Adhesive Reconstruction of Vertical Dental Root Fractures

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Abstract
Purpose: Improvements in adhesive resins have allowed the restoration of vertically-fractured teeth. We investigated the strength of reconstructed roots as well as roots reconstructed on an abutment, and the outcome of the adhesive reconstruction/replantation of vertically-fractured teeth.

Methods: Experiment 1: The roots of bovine anterior teeth frozen after extraction were cut at their center parallel to the root axis. After applying Superbond C & B (SB), thermal or mechanical stress was applied before testing. Microtensile bond strength was measured, and the fractured cross-section surface was observed by scanning electron microscopy. Experiment 2: A post hole was created along the root canal, and a metal post was inserted into the hole. Vertical pressure was applied to the metal post in order to measure the initial fracture strength. Adhesive reconstruction was performed using SB. Reconstructed root fracture strength was measured when a metal post or a resin post was pressed vertically. The reconstructed root fracture strengths were compared with the initial fracture strengths, and the percent decrease was defined as the value of the sample (comparison value). The reconstructed root fracture strength after application of a thermal cycle (TC) of 5–55°C was measured, and a comparison value was calculated. Experiment 3: The initial fracture strength was measured as described in Experiment 2. After posts were bonded to reconstructed teeth, reconstructed root fracture strengths were measured in order to calculate comparison values. The results obtained were analyzed by one-way analysis of variance and Tukey’s HSD method (α = 0.05).

Results: No significant difference was observed in the tensile bond strength among the groups. Although a significant difference was found in comparison values depending on the presence of TC loading, no significant differences were observed among different post materials. The risk of refracture in the metal post at the reconstruction site was high, whereas the risk of refracture in the resin post was low.

Conclusions: The durability of the root with adhesive reconstruction was less than 25% for stress parallel to the dental axis compared with that of the sound root. The risk of refracture in the metal post at the reconstruction site was high, whereas the risk of refracture in the resin post was low.

Key words: vertically fractured root, adhesive resin cement, microtensile bond strength

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Introduction

Conventionally, vertically-fractured teeth have been extracted. However, improvements in adhesive resins have allowed for the restoration of vertically-fractured teeth through intentional replantation by bonding the fractured fragments with resin cement and replanting them in the original socket\textsuperscript{13}. Various methods\textsuperscript{2-4} have been reported for the conservative treatment of fractured teeth using the adhesive reconstruction/replantation technique. One example is Masaka’s method\textsuperscript{56} in which the fractured tooth is extracted, a metal core acidized by heating is bonded to the tooth using Super Bond C & B (Sun Medical, SB), and then the tooth is replanted. The most frequently used cement in previous studies is SB, which is applied after treating the dentin with a 10% citric acid with 3% ferric chloride solution. A combination of MMA resin cement and composite resin cement, which is applied after treating the dental surface using a self-etching primer, has recently been developed and is now commercially available, thereby broadening the range of cement selection.

The type of resin cement used in the adhesive reconstruction/replantation technique is an important factor affecting the clinical outcome. Each resin cement has a unique agent for the dentin treatment, involves a distinct surgical procedure, and has a special base monomer and adhesive monomer composition for the tooth substrate. These agents lead to differences in adhesiveness. The long-term bonding of the resin cement itself to the tooth is also important, and micro-leakage at the bonding interface, as well as deterioration and destruction of the resin cement, markedly affect the clinical outcome\textsuperscript{6-8}.

It is important that the periodontal ligament is not desiccated or injured during the adhesion process. However, there are challenges associated with preserving an intact periodontal ligament during the adhesion of fragments\textsuperscript{19}. The reliable attachment of fractured dentin is essential for adhesive reconstruction. However, it is difficult to simultaneously maintain the periodontal ligament in a favorable state and achieve secure bonding of dentin because of the toxicity of the bonding solutions used, desiccation of the periodontal ligament during drying of the dentin surface for application of the cement, and damage to the periodontal ligament caused by compression during setting of the cement. Therefore, since the state of the periodontal ligament markedly influences the clinical outcome, a special bonding procedure is needed for the restoration of fractured teeth. Masaka previously reported satisfactory results with a self-devised instrument to compress cement while minimizing invasion of the periodontal ligament\textsuperscript{5}. Furthermore, a post is often placed in the canal after the adhesive reconstruction/replantation procedure. The prevention of refractures at the reconstructed site must be considered during prosthetic treatment.

