The effect of alveolar bone loss on the load capability of restored endodontically treated teeth: A comparative in vitro study

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1. Introduction

The survival of endodontically treated teeth depends on the number of proximal contacts, 1 occlusal contacts, 2,3 tooth position in the dental arch, 4,5 crown placement, 6,7 type of abutment, 4,8 the apical status 9 and hard tissue loss due to carious lesions, previous restorations or endodontic access.10-14 An impact of the periodontal status on the survival of endodontically treated teeth was also reported by other investigators.15 Periodontal failures of endodontically treated teeth are with 32% the second most frequent type of failure after crown fractures with almost 60%.15 Clinical studies
indicate that there is an increased risk of fracture of endodontically treated teeth with reduced bone support compared to vital teeth with a comparable bony situation.\textsuperscript{16} Finite element analysis (FEA) studies have suggested that mechanical stress increases as bone support is reduced.\textsuperscript{17} When incisors were loaded at a 45° angle, maximum compressive forces occurred next to the lingual aspect of the post-tip, independent of the bone level. The outer labial surface is another area of compressive force. As bone level decreased, compressive stress in this region increases. At the lowest level of bone height tested (6 mm below cemento–enamel junction) dentin stresses were 4–10 times higher than in teeth with normal bone height.\textsuperscript{17} Reinhardt and co-workers\textsuperscript{17} concluded that alveolar bone loss may lead to an increased risk for root fracture. Another study using FEA reported that when using adhesive and non-adhesive cementing modes, stress on the root increases as horizontal bone support decreases. Maximum stresses occur at the area of the post-tip with non-adhesive cemented posts. In contrast, maximum stresses occur at the root surface at the crestal bone when using adhesive post-cementation.\textsuperscript{18} While all of these FEA analyses suggest that load capability decreases with increasing alveolar bone loss, no in vitro studies have attempted to validate these data.

The purpose of the present in vitro study was to evaluate the influence of horizontal bone loss on the load to fracture of incisors that were restored with adhesively luted fibre-reinforced composite posts, composite core build-ups and all-ceramic crowns.

2. Materials and methods

The method of specimen preparation and loading was adopted from Butz et al.\textsuperscript{19} Caries-free, undamaged human maxillary

| Table 1 – Specimens characteristics and load values of load testing after TCML |
|--------------------------------------------------|--------------------------|--------------------------|
| Load capability (N)                              | Group I (no bone loss)   | Group II (25% bone loss) | Group III (50% bone loss) |
| Median                                           | 501                      | 422                      | 352                      |
| p25, p75                                         | (476, 530)               | (418, 467)               | (266, 395)               |
| Min, Max                                         | (326, 561)               | (322, 494)               | (265, 405)               |
| Mean wall thickness* (mm)                        |                          |                          |                          |
| Median                                           | 2.7                      | 2.6                      | 2.9                      |
| p25, p75                                         | (2.6, 3.1)               | (2.6, 2.9)               | (2.7, 3.0)               |
| Min, Max                                         | (2.6, 3.1)               | (2.6, 3.0)               | (2.6, 3.1)               |
| Minimum wall thickness* (mm)                     |                          |                          |                          |
| Median                                           | 1.9                      | 1.7                      | 1.4                      |
| p25, p75                                         | (1.6, 2.0)               | (1.4, 1.9)               | (1.3, 1.9)               |
| Min, Max                                         | (1.3, 2.2)               | (1.2, 2.2)               | (1.2, 2.6)               |
| Crown length (mm)                                |                          |                          |                          |
| Median                                           | 7.3                      | 6.3                      | 6.6                      |
| p25, p75                                         | (6.6, 8.0)               | (6.0, 7.3)               | (5.9, 7.4)               |
| Min, Max                                         | (5.8, 8.5)               | (5.3, 8.0)               | (5.8, 7.5)               |
| Root length (mm)                                 |                          |                          |                          |
| Median                                           | 19.0                     | 17.3                     | 18.0                     |
| p25, p75                                         | (17.7, 20.6)             | (16.4, 18.6)             | (17.3, 18.8)             |
| Min, Max                                         | (11.3, 22.6)             | (15.9, 18.7)             | (17.0, 21.0)             |
| Oro-facial extension* (mm)                       |                          |                          |                          |
| Median                                           | 7.3                      | 7.4                      | 7.1                      |
| p25, p75                                         | (7.0, 7.6)               | (7.1, 7.7)               | (6.9, 7.1)               |
| Min, Max                                         | (6.9, 7.8)               | (6.6, 7.7)               | (6.9, 7.6)               |
| Mesial-distal extension* (mm)                    |                          |                          |                          |
| Median                                           | 7.1                      | 7.1                      | 7.4                      |
| p25, p75                                         | (6.6, 7.6)               | (6.7, 7.3)               | (7.2, 7.7)               |
| Min, Max                                         | (6.4, 7.8)               | (6.7, 7.5)               | (6.7, 7.7)               |
| Surface* (mm²)                                   |                          |                          |                          |
| Median                                           | 52.3                     | 52.2                     | 52.1                     |
| p25, p75                                         | (46.9, 57.8)             | (48.2, 56.2)             | (51.1, 53.9)             |
| Min, Max                                         | (44.2, 58.5)             | (44.9, 56.3)             | (46.2, 57.0)             |
| Post-length (mm)                                 |                          |                          |                          |
| Median                                           | 11.0                     | 9.3                      | 10.0                     |
| p25, p75                                         | (9.7, 12.6)              | (8.4, 10.6)              | (9.3, 10.8)              |
| Min, Max                                         | (3.3, 14.6)              | (7.9, 10.7)              | (9.0, 13.0)              |

