Investigation of Dynamic Loading Fatigue of PMMA Resin Provisional Crowns

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Summary

A temporary crown or bridge is the best protection of a prepared tooth from pain, saliva contamination and caries propagation. It must have all the properties and qualities of a permanent restoration in order to properly function in the oral cavity.

The aim of the investigation was to determine the influence of two types of cervical preparation of the abutment, as well as the influence of cyclic thermal changes (5°C-55°C), on the dynamic strength of temporary crowns made of poly(methilmethacrylate) resin. The fatigue tests were performed in an Amsler's high frequency pulzator under cyclic dynamic loading in the range from 400N to 1000N.

The results of the investigation showed negative reciprocal relationship between the values of the dynamic load and the number of cycles endured without the fracture of the sample (r=-0.98). The thermocycled samples demonstrated significantly lower fracture resistance than the nonthermocycled samples (p>0.05).

Key words: *dynamic loading, provisional crowns.*

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Introduction

Temporary crowns on a prepared tooth during fixed prosthodontic treatment is an established step in everyday clinical practice. They provide protection for the tooth pulp from thermal, physical, chemical and bacterial injury, as well as stabilization of occlusal relationships, masticatory function, and aesthetic acceptability until the long-term fixed restorations are ready for placement (1-4). Temporary crowns are expected to comply with several factors which include: resistance to fracture, marginal accuracy, color stability, wear resistance, tissue compatibility, ease of manipulation, and low cost of manufacture. The relative importance of most of these factors is related to the intended length of time that a temporary restoration is used. During complex restorative procedures this length of time can turn out to be significantly longer than planned. Thus, the mechanical properites of provisional restorations must be adequate to enable the restorations to stay in pristine function over a prolonged period of time.

Several authors have evaluated the techniques used for making provisional restorations with respect to the marginal fit, and the superiority of the indirect technique was demonstrated (5, 6). Gegauff & Pryor (16) and Ireland et al. investigated the mechanical characteristics of experimental models made of materials for provisional restorations, but they did not use dynamic loading tests. Several dynamic loading tests have been devised by various authors who investigated fracture and strength toughness of human teeth (9), dental ceramic (10--12) and bond between aesthetic materials and metal (13, 14). Thermal changes have also been reported as an instrumental factor in the fracture toughness of dental materials (18-20).

The aim of the presented experiment was to evaluate the influence of the marginal abutment preparation design on the mechanical characteristics of provisional crowns made from poly(methylmetacrylate) (PMMA) resin by standard laboratory procedure. Also, the study was aimed at determining the effect of thermal changes on the fracture resistance of PMMA resin provisional crowns.

Materials and methods

The material used in the study was poly(methylmetacrylate) resin* (PMMA). Indirect technique was used to make 64 provisional crowns according to the manufacturer's instructions with respect to resin proportioning, manipulation and timing. An impression of one of the two identical unprepared typodont models of the upper right first incisors was made with the polyvinyl siloxane impression material. A stone model, simulating the tooth before preparation, was obtained from the impression, and this model was used to make a stent.

One typodont model of the upper right first incisor was prepared with the circular shoulder and another with the circular knife-edge type marginal preparation. The same impression material was used to make impressions of prepared models. Sixty-four stone dies were obtained from the impressions of each prepared model for a total of 64 dies. The resin-filled stent was fitted over the lubricated dies, one at a time, and secured with rubber bands. According to the manufacturer's instructions the material was cured in a pressure pot at 6 atm and 120°C for 15 minutes. Thirty-two provisional crowns were made for each of the two prepared models. After curing each crown was examined, excess material removed, the margin was finished and the crown polished. The provisional crowns were equally divided into two subgroups. The first subgroup was loaded dynamically immediately after the crowns were finished, and the second subgroup of provisional crowns was thermocycled 1000 times in water between 5°C and 55°C before loading.

Two additional impressions were made of the prepared typodont models of the upper right first incisors, one with shoulder and the other with knife--edge type margin preparation. They were used to make two stents from which a cast metal die was made (CoCr alloy) for each type of marginal preparation design. The metal dies exactly corresponded to the dimensions of the dies used to make provisional crowns. Provisional crowns were cemented (Harvard zinc-phosphate cement) onto the corresponding metal die, which was fixated in an Amsler high-frequency pulsator where the dynamic loading tests were performed at a frequency of 100 Hz. The dynamic force values were gradually increased from 400N, 600N, 800N and 1000N. End of the experiment was determined by crown fracture, at which the active load value and the number of cycles up to the fracture point were recorded. The failure load values and the number of cycles until fracture of all specimens were statistically evaluated by Student's t-test. Pearson's correlation analysis was used to determine the relationship between the dynamic loading and the fatigue resistance of provisional crowns.

Results

For both groups of specimens, the number of cycles was determined at set values of dynamic loading until fracture of the provisional crown occurred. For the non-thermocycled provisional crowns on knife-edge type marginal abutment preparation the average number of dynamic loading cycles (6753796) until fracture of crown was observed at a force (Figure 1) of 400N. The number of dynamic loading cycles endured until fracture decreased proportionally with the increase of force applied to the specimen. The non-thermocycled provisional crown on knife-edge type abutment on the average fractured at 1030424 cycles at a force (Figure 1) of 1000N. For the non-thermocycled provisional crowns on shoulder type marginal abutment preparation the average number of dynamic loading cycles (8215145) until fracture was observed at a force (Figure 1) of 400N, while the number of dynamic loading cycles until fracture at a force of 1000N was 1363900 on the average (Table 2).

