Original Article

A Newly Formulated Vinyl Polysiloxane Impression Material with Improved Mechanical Properties

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Abstract

Aim: To evaluate the mechanical properties of a newly formulated vinyl polysiloxane (VPS) impression material. **Materials and Methods:** Experimental, Capture (S&C Polymer), Express, Imprint 3 and Imprint 4 (3M ESPE), Start VPS (Danville), Honigum (DMG), Virtual (Ivoclar Vivadent), Elite HD+ (Zhermack) were evaluated for tear strength, tensile strength, and elongation at break. Un-nicked specimens with a 90° angle on one side (type C) for tear strength were prepared and tested according to ASTM-D624. Dumbbell-shaped specimens (type 1) for tensile strength and elongation at break were prepared and tested according to ISO 37. All tests were carried out at 500 mm/min on a Shimadzu (AGS-X-10 KN-table top) tester. A one-way analysis of variance (ANOVA) was used to analyze the data. **Results:** Experimental material showed significantly higher or higher tear strength and elongation at break compared to other impression materials for both light body (LB) and heavy body (HB). For tensile strength, Experimental is similar to most impression materials; however, significantly lower than Imprint 3 and Start VPS for LB. This parameter for HB is higher or significantly higher than other impression materials except Start VPS. Tear strength and tensile strength were not correlated for LB but have a weak or moderate correlation for HB. Elongation at break is inversely proportional to tensile strength moderately for LB; however, there is no or very weak relation for HB. **Conclusions:** Experimental VPS impression material demonstrated a significantly higher tear strength and adequate tensile strength with higher elongation compared to other commercially available VPS impression materials. Adequate mechanical properties can provide accurate impressions for successful clinical fabrication of restorations. Experimental VPS impression material is suitable for use in dental impressions for fabrication of restorations.

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Introduction

Impression is an important step in dentistry for the successful fabrication of restorations such as crowns, fixed partial dentures, or removable prostheses.[1-4] The successful fabrication of restorations mainly depends on the accurate impression, which was formed from a precise replica of the intraoral structure (the tooth structure and the soft tissue surrounding it).[5,6] Although digital impression has gained great interest and some

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progress has been made in recent years,[7] adopting digitization is still costly and may take much longer time to significantly unfold; therefore, most clinicians continue to use a lot of different impression materials,[8] and major companies and some researchers continue to improve some properties of impression materials and to invent novel impression materials.[9-14] This can be evidenced by the consumption of impression materials in the US market. According to IData research, the total value of the impression materials market in the U.S. exceeded $245 million in 2016 and will be $262.4 million in 2023.[15] There exists a variety of impression materials in the market for clinicians to take dental impressions. The most used dental impression materials are vinyl polysiloxane (VPS, 71.5% in 2016 and 74.6% estimated in 2023), polyether (PE, 20% in 2016 and 17.9% estimated in 2023), and alginate (5% in 2016 and 3.3% estimated in 2023).[15,16] VPS impression materials have captured the majority of the impression material market due to their precise detail reproduction, excellent dimensional stability, and good recovery from deformation.[15-18]

To obtain an accurate impression and a successful clinical outcome, an impression material must have adequate mechanical properties, such as tear strength, tensile strength, and elongation, because adequate mechanical properties ensure that the impression material can withstand stress under various situations without tearing and permanent deformation during removal from the mouth.[19-22] During impression removal and cast separation from the set impression, an impression material is susceptible to tearing in gingival crevices and interproximal areas, which causes defects or even rupture and finally affects the accuracy of the final restoration.[18] In addition, if an impression material does not have sufficient elasticity or ductility (too rigid), the impression material causes/becomes permanent deformation when distorted beyond its elastic range, which hinders its removal from the soft tissue undercuts and increases the possibility of die breakage once removed from the stone die.[6] Therefore, favorable mechanical properties are critical for achieving accurate impressions and the successful fabrication of restorations. It is highly desirable for the impression material to have high tear strength and high elongation.

