Polyvinyl siloxane impression materials: An update on clinical use

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Abstract
Polyvinyl siloxane impression materials have applications in a variety of indirect procedures in prosthodontics and restorative dentistry. Favorable handling properties, good patient acceptance and excellent physical properties have resulted in their popularity in today's practice. In this review, the chemistry and important physical properties of polyvinyl siloxanes are summarized, and recent clinical questions of improved hydrophilities, tray adhesives, disinfection, and glove-induced polymerization inhibition are addressed.

Key words: Polyvinyl siloxane, elastomer, impression materials, hydrophilic, polymerization inhibition.

(Received for publication November 1997. Revised March 1998. Accepted April 1998.)

Introduction

The polyvinyl siloxane impression materials are addition reaction silicone elastomers which were first introduced in the 1970s. Since that time and especially in the past decade, these materials have gained in their acceptance and account for a large share of the impression material market. Polyvinyl siloxanes have applications in fixed prosthodontics, operative dentistry, removable prosthodontics and implant dentistry. The materials are presented in the form of two pastes (a base and an accelerator) which can be hand spatulated or autodispensed from a dual cartridge, and mixed in equal quantities for use. They have achieved a high level of dentist and patient acceptance as they are clean, odourless and tasteless.

Chemistry

Polyvinyl siloxane materials are a modification of the original condensation silicones. Both are based on the polydimethyl siloxane polymer, however the presence of differing terminal groups accounts for their different curing reactions.\textsuperscript{1} As the dimensional stability of the polyvinyls is so much improved and the setting reaction is sufficiently different from the condensation curing silicones, the polyvinyl siloxanes warrant classification as a separate category of material.\textsuperscript{4}

The base material contains a polymethyl hydrogen siloxane copolymer, which is a moderately low molecular mass polymer with silane terminal groups.\textsuperscript{5,6} The accelerator material contains the vinyl-terminated polydimethyl siloxane. This is also a moderately low molecular mass polymer but has vinyl terminal groups.\textsuperscript{14} The accelerator material also contains chloroplatinic acid as a homogeneous metal complex catalyst.\textsuperscript{15} On mixing, an addition reaction occurs between the silane and vinyl groups (Fig. 1). There is minimal dimensional change during this polymerization and there are no by-products.

Several authors have reported hydrogen gas bubble formation on the surface of gypsum dies poured immediately from polyvinyl siloxane impressions.\textsuperscript{1,6} A side reaction of the hydrides on the base polymer can produce hydrogen gas if moisture or residual silanol groups are present. Manufacturers have now eliminated the possibility of this side reaction by proper purification and accurate proportioning of the materials, and by the addition of palladium to the pastes as a hydrogen absorber.\textsuperscript{17} It is no longer necessary to wait for one hour before pouring these impressions.

The base and accelerator pastes also contain fillers. Amorphous silica or fluorocarbons are used as fillers to add bulk and improve the properties of the paste. The filler is also normally silanated to increase the bond strength between filler and polymer, which better allows it to function as a cross-linker.\textsuperscript{8} Colouring agents are added to distinguish the base and catalyst pastes and to aid evaluation of mixing. More recently, intrinsic surfactants have also been added in an attempt to negate the hydrophobicity of these materials.\textsuperscript{9}

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Properties

a. Viscosity

Polyvinyl siloxanes are available in viscosities ranging from very low (for pouring, syringing or wash use), to medium, high and very high. The viscosity of the material increases with the proportion of filler present. Viscosity is also affected by the shear force placed on the material. The mixed base and catalyst pastes exhibit a decrease in their relative viscosities in response to high shear stresses. This is termed shear thinning. Thus a medium body impression material can possess sufficient viscosity to avoid excess flow if loaded into an impression tray, yet it can also exhibit an apparent lowered viscosity suitable for intrasulcular impressions, when it is expressed through an impression syringe tip. The higher the viscosity of the material, the more pronounced is the effect of shear thinning. This phenomenon is suggested to be due to the extremely small filler particle size.