* On the level of the CEJ.
Central incisors were selected. To ensure an even distribution of the size of teeth within the specimen groups, mesio-distal (MD) and facial-lingual (FL) dimensions were measured at the level of the cemento–enamel junction (CEJ). A size assessment value was calculated from the product of MD × FL. Teeth of extreme size were excluded. Thirty specimens were randomly distributed into three test groups (group size of n = 10) by means of 10-digit random table (Table 1). All teeth were stored at room temperature in a 0.1% thymol solution. Root canals were enlarged to size 60 (Antaeos, VDW, Munich, Germany) and rinsed with 2.5% sodium hypochlorite. Root canal filling was done by lateral condensation with gutta-percha (Roeko, Langenau, Germany) and a sealer (AH 26, De Trey, Constance, Germany). The clinical crowns were cut 2 mm coronal to the most incisal point of the proximal CEJ.

Gutta-percha was removed (Gates-Glidden-burs) leaving at least 4 mm of the root filling in the apical portion. The root canal was prepared with a tapered drill of 1.4 mm maximum diameter (Fiberpoints Root Pins post-kit, Schütz-Dental, Rosbach, Germany) to achieve an intraradicular post-length of 8 mm. The root canals and the tooth surfaces were cleaned with an air-particle abrasion system (Dento-Prep™, Aluminium Oxide Microblaster, Rønvig, Danmark and Cojet™, 3M ESPE, Seefeld, Germany). Glass fibre posts (Fiberpoints Root Pins Glass, diameter 1.4 mm, length 13 mm, Schütz-Dental) were luted with a self-adhesive resin cement (RelyX Unicem, 3M ESPE) and light activated for 2 s (Optilux light curing unit, Demetron Research Corp., Danbury, USA). Excess luting material was removed. Final light curing was performed for 1 min. The composite cores (NewBond, Clearfil Core, Kuraray Europe, Düsseldorf, Germany) were built up. All teeth were prepared with a circumferential 1.2 mm shoulder to meet all-ceramic crown requirements. The preparation ended 2 mm below the build-up material in dentin to ensure proper ferrule design.

With the help of a silicone mould, 30 similar crowns were fabricated from an all-ceramic (Empress II, Ivoclar-Vivadent, Schaan, Liechtenstein). The crowns were adhesively luted with RelyX Unicem (3M ESPE) according to the manufacturer’s instructions.

