The use of visible light-curing resin for vertebral body replacement


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The technology of visible light-curing resin has recently been developed for use in removable prosthodontics. A quartz halogen lamp producing a 400- to 500-nanometer wave-length spectrum of visible light is used to polymerize high-molecular-weight acrylic resin monomers. While several in vitro and in vivo studies of visible light-curing resin are found in the dental literature, no studies have yet been performed to evaluate it as an intracorpooreal implant in surgery.

The authors have designed a rat model of microcervical corpectomy to assess vertebral body replacement with visible light-curing resin in comparison to conventional autopolymerizing methyl methacrylate. Spinal cord function tests, spinal-implant stability assessments, and histological evaluations were made in a total of 41 rats at 2, 4, or 6 months postimplant. No animal developed a neurological deficit or radiographic instability, and at sacrifice there was no evidence of implant fracture-extrusion. In addition, there were no signs of adverse reaction in the surrounding tissues. Morphological investigation of the resin/bone interface at 6 months revealed very good implant anchorage.

Visible light-curing resin was found to be far superior to methyl methacrylate for construction of spinal implants. Its waxy consistency makes it easy to handle. It remains pliable until light is applied, allowing adjustments in shape for a well-fitted implant without time constraints. Applied in layers, adjustments can be made even after polymerization of a previous layer. This new implantable resin will allow safer, immediate stabilization in patients with neoplastic destruction of the spine, and may also be advantageous for other neurosurgical applications, such as cranioplasty.

KEY WORDS - resin - spinal stabilization - methyl methacrylate - vertebral body replacement - metastasis - spinal implant - rat

THE availability of autopolymerizing methyl methacrylate resin has led to the increased use of these systems for reconstruction of cranial defects and for stabilization of the spine in cases of neoplastic destruction. In patients with metastatic disease, methyl methacrylate is used for vertebral body replacement following corpectomy and is aimed at providing immediate stabilization. This allows early ambulation and minimizes pulmonary and embolic complications. In view of the limited life expectancy of these patients, it is believed that methyl methacrylate implants offer major advantages over bone grafts.

Although methyl methacrylate has been used widely in dentistry and as bone substitutes in neurological and orthopedic surgery for four decades, it presents the following significant disadvantages: 1) It is difficult to manipulate because of time constraints put on the surgeon to construct the implant before it autopolymerizes and hardens. However, if used at the semiliquid stage of mixing to delay the self-curing setting, it is then awkward to fit over a skull defect. Care must also be taken to prevent spilling when it is used for spacing between vertebral bodies. 2) The polymerization is an exothermic reaction. The heat may exceed the coagulation temperature of the tissue proteins (about 80° to 100°C), and may result in damage to neural tissues. 3) There are cytotoxic and lipolytic effects of the non-polymerized monomer to the surrounding tissue. Loss of excess free monomer by evaporation during late polymerization also results in a weaker, more porous final product with a rough surface, which could lead to possible bacterial adherence and potential late infection. 4) There is increased risk of infection due to decreased chemotaxis and leukocytes. Impairment of the phag-
ocytosis and inherent bacterial-killing properties of polymorphonuclear leukocytes may also occur. 5) There is a dimensional change involving contraction and shrinkage when polymerization is complete, resulting in inferior fit, with less accuracy and adaptation to the defect. 6) There is decreased mechanical stability of methyl methacrylate implants with time under conditions of cyclical loading.

A visible light-curing urethane dimethacrylate resin system, which is generally referred to as "visible light-curing resin," has been introduced to the dental health sciences to further improve alloplastic implants in accuracy of fit, simplicity of construction, strength, and dimensional stability. In addition, visible light-curing resin provides less inflammatory response and lower bacterial adherence compared to methyl methacrylate.

Visible light-curing resin is similar to the light-cured composite filling material which has been used for dental restorations, except that it contains organic rather than inorganic filler. This filler is made of different-sized acrylic beads which become part of the polymer network structure upon curing. The matrix is urethane dimethacrylate with microfine silica to control rheology and handling characteristics. It contains camphoroquinine-amine photoinitiator, which is sensitive to 400- to 500-nanometer wave lengths of shorter blue intense collimated shielded light from a quartz halogen lamp. This activates polymerization of the resin in the matrix and results in deep curing of the material. There is no free monomer in the uncured or cured material.