Thixotropy is the property of certain gels to liquefy when subjected to vibrating forces (for example, ultrasonic waves) and then to solidify when left to stand again. Polyvinyl siloxanes behave similarly to this but have not been sufficiently investigated to be classified as thixotropic materials.

b. Working and setting times

Modern polyvinyl siloxanes have a working time of two minutes and a setting time of six minutes (with slight variation). These times are considered to be adequate if not ideal. Occasionally, situations will present which require extended working times and some methods of altering working and setting times have been reported in the literature. Alteration of the proportion of catalyst is to be avoided as this leads to variable results and has been suggested to facilitate the side reaction which produces hydrogen gas.

Some manufacturers supply a retarder that can be incorporated into the mix to provide additional working time without compromising other properties. The retarder is a small, reactive, tetra cyclic vinyl molecule that polymerizes preferentially to the siloxane copolymers. This small molecule is cyclic and does not form a chain. It is thus a chain stopper, and temporarily prevents polymerization of the linear siloxane molecules. The retarder continues to polymerize until it is completely consumed and then the linear siloxane molecules polymerize causing the impression material to set. The retarder was used by two dental schools in the USA to provide students with extended working times in a teaching
environment. It has become less commonly used since the polyvinyl siloxanes became available in automatic dual cartridges.

The most convenient and widely advocated method for extending working time is to refrigerate the materials before mixing. Gains of up to 90 seconds have been reported when the materials are chilled to 2°C.51

**c. Reproduction of detail**

Polyvinyl siloxanes are currently considered to reproduce the greatest detail of all the impression materials. The international standard for dental elastomeric impression materials\(^1\) states that a type III (light body) impression material must reproduce a line 0.020 mm in width. With the exception of the very high viscosity putty materials, all polyvinyl siloxanes (light, medium and heavy body) achieve this. Very low viscosity materials can reproduce lines 1-2 μm wide.52,42,43

It should be noted that the literature does not tend to support the use of putty and wash impression techniques for greatest accuracy in impressions. Wassell and Ibbetson\(^4\) reported that heavy body and wash impressions were more accurate than putty and wash impressions. Frederick and Caputo\(^5\) further showed that the putty and wash technique was significantly less accurate than polyether (heavy and light body) or reversible hydrocolloid impressions.

**d. Dimensional stability**

The accuracy of an impression material is dependent on the dimensional stability. There are a number of possible causes for dimensional changes in elastomeric impression materials. All rubber polymers must contract slightly during polymerization as a result of reduction in spatial volume as they cross-link. If the setting reaction produces a by-product or if accelerator components are liberated, then the set volume is further decreased. Some impression materials like the polyethers are less hydrophobic and can absorb and then even lose water if they are placed in wet or varying humidity environments. Changes in temperature can also lead to varying changes in the final dimensions.

Polyvinyl siloxanes show the smallest dimensional changes on setting of all the elastomeric impression materials. The majority of this shrinkage is due to continued polymerization occurring within the first three minutes of removal of the impression from the mouth.6 Reductions in volume due to polymerization have been reported to be as low as 0.1 to 0.05 per cent.5,6 This linear contraction is well matched to the setting expansion of modern type III and type IV die stones and results in a slightly larger replication of the preparation.5,15,16

Long term dimensional stability of polyvinyl siloxanes is reported in the literature. This is because they are not susceptible to changes in humidity, and they do not undergo any further chemical reactions or release any by-products.15,34,16 Polyvinyl siloxane impressions may be repoured to produce stone dies which are as accurate as the original, as many as seven days later.34,16

The linear coefficient of thermal contraction is relatively high for all elastomers. When an impression is removed from the mouth, there is an element of shrinkage due to the decrease in temperature that occurs as the material moves from the mouth to the bench. Lower viscosity materials show the greatest change (0.02-0.05 per cent shrinkage) due to their lower filler content.16 Reheating an impression to 37°C before pouring has been demonstrated to improve the accuracy of the resultant die; however it is doubtful that this is clinically significant.17

**e. Tear energy, elastic recovery and deformation**

Impression materials must have sufficient strength to allow removal from a gingival sulcus without tearing. Tear energy is that energy required to sustain a tear through a material, and is of obvious importance in thin intrasulcular or interproximal areas.

