Effect of exposing dentine to sodium hypochlorite and calcium hydroxide on its flexural strength and elastic modulus

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Abstract

Aim The aim of this study was to evaluate the effect of sodium hypochlorite (NaOCl) solutions (3%, 5%) and saturated calcium hydroxide (Ca(OH)2) solution, individually and consecutively, on the flexural strength and modulus of elasticity of standardized dentine bars.

Methodology Standardized plano-parallel dentine bars (n = 121) were divided into five test groups and one control group. The control group 1 consisted of dentine bars, stored in normal saline until testing. The dentine bars in the five test groups were treated by exposure to the following solutions; group 2 – 3% NaOCl, 2 h; group 3 – 5% NaOCl, 2 h; group 4 – saturated Ca(OH)2 solution, 1 week; group 5 – 3% NaOCl, 2 h and then saturated Ca(OH)2 solution 1 week; group 6 – 5% NaOCl, 2 h and then saturated Ca(OH)2 solution 1 week. The dentine bars were then loaded to failure in a three-point bend test.

Results The data revealed a significant (P < 0.001) decrease in the modulus of elasticity and flexural strength of the dentine bars treated with 3% and 5% NaOCl. There was no significant difference in the flexural strength and the modulus of elasticity between the 3% and 5% NaOCl groups. Exposure to Ca(OH)2 significantly (P < 0.001) reduced the flexural strength but had no significant effect on the modulus of elasticity. The groups treated with sodium hypochlorite followed by calcium hydroxide did not have moduli of elasticity and flexural strengths that were significantly different from those treated only with sodium hypochlorite.

Conclusions NaOCl (3 & 5%) reduced the modulus of elasticity and flexural strength of dentine. Saturated Ca(OH)2 reduced the flexural strength of dentine but not the modulus of elasticity. Sequential use of NaOCl and Ca(OH)2 has no additional weakening effect.

Keywords: calcium hydroxide, dentine, elastic modulus, flexural strength, sodium hypochlorite.

Introduction

Dentine is composed of approximately 22% organic material by weight (Trowbridge & Kim 1991). Most of this consists of collagen type I, which contributes considerably to the mechanical properties of dentine. It
would be reasonable to assume that the dissolution effect of NaOCl and Ca(OH)$_2$ would affect dentine. It is therefore pertinent to ask whether NaOCl and Ca(OH)$_2$ weaken dentine.

Cvek (1992) queried the possible association between long-term Ca(OH)$_2$ dressing of traumatized anterior teeth and their susceptibility to cervical fracture. He reported finding no published evidence for mechanical weakening of dentine as a result of such dressing. Lam & Gulabivala (1996) found that exposure of teeth to only 1% NaOCl rendered the dentine more susceptible to removal by filing. More recently, it has been shown that exposure of dentine to 5% NaOCl may reduce its flexural strength and modulus of elasticity (Sim 1996) when 0.5% had no significant effect. Sim (1996) further examined the influence of irrigating root canals with NaOCl (0.5%, 5%) on tooth surface strain when the teeth were loaded and found a significant difference between the two concentrations. The extent of this effect at other concentrations of NaOCl (3%, 5%, 7%) was evaluated by Goldsmith (1998) but the results were inconclusive.

The possible mechanisms involved in dentine depletion and consequently the weakening effect of NaOCl have been investigated (Sakae et al. 1988, Barbosa et al. 1994). Although Sakae et al. (1988) and Barbosa et al. (1994) considered both the organic and inorganic components of dentine to be affected, O'Driscoll (1999) conclusively showed that only the organic element was depleted.

The influence of Ca(OH)$_2$ or the sequential use of NaOCl and Ca(OH)$_2$ on the mechanical properties of dentine have not been reported. Given the widely recommended regimen of sodium hypochlorite irrigation followed by calcium hydroxide dressing (Metzler & Montgomery 1989, Sjögren et al. 1991, Ørstavik et al. 1991), it would seem appropriate to determine their effect on the mechanical properties of dentine.

The aim of this study was to evaluate the effect of 3% and 5% NaOCl and saturated Ca(OH)$_2$ solutions on the flexural strength and modulus of elasticity of standardized dentine bars. In addition, the effect of sequential exposure to NaOCl (3% or 5%) and saturated Ca(OH)$_2$ solutions on the flexural strength and modulus of elasticity of standardized dentine bars was also investigated. This method has been previously used by Jameson et al. (1994) and Sim (1996).

