DENTAL MATERIALS

Materials developed over 100 years

BACKGROUND

Dental materials have undergone extreme evolution since their introduction over 100 years ago. Pivotal advances in dental amalgams, composites and light curing, dental adhesives and cements, dental ceramics, and functional repair materials were outlined, with special note made of their contributions to the dental profession and the oral health of dental patients.

DENTAL AMALGAM

The initial formulation of dental amalgam was basically silver and tin (Ag_3Sn) (γ) plus some copper (Cu) and zinc (Zn). This material did not change significantly until the 1960s. Spherical particles were introduced to diminish the amount of mercury required. However, amalgam creep caused deterioration of the margins. Despite this drawback, amalgam restorations offered high compressive strength and excellent clinical longevity.

Additional Cu was introduced, which reacted preferentially with Sn, forming more Cu_6Sn_5 and less tin and mercury (Sn_8Hg). This replacement resulted in better oral corrosion resistance and improved mechanical properties, especially less creep. Margins were improved, as was clinical survival of the restoration.

Several phase changes occur with amalgam restorations. Palladium (Pd) was added to improve the corrosion resistance of the amalgam. Adding a polymeric bonding agent improved fracture resistance. However, further improvements were halted when there was a move to eliminate amalgam use because of its mercury content. Although dental and scientific communities generally see amalgam as a safe, effective material because the mercury leakage is minimal, some countries have banned its use and many others are enforcing a significant decline in its use, with the eventual phase-out of amalgam in response to the 2013 Minamata convention.

DENTAL COMPOSITES AND LIGHT CURING

Dental composite materials have been used for esthetic intraoral restorations. The mix of polymerizable monomers and fine glass-reinforcing inorganic filler particles yields an easily manipulated paste that cures rapidly and provides highly esthetic restorations.

Composite development began in the 1950s with self-curing polymethyl methacrylate (PMMA) with quartz particles added for strength. The original formulation had high shrinkage and poor abrasion resistance, so dimethacrylate monomers replaced the monomethacrylate. For decades the bisphenol A glycidyl methacrylate (Bis-GMA) dimethacrylate molecule has served as the basis for dental composites. Even with outstanding physical qualities, polymerization shrinkage has been substantial, which stresses the tooth-composite interface and requires the use of adhesives with high bond strengths for retention. Both intensive study of adhesives and alternative placement methods have been undertaken to mitigate curing stresses.

Two problems have attended the use of composites. The movement to a single-paste system that polymerized on exposure to ultraviolet (UV) light not only created a limited depth of cure but also raised concerns over the health of personnel exposed to UV. Alternative light-curing systems were then introduced to help manage these situations, including moving to visible blue light from a quartz tungsten halogen (QTH) source. Bis-GMA was partially or fully replaced by alternative monomer systems.

It was also difficult to achieve a highly polished surface with early composites. Fixes for the problem included the design of finer particle sizes, which led to microfill composites, hybrid composites, and midifill and minifill composites. Clinical wear was diminished with reduced space between particles. Eventually the development of microhybrids and nonohybrids yielded highly clinically successful and popular surfaces with sufficient strength and wear resistance.

Light-emitting diode (LED) curing devices eventually replaced QTH lights. LED lights produce considerably less heat, require less energy, and are more amenable to battery-powered options. More esthetic photo-initiators have also been used, but require a light with an additional LED to match their absorbance, leading to polywave lights.

Further advances in composites include flowable materials, packable composites, and bulk-fill composites. Advantages achieved with these developments include ease of manipulation and placement, ease in shaping and mimicking of the amalgam handling qualities, and enhanced translucency, which can save clinical placement time and allow light to penetrate more deeply. Shrinkage stress has also been reduced.

DENTAL ADHESIVES AND CEMENTS

Salivary leakage and bacterial penetration are supposedly diminished with well-adapted, bonded dental materials. Advances in adhesive materials began with acid etching to enhance retention of an acrylic resin to enamel. The advances that ensued were the result of investigation into etching parameters, surface reactions, procedural variables, and hybrid layer contributions. Few clinical trials of these variables exist or have covered a period of time sufficiently long to reveal differences between adhesive agents.