The roots of group I (control) were blocked out with wax 2 mm below the finish line to representing the width without horizontal bone loss. Specimens in group II were blocked out 25%, and in group III 50% of the root length of each specimen to simulate a respective bone loss (Fig. 1). To imitate a human periodontium, the roots of the teeth were covered with a 0.1 mm thick layer of auto-polymerizing silicone (Anti-Rutsch-Lack; Wenko, Wesselsaer, Germany). The teeth were embedded in auto-polymerizing acrylic resin (Technovit 4000, Kulzer, Wehrheim, Germany) orienting their long axes facially 135° from the horizontal (Fig. 2). To prevent overheating, the teeth were submerged in water for 5 min during resin polymerization.

Thermal cycling and mechanical loading (TCML) was performed on eight specimens from each group [parameters: 6000 thermal cycles (5°C/55°C, 2 min each cycle, H₂O dist.) and 1.2 × 10⁶ mastication cycles at an angle of 135° as described previously.²¹ A force of 50 N was applied 3 mm below the incisal edge on the palatal surface of the crown (Fig. 2). After TCML the specimens were loaded in a universal testing machine (Zwick, Germany; crosshead speed of 1 mm/min) until fracture occurred. Failure detection was set at a 10% loss of the maximum applied force. To reduce excessive stress concentrations, a 0.3 mm thick tin foil was positioned between the steel piston and the lingual surface of the crown. As a TCML control, two randomly chosen specimens of each group were loaded in a universal testing machine without TCML. The maximum fracture load at which failure occurred and the fracture pattern were recorded for all teeth.

Fig. 1 – Fracture patterns and frequencies in groups I (right) to III (left), two specimens each of groups II and III (one loss of crown retention, one oblique fracture) are not included due to early failure during TCML, thin lines mark border of differentiation of periodontal horizontal bone loss.
Summary statistics were calculated for each group. A nonparametric Kruskal–Wallis test was used to test differences between group medians of the maximum load capability $F_{\text{max}}$. Non-parametric Mann–Whitney U post hoc tests were used to evaluate differences between individual groups. To test for differences in the frequency of failure modes/fracture patterns between groups, the Fisher exact test was utilized. All statistics were two-sided at $\alpha = 0.05$.

3. Results

Results of linear compressive loading after TCML and specimens characteristics are displayed in Table 1. The comparisons of values of every single characteristic between the experimental groups indicate that a sufficient randomisation was performed. All specimens in group I and six specimens in groups II and III each survived TCML. One oblique fracture and one loss of crown retention occurred in group II during TCML, while in group III one oblique fracture and one loss of retention of the whole specimen within the embedding material were observed. These specimens were excluded from the analysis.

There was a statistically significant difference in load capability between experimental groups (Kruskal–Wallis test $p = 0.004$, Table 1). Teeth without bone loss had median fracture loads of 501 N, teeth with 25 and 50% bone loss had median load capacities of 422 and 352 N, respectively. Application of the Mann–Whitney U-test showed statistically significant differences between groups I and II ($p = 0.039$), groups I and III ($p = 0.007$) and groups II and III ($p = 0.016$) (Fig. 3).

The fracture modes and frequencies are displayed in Fig. 1. Fracture modes were categorized into four patterns: oblique fracture (from the CEJ palatally to the third quarter facial-apical), horizontal fracture (on the level of the third quarter of the root close to the post-tip), horizontal fracture (below the third root quarter of the root) and wave-like horizontal fracture above the embedding material. Four specimens of group I and one of group II fractured horizontally on the level of the third quarter of the root close to the post-tip. Five specimens of group III fractured below the third root quarter of the root. Four specimens of group II and one of group III showed a wave-like fracture line above the embedding material. The comparison of these fracture modes with the Fisher exact test revealed significant differences between the groups ($p = 0.008$). Group I showed most frequently oblique fractures, group II wave-like fracture lines above and group III horizontal fractures close to the post-tip. The control specimens without TCML fractured at forces of 471 and 517 N for group I, 412 and 367 N for group II, 296 and 308 N for group III.

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![Fig. 2 – Experimental set-up for chewing simulation, figure shows example for no horizontal bone loss thermo-mechanically loaded in chewing simulator (1.2 million cycles; 6000 times 5°C/55°C).](image-url)
4. Discussion

The present in vitro investigation evaluated the effect of alveolar bone level on the load capability of endodontically treated teeth restored with glass fibre-reinforced posts, composite build-up and all-ceramic crowns. The load capability decreased significantly as simulated alveolar bone loss increased. Most fractures occurred horizontally in between the middle of the root and the post-tip irrespective of the simulated bone loss.