On the average, the thermocycled provisional crowns on knife-edge type abutment at force (Fg) of 400N endured 4’096,828 dynamic loading cycles, and at 1000N the number of dynamic loading cycles was 852,129 (Table 1). The thermocycled provisional crowns on shoulder type abutment on the average at force (Fg) of 400N fractured at 5.134.350 dynamic loading cycles, and at 1000N the average number of dynamic loading cycles was 896.623 (Table 2). Thermocycled provisional crowns demonstrated less fracture resistance than the non-thermocycled crowns for either type of marginal abutment preparation, the difference being statistically significant ($p<0.05$, Tables 1, 2). Thermocycled provisional crowns on knife-edge type abutment for the same dynamic load (Fg) of 400N demonstrated on the average a 39.3% reduction in fatigue resistance compared to the non-thermocycled crowns of the same type, and for dynamic load (Fg) of 1000N the fatigue resistance reduction was 38.5%. Thermocycled provisional crowns on shoulder type abutment for the load (Fg) of 400N demonstrated on the average a 37.5% reduction of fatigue resistance compared to the non-thermocycled crowns of the same type, while for the load (Fg) of 1000N the fatigue resistance reduction was 13%.

Pearson's correlation factor showed negative correlation between the fracture resistance and the amount of dynamic load applied, regardless of the abutment type and preparation conditions (Table 3).

Discussion

Results have shown the reciprocal relationship between the amount of dynamic loading force (Fg) applied to the specimen and the fatigue strength, expressed by the number of loading cycles endured until fracture. This reciprocal relationship is evident for all groups of specimens and is not dependent on conditions or the type of specimen marginal preparation. Both the fractografic results and their statistical analysis (negative value of the Pearson's correlation factor $r=-0.96$, $p<0.05$, Table 3) have shown that the increase of the dynamic loading force resulted in reduction of the number of loading cycles the provisional crowns endured until fracture. This result is in agreement with the results of Morena et al. (19) who investigated the fatigue strength of dental ceramic, and proved a reciprocal relationship between the amount of dynamic loading force and the fatigue strength expressed by the length of loading time until fracture. The reciprocal relationship between the amount of dynamic loading force and the fatigue strength was also demonstrated by Poljak-Guberina et al. (15) who investigated the fatigue strength of the metal-ceramic interface between the Ag-Pd alloy and hydrothermal ceramic. Results of Poljak-Guberina et al. (15) showed 20--30% higher fatigue resistance values than our results, which demonstrates the advantage of the metal-ceramic systems compared to the provisional acrylic crowns due to higher fatigue strength.

Comparing the fatigue strength of the non-thermocycled provisional crowns on knife-edge type marginal abutment preparation with the non-thermocycled crowns on shoulder type abutment at the dinamic load (Fg) of 400N, it is evident that the crowns on shoulder type abutment on the average endured 17.8% more loading cycles until fracture than the crowns on knife-edge type abutment (Table 1). Therefore, the value of 400N with maximum number of 8'654,000 dynamic loading cycles which a non-thermocycled shoulder type margin preparation provisional crown endured until fracture can be set as the fatigue strength limit of the non-thermocycled PMMA resin provisional crown. This number of cycles surpasses by far the number of chewing cycles a person performs in a 5 year period, and thus the dynamic load of up to 400N can be regarded as the zone of permanent dynamic resistance for the PMMA resin provisional crowns.

Between thermocycled and non-thermocycled crowns there was a significant difference of over 50% of the average number of cycles thermocycled crowns on knife-edge type abutment endured until fracture. The difference for the load of 1000N was 60% of the average number of cycles for thermocycled crowns on knife-edge type abutment. The differences were similar for provisional crowns on shoulder type abutment.

Kappert & Shüren (13) showed the average fracture resistance reduction of the acrylic resin-metal interface, due to thermal cycling between 5°C and 55°C, of 50% after 500.000 dynamic loading cycles. These are significantly lower values compared to the result of our investigation, which shows the average fatigue resistance reduction of 38.5% after 2'650,000 dynamic loading cycles. This difference demonstrates the advantage of the mechanical properties of a homogenous system tested in our investigation compared to the heterogeneous system tested by Kappert & Shüren (13). Their significantly lower values could be attributed to the difference between the thermal expansion coefficients of the acrylic resin and metal, resulting in fracture resistance reduction of the acrylic resin--metal junction.

At the same dynamic loading of 400N thermocycled crowns on knife-edge type abutment demonstrated on the average 20.3% less fatigue resistance compared to the thermocycled crowns on shoulder type abutment. Thus, the mechanical properties of the thermocycled PMMA provisional crowns greatly depend on the marginal abutment preparation design, and in conditions present in oral cavity, with regard to thermal changes, the provisional crowns on shoulder type marginal abutment preparation design have better chances to stay in function for a longer period of time due to the superior mechanical characteristics compared to the PMMA resin provisional crowns on knife-edge type abutment.

Conclusions

1. The dynamic load is reciprocally correlated to the fracture strength of the PMMA resin provisional crowns ($r = -0.95$; $p < 0.05$).
2. Thermocycling reduces the fatigue resistance of PMMA resin provisional crowns up to 40%, regardless of the marginal abutment preparation.
3. The type of marginal abutment preparation design influences the fatigue strength of the PMMA resin provisional crowns, with crowns on shoulder type abutment having 20% higher fatigue resistance values than the crowns on knife-edge type abutment.