The aim of this research is to assess the mechanical properties of a new VPS impression material and compare it with other commercially available VPS impression materials. The hypothesis is that the new VPS impression material has high tear strength, high elongation at break, and adequate tensile strength compared to the commercially available VPS impression materials.

Materials and Methods

Materials

Experimental impression material was prepared based on our resin-based composite technology, which included vinyl polydimethylsiloxanes, polymethyl hydrogen siloxane, surfactant, organoplatinum complex catalysts, and fillers. All resin monomers and additives were mixed with an overhead stirrer (IKA RW20 digital, Wilmington/NC, USA) for at least 3 h. to form a homogeneous resin. The resulting resin mixtures were further mixed with fillers via a speed mixer (Hauschild, DAC 150.1, Hamm, Germany) for at least 2 h. until a uniform flowable paste was produced for both the base and catalyst pastes, respectively. Eight commercially available VPS impression materials, including Capture (S&C Polymer, Elmshorn, Germany), Express, Imprint 3 and Imprint 4 (3M ESPE, St. Paul, Minnesota), Start VPS (Danville, Anaheim, California), Honigum (DMG, Hamburg, Germany), Virtual (Ivoclar Vivadent, Schaan, Liechtenstein), and Elite HD+ (Zhermack, Badia Polesine (RO), Italy), were selected for comparison [Table 1].

Tear strength

Un-nicked specimens with a 90° angle on one side and with tab ends (type C-right angle, $n = 5$) were prepared, gripped symmetrically at 15 mm away from each end, and stretched at 500 mm/min until they broke using a Shimadzu (AGS-X-10 KN-table top) tester in accordance with ASTM-D624.

Tear strength (T_s) was calculated as follows:

$$T_s = F/d$$

where F = the maximum force in Newton, d = the median thickness of the sample in millimeters (measured at three places across the right angle and the end of each sample).

Tensile strength and elongation at break

The specimens (type 1, $n = 5$) for tensile strength and elongation at break were prepared and tested at 500 mm/min on a Shimadzu (AGS-X-10 KN-table top) tester in accordance with ISO 37. The test length was 25 ± 0.5 mm. Tensile strength (TS or σ) was calculated using the following formula:

$$\sigma = F_m/Wt$$

where F_m = the maximum force recorded in Newton, W = the mean width of the narrow portion of the sample in millimeters, t = the mean thickness of the test length of the sample in millimeters.

Elongation at break (E_b or ε) as a percentage was expressed as follows:

$$\varepsilon = (\Delta L/L) \times 100$$

where ΔL is increased length, and L is the initial test length.

Examples of specimens and testing on a Shimadzu (AGS-X-10 KN-table top) tester for tear strength and tensile strength are shown in Figures 1 and 2.

Statistical analysis

Minitab 18 Statistical Software (Minitab, LLC., State College, Pennsylvania) was employed to do statistical analysis for all obtained results. A one-way ANOVA ($P = 0.05$) was used to analyze the mean values for tear strength, tensile strength, and elongation at break, respectively, followed by Tukey's *post hoc* comparison ($P = 0.05$). The relationships between tear strength and tensile strength and between tensile strength and elongation at break were characterized by Pearson correlation coefficient (R).

Results

Experimental material showed significantly higher tear strength and elongation at break compared to other impression materials for both light body (LB) and heavy body (HB) ($P < 0.001$) [Figures 3 and 4]. For tensile strength, Experimental is similar to most impression materials (Elite HD+, Express, Honigum, Virtual, etc., $P > 0.05$) but significantly lower than