**Materials and methods**

The flexural properties of rigid or semi-rigid materials in the form of rectangular bars, that break at comparatively small deflection, can be determined by the use of a three-point loading system utilizing central loading on a simply supported beam (American Society for Testing & Materials 1989).

**Table 1**  Groups and numbers of specimens

<table>
<thead>
<tr>
<th>Test Medium</th>
<th>No. of specimens</th>
</tr>
</thead>
<tbody>
<tr>
<td>Group 1 (control) Saline</td>
<td>19</td>
</tr>
<tr>
<td>Group 2 3% NaOCl</td>
<td>21</td>
</tr>
<tr>
<td>Group 3 5% NaOCl</td>
<td>20</td>
</tr>
<tr>
<td>Group 4 Saturated (S) Ca(OH)$_2$</td>
<td>20</td>
</tr>
<tr>
<td>Group 5 3% NaOCl + S. Ca(OH)$_2$</td>
<td>21</td>
</tr>
<tr>
<td>Group 6 5% NaOCl + S. Ca(OH)$_2$</td>
<td>20</td>
</tr>
<tr>
<td>Total 121</td>
<td></td>
</tr>
</tbody>
</table>

**Fabrication of dentine bars**

Standardized plano-parallel dentine bars (1 mm x 1 mm x > 11.7 mm) were cut from freshly extracted, intact human teeth (stored in 4% formal-saline), using a diamond saw (Exakt GmbH, Nordestedt, Germany). The dentine bars were randomly assigned to one control group and five test groups as shown in Table 1. The control group was stored in normal saline until testing.

**Preparation of test solutions**

Sodium hypochlorite (3%) solution was prepared by diluting household bleach (3.8% available chlorine, J. Sainsbury PLC, London, England, UK) with distilled water. Sodium hypochlorite (5%) solution was prepared by diluting a 15% solution (Jeyes Group PLC, Norwich, England, UK) with distilled water. The concentration of the solutions was verified by iodometric titration (British Pharmacopoeia 1973) immediately prior to use. The saturated Ca(OH)$_2$ solution was prepared by mixing Ca(OH)$_2$ powder (BDH Merck, Poole, England, UK) with distilled water until undissolved solute remained at 37°C for 8 h. The concentration was standardized to 1 g 1 mL$^{-1}$.

**Treatment of dentine bars with test solutions**

**Application of sodium hypochlorite**

The dentine bars in groups 2, 3, 5 and 6 were placed into four separate vessels, each containing 50 mL NaOCl of the various test concentrations (3% for groups 2 and 5, 5% for groups 3 and 6). The test solutions in
the four containers were agitated at 120 strokes min$^{-1}$ in a shaking bath (Grant SS40-D Grant Instruments Ltd, Cambridge, England, UK) for 2 h. The NaOCl solution was changed every 1.5 min to prevent saturation by reaction products and to ensure that all surfaces of the dentine bars would be exposed. The temperature of the shaking bath was set at 37 °C. After 2 h, the dentine bars were removed from the containers and any NaOCl was neutralized by washing with five 50 mL changes of distilled water in new containers. Groups 2 and 3 were stored for testing in distilled water, whilst groups 5 and 6 were then treated with Ca(OH)$_2$.

Application of calcium hydroxide

The dentine bars in groups 4, 5, and 6 were immersed in the Ca(OH)$_2$ solution, using three separate containers. These were placed in a larger plastic vessel and the relative humidity was maintained at 100% by placing moist gauze around the small containers. They were then placed in the shaking bath for a week. The temperature was set at 37 °C. The dentine bars were removed from the containers and thoroughly washed with saline until no visible traces of Ca(OH)$_2$ remained on the dentine bars. The dentine bars were stored in distilled water until testing.

Three-point bend testing of dentine bars

The 121 dentine bars were subjected to three-point bend tests, using a test-jig mounted on a load testing machine (Hounsfield Ltd, London, England, UK). Each bar was placed across the lower supports of the test jig and loaded at the mid-point through the loading head and shaft. All the dentine bars were kept moist during testing with distilled water. The load testing machine was run at a cross-head speed of 0.5 mm min$^{-1}$ to failure. Data were recorded on a plotter to give (PL3, JJ Instruments Ltd, London, England, UK) load-displacement curves on graph paper. The load at fracture was recorded directly from the load testing machine and verified against the load/displacement curve.