Elasticity is inherent to all the elastomeric impression materials as they are polymers with highly flexible kinked segments that allow freedom of movement. Under a load, the flexible kinked segments of these polymers will uncoil allowing movement. Upon removal of the load, an ideal elastomer will exhibit complete elastic recovery and return to its prestressed configuration. The degree to which this occurs is a measure of the elastic recovery of the material. Permanent deformation occurs when a polymer is elongated beyond the point where elastic recovery is possible. Permanent deformation is related to the degree of cross-linking of the polymer strands, temperature, and the rate of applied stress.20

The ideal impression material should exhibit maximum energy absorption with minimal distortion. However, it is also desirable that the material tears rather than deforms past a critical point such as a margin. Polyvinyl siloxanes deform at much slower rates and tear at points of less permanent deformation than do the other elastomeric materials.20 Polyvinyl siloxanes are frequently reported to be the most ideally elastic impression materials because they exhibit better elastic recovery and less permanent deformation than the other elastomers. They can absorb over three times more energy up to the point of permanent deformation than other elastomers, and if elongated to over 100 per cent (strain at tear),
they rebound to only 0.6 per cent permanent deformation.16,20

f. Creep compliance

All elastomers are viscoelastic materials, implying that deformation and elastic recovery are time dependent as well. Therefore, the longer the material is deformed (as occurs when impressions are removed slowly from the mouth or separated slowly from a poured model), then the longer time it takes for elastic recovery and the possibility of permanent deformation becomes higher. Polyvinyl siloxanes have the least viscoelastic qualities thus requiring the least time for recovery from viscoelastic deformation. Blomberg et al.21 reported that polyvinyl siloxanes have sufficient elastic recovery to allow an impression to be poured only six minutes after removal from the mouth.

g. Radiopacity

Radiopacity of impression materials is important for radiographic identification of excess material which may be accidentally swallowed, aspirated or left in gingival tissues. Presently, only the polysulphide materials exhibit significant radiopacity due to their lead dioxide content. Shillingburg et al.22 tested an experimental polyvinyl siloxane material containing 20 per cent barium sulphate to improve radiopacity. Although they were able to demonstrate qualities of radiopacity equal to that of the polysulphides, there were associated physical property drawbacks including hydrogen bubble formation in dies poured from the impressions, and evidence of long term breakdown limiting the shelf life.

h. The hydrophilic question

According to O'Brien,6 wetting describes the relative affinity of a liquid for a solid. It is the degree to which a drop will spread on a solid surface, and can be quantified by observing the contact angle. High angles (greater than ninety degrees) indicate poor wetting, whilst a zero angle would indicate perfect wetting of the surface. When discussing the wetting characteristics of impression materials, it is important to distinguish between the ability of the material to flow around the soft and hard tissues of the mouth, and the ability of the material to be wet by a gypsum slurry. Polyvinyl siloxanes are inherently hydrophobic.23 However in recent times, new ‘hydrophilic’ polyvinyl siloxanes have been introduced with manufacturer claims that they better wet moist dental surfaces. These new formulations have intrinsic surfactants added. Typically these are non-ionic surfactants of nonylphenoxypolyethylene homologues.7,24 Research in this area has involved observations of the wetting of set surfaces of polyvinyl siloxanes. The conclusion then is that the ‘hydrophilic’ statements refer to the newer materials being more readily poured up with a gypsum-based die stone than the previous generation materials. There is no scientific evidence to indicate that polyvinyl siloxanes advertised as ‘hydrophilic’ can be syringed into a wet sulcus for an accurate impression.20,21,23

This has been confirmed by Takahashi and Finger,24 who demonstrated that under a simulated clinically dry field, both the hydrophilic and original formulations of polyvinyl siloxane wet tooth structure with equal results. It has also been shown that the newer hydrophilic materials perform no better than the original formulations of polyvinyl siloxane in wettability for pouring dies, if a compatible, extrinsic, spray-on surfactant is applied before pouring.23

The application of an extrinsic surfactant to the surface against which an impression is to be made has also been suggested. Millar and co-workers25 reported a significant reduction in the number of voids and an overall increased quality of polyvinyl siloxane impression when a modified polydimethyl siloxane wetting agent was applied to the prepared tooth surfaces before impressions were made.