Table 1: VPS impression materials used in this study

Materials	Manufacturer	Type (ISO-4823)	Composition
Exp.	Glidewell	3-LB, 1-HB	Vinyl polydimethylsiloxane, polymethyl hydrogensiloxane, surfactant, organoplatinic complex, fumed silica, wollastonite, cristobalite
Capture	S&C Polymer	3-LB, 1-HB	Polydimethyl polymethyl vinyl siloxane, polydimethyl polymethyl hydrogen siloxane, silica, paraffin
Express	3M ESPE	3-LB, 1-HB	Vinyl polydimethylsiloxane, dimethyl methyl hydrogen silicone, poly(dimethylsiloxane), quartz silica, silane-treated silica, c.i. pigment blue 28
Imprint 3	3M ESPE	3-LB, 1-HB	Vinyl polydimethylsiloxane, dimethyl methyl hydrogen silicone, glycols, polyethylene, methyl 3-[1,3,3,3-tetramethyl-1-(trimethylsiloxy) disiloxanyl]propyl ether, silane-treated silica, cristobalite, quartz silica
Imprint 4	3M ESPE	3-LB, 1-HB	Vinyl polydimethylsiloxane, poly(dimethylsiloxane), silane-treated silica, cristobalite
StartVPS	Danville	3-LB, 1-HB	Polydimethylsiloxane, silica, and paraffin
Honigum	DMG	3-LB, 1-HB	Polyvinyl siloxane, platinum catalyst, silicon-dioxide-based fillers, additives, pigments
Virtual	Ivoclar Vivadent	3-LB, 1-HB	Vinylpolysiloxane, methyl hydrogen siloxane, silica, organoplatinic complex and food dyes
Elite HD+	Zhermack	3-LB, 1-HB	Alkyl phenol polyethylene glycol ether, quartz, cristobalite

*LB = light body, HB = heavy body

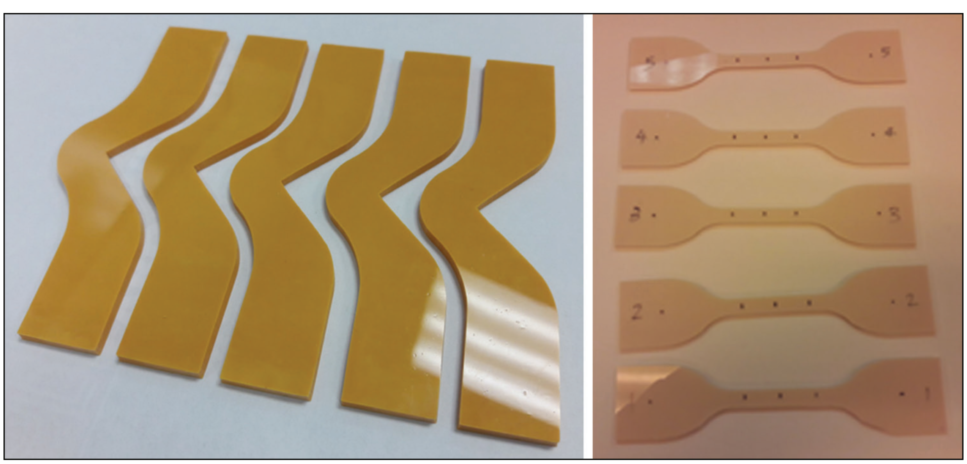

Figure 1: Examples of specimens for tear strength (left) and tensile strength (right)

Imprint 3 and Start VPS for LB ($P < 0.001$) [Figure 5]. The tensile strength of Experimental HB is slightly or significantly higher than that of other impression materials ($P > 0.05$ or $P < 0.001$) except for Start VPS [Figure 5].

Pearson's correlations for tear strength and tensile strength, and tensile strength and elongation at break, are shown in Figures 6–9. Based on Evans' and Moore's guides,[23,24] no or very weak correlation for light bodies (Pearson's correlation coefficient $R = 0.0775$) and a weak or moderate correlation for heavy bodies ($R = 0.4651$) was observed between tear strength and tensile strength, and a moderate correlation ($R = 0.5428$) for light bodies and very weak or no correlation ($R = 0.1162$) for heavy bodies were found between tensile strength and elongation at break.