In clinical situations, most bonded restorations are placed in previous cavity preparations and show no correlations between clinical performance and laboratory results. Successful bonding often involves 20 MPa in macro-shear or 30 to 40 MPa in micro-tension. Bond strengths vary with time and storage solutions. The longevity of a restoration is influenced by fatigue, bond decomposition, and the extent of enamel versus dentin interface. New bonding strategies have focused on preventing endogenous dentin enzymes from degrading the integrity of the hybrid layer's collagen needed to achieve good bonding.

Cements can be based on a traditional acid or on polymeric acid, or be of the composite variety. Zinc phosphate (ZP) or zinc oxide eugenol (ZOE) cements have been used widely. Silicate cements are used as filling materials and offer the advantage of fluoride release, but suffer clinical disintegration rather readily. Dental cements have microstructures that experience continuous (or matrix) and dispersed (or filler) phases. Dispersed components are stronger and control the properties of the final mixture but increase preset viscosity. Although cement film thicknesses have traditionally been pegged as $\leq$ 25 μm, laboratory sectioning indicates true cement thicknesses vary from 50 to 250 μm. A practical target for a good fit is $\leq$ 100 μm, which is supported anecdotally as achieving good outcomes.

Factors that influence cement retention include luting and/or chemical adhesion, as well as esthetics. The release of fluoride over time occurs as a large burst initially, followed by lower levels. Some materials can experience fluoride recharging, but the levels fall quickly. Resin cements have an aqueous nature that facilitates better adaptation to tooth structure and may offer better micromechanical retention. Composite cements are most appropriate for all-ceramic restorations, whereas composite or glass ionomer cements work better for metal surfaces.

DENTAL CERAMICS

In the 1960s ceramic applications in dentistry were made to address the shortcomings of feldspathic ceramic. One approach was the use of a cast metal substructure onto which a thin veneer of the ceramic was fired, creating a porcelain-jacket crown (PJC). The second approach formed a high-strength ceramic substructure by adding alumina. As a result of these changes, patients could receive highly esthetic anterior and posterior restorations, which remain in use today. Use of a higher alumina content of the core combined with a highly effective presintering of pure alumina and infiltration of the porous structure with lanthanum glass yields a high-strength core. Further developments have allowed the use of ceramic crowns and bridges for any location in the mouth.

Digital processing helped to make the use of zirconia-based dental ceramics. Zirconia ceramics are often used for posterior teeth without veneering, but these materials have proved to be less acceptable for anterior applications. Resin-bonded ceramic was also developed. These offer a highly effective clinical modality that esthetically restores discolored teeth. Dentin bonding systems are also useful for resin-bonded crowns. With no metal substructure, compatible thermal expansion coefficients are eliminated. New veneering ceramics optimize leucite content and strength. Because leucite-reinforced feldspar ceramic has insufficient strength to serve in resin-bonded bridge and posterior crowns, lithium disilicate glass ceramic was developed, offering not only sufficient strength for anterior bridges and low-load short-span posterior bridges but also esthetics. Further development is under way.

FUNCTIONAL REPAIR MATERIALS

A hundred years ago, dental materials were designed simply to replace tissue lost to disease or trauma. With better understanding of the various disease processes, functional restoration began to include repairing dental tissues. Fluoride was used to reverse early enamel caries. Several topically applied fluoride delivery systems exist. Fluoride's ability to promote surface precipitation can block remineralization in deeper demineralized areas, prompting research into casein-amorphous calcium phosphates (ACPs) and chitosan-ACPs, which can slow early surface precipitation and promote subsurface remineralization. Silicate-based bioglass is also useful. With research into how enamel is formed, future approaches may be made to build enamel artificially.

