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Analysis of stress relaxation in temporization materials in dentistry

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ABSTRACT

Objective. Although temporization is intended as an interim step, complexity of individual treatment situations may demand medium to longer term use of temporary appliances in clinical practice. The durability and integrity of these restorations for continued use to meet the treatment demands is therefore an important clinical problem. The goal of this study was to evaluate the short to medium term stability of these materials under controlled loading to study their stress relaxation behavior.

Methods. Acrylic resins (poly(methyl) and poly(ethyl) methacrylate) and bis-acryl composite resins were tested in vitro in this study. The stress decay data with time (under an applied constant strain) due to internal strain caused by molecular relaxation were systematically analyzed using important parameters derived from stress changes with time.

Results and Significance. The results showed significant differences in the stress relaxation behavior between different materials which may have significant bearing on their durability in medium to longer term interim clinical applications. Poly(ethyl) methacrylate (PEMA) resins subjected to applied constant strain over a period of time showed large time dependent decay of applied stress, indicating very high internal molecular relaxation effects, relative to those of poly(methyl) methacrylate (PMMA) and bis-acryl composites. The results showed that PMMA and composite resins were superior in their ability to maintain constant strain without excessive dissipation of applied stress than PEMA resin. This suggests that internal strain caused by molecular relaxation events may lead to excessive dimensional instability in PEMA.

1. Introduction

Temporization is now a routine procedure in dentistry for treatment involving fixed prosthodontics, implant dentistry, cosmetic dentistry or other similar procedures. Several temporization materials are used to fabricate interim appliances such as single unit crowns and fixed partial dentures (FPDs). Such appliances are traditionally meant to be used in fixed prosthodontics for a relatively short period such as a few weeks to a few months until a permanent appliance is fabricated to replace the interim device. However, with recent popularity of implant supported prosthodontics or more complex procedures requiring longer term treatment planning, it is often necessary for interim appliances to remain in the mouth for several months because of a longer period needed

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for safe, effective and robust treatment. The medium to longer term integrity of the temporization material is then of critical importance both for the patient and the dental practitioner. The major reasons for mechanical or functional failure of a temporization material are potential fracture and excessive dimensional change. The ability to resist dimensional change is typically achieved by increasing the material stiffness, and this often increases the brittleness of a material leading to enhanced risk of fracture. It is therefore necessary to design materials for interim prosthesis using trade-offs between stiffness and dimensional stability within an optimum range. Creep and stress relaxation studies are important tools to optimize both stiffness and dimensional stability of polymeric materials which are used in temporization. Creep is studied by measuring deformation under constant stress, while stress relaxation is measured by monitoring stress under constant strain. The changes in stress (or stress decay) that occur under constant strain in a stress relaxation test result from in situ molecular relaxation events that may add an additional time and temperature dependent strain to the initial mechanical strain produced immediately on application of the initial stress, and this increases the total strain on the material as a function of time and temperature. If the total strain is held constant, there is a corresponding decrease in the applied stress as a function of time and temperature. This decrease in stress results in time/temperature dependent changes in its transient modulus. The transient modulus is given by the ratio of stress at any time *t* to the constant strain applied, i.e., $\{\sigma(t)/\varepsilon_0\}$ where $\sigma(t)$ is the stress at any time (t) during stress measurement and ε_0 is the constant strain used in the experiment. The transient modulus as a function of time at a selected temperature is referred to as stress relaxation modulus (or simply as relaxation modulus) to signify the relationship of the modulus changes to the relaxation events under stress at the selected temperature. The relaxation modulus changes that occur with time can be analyzed for some valuable information in the stress relaxation tests. They are:

(a) The initial relaxation modulus (IRM) that occurs immediately on application of stress is the elastic modulus $(\sigma(0)/\varepsilon_0)$. The value of IRM is important because it represents the resistance to elastic deformation or initial stiffness in the material.

(b) The difference between the IRM and the transient relaxation modulus at time *t* {RM(t)} is given by $\{\sigma(0)-\sigma(t)\}/\varepsilon_0$ or $\Delta\sigma(t)/\varepsilon_0$ where $\Delta\sigma(t)=\{\sigma(0)-\sigma(t)\}$, and is designated in this study as ΔRM(t). Physically this modulus change is determined by the dimensional change associated with time dependent deformation of the material due to in situ molecular relaxation events. The greater the value of the above time dependent deformation, the greater is the value of ΔRM(t). The ratio of this modulus difference to the elastic modulus of the material {i.e., ΔRM(t)/IRM} thus varies with the ratio of the dimensional change due to relaxation events to that due to elastic deformation. This ratio has a value of 0 when a material is an ideal elastic material with no time dependent modulus changes during deformation, i.e.: $\sigma(t)=\sigma(0)$ for any time *t*. In the above case, all deformation is elastic deformation generated by applied stress only with no relaxation effect with time. A mechanical analog is a spring. If, on the other hand, in a material with strong time dependent relaxation behavior, $\sigma(t)$ may decrease with time to reach a value of 0 when a steady state is reached. In this case, the above ratio assumes a value of 1 indicating that strain due to relaxation events has replaced all initial mechanical strain. A dashpot with a Newtonian fluid is a mechanical analog for such a material. Typically, most biomedical polymeric materials exhibit varying levels of stress relaxation behavior between these two cases because they combine the instantaneous elastic response of a spring and time dependent relaxation of a dashpot containing a Newtonian liquid. The ratio ΔRM(t)/IRM can therefore be used as a numerical index that varies with time, and bears a functional relationship to the fraction of the initial dimensional change replaced by time dependent deformation due to molecular relaxation at time *t*. This ratio will be designated arbitrarily as Relaxation Index {RI(t)} in this study.

(c) Finally, the final relaxation modulus (FRM) at the end of the stress relaxation experiment also is an important parameter because it indicates how much stress the material continues to support in spite of relaxation effects.

Many authors have characterized various properties of materials used for temporization.

Several investigators have reported on mechanical properties such as compressive strength, flexural strength, fracture toughness, micro-hardness, etc. for selected materials [1–14]. Other authors have focused on microstructures [15], marginal adaptation [16], color stability [16–18], surface roughness [19,20], monomer conversion [21], etc. There is very limited published work on the dimensional stability or time dependent modulus changes of these materials under stress. Pae et al. [22] reported the overall dimensional changes of selected materials subjected to compressive stress of 4 MPa for 30 min, and showed significant differences in the dimensional stability between bis-acryl composite and mono-methacrylate polymer systems used to fabricate interim prosthetic appliances. Their analysis was limited to overall dimensional changes after compressive loading over 30 min, and did not monitor real time dimensional changes during loading. The stress relaxation behavior of selected interim restorative materials in oral surgery (such as zinc oxide eugenol and Cavit) was reported by Maerki et al. [23] in 1979. To the best of our knowledge, no stress relaxation study on recent polymeric materials used for temporization has been published in the recent literature.

The objective of the current study was to determine and analyze the stress relaxation behavior of selected recent temporization materials used for fixed interim appliances. The null hypothesis is that there is no significant difference in the stress relaxation behavior of different types of polymeric materials used for temporization in prosthodontic clinical practice. The parameters used to analyze stress relaxation behavior included (a) IRM, (b) transient relaxation modulus as a function of time {RM(t)}, (c) transient relaxation modulus change from IRM with time {ΔRM(t)} and the corresponding Relaxation Index {RI(t)}, defined earlier and (d) FRM. The