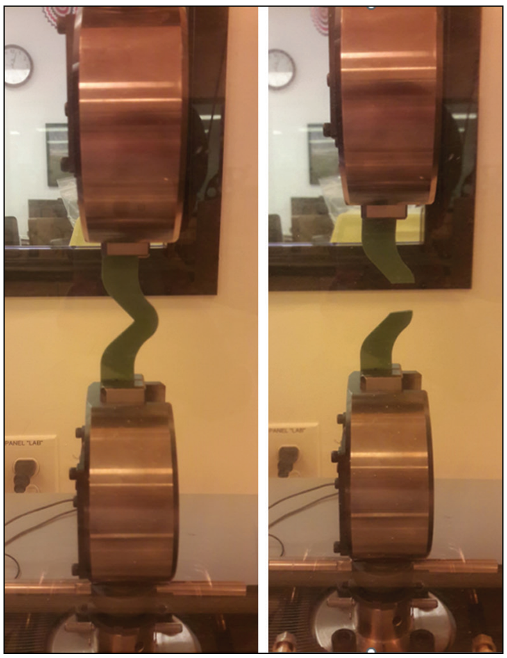

Figure 2: Example of a specimen loaded and failed on a Shimadzu universal testing machine

Discussion

Tear strength is an essential mechanical property for the impression material to resist tearing during impression removal. Tear strength is the capability of the material to resist tearing under tensile stress, which was determined using a right angle (type C) according to ASTM-D624. Experimental exhibited significantly higher or higher tear strength than other impression materials for both LB and HB ($P < 0.001$).

During impression removal from the mouth, tensile stress is applied. Impressions should not only resist tearing but also have adequate tensile resistance and sufficient elongation for elastic recovery. Tensile strength is the maximum stress that a material can withstand while being stretched or pulled before breaking, which was determined according to ISO 37 (type 1). It is reported that impression materials are subjected to both compressive and tensile forces;[25] however, the maximum tensile removal stress of impression materials is greater than the maximum compressive seating force,[26] especially when the impression materials are pulled from undercut and interproximal areas.[27]

Elongation at break is a material's resistance to breaking when stretched, which indicates how much a material can elastically and plastically deform before failure. Soft elastic materials can deform several times their own length before breaking and typically feature a higher elongation at break. Therefore, a high elongation is desired, especially for the light bodies

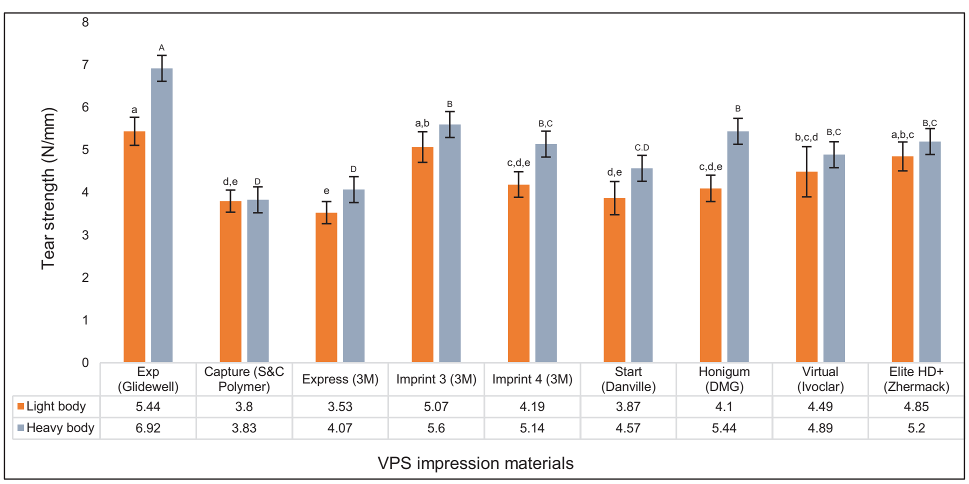

Figure 3: Tear strength of VPS impression materials (*Value bars with the different letters are statistically different between the tested groups)