Calculation of modulus of elasticity and flexural strength

Modulus of elasticity

The means and standard deviations of the modulus of elasticity calculated from the raw data are presented in Table 2. The Kolmogorov–Smirnov and Shapiro–Wilk tests. Nonparametric tests (Mann–Whitney U-test) were used to detect statistical significance (SPSS for Windows 6, 1996 SPSS Inc, Chicago, IL, USA).

Results

Modulus of elasticity

The means and standard deviations of the modulus of elasticity calculated from the raw data are presented in Table 2. The Kolmogorov–Smirnov and Shapiro–Wilk tests.
showed that the data in groups 5 and 6 had a skewed distribution. Nonparametric tests (Mann–Whitney U-test) were used to evaluate the significance of difference in the modulus of elasticity between the different groups. Analysis showed that there was a highly significant (P < 0.001) reduction in the modulus of elasticity after treatment with both 3% and 5% NaOCl. The difference in the modulus of elasticity between 3% and 5% NaOCl treated dentine was not statistically significant, although the values for the 5% group were higher. There was no statistically significant difference in the modulus of elasticity between the controls and the Ca(OH)$_2$ treated dentine bars. The differences between Ca(OH)$_2$ treated dentine bars and those treated with 3% or 5% NaOCl were statistically significant (P < 0.001). The dentine bars treated with Ca(OH)$_2$ had a higher modulus of elasticity than those treated with either 3% or 5% NaOCl. Statistical analysis showed that treatment of the dentine bars with calcium hydroxide after their exposure to 3% and 5% NaOCl, had no significant additional effect on their modulus of elasticity.

**Flexural strength**

The means and standard deviations of the flexural strength calculated from the raw data are presented in Table 1. Groups 1–6 were checked for normality using Kolmogorov–Smirnov and Shapiro–Wilk tests, and groups 5 and 6 were found to have a skewed distribution. The Mann–Whitney U-test was used to evaluate the significance of difference in flexural strength between groups. Statistical analysis showed a highly significant (P < 0.001) reduction in the flexural strength after treatment with 3% and 5% NaOCl. The difference in the flexural strength of dentine bars treated with 3% and 5% NaOCl was not statistically significant. Treatment of the dentine bars with the saturated Ca(OH)$_2$ solution significantly (P < 0.001) reduced their flexural strength. The flexural strength of the NaOCl (3%, 5%) treated dentine bars was significantly lower (P < 0.001) than the Ca(OH)$_2$ treated ones. Statistical analysis showed that treatment of the dentine bars with calcium hydroxide after their exposure to 3% and 5% NaOCl, had no significant additional effect on their flexural strength.

**Discussion**

There was a striking difference in the mode of fracture of the dentine bars, between the control group and some of the specimens in the test groups. All the dentine bars in the control group and most of the bars from the other groups exhibited sudden 'brittle' fracture upon incremental loading with the fragments being ejected out of the jig.

A small number of bars treated with Ca(OH)$_2$, and almost half of those treated with 3% and 5% NaOCl and those additionally treated with Ca(OH)$_2$ did not exhibit such fracture. Instead, the dentine bars appeared to exhibit 'green stick' fracture without displacement from the jig supports. In some cases, the specimens did not fracture at the maximum load but continued deforming, fracturing at a lower load. This observed difference in fracture patterns was corroborated by the load/displacement plots. In the control group the plots generally displayed a steep linear slope with little or no disproportionate deformation prior to fracture. In the Ca(OH)$_2$ treated group, the pattern was similar to that of the control group but the bars fractured at lower loads and there was an obvious increase in the deformation of the specimens on loading. In a small number of specimens, the upper part of the load/displacement curve became nonlinear.

In the 3% and 5% NaOCl treated groups, there was a considerable difference in the mode of fracture as compared to the controls. The fracture loads were much lower with considerable deformation of the dentine bars prior to fracture. In groups where bars were treated with Ca(OH)$_2$ after exposure to 3% or 5% NaOCl there appeared to be an even more drastic decrease in the fracture loads, even though the difference did not reach statistical significance. Particularly in those pretreated with 5% NaOCl all the loads recorded on fracture were several orders of magnitude lower than those of controls. Contrary to the trend observed in 3% and 5%
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NaOCl, the deformation of the specimens remained more proportionate prior to fracture. Just one specimen in the 5% NaOCl and Ca(OH)₂ treated group continued displacing after the maximum load was reached. Slippage during loading occurred in five specimens of each group. Specimen no. 10 of group 5 did not fracture upon loading but continued to deform. The testing had to be stopped because no more data could be recorded and the cross-head approached its lower safety limit. The specimen was removed in toto but separated on manipulation. The fractured surfaces appeared to be ‘laminated’ and were probably interlocked during the deformation.