Impression trays and adhesives

Tray spacing and tray design have often been cited as potential sources of error in impressions for fixed prosthodontic procedures. When only polysulphide materials were available, even tray spacing was critical to minimize distortion due to uneven polymerization shrinkage in areas of greater impression material bulk. The improved physical properties of modern elastomers and particularly polyvinyl siloxanes have diminished this concern and now the use of stock trays for impressions has become common practice for reasons of cost and convenience.26

Common stock trays made of polystyrene or chromium plated brass are reported to be suitably stiff to prevent flexure or distortion, although there remains some possibility of tray wall flexure with polystyrene trays.7 Wassell and Ibbetson27 and Payne and Pereira28 identified poor fitting stock trays and consequent tray wall flexure as the greatest concern for inaccuracy.

Whether custom or stock trays are used for impressions, another potential source of error may arise if the material is not adequately retained in the impression tray when it is removed from the mouth. The use of adhesives in trays has been shown to achieve higher material bond strengths for polyvinyl siloxanes than has mechanical retention.29,30 The adhesives used are usually polydimethyl siloxane and ethylsilicate. The adhesive reacts with the surface of
the tray material and forms a chemical bond to the tray and to the impression material. It is generally recommended to wait ten to fifteen minutes after application of the adhesive before making the impression. This allows time for the solvent to react with the tray material.

The polyether systems have the greatest bond strengths while the polyvinyl siloxanes show great variability between manufacturers with some being very poor, and others rivalling the polyether systems. Bond strengths will also vary depending on the tray material. In contrast to the polyethers and polysulphides, Chai et al. reported that adhesive strength to acrylic resin (custom trays) was significantly lower than polystyrene or metal stock trays for the polyvinyl siloxanes.

Visible light-cured tray materials based on urethane dimethacrylate have found recent acceptance. Investigations into their bond strengths with polyvinyl siloxane adhesives indicate that they bond better than polymethyl methacrylate materials provided that the air inhibited non-polymerized layer is removed with isopropyl alcohol or a carbide bur. Sulong and Setchell demonstrated that roughening the surface of the impression tray will significantly improve the effectiveness of polyvinyl siloxane adhesives.

It is important to note that although other elastomers have stronger bonding adhesives, these cannot be substituted for use with polyvinyl siloxanes. Also, polyvinyl siloxane putties are reported to show no chemical adhesion to their adhesive and so the use of putties requires mandatory mechanical retention in the impression tray.

In many clinical situations, the impression tray must be tried in the mouth prior to impression making and this leads to saliva contamination. If the tray has already been painted with adhesive, then subsequent application is recommended to maintain bond strengths. Contaminated adhesives have shown a drop in bond strength to one-fifth of their original amount.

Disinfection

Disinfection is the inhibition or destruction of pathogens and can be achieved by immersion of an impression into antimicrobial chemical solutions for 3 to 90 minutes depending on the agent. Sterilization is the total elimination of all micro-organisms and spores and requires immersion periods of 6 to 10 hours. Extended periods of immersion can risk distorting impressions by liquid uptake and subsequent swelling of the material. Consequently, procedures currently used to control the transmission of pathogens from impressions have tended to be disinfecting and not sterilizing due to concern for the accuracy of the impression.

Herrera and Merchant tested the dimensional stability of different impression materials following immersion disinfection for thirty minutes. They observed that polyvinyl siloxane and polysulphide were unaffected after immersion in sodium hypochlorite, 2 per cent glutaraldehyde, 0.5 per cent povidone-iodine and 0.16 per cent halogenated phenol whilst polyethers were significantly unstable. Even after extending the immersion times to sixty minutes, del Pilar Rios et al. agreed with the findings of Herrera and Merchant. Johansen and Stackhouse demonstrated that polyvinyl siloxanes were able to be immersed in 2 per cent glutaraldehyde for 16 hours without any observed dimensional changes, whilst polyether materials showed dramatic distortions under the same conditions.