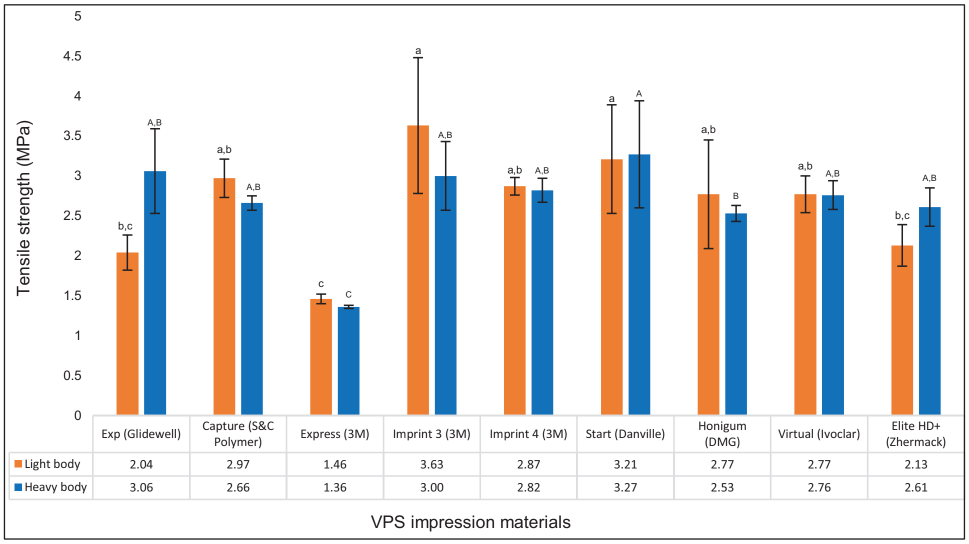

Figure 4: Elongation at break of VPS impression materials (*Value bars with the different letters are statistically different between the tested groups)

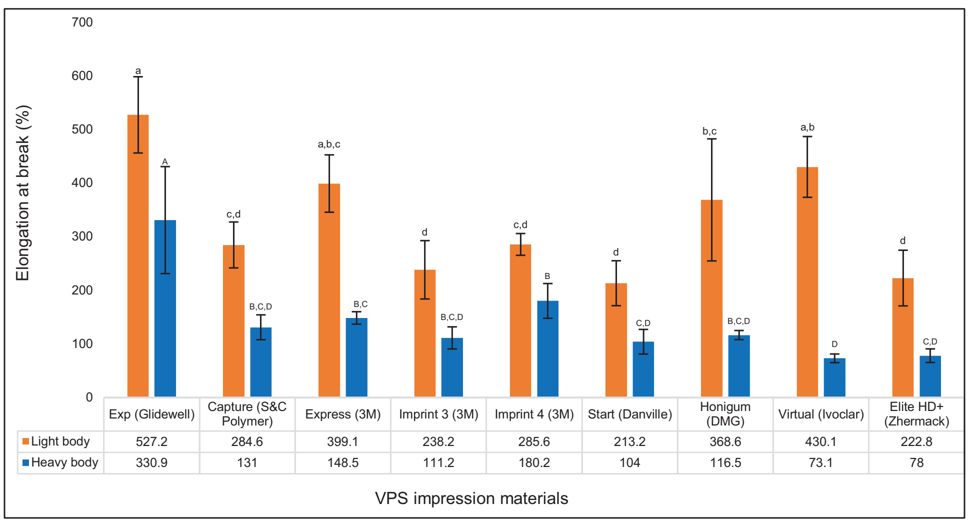

Figure 5: Tensile strength of VPS impression materials (*Value bars with the different letters are statistically different between the tested groups)

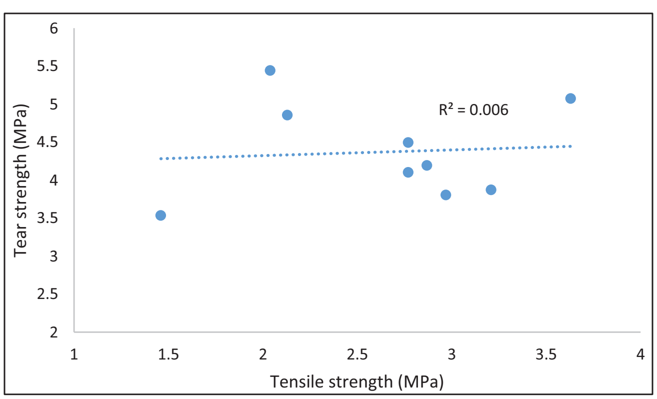

Figure 6: Correlation of tear strength and tensile strength of VPS impression materials (light bodies)