Like enamel, dentin is also an apatitic structure but has lower mineral content, smaller apatite crystallite size, and higher carbonate content. These characteristics make it more susceptible to rapid demineralization by cariogenic acids than is enamel. Mineral content must be reintroduced both within and between collagen fibrils. Research into this problem has led to the development of the polymer-induced liquid precursor (PILP) system, which has been applied to many collagen-based matrices and provides in vitro remineralization of artificial caries lesions. Intrafibrillar mineralization in dentin and bone collagens has been

achieved using nucleation inhibitors. Although the efficacy of PILP remineralization for dentin caries has not been proved clinically, various additional barriers remain to be overcome.

FUTURE ADVANCES

Many possibilities are on the horizon for new dental materials. Among these are the development of a limitless bulk-fill composite that self-adheres to all tooth structure and offers antibacterial properties; instant curing technologies; the ability to functionally restore and stimulate beneficial biological responses that encourage natural repair of small tooth defects; in situ tissue-engineered replacements of whole tooth structures and entire dental pulps; materials with native antimicrobial characteristics; materials that contain sensor molecules or compounds that monitor events at margins and surfaces and can alert clinicians and patients about potential problems so they can be addressed preventively; and new ceramics that are strong, highly esthetic and translucent, and fabricated chairside by additive manufacturing methods using a fully digital clinical workflow and also incorporate computer-controlled ion implantation techniques that esthetically color the final prosthesis.

Clinical Significance

The development of materials to support dental care and allow the practice of dentistry to provide functional, esthetic, and strong dental structures has been an ongoing effort for over 100 years. During that time, materials and methods have been created in response to problematic situations as well as in an effort to make patients happy with the result. Based on what has been achieved in the past 100 years, it's exciting to consider what might be achieved in the next 100.

Bayne SC, Ferracane JL, Marshall GW, et al: The evolution of dental materials over the past century: Silver and gold to tooth color and beyond. *J Dent Res* 98:257-265, 2019

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DENTAL PRACTICE CHANGES

Changes in dentistry in the United Kingdom

BACKGROUND

Over the course of 15 years, it's likely that dental practice would change, especially with all the new materials and methods that have been developed for dentistry. The dental practices of general dental practitioners in the United Kingdom were compared based on questionnaires completed in 2002, 2008, and 2015 to determine which areas have changed and which have not.

METHODS

A self-report questionnaire was distributed to 1000 UK-based general dental practitioners in 2002 and 2008 and to an additional 500 practitioners in 2015. The questions dealt with a wide range of topics concerning practice patterns, techniques, and materials used. Response rates were 70%, 66%, and 78%, respectively, in 2002, 2008, and 2015. The results were reported in topical groups, including demographics, techniques used, indirect dentistry, and postgraduate education.

RESULTS

Demographics

The proportion of men responding diminished from 73% in 2002 to 60% in 2015. This was interpreted as proof that more women are choosing to enter dentistry. In addition, mean years since graduation has risen from 18 years in 2008 to 20 years in 2015.

The number of dentists in a practice also tended to increase. Of those surveyed in 2002, 28% of the practices had 2 dentists, 27% had 3 dentists, and 14% had 4. The mean number of dentists per practice was 3.6 in 2008 and 4.2 in 2015. More dental practices were located in a town or city center in 2015 as well. A mean of 23.9 dentist-delivered patient treatment sessions per week was found for the 2015 survey, which is in line with the numbers reported for earlier periods. Dental hygienists are also found more often in dental practices, with nearly half of those surveyed in 2002 having no dental hygienist but the 2015 practices averaging 1.2 hygienists per practice. This does not, however, represent a dramatic increase, which was expected with the increased emphasis on preventive measures.

When considering payment for services, 82% of those responding in 2002, 57% of those in 2008, and 50% of those in 2015 were treated under the National Health Services (NHS) arrangements. Thus fewer patients are receiving NHS treatment now than 15 years ago.

When asked about the use of computers, the vast majority of practices in 2015 used a computerized system. Nearly three