Fatigue failures are defined as fractures of a material caused by cyclic or repeated sub-critical loads.\(^22,23\) Since the amount of shear forces is higher in the anterior compared to the posterior region, anterior restorations are particularly susceptible for technical failures caused by fatigue.\(^{24,25}\) The chewing simulation applied in this study aims to simulate the fatigue phenomenon, attempting to avoid false conclusions based on application of compressive loads only.\(^{26}\)

Fibre-reinforced composite posts were chosen because their Young’s Modulus of 30–40 GPa\(^{26,27}\) is, compared to metallic posts, closer to that of dentin ranging from 15 to 25 GPa.\(^{24,28}\) Fibre-reinforced materials are known to have high impact resistance, shock absorption ability and an increased fatigue resistance.\(^{29}\) Furthermore, the ability of the used self-adhesive cement to bond effectively to dentin has been demonstrated before.\(^{30,31}\) The restorative materials used in this study conformed with recent suggestions that the complex of resin cement for fibre post-cementation, composite build-up material, and adhesively cemented crown should ideally have a similar modulus of elasticity.\(^{29}\)

Restored teeth without bone loss had the highest load capability. Loss of 25 and 50% bone height markedly decreased load capability in a ‘dose’-dependent fashion. These results may be clinically relevant as the clinically observed maximum bite force has been estimated at 370 N\(^{32}\) which is well within the range of load capabilities observed in this study.

A longitudinal clinical study of 299 patients (aged 23–72 years, mean age 48.7 years) found that endodontically treated teeth in patients with advanced periodontal disease tend to fracture more frequently, primarily endodontically treated teeth that received endodontic posts.\(^{35}\) However, in this study the posts were not bonded to tooth structure and the results may therefore not be directly comparable.

Our observations can likely be explained mechanically. It is known from previous investigations that when loaded palatally, the facial crestal bone acts as the rotational axis and stress centre of the loaded tooth, whereas – regarding stress concentration – the post represents a neutral area. Maximum stresses are located around the circumference of the root.\(^{33}\) As bone support decreases the lever increases. Thus lower loads are necessary to fracture the tooth.

In teeth without diminished bone support, the palatal crown margin is considered the weak link, since with crown placement a stress increase was found around the crown margin\(^{34}\) and fatigue fracture were observed where maximum stress occur.\(^{35}\) Repetitive palatal loading causes tension on the palatal and compression on the facial site. Fatigue fracture of the cement layer between crown and tooth results in a crown loosening and wedging provided that tooth preparation was of sufficient height.\(^{34}\) The combined tension and compression forces result in crack propagation and finally fracture. This should result in an oblique fracture from the palatal CEJ to the apical third quarter of the facial aspect as observed in this study.

When bone support is reduced, the fracture patterns tend to change since the weak link becomes now the tensile strength of the dentin which is dependent on the lever, presence of pre-existing flaws,\(^{28}\) and the amount of remaining hard tissue.\(^{34,14,11,36}\) The amount of residual hard tissue is determined by the endodontic treatment, post-space preparation, and tapering of the root. The area close to the post-tip is supposed to be the locus minoris resistenciae. Hence – as found in all groups tested – the fracture will likely occur in the region in between the crestal bone and the post-tip, even when no bone loss is present. However, in the case of no bone loss there is an equal likelihood of initial fracture of the cement layer at the crown margin and root fracture close to the post-tip. This mechanism is dentin-dependent, since it is determined mainly by pre-existing flaws and the bulk of the remaining hard tissue surrounding the root canal. Only adhesive post-placement might reduce the negative side effects of post-space preparation by stabilizing the root in terms of inner splinting and might transfer stresses to the post-tip where adhesive support is missing.\(^{37}\)

The findings of the present in vitro study confirm conclusions from finite element analysis.\(^{17,18}\) It is suggested that an advanced reduction of the bone support might lead to a marked decrease of the load capability of a post-retained post-endodontic restoration.

5. Conclusion

The horizontal bone loss of endodontically treated teeth restored with glass fibre-reinforced composite posts does have a significant effect on their load capability.

R E F E R E N C E S

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