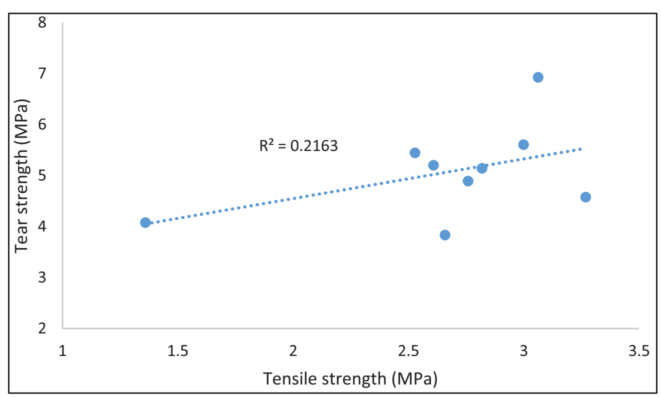

Figure 7: Correlation of tear strength and tensile strength of VPS impression materials (heavy bodies)

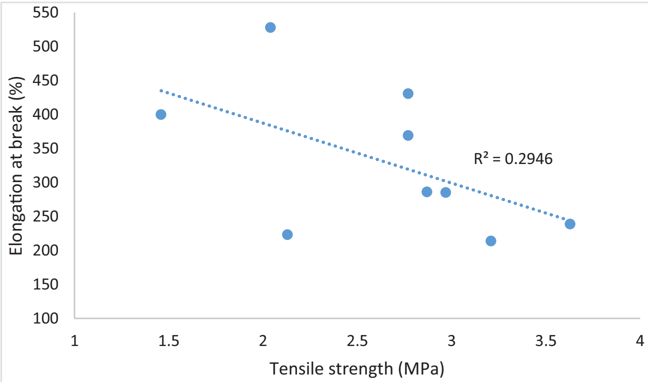

Figure 8: Correlation of tensile strength and elongation of VPS impression materials (light bodies)

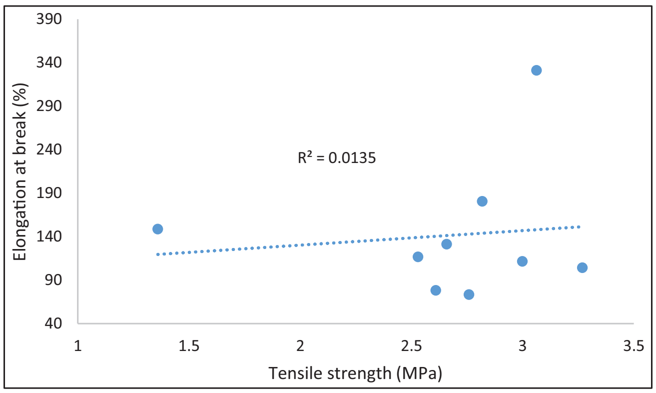

Figure 9: Correlation of tensile strength and elongation of VPS impression materials (heavy bodies)

when impression materials are pulled from undercuts and interproximal areas and stretched in tension. For LB impression materials, Experimental showed tensile strength slightly lower than or similar to most of the impression materials ($P > 0.05$) but significantly lower than Imprint 3 and Start VPS ($P < 0.001$). For HB impression materials, Experimental has slightly or significantly higher tensile strength than other impression materials ($P > 0.05$ or $P < 0.001$) except Start VPS. Experimental showed significantly higher elongation at break than other impression materials for both LB and heavy bodies ($P < 0.001$).