The constructed abutment consists of a post and core. The post supports the core and is subjected to the stress of occlusion\textsuperscript{10}. Satisfactory clinical findings have been reported for abutments constructed of a fiber post covered with composite resin, as well as for conventional cast metal posts\textsuperscript{11}. Stress distributions in cast metal and resin posts have been analyzed by applying a compressive load to teeth reconstructed on an abutment and employing finite element analysis\textsuperscript{5,12,13}. Stress was found to be concentrated at the interface between the post and cast metal in teeth restored on an abutment using a cast metal post. However, the stress was distributed evenly on the periphery of the roots rather than around the post in teeth restored using a resin post, in which the elastic modulus was close to that of dentin\textsuperscript{5,12,13}. These findings suggested that an abutment constructed with a fiber post after adhesive reconstruction/replantation effectively prevents refractures. However, there has been no study that measured the strength of roots reconstructed with a fiber post or a metal post.

We investigated the strength of reconstructed roots as well as roots reconstructed on an abutment and the influence on the outcome of the adhesive reconstruction/replantation of vertically-fractured teeth.

Materials and Methods

Table 1 shows the materials used in the present study. The roots of bovine incisors frozen after extraction were employed. In order to standardize bovine incisors, the roots were vertically cut parallel to the tooth axis 24.0 mm from the apex. Teeth with a sectional diameter of 8.0 mm±0.5 mm and slight curve were
Table 1  Adhesive systems used in this study

<table>
<thead>
<tr>
<th>Material</th>
<th>Lot number</th>
<th>Manufacturer</th>
<th>Code</th>
</tr>
</thead>
<tbody>
<tr>
<td>Superbond C &amp; B</td>
<td></td>
<td>Sun Medical</td>
<td>SB</td>
</tr>
<tr>
<td>Green Activator</td>
<td>SK2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Monomer</td>
<td>TG1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Catalyst</td>
<td>TF52</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Polymer (Ivory)</td>
<td>TSI</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fuji I</td>
<td></td>
<td>GC</td>
<td>GIC</td>
</tr>
<tr>
<td>Powder</td>
<td>1303251</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Liquid</td>
<td>1304111</td>
<td></td>
<td></td>
</tr>
<tr>
<td>SA Luting</td>
<td>270003</td>
<td>Kuraray Noritake Dental</td>
<td>SA</td>
</tr>
<tr>
<td>Cleasil DC Core Automix</td>
<td>0037AA</td>
<td>Kuraray Noritake Dental</td>
<td>DC</td>
</tr>
<tr>
<td>Paste</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Adhesive</td>
<td>00001B</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

used.

1. Experiment 1: Bond strength at the reconstructed site of the root

The roots of bovine teeth were cut at their center parallel to the dental axis using a low-speed diamond saw (Model 650, South Bay Technology, USA), followed by the bonding procedure using 4-META/MMA-TBB resin cement (SB) according to the manufacturer’s instructions. The roots were reduced under pressure using a clip until initial setting, and then used as samples. Samples were immersed in water at 37°C for 24 h, and used as a control. Teeth were subjected either to a thermal cycle (TC) of 5-55°C applied 5,000 times (TC group), or to cyclic loading of 5-100 kgf applied 30,000 times (RL group).

Each sample was cut vertical to the dental axis at a thickness of 1.0 mm using a low-speed diamond saw, and trimmed by a diamond point in order to fabricate dumbbell-shaped specimens with an adhesive interface of 1.0×1.0 mm. Microtensile bond strength (μTBS) was measured using a compact table-top universal tester (EZ-Test, Shimadzu) at a crosshead speed of 1.0 mm/min. The results obtained were analyzed by a multiple comparison one-way analysis of variance and Tukey’s HSD method. After μTBS measurements, gold evaporation was performed on the fractured cross-section surface using an ion coater following the conventional method, and the surface was observed using a scanning electron microscope (JSM-5610LU, JEOL). A fracture cross-sectional shape occupying more than 70% of the entire surface was regarded as the fracture morphology of the sample, while a shape occupying less than 70% was regarded as a mixed fracture.