Visible light-curing resin is available in sheets of base-plate thickness, as a rope, or as gel ointment, in light-shielded envelopes to prevent premature polymerization. This material is thermoplastic. At room temperature it has the consistency of glazing putty and can be readily shaped using either finger pressure or instruments. When lower viscosity is desired, it can be heated in a water bath before the package is opened. This affords control of the material for various application procedures, with easy flow, to adapt to tissues of various ranges of dispalceability.

In several in vitro studies, visible light-curing has been found to be nonmutagenic to Salmonella and noncytotoxic to fibroblasts. There is also evidence of less bacterial adherence to visible light-curing resin than to other resins. The in vivo studies show that cured visible light-curing resin does not cause any mucous membrane or skin irritation. The biocompatibility tests also meet the American Dental Association specifications.

To the extent of our knowledge, visible light-curing resin has not been evaluated for applications other than in dental prosthetics. The purpose of the present study is to assess the biocompatibility and mechanical performance of visible light-curing resin as an implant for vertebral body replacement and immediate stabilization following corpectomy.

Materials and Methods

Animal Preparation

A total of 41 adult Sprague-Dawley rats were used in this study. The population was divided into three groups comprising 21, 12, and eight rats with sacrifice planned at 2, 4, or 6 months, respectively, after construction of the implant. During the surgical sessions the animals were anesthetized with intraperitoneal injections of ketamine hydrochloride (100 mg/kg) and acepromazine (2 mg/kg).

Surgical Technique

Each animal underwent a microsurgical anterior cervical approach and corpectomy under aseptic conditions. They were randomly allocated to one of two groups of 20 and 21 rats. In the first group, the corpectomy defect was filled with visible light-curing resin applied in multiple thin layers, each of which was exposed for 60 seconds to visible light (500-nm wave length) to ensure complete depth of polymerization. A hand-held visible light source with an 8-mm diameter curved lightguide was used. In the second group, sterile autopolymerizing methyl methacrylate was used, applying standard techniques.

The microsurgical procedure involved skin incision along the medial edge of the sternocleidomastoid muscle, division of the omohyoid muscle, retracting aside the trachea and esophagus from the carotid artery, internal jugular vein, and vagus nerve, and exposure of the vertebral bodies by cauterizing and laterally detaching the longus colli muscles. Medial corpectomy of the C-3 vertebral body was achieved using a high-speed drill. Key holes were drilled through the plate into the vertebral body above (C-2) and below (C-4) after the C2-3 and C3-4 discs were removed to secure the implant material spacing the vertebrae. After the implant was constructed, the soft tissues were sutured in layers.

Neurological Evaluation

After surgery, antibiotics were not given nor was an external orthosis used; immediate unrestricted activity was allowed. Clinical evaluation was performed throughout the duration of the experiment. Neurological functions (forelimb motor strength, gait, and feeding ability) were graded 1 to 4, and each rat was assigned a score. This allowed for quantitative comparable measurement of neuromuscular coordination and work capacity of muscle groups.

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* Triad manufactured by Dentsply International Corp., York, Pennsylvania.
† Efos manufactured by Fiber Optic Systems, Buffalo, New York.
‡ Methyl methacrylate manufactured by Caulk Company, Milford, Delaware.
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Radiological Examination
Cervical stability was assessed with lateral cervical radiographs in flexion and extension obtained before sacrifice at 2, 4, or 6 months after implant surgery.

Preparation of Specimens
The cervical spines were retrieved en bloc and fixed in a 2% paraformaldehyde solution with phosphate buffer at pH 7.4. Axial sections cut with a jeweler's saw at 5 mm thickness were dehydrated in alcohol and embedded in acrylic resin. Sections were cut 20 μ thick with an Isomet Exact sawing machine§ under water irrigation and stained with hematoxylin and eosin for light microscopy.

