



Recent advances in composite resins for clinical dentistry

Osiągnięcia w dziedzinie żywic kompozytowych w stomatologii klinicznej

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ABSTRACT

The literature on composite resins has been surveyed, with particular emphasis on recent publications, to build up a picture of the current state of the art concerning their use in dentistry. They are shown to be versatile materials, capable of being formulated for a variety of clinical applications. A major current division is into packable (high viscosity) and flowable (low viscosity) types that between them can be used to repair full cavities, including in posterior teeth, as well as provide repairs for abfraction (Class V) lesions and for fractured incisors. Current trends in material composition, including varying filler loadings and use of new photo-initiators, are described. Recent clinical findings show good outcomes with these materials and are described in appropriate detail.

Keywords: composite resin, polymerization, properties, durability.

STRESZCZENIE

W pracy przedstawiono najnowsze doniesienia dotyczące materiałów kompozytowych stosowanych w stomatologii odtwórczej. Kompozyty to wszechstronne materiały o wielu zastosowaniach klinicznych, które w zależności od składu i wynikającej z niego lepkości mogą być stosowane do pourazowej odbudowy zębów przednich, wypełniania ubytków przyszyjkowych niepróchnicowego pochodzenia czy odbudowy ubytków próchnicowych, w tym rozległych ubytków w zębach bocznych. Najnowsze tendencje zmian tych materiałów dotyczą ilości i jakości wypełniacza oraz zastosowania nowych systemów fotoinicjatorów polimeryzacji. W pracy szczegółowo opisano ostatnie wyniki badań klinicznych potwierdzające wysoką skuteczność materiałów kompozytowych.

Słowa kluczowe: żywice kompozytowe, polimeryzacja, właściwości, wytrzymałość.

Composite resins in dentistry

In modern clinical dentistry, composite resins are important restorative materials with good physical properties (**Table 1**). They are made up of a polymeric matrix together with an inert filler, and they set by addition polymerization [1]. In modern materials, this setting is initiated by blue light of wavelength 470 nm provided by a dental cure lamp.

The components of a modern dental composite resin are [2]:

- › A polymer phase typically based on a blend of dimethacrylate monomers;
- › Fillers made of powdered silicate or inert glasses, together with a radio-opacifying agent, such as barium oxide;
- › A silane coupling agent to attach the filler and the matrix together;

- › A photo-initiator system which starts off the polymerization reaction.

The main monomer used is bisGMA (systematic chemical name is 2,2-bis[4-(2-hydroxy-3-methacryloyloxypropoxy)phenyl]propane). This monomer is a liquid with a high viscosity and has to be blen-

Table 1. Properties of contemporary composite resins

Tabela 1. Właściwości tymczasowych żywic kompozytowych

Property	Range of values
Compressive strength	260–300 MPa
Tensile strength	40–50 MPa
Flexural strength	80–150 MPa
Young's modulus	6–14 GPa

ded with other lower viscosity substances, such as di-triethylene glycol dimethacrylate, DEGDMA and TEDGMA respectively. An alternative monomer urethane dimethacrylate is used in certain brands. It has the advantage that its viscosity is lower than that of bisGMA, so there is no need to include any lower viscosity diluents [3].

Contemporary composite resins are cured by a light-activated process with camphorquinone as the photoinitiator. This substance needs to be used in association with an aromatic tertiary amine as accelerator [4]. This system is sensitive to blue light, and shining such a light onto the composite resin initiates the polymerization reaction and causes the material to harden.

There have been recent studies that suggest that this initiator could be improved upon. The alternative initiator diphenyl(2,4,6 dimethylbenzoyl) phosphine oxide, TPO, has been found to give higher degrees of conversion in equivalent periods of time because it produces free radicals more readily than the camphorquinone-amine system [5]. This result suggests that TPO has the potential to increase the chemical resistance of composite resins and reduce their susceptibility to mechanical breakdown. These would lead to improved durability. TPO has also been shown to reduce the yellowness of finished composite resins [6].

The use of light-cure means that composite resins show variations in degree of cure with depth [7]. The lower intensity of light available deeper inside the composite causes fewer initiator molecules to be excited, with the result that fewer free radicals are produced and less cure reaction takes place.