2. Experiment 2: Strength of the reconstructed dental root before post placement

1) Sample fabrication

A post hole was created from the crown side using a half sprue reamer with a taper angle of 5° (Eikosha) parallel to the dental axis, such that the greatest dimension of the hole became 4.0 mm. Teflon tape was wrapped around the root with a post hole with a thickness of 200-400 μm, and the root was embedded in acrylic resin (Unifast II, GC). The crown side of the root was left without being embedded for 20 mm. After the acrylic resin had set, the Teflon tape was removed and replaced with silicone impression material as an artificial periodontal membrane to be used as a sample (Fig.1).

2) Post fabrication

An impression of the post hole of the sample was taken, followed by wax-up, casting with a 12% gold-silver-palladium alloy (Prumie, Morita), an acidic bath, and sand blasting, and was then used as a metal post. A resin post was also fabricated using the auto-mix type of dual cure composite resin Cleasil DC Core Automix (Kuraray Noritake Dental, DC) and a fiber post treated with silane coupling agent (Integra Fiber Post, Premier, USA). Each post was cut perpendicular to the long axis 16 mm apical from the point at which the diameter was 4 mm, and was then used.

3) Initial fracture strength measurements

A metal post was inserted into the post hole of a sample, and vertical pressure was applied to the metal
post at a crosshead speed of 1.0 mm/min using a tabletop precision universal tester (AGS-5kND, Shimadzu) in order to measure the initial fracture strength.

4) Adhesive reconstruction
The root with the initial fracture completely fractured vertically along the fracture line, and adhesive reconstruction was performed using SB according to the manufacturer’s instructions, as described in Experiment 1. The root was then immersed in water at 37°C for 24 h, and a post hole was created.

5) Reconstructed root fracture strength measurements
The reconstructed root after water immersion was used as the control group (r-cont group), and the group in which TC loading of 5-55°C was applied 5,000 times after water immersion was used as the r-TC group (r-TC). Samples were produced from the reconstructed roots after water immersion and TC load application. The following four conditions were set: 1) a metal post was inserted in the r-cont group, and reconstructed root fracture strength was measured under pressure (Condition A), 2) a metal post was inserted in the r-TC group (Condition B), 3) a resin post was inserted in the r-cont group (Condition C), and 4) a resin post was inserted in the r-TC group (Condition D). Eight samples were used for each condition. The measured reconstructed root fracture strengths were compared with the initial fracture strengths, and the calculated decrease rate was defined as the value of the sample (comparison value).

The results obtained were analyzed by one-way analysis of variance and Tukey’s HSD method (α = 0.05).

3. Experiment 3: Strength of the reconstructed root with a post
Samples and metal posts were fabricated as described in Experiment 2. The initial fracture strength was measured, and the reconstructed group and group in which the TC load was applied after reconstruction were fabricated. Metal posts were bonded to each group using SB, glass ionomer cement (Fuji I, GC, GIC), and self-adhesive cement (SA Luring, Kuraray Noritake Dental, SA). The groups in which metal posts were placed after reconstruction were defined as M-SB, M-GIC, and M-SA, while those in which the TC load was applied were defined as M-SB-TC, M-GIC-TC, and M-SA-TC. The groups in which resin posts were directly built-up using a resin core system (DC) were defined as R-DC and R-DC-TC. Samples were immersed in the water at 37°C for 24 h, and reconstructed root fracture strengths were measured in order to calculate comparison values. The results obtained were analyzed by one-way analysis of variance and Tukey’s HSD method (α = 0.05).

Results
Figure 2 shows the results of Experiment 1. No significant difference was observed in the μTBS between each group. Fractured images revealed the cohesive failure of dentin in the control group. Cohesive failure of dentin and interface failure were not observed, and mixed failure and cohesive failure of cement were observed in the TC group.

Figure 3 shows the results of Experiment 2. Although a significant difference was found in comparison values that depended on the presence of TC loading, no significant differences were observed between the different post materials.