Histological Examination
At different time intervals (2, 4, or 6 months after implant surgery) the spine, meninges, and spinal cord were studied by light microscopy for histological changes, with special attention to the bone/implant interface. This evaluation was carried out by a pathologist who was not advised of group allocation. The parameters studied on the bone/implant interface were the presence and degree of: 1) inflammatory infiltrate; 2) granulation tissue; 3) fibrosis; and 4) presence of giant cells. These changes, if present, were graded 1 to 3 according to the severity of the process. Finally, the minimum width of the bone/implant interface was measured in microns and recorded (Fig. 1).

Statistical Analysis
Chi-square analysis was used to test for differences in reaction categories for the granulation and fibrosis variables between the visible light-curing resin and methyl methacrylate groups. The rank-sum test was used to test for differences between the groups at the bone/implant interface thickness variable.

Results

Neurological Outcome
All rats in both groups (the visible light-curing resin and the methyl methacrylate groups) tolerated the vertebral body replacement well and did not develop either transient or permanent deficit during the 2-, 4-, or 6-month period of observation.

Radiographic Evaluation
All cervical spine radiographs revealed a C-3 body radiolucency (resins are not radiopaque). There were no signs of instability with flexion or extension views in either the visible light-curing resin or the methyl methacrylate group before sacrifice at 2, 4, or 6 months postoperatively.

Fig. 1. Minimum bone/implant interface width at 2 months postoperatively. VLC = visible light-curing resin; MM = methyl methacrylate.

Autopsy Findings
Gross Appearance. The implants were found to be intact, without evidence of fracture or extrusion, in both the visible light-curing resin and the methyl methacrylate groups. They were also well anchored into the slots drilled in the adjacent vertebrae. There was no gross evidence of biological reaction on the adjacent bone, dura, or spinal cord.

Histological Findings. The histological findings in the specimens with visible light-curing resin and methyl methacrylate implants at 2 months postoperatively are summarized in Table 1. There was a thin layer of soft tissue at the bone/implant interface in some sections. This tissue always included fibrocytes with their long axis oriented parallel to the interface, and sometimes also granulation tissue. There were no statistically significant differences for the degree of fibrosis or interface width; however, fewer visible light-curing resin implant specimens demonstrated granulation tissue (which was also milder) compared with the methyl methacrylate implant specimens (p = 0.059).

The histological findings in the visible light-curing resin and methyl methacrylate implant specimens are summarized at 4 and 6 months postoperatively in Table 1. The implants were tightly anchored to the lateral masses of the vertebral body as well as to the slots drilled in the upper and lower vertebrae. The presence of soft tissue in the interface was less common than was seen at 2 months. There were no statistically significant differences in the features between visible light-curing resin and methyl methacrylate groups.

Giant cells were found in only two rats, one implanted with visible light-curing resin and the other with methyl methacrylate. The bone adjacent to the implant interface presented normal haversian canals, osteocytes, and intercellular stroma, without signs of necrosis. The minimum width of the bone/implant interface measured at 2 months postoperatively is summarized in Fig. 1. There were variable interface dis-

§ Isomet Exact sawing machine manufactured by Buehler Ltd., Evanston, Illinois.


<table>
<thead>
<tr>
<th>Tissue Reaction</th>
<th>Extent of Reaction</th>
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<tr>
<td></td>
<td>None</td>
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<tr>
<td>2 months postimplant inflammation</td>
<td>VLC</td>
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<tr>
<td>6 months postimplant inflammation</td>
<td>VLC</td>
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* VLC = visible light-curing resin; MM = methyl methacrylate.
† Level of significance by chi-square test: p < 0.05.