There was a wide variation in the behaviour of the dentine bars within groups, even in the untreated group. This can be explained by the variety of teeth and differences in their physical properties. Despite these differences however, the influence of the treatment rendered was dominant enough to show significant differences (P < 0.001) between the groups. Treatment of dentine bars with 3% and 5% NaOCl solutions both caused a significant (P < 0.001) decrease in their modulus of elasticity and flexural strength but there were no differences between these treated groups. The findings are in accordance with those of Sim (1996). An unexpected finding was that the modulus of elasticity as well as the flexural strength of the specimens treated with 5% NaOCl were higher than those treated with 1% NaOCl. Statistical analysis of the data however, did not reveal this difference to be significant. A possible explanation of this effect could be the different origin of the NaOCl solutions (Sainsbury’s household bleach and Jeyes Group PLC).

Exposure of the standardized dentine bars to Ca(OH)₂ significantly (P < 0.001) reduced their flexural strength but had no significant effect on the modulus of elasticity. Because Ca(OH)₂ does not penetrate dentine well because of the buffering capacity of hydroxyapatite (Wang & Hume 1988), it is logical to assume that its effect is more pronounced on the surface of the dentine bars without considerably affecting the bulk of the dentine. Treatment with Ca(OH)₂ could thus potentially enhance crack initiation and propagation on the surface of dentine rendering it more prone to fracture. The central bulk of the dentine would remain unaffected and so the effect on the modulus of elasticity minimal. Further treatment of dentine bars exposed to 3% and 5% NaOCl with saturated Ca(OH)₂ solution for 1 week, had no statistically significant additional effect on their modulus of elasticity and flexural strength. Nevertheless, the load/displacement plots do reveal differences in behaviour which are not reflected in the measured outcomes. As this observation was unexpected, the design of the study did not allow further analysis. A rational explanation of the observations requires an understanding of the mode of action of both NaOCl and Ca(OH)₂ on dentine. The precise mechanisms of action are unknown, leaving room for speculation.

It is evident from previous studies (Hasselgren et al. 1988, Andersen et al. 1992, Shue-Fen et al. 1995) that the modes of action of these two agents are different. The studies concurred that the tissue responded differently to NaOCl and Ca(OH)₂ in terms of physical appearance as well as dissolution kinetics. They were also in agreement that Ca(OH)₂ had a solvent effect; only Morgan et al. (1991) found to the contrary. The concentrations of the solute varied widely in these studies as did the substrate under test, perhaps accounting for the differences. It should also be noted that the teeth in the present study were fixed in 4% formal-saline and may have reduced the dissolution effect expected in vivo (Thé 1979).

The synergistic effect so well demonstrated in other studies (Hasselgren et al. 1988, Andersen et al. 1992, Shue-Fen et al. 1995) was not obviously borne out statistically by the outcome measures used, but observations did indicate such an effect. The encasement of the organic component within a mineralized matrix may account for the lack of direct correlation with other studies. If both NaOCl and Ca(OH)₂ act primarily on the organic portion of dentine, then NaOCl may deplete dentine to the extent that Ca(OH)₂ may not have any more accessible substrate left to exert its effect. The depth of penetration of the solutions and pastes should also be taken into consideration. Ca(OH)₂ does not penetrate dentine very well (Gomes et al. 1996), so most of its effect will probably be limited to the surface, where the effect of NaOCl pretreatment will be maximal. It should be noted that although the mean flexural strength of the sodium hypochlorite-treated dentine decreased after treatment with calcium hydroxide, the modulus of elasticity actually increased. It seems, based on this observation, that further treatment with calcium hydroxide – although weakening the dentine – allows less deformation of the dentine prior to fracture. This supports the concept of a different mode of action for sodium hypochlorite compared with calcium hydroxide.

It is evident that further studies should be undertaken on the effect of NaOCl and Ca(OH)₂ on the properties of dentine. The reduction in the mechanical properties of dentine may help to explain, in part, the observations of cervical fractures in Cvek’s (1992) material.
Acknowledgement

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References