Figure 4 shows the results of Experiment 3. The fracture strength of M-SB increased more with the application of stress parallel to the dental axis than that in the root before the fracture. No significant differences were found between M-non, M-GIC, M-non-TC, and M-GIC-TC.

Although there was no significant difference between M-SA and R-DC, fracture morphologies were refractures at the reconstructed site in M-SA, and fractures at non-reconstructed areas such as the tooth structure and post in R-DC. However, refractures were frequently observed at reconstructed sites in R-DC-TC. A significant decrease in comparison values was observed after TC loading in M-SB and R-DC, and no deterioration by TC loading was observed in M-SA.

No significant differences were observed in comparison values between M-non and M-GIC. Fractures in M-GIC-TC were more frequently observed in GIC with a post than in M-GIC (Table 2).

Discussion
Implant treatments have been widely used to restore missing teeth14. Since self-regeneration of the periodontal membrane has not yet been applied in the clinical
setting, the adhesive reconstruction/replantation technique, which restores the self-tissue of fractured teeth indicated for extraction using adhesive resin cement and protects chewing sensation, is regarded as a very effective conservative treatment\(^6\).

Two major factors of vertical root fractures include pressure elements and pressure-detecting elements. Pressure elements are derived from strong occlusal forces and bruxism, while pressure-detecting elements include poorly-designed prostheses and posts\(^5\). These elements need to be eliminated following the adhesive reconstruction/replantation of a fractured tooth. Although ideal adhesive reconstruction involves the

![Graph](image)

Fig. 2 Experiment 1: Microtensile bond strength and failure mode of the debonded specimen

<table>
<thead>
<tr>
<th>Condition</th>
<th>Root strength (%)</th>
</tr>
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<tbody>
<tr>
<td>A</td>
<td>25</td>
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<tr>
<td>B</td>
<td>20</td>
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<tr>
<td>C</td>
<td>15</td>
</tr>
<tr>
<td>D</td>
<td>10</td>
</tr>
</tbody>
</table>

![Graph](image)

Fig. 3 Experiment 2: Comparison of root strength after bonding and replantation as a percentage of the strength of the sound root

- : significantly different (p<0.05)

![Graph](image)

Fig. 4 Experiment 3: Comparison of root strength after bonding and replantation as a percentage of the strength of the sound root

The same letter are not significantly different (p<0.05).

| Table 2 Experiment 3: Failure mode |
|-----------------------------------|-----------------|-----------------|-----------------|-----------------|
| Refracture at adhesive surface   | Fracture within 1/3 for the crown | Failure cement | Failure post |
| M-\(\text{non}\)                | 8                |                 | 2               |
| M-GIC                            | 6                |                 |                 |
| M-SA                             | 8                |                 |                 |
| M-SB                             | 8                |                 |                 |
| R-DC                             | 2                | 2               | 4               |
| M-\(\text{non}\)-TC              | 8                |                 |                 |
| M-GIC-TC                         | 3                |                 | 5               |
| M-SA-TC                          | 6                | 2               |                 |
| M-SB-TC                          | 8                |                 |                 |
| R-DC-TC                          | 6                |                 | 2               |
reconstruction of fractured teeth similar to natural teeth regardless of the existence of pressure elements, this is very difficult to achieve. Pressure and pressure-detecting elements need to be considered. The post material has been evaluated as a pressure element, and the strength of the reconstructed root as a pressure-detecting element.

Analyses using the finite element method elucidated the stress distribution of various abutments for sound dental roots. However, the strength of a root prior to a fracture and after adhesive replantation has not yet been compared.

Therefore, the present study evaluated the strengths of roots with adhesive reconstruction and reconstructed roots after abutment build-up. The cohesive failure of dentin in reconstructed root fracture images in the control group was not observed in the other groups. Therefore, a decrease in adhesion on the interfacial surface and cement was considered. However, no significant difference was found in tensile strengths between the TC and RL groups and control group with load application. Although concerns have been expressed regarding the influence of the reconstructed site on the long-term prognosis, adhesive durability is considered satisfactory. Although interfacial failure was observed in the control and RL groups in the absence of a thermal load, it was not detected in the TC group.