Holtan et al. measured the dimensional stability of polyvinyl siloxanes after sterilization procedures using a conventional steam autoclave, and an ethylene oxide gas autoclave. They determined that sterilization in ethylene oxide gas resulted in gas inclusions into the impression material which then formed bubbles in dies poured immediately from them. Waiting to pour dies for 24 hours after gas autoclaving prevented this problem. Impressions sterilized in the steam autoclave did undergo distortion that would have been significant enough to prevent a casting from seating. It was concluded that steam autoclaving was a suitable sterilization method if the impressions were not to be used for fixed prostheses.

Most recently, radiofrequency glow discharging has been advocated for use as a disinfecting procedure for polyvinyl siloxane impressions. Whilst this procedure is claimed to clean and improve the wettability of the impression surface, it is not clear if glow discharging results in sterilization.

Compatibility with die materials

The hydrophobicity of polyvinyl siloxanes is well established, however, as mentioned previously, the introduction of newer materials with intrinsic surfactants or the conjunctive use of extrinsic surfactants topically, can greatly improve wettability. This makes polyvinyl siloxanes compatible with gypsum, epoxy resin, and polyurethane resin materials.

Gypsum stones cannot reproduce detail much smaller than 20 μm because their crystal size ranges from 15 to 25 μm. Epoxide and polyurethane resins can reproduce detail down to 1 to 2 μm making them highly compatible with the detail capture possible with polyvinyl siloxane impressions. Polyvinyl siloxanes can also be silver electroplated. This procedure can be facilitated by soaking the  

† Baier RE. Written communication, September 1996.
impressions in water for 24 hours before application of the silver powder. It is thought that this alters the concentration of surfactants in the surface layers of the impression.\textsuperscript{49} Crispin et al.\textsuperscript{49} reported that silver dies recovered from polyvinyl siloxane impressions are the most accurate dies.

The ability to pour duplicate dies from one impression is highly advantageous. Morgano et al.\textsuperscript{50} reported that the removal of dies and subsequent repouring of polyvinyl siloxane impressions produced clinically accurate duplicate models.

Gloves and the inhibition of polymerization

Occasionally an inhibition or retarding effect is seen on polyvinyl silicones when they are used in a clinical setting. This phenomenon can occur after direct contact between the impression material and latex gloves, or a region of the mucosa previously touched by latex gloves.\textsuperscript{49} It was initially suspected that the corn starch powder used as a lubricant in the gloves was interacting,\textsuperscript{49} while other authors suggested atmospheric oxygen inhibition, or interactions with haemostatic agents were the cause. Several haemostatic agents were tested before de Camargo et al.\textsuperscript{51} concluded that they were not the inhibitors. Jones et al.\textsuperscript{52} were able to show that provisional luting agents did not interfere with the polymerization.

A sulphur compound has since been identified as being responsible for the retarding effect on polymerization. Zinc diethyl dithiocarbamate is an accelerator used in the manufacture of the latex gloves. It reacts with the platinum catalyst in the polyvinyl siloxane to cause a delay or total inhibition of polymerization.\textsuperscript{53,54,55} Baumann\textsuperscript{49} reported that even in concentrations as low as 0.005 per cent, total inhibition of polymerization of polyvinyl silicone can be observed. It is also believed that the compound can remain on a previously gloved hand, and so washing gloves or washing hands after glove use is not recommended as a means of avoiding contamination.

Interestingly, not all latex gloves will cause an inhibition of set. It has been observed that synthetic latex gloves do not produce this phenomenon, while some natural latex gloves do.\textsuperscript{53,54} One's own testing and subsequent use of a non-retarding glove is recommended.

Conclusions

The results of investigations into polyvinyl siloxane impression materials indicate that they produce highly accurate impressions because they reproduce fine surface detail, and have excellent elastic recovery, adequate tear strengths, and exceptional dimensional stability. They are compatible with all common die materials, can be disinfected or sterilized, and can be repoured after delayed periods. They are dispensed in convenient automixing dual cartridges or single tubes and are available in several viscosities. If handled appropriately, polyvinyl siloxanes can be applied in almost any indirect procedure.

Acknowledgements

The author would like to thank Dr J. Malcolm Carter, Associate Professor Biomaterials, Department of Restorative Dentistry, State University of New York at Buffalo, for his advice in preparing this manuscript.

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