In the dental clinic, this problem is dealt with by placing the composite layer-by-layer in the cavity at thicknesses of about 2 mm [2]. This makes sure that there is adequate cure all the way through the material. There has been considerable research into how this incremental build-up should be done in practice, with different patterns of overlaying used, and various orientations with respect to the floor of the cavity [8, 9] but no one method appears to be ideal and they all seem to give similar results [2].

Depth of cure does vary with the shade of the composite and for dark shades the suggested 2 mm layer may be too thick to allow the material to completely cure all the way through [10]. This is because some light is absorbed by the pigments [11], and this means that darker shades usually have lower recommended depths of cure than lighter ones [12].

Polymerization shrinkage and shrinkage stress

An important topic of recent research has been that of shrinkage on polymerization, and the associated stress that this induces. This arises from the fact that, when composite resins set, they shrink slightly [13, 14]. For a dental composite resin, there is a link between contraction and degree of polymerization [15]. Shrinkage has important clinical consequences for these materials, and can result in either a gap forming between the margins of the restoration and the tooth surface or movement of the cusps of repaired teeth [16–18]. As composites undergo cure, so complicated stresses develop within the material. However, it is not clear whether these effects make a significant difference to the clinical performance of composite resins [18]. Certainly, low shrinkage composite systems do not seem to show any improvement in clinical performance, and attention is being increasingly shifted to enhancing the durability via increasing the resistance to chemical degradation and biofilm colonisation [19].

Soft start polymerization

The technique of so-called soft start polymerization was developed in order to reduce the initial rate of shrinkage and to cause the stress on the bond to the tooth to build up slowly [20, 21]. It uses a specially designed cure lamp that either emits at low power for the first 10 seconds, then switches to maximum output for the remaining time, or emits with gradually increasing power, followed by a short time at maximum output [20, 22].

Results from laboratory studies suggest that soft start polymerization may be good for the restoration [23–27]. Marginal adaptation seems to be better [28–30], and there is a corresponding reduction in marginal leakage [31]. Unfortunately, these results do translate into better clinical performance.

Cure lamps

The original cure lamps used quartz-tungsten-halogen (QTH) bulbs [32], which emit light of wavelength around 470 nm, i.e. the blue end of the visible spectrum. This corresponds well to the active region of the camphorquinone-amine initiator system. QTH lamps also emit heat [33, 34], and this may help to increase the degree of cure [35].

More recently there have been moves to replace QTH lamps with light-emitting diodes, LEDs [35]. LEDs have an emission that is concentrated in the blue wavelength region of the spectrum i.e. in the range 440–480 nm [36, 37]. Consequently, they are

able to cure composites as well as QTH lamps [38], while at the same time generating much less heat [39, 40]. Composites cured using LEDs have been found to be well polymerized [36] and to have similar mechanical properties to those cured with QTH lamps [41].

It is difficult to draw conclusions concerning which, if any, are the best types of lamp available to the dentist. All of them are able to produce a well-cured material, and there are no obvious differences between them.

Fillers

Over the years, there has been a lot of interest in fillers of varying particle sizes for use in dental composites (**Table 2**). Recently, nanofilled and nano-hybrid materials have been studied in some detail [42]. Although claimed to be based on fillers of nanometre dimensions, there is recent experimental evidence that these materials mainly contain mainly particles with sizes above 1 μm [43]. Because of the problems of incorporating such fine particles into the pre-cured composite formulation, they have usually been incorporated first into a pre-polymerized sample, which is then broken up and dispersed in more resin monomer, usually with an amount of filler with slightly larger particle size [44].

Physical properties of nano-filled composites are generally very good [45, 46] and their volumetric shrinkage and water sorption properties are comparable with composites containing larger particle size fillers [45]. They combine the mechanical strength of hybrid composites with the polishability of the microfills [47, 48] and they also have good wear resistance [49, 50] and good optical properties [47]. Overall, filler content rather than particle size seems to be the most important factor in determining the mechanical properties of the cured composite [43]. This has led to the recent suggestion that filler loadings should be reclassified as

Table 2: Particle size and size distribution of fillers in composites

Tabela 2. Wielkość i rozmieszczenie cząstek wypełniowych w kompozytach

Type	Size distribution
Macrofill	10–50 μm
Microfill	40–50 nm
Hybrid	10–50 μm + 40 nm
Minifill	1–10 μm + 40 nm
Nanofill	5–100 nm

ultra-low, low and compact, with the latter giving the best mechanical properties because they have the highest filler loading [43].