Regarding reconstructed root strengths, a significant difference was observed in comparison values with or without TC loading, but not with different post materials. This may be due to the resin post responding flexibly to dentin bending because the elastic modulus of the resin post is closer to that of dentin than the metal post. Furthermore, since the resin post is more deformable than the metal post, it has the ability to adhere to a post hole. Since the resin post is made of a high-polymer material, stress was considered to be evenly distributed. When stress not parallel to the post axis was applied to the metal post, it was more likely to be concentrated on the tip of the post and margin area on the crown side due to the principle of leverage. However, stress was applied parallel to the post axis in the present study. Therefore, stress was distributed over the entire post surface in contact with the tooth structure.

Although reconstructed root strengths were decreased by TC loading, no significant differences were observed with different post materials. When a vertically-fractured root is reconstructed or replanted, the durability of the root after 24 h of cement curing is less than 25% of that before fracture. This result, in combination with the age-associated deterioration of cement, indicates that careful attention is required when the prosthetic procedure and prognosis are considered.

The risk of refracture in the metal post at the reconstruction site was high, whereas the risk of refracture in the resin post was low. Further study on stable long-term preservation of adhesive reconstructed teeth is needed.

**Conclusions**

1. A stable long-term adhesive force might be expected when the root surface is bonded using SB.
2. When a post is not bonded to the tooth structure, no significant difference was observed in the fracture risk between the different post materials.
3. The durability of the root with adhesive reconstruction was less than 25% when the stress was parallel to the dental axis, compared with the sound root.

**References**


垂直歯根破折歯の接着再建に関する研究

恩 田 康 平 初 岡 昌 憲 保 尾 謙 三
三 浦 樹 津 谷 佳 代 井 村 和 希
森 川 裕 仁 岩 佐 一 弘 吉 川 一 志

山 本 一 世

大阪歯科大学歯科保存学講座

抄録
緒言：レジンセメントの歯質接着性の向上に伴い，破折歯を保存することが可能となってきている。われわれは破折歯の『接着再建・再植法』の予後を知るために，接着再建した歯根の強度と，支台製造後の再建歯根の強度について検討を行ったので報告する。

材料と方法：実験1：抜去後冷凍保存したウシ歯根を歯軸と平行に切断し，Superbond C & B（以後，SB）で接着し負荷をつけた後，微小引張強さを測定し，破断面の形態を走査電子顕微鏡で観察した。実験2：ウシ歯根にポスト孔を形成し，それに適合したメタルポストを作製し，ポスト孔に挿入した。メタルポストを歯軸と平行に加圧し，初期破折強度を測定した。破折した歯根をSBで再建を行い，再度メタルポストもしくはレジンポストで加圧し，再生歯根破壊強度を測定した。測定した再生歯根破壊強度を初期破壊強度と比較し，算出した低下率をその試料の値（以下，比較値）とした。同様に再建を行った後5-55℃のサーマルサイクル負荷をつけ，再生歯根破壊強度を測定し，比較値を算出した。実験3：実験2と同様に初期破壊強度を測定し，SBで再建を行った後，メタルポストを各種セメントで接着させ，再生歯根破壊強度を測定し比較値を算出した。またレジンポストを加えて，同様に比較値を算出した。再建後の歯根の破壊形態を観察した。得られた結果は一元配置分散分析，およびTukeyのHSD法を用いて多重比較を行い，統計学的に検討を行った（α=0.05）。

結果：実験1：引張接着強さにおいて，どの群にも有意差は認められなかった。実験2：TC負荷の有無により比較値に有意差が認められたが，ポストの材質の違いによる差は認められなかった。実験3：メタルポストはセメントにより高い比較値を示すが，破壊形態は再破折であった。レジンポストはSBに比べて比較値は低いか，再破折以外の破壊形態を示した。

結論：接着再建を行った歯根は健全歯根に比べ，歯軸に平行な応力に対して25%以下の耐久力しかもたない。メタルポストの使用は再建部の再破折を起こす危険が高いが，一方，レジンポストの再破折の危険性は低い。

キーワード：垂直歯根破折，接着性レジンセメント，微小引張強さ