾. There has also been an attempt to use calcium silicate-based cements as a source of calcium ions to induce dentin calcification while focusing on their calcium ion releasing capacity³³⁾, and their ability to induce recalcification in decalcified dentin has been confirmed^{34,35)}. Furthermore, application of the sustained release of various ions by MTA may also be an effective way to induce recalcification of carious dentin that is left in IPC, as recalcification through uptake of calcium ions, phosphate ions, and fluorine ions occurs in carious dentin³⁶⁾. Meanwhile, disadvantages of MTA include difficulty in powder/liquid mixing and application to the affected area, as well as clinical operability due to the time required to achieve sufficient strength⁵⁾. These pulp-capping agents also have no adhesiveness to dentin or restoration materials, with the risk of insufficient strength and small leakage after

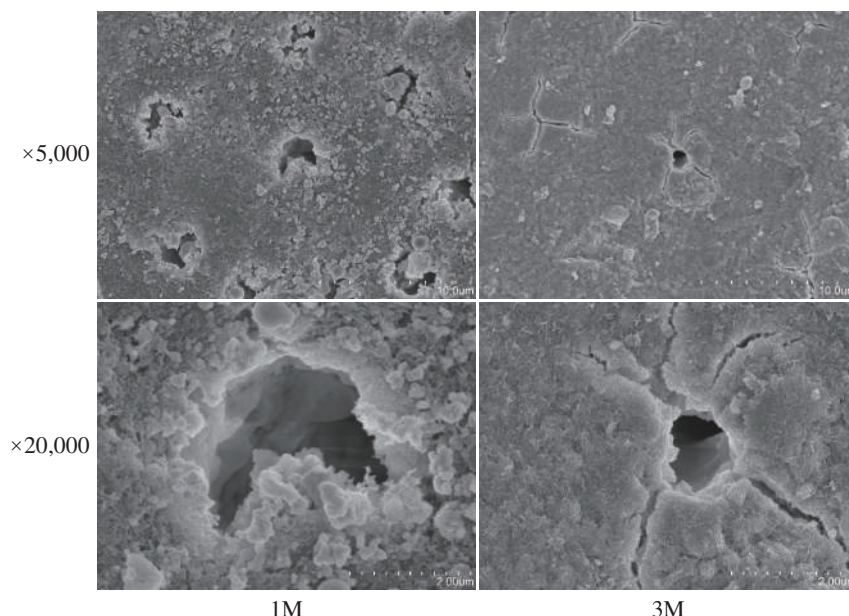


Fig. 5 SEM images of dentin applied with SMP

The intertubular dentin had become finer after 1 month due to calcification, with minute crystal deposits observed, and the intertubular dentin had become even finer after 3 months due to calcification, with minute crystal deposits.

restoration treatment. To overcome these disadvantages, there have been various studies in recent years on materials with MTA-like compositions with resins added^{17,18,37-40)}, but no study has examined the temporal changes in hardness after applying resin-modified pulp-capping agents containing MTA on decalcified dentin.

In this study, we examined the effectiveness of various resin-modified pulp-capping agents containing MTA by measuring the Knoop hardness 1 month and 3 months after application of the pulp-capping agents and comparing the results with conventional MTA cements, and also observing SEM images of the surfaces to which the agents were applied.

TMR and NEX are MTA cements whose main component is Portland cement, and they are clinically used as pulp-capping materials and root canal filling agents. In this study, TMR and NEX, which are conventional MTA cements, did not improve the hardness to an equivalent level of healthy dentin, even though they improved it significantly compared to the hardness of softened dentin after 1 month and 3 months. Sawai et al. observed that the hardness improved to a level that was not significantly different from that of healthy dentin after 1 month and 3 months when NEX was applied

to softened dentin immediately after mixing and before curing, and also observed the application surface to be finely calcified in SEM images³⁰⁾. We assume that different experiment results were obtained as we applied NEX as a cured body in this experiment. The effects on softened dentin surface within 24 hours of mixing need to be examined in the future.

TCL is a photocuring flowable resin containing calcium silicate, which was developed as a material for direct and indirect pulp capping. TCL is attracting attention as a material which has both excellent biocompatibility equivalent to MTA and favorable operability of photocuring flowable resin. According to the results of this experiment, TCL, which is a photo-polymerizable resin-modified pulp-capping agent containing MTA, did not improve the hardness to an equivalent level of healthy dentin, even though it showed a tendency to improve the hardness to a higher level than that of softened dentin in 3 months. A possible reason for this is the high polymerization rate by photopolymerization; when a cured body was applied, its effect may have been suppressed, as an *in vitro* study by Gandolfi et al.⁴¹⁾ showed that its solubility was lower than that of MTA. In the present experiment, we placed the pulp-capping agent that had been cured in

advance on top of the artificially softened dentin to observe the changes in sample hardness. However, the method in this experiment varied from actual clinical practice; in clinical IPC, the paste of the pulp-capping agent is applied before curing over the softened dentin and cavity basing with glass ionomer cement is provided after it has cured. We adopted this method because we observed the formation of a resin impregnated layer-like structure on the surface in our preliminary experiment and found that it was likely to affect the results of hardness measurement when we applied a resin-curing pulp-capping agent before curing over softened dentin. To avoid its effect, we cured the pulp-capping agents in advance in this study. We plan to examine the conditions including preparation of pulp-capping samples immediately after photocuring in the future.