As well as classifying composite resins by their particle size and size distribution, modern composites are often distinguished by their consistency. The two groups are termed “packable” (sometimes referred to as “condensable”) and “flowable”, and they differ mainly in how viscous they are.

Packable composites have higher viscosity, and this is because of careful control over their filler particle size distribution [51]. Flowable composites, by contrast, have lower viscosities, and this enables them to be dispensed from syringes with very fine bore needles and to flow into small spaces [52]. This improves the marginal adaptation of the resulting restoration. Their low viscosity is obtained by reducing the filler content slightly and by including surfactants to improve their flow [53]. These reductions in viscosity are achieved without compromising the mechanical strength properties of the set material. However, polymerization shrinkage is increased, with one recent study showing flowables with shrinkages of around 4.7% compared with 1.8% for so-called bulk-fill, values that compare well with those of traditional composites [54].

Different consistency composite resins have different uses in the clinic. A universal restorative is designed to be used both for fine margins of restorations and for bulk (incremental) filling. In contrast, the packable and flowable types are designed for different purposes, and usually are used together for different parts of a given cavity restoration.

Packable composites are placed using an amalgam condenser and set to have good mechanical and wear properties [55]. Because their viscosity is high they do not slump and hence tight interproximal contacts can be obtained in practical use [56]. Flowable composites, on the other hand, are able to penetrate into small spaces, and this allows a good seal to be obtained at the margins of restorations. When set they have some flexibility and this allows them to perform well in regions of high stress, such as at the margins of Class I or Class II cavities, and in Class V cavities [57].

Clinical uses

The main application of composite resins is as direct repair materials in cavities of teeth [58]. The current estimate is that 95% of all anterior restorations and 50% of all posterior restorations are now made with composite resin [59]. They have good aesthetics, and are capable of matching the natu-

ral tooth in terms of shade and translucency. Modern composites last well in the mouth and can continue to function for long periods of time i.e. around 10 years or more [60].

Flowable composites have distinctive properties that allow them to be used for specific applications [52]. These include pit-and-fissure sealants, cavity liners and Class V abfraction lesions. Because of their ability to flow into surface irregularities, these materials provide good marginal adaptation, and there is evidence that microleakage is significantly reduced when they are used as cavity liners and bases.

As well as being used to repair teeth damaged by caries, direct composites can be used to repair fractured teeth that arise as the result of trauma [61]. This use also exploits their good aesthetics, while taking advantage of their toughness and durability. Lastly, composites can be used as pit and fissure sealants in children's teeth, where they survive well and are effective in reducing the occurrence of caries [62].

Fluoride-releasing composite resins

Lastly it is worth mentioning briefly that some composite resins are available to the profession that are able to release fluoride over a sustained period following placement. This is achieved by adding appropriate fluoride compounds to the formulation. The compounds used include inorganic salts (NaF or SnF₂), fluoridated glasses and organic fluoride compounds. Longer-term sustained release requires only sparingly soluble fluoride salts, (SrF₂ or YbF₃), or leachable glass fillers [32].

The total amount of fluoride released by composites tends to be relatively low. The release profile also lacks an "early burst", but is at a maintained low level throughout the lifetime of the restoration [64, 65]. Whether this is sufficient to have a significant clinical effect is debatable, and current research findings are not clear about this point [66]. However, low levels of fluoride are generally known to be beneficial [67], so there is the possibility that making composites that are capable of releasing fluoride may have some positive preventive effects *in vivo*.

Conclusions

This paper has the current state of the art with dental composite resins. These materials are versatile, but show a range of properties, depending on the composition. Selecting a particular material for a specific clinical situation requires a sound knowledge of the features and limitations, and should

also involve careful attention to manufacturers' guidelines and instructions. Composites remain the material of choice for aesthetic restorations in teeth and are likely to remain so well into the future.

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Conflict of interest statement

The authors declare that there is no conflict of interest in the authorship or publication of contribution.

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