Discussion

In constructing a spinal implant with visible light-curing resin, we found that working time was virtually unlimited; in contrast, the amount of time available with methyl methacrylate self-polymerization is limited, and the surgeon is forced to complete the implant construction in a hurried manner. Visible light-curing resin remains pliable until light is applied. This allows time to achieve optimum shape adjustment. In this study, we found visible light-curing resin far superior to methyl methacrylate in simplicity of use, and perhaps in biocompatibility as well. Its waxy consistency allows easy handling, enabling the construction of a well-fitted implant. It is much easier to prevent the flow of visible light-curing resin paste into the spinal canal than that of semiliquid methyl methacrylate. Visible light-curing resin is a single-paste system; therefore, there is no need for mixing and the possibility of trapping air is minimized. Because light-induced polymerization does not involve an exothermic reaction, we did not need to protect the dura mater with Gelfoam or cold irrigation.

The main limitation of visible light-curing resin lies in insufficient polymerization at the deep layers. Although some investigators describe polymerization up to 5 to 6 mm in depth, others found insufficient curing at a depth of more than 4 mm. Nevertheless, the depth of polymerization also depends on the intensity of the light; more powerful light sources such as lasers are currently being evaluated. A longer illumination time increases polymerization at deeper layers, but maximum hardness is already achieved after 80 seconds. Matsumoto, et al., found that the deep layers were harder at 6 months than at 48 hours after curing, suggesting possible continued polymerization. It is suggested that, for cavities with a depth of more than 3 to 4 mm, optimum hardness of visible light-curing resin is achieved by sequential polymerization in a series of thin layers. Visible light-curing resin has been used in prosthodontics with a pink tint to blend with the mucosa color. In our study we constructed the implants with an ivory tint, seeking to increase the total number of photons of light reaching the deep layers, with formation of more free radicals, and therefore initiation of more polymerization. We are trying to obtain a more translucent visible light-curing resin in order to further reduce illumination time. A disadvantage of visible light-curing resin, as well as of other resins, is the absence of a radiopaque agent; this will have to be solved in neurosurgical applications.

The mechanical performance of the implants was very satisfactory. None fractured or extruded despite the fact that the implants were simply anchored in the slots drilled into the adjacent vertebrae, without fixation to the spine by incorporation of metallic stents. Furthermore, the animals were not fitted with braces and were subjected to hyperextension and flexion. Because this study was not performed in bipeds, the performance of the implants as spacers could not be simply extrapolated to conditions of compression loading such as the human spine withstands.

The only data available about the mechanical properties of visible light-curing resin have been collected by the American Dental Association. Visible light-curing resin has been evaluated and found to exceed the American Dental Association specifications for denture base resins. Furthermore, it demonstrated slightly higher tensile strength and elastic modulus, with less linear shrinkage than either heat-cured or autopolymerizing methyl methacrylate. The data from the dimensional change tests indicate that it is superior in fit to both heat-cured and autopolymerizing methyl methac-
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Fig. 2. Photomicrographs of a visible light-curing resin implant at 6 months. This 20 μ-thick axial section at the rostral level of the implant demonstrates excellent anchorage (left, ×6) and no residual bone/implant interface distance (right, ×38). H & E.

We have not found in our specimens the “pseudocapsule” which other investigators have described around methyl methacrylate implants and which in some cases lasts for as long as 11 months. At the early stage (2 months), we found significantly more granulation reaction around the methyl methacrylate implants compared with visible light-curing resin implants. This may indicate that visible light-curing resin is more biocompatible than methyl methacrylate. However, these differences were transient and there were no significant differences on granulation reaction at the late stages (4 and 6 months).

Collections of giant cells have been reported around methyl methacrylate implants, arousing concern about possible malignant transformation. We have observed the appearance of some giant cells in only one of 20 methyl methacrylate implants and one of 20 visible light-curing resin implants.

Conclusions

Our experimental results suggest that visible light-curing resin may be used safely for vertebral body replacement. The use of this new biocompatible implant material, which is easier to manipulate and possibly less prone to failure or to cause infections than autopolymerizing methyl methacrylate, will allow safer, immediate stabilization and early ambulation in patients with neoplastic destruction of the spine. Additional advantages may well result from extending the use of this material instead of conventional methyl methacrylate for other surgical procedures, such as cranioplasties and maybe posterior spinal fixation.

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References


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