SMP employs a mechanism to polymerize and cure the paste containing MTA with tri-n-butylborane (TBB). TBB is the polymerization initiator for “Super-Bond,” a dental adhesive resin cement, and has been reported to have characteristics such as a small amount of monomers that remain unreacted⁴²⁾ and more effective progress of polymerization reaction in environments where a small amount of water is present⁴³⁾. Furthermore, a resin-based MTA has a lower ratio of Portland cement in the material compared to hydraulic MTA. It is therefore expected that the amount of calcium ions and OH^- released, which is an important property of MTA, will decrease. However, it has also been claimed that the high-purity white Portland cement used for dental applications which is contained in SMP has a larger calcium ion releasing capacity than the conventional cements, and SMP has been reported to release calcium ions and to form calcium phosphate at an equivalent level to hydraulic MTA-based materials⁴⁴⁾. Since SMP significantly improved the hardness compared with softened dentin after 1 month and 3 months to a level that was not significantly different from healthy dentin in this study, we were able to confirm that it affected decalcified dentin even when it was a cured body. Meanwhile, some MTA-based materials use Portland cement that is manufactured by using natural minerals as raw materials, causing concern over the effects of heavy metals contained as impurities⁴⁵⁾. However, SMP is expected to have higher biocompatibility, since it uses high-purity white Portland cement

for dental applications which is produced in Japan and has been reported to contain no heavy metals²⁰⁾.

Conclusion

We conducted experiments in which we applied cured MTA cements on softened dentin and obtained the following findings:

1. TMR and NEX, which are conventional MTA cements, did not improve the hardness to an equivalent level of healthy dentin, even though they significantly improved the hardness compared with softened dentin after 1 month and 3 months.
2. TCL, which is a photo-polymerizable resin-modified pulp-capping agent containing MTA, did not improve the hardness to an equivalent level of healthy dentin, even though it improved the hardness compared with softened dentin after 3 months.
3. SMP, which is a chemical polymerization type resin-modified pulp-capping agent containing MTA, significantly improved the hardness compared with softened dentin to a level that was not significantly different from that of healthy dentin after 1 month and 3 months.

The authors declare no conflicts of interest associated with this manuscript.

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レジン添加型 MTA 配合覆髄剤の有効性の検討

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抄録

目的：Minimal Intervention (MI) の概念に基づき、齲蝕が深部にまで進行し歯髄に近接する場合、歯髄に近接する深部象牙質を保存し、露髄を回避する目的で暫間的間接覆髄法 (IPC) が行われる。本研究では、Knoop 硬さ測定システムであるカリオテスターを用いて象牙質試料の硬さを測定し、レジン添加型 MTA 配合覆髄剤が軟化象牙質へ与える影響を検討した。

材料と方法：象牙質試料のエナメル質側面の硬さを測定し、硬さが 60 KNH 前後となったものを健全象牙質試料とした。健全象牙質試料を松田らの方法により脱灰し、硬さが 20 KNH 前後となったものを軟化象牙質試料とした。軟化象牙質試料に、覆髄剤として従来型 MTA セメントの TMR-MTA セメント、NEX MTA セメント、レジン添加型 MTA 配合覆髄剤としてセラカル LC、スーパー MTA ペーストを貼付し、ベースセメントで被覆し、覆髄試料とした。作製した覆髄試料は、湿度 100% 容器中で 1 カ月および 3 カ月保管後、覆髄した象牙質の Knoop 硬さを測定した。試料数は各条件につき 3 試料とし、得られた値は一元配置分散分析および Tukey の検定にて統計解析を行った ($p < 0.001$)。

成績：覆髄剤貼付後の硬さ測定の結果、TMR-MTA セメント群では 1 カ月後の硬さは 32.8 ± 2.7 KNH、3 カ月後の硬さは 33.2 ± 0.4 KNH となった。軟化象牙質試料と比較して、1 カ月後および 3 カ月後の硬さは有意に向上した。健全象牙質試料と比較して、1 カ月後および 3 カ月後の硬さは有意に低かった。NEX MTA セメント群では 1 カ月後の硬さは 41.1 ± 2.3 KNH、3 カ月後の硬さは 41.6 ± 4.0 KNH となった。軟化象牙質試料と比較して、1 カ月後および 3 カ月後の硬さは有意に向上した。健全象牙質試料と比較して、1 カ月後および 3 カ月後の硬さは有意に低かった。セラカル LC 貼付群では 1 カ月後の硬さは 20.1 ± 0.5 KNH、3 カ月後の硬さは 27.7 ± 4.4 KNH となった。軟化象牙質試料と比較して、1 カ月後および 3 カ月後の硬さに有意差は認められなかった。健全象牙質試料と比較して、1 カ月後および 3 カ月後の硬さは有意に低かった。スーパー MTA ペースト貼付群では 1 カ月後の硬さは 56.5 ± 5.9 KNH、3 カ月後の硬さは 62.0 ± 2.5 KNH となった。軟化象牙質試料と比較して、1 カ月後および 3 カ月後の硬さは有意に向上した。健全象牙質試料と比較して、1 カ月後および 3 カ月後の硬さは有意差が認められない硬さに向上した。本実験により、レジン添加型 MTA 配合覆髄剤を軟化象牙質に貼付することによって、再石灰化を促し、軟化象牙質の硬化が認められた。

結論：以上の結果により、MTA を配合したレジン添加型覆髄剤の軟化象牙質の硬化への有効性が示唆された。

キーワード：Knoop 硬さ、レジン添加型覆髄剤、MTA、再石灰化