The abovementioned different mechanical properties between Experimental and other impression materials resulted mainly from the differences in the chemical composition (resins, catalysts, additives, and fillers) and viscosity of impression materials, and so on.[21,28-31] Most commercially available VPS impression materials used one or two or more vinyl polydimethylsiloxanes as curable resins and one or two or more silica powders as fillers such as cristobalite and quartz [Table 1], along with some additives such as surfactant. As vinyl polydimethylsiloxane is a base prepolymer for addition-curing room temperature vulcanization (RTV), the actual vinyl polydimethylsiloxanes used by different manufacturers may be different due to the difference in structure, vinyl content, molecular weight, and viscosity, for example, vinyl polydimethylsiloxanes from Gelest and Evonik. Even for the same manufacturer like Evonik, vinyl polydimethylsiloxane resins with the same viscosity from different series have different vinyl content; for example, VQM 900 series has a higher vinyl content compared to the Polymer VS series.[32,33] Catalysts and some additives have similar situations to resins. A variety of inorganic fillers may be employed, such as silica and metallic oxides, to provide the impression materials with adequate strength because unfilled impression materials have extremely poor mechanical properties. The composition, loading, particle size, and distribution of the filler have a crucial impact on the mechanical properties. Experimental impression material was made by our resin and filler composite technology, which was based on multiple vinyl polydimethylsiloxane resins with different vinyl content (0.04–0.43 wt.%), molecular weight (17,200–117,000 g/mol), and viscosity (200–60,000 cSt), and on combination of three silica fillers (fumed silica, wollastonite, and cristobalite) with consideration of good balance of mechanical strength and other properties such as viscosity. Therefore, the optimal formula, like ratios of different polydimethylsiloxane resins, and of three silica fillers and ratio of resins and fillers, can meet the consistency/viscosity requirement required by ISO-4823 and provide improved mechanical properties. As manufacturers provided limited information for the compositions, it is hard to obtain detailed information about the resins and fillers used and to compare the composition differences for these impression materials.

Clearly, the heavy bodies of impression materials have significantly higher ($P < 0.05$, or <0.001) or higher ($P > 0.05$) tear strength and significantly lower ($P \leq 0.001$) elongation at break compared to their corresponding LB impression materials, which were mainly contributed by their viscosity [heavy bodies (type 1) have higher viscosity than light bodies (type 3) based on ISO-4823 classification], depending on their composition (filler loading and properties, resins, etc.).[20,21,30] But, in terms of tensile strength, some impression materials showed no significant difference between LB and HB of the same impression materials ($P > 0.05$), such as Imprint 3, Imprint 4, Start VPS, Honigum, and Virtual; others showed significant difference between light bodies and heavy bodies ($P <$ 0.05 but close to 0.05), such as Experimental, Capture, Express, and Elite HD+, which indicated that the viscosity influence from LB to HB on tensile strength is not remarkable as on tear strength and elongation at break. Although HB has higher tear strength than LB, LB is typically applied in the interproximal/ subgingival areas where the impression is most likely torn; therefore, the tear property of LB impression materials is more clinically relevant.[20]

Tear strength and tensile strength are crucial properties for impression materials; however, to the best of the authors' knowledge, there is little information on the relationships between tear strength and tensile strength and tensile strength and elongation at break for impression materials. Based on all impression materials tested, there are very weak or no correlations between tear strength and tensile strength for light bodies (Pearson's correlation coefficient R = 0.0775) and a weak or moderate correlation for heavy bodies (R = 0.4651) according to what Evans and Moore suggested.[23,24] The correlation between tear strength and tensile strength of light bodies is similar to the results that tear strength was not correlated with tensile strength by Lu *et al.*[20] (R = −0.033) and Pandey *et al.*[21] (R = −0.056). However, the results of Lu *et al.*[20] and Pandey *et al.*[21] are based on only three impression materials that belong to different types of impression materials (VPS, PE, and polyvinyl ether silicone), yet their results are probably based on both LB and heavy bodies. A moderate correlation between tensile strength and elongation at break was found for light bodies (R = 0.5428); that is, elongation at break is moderately inversely proportional to tensile strength for LB impression materials tested in this study. This is consistent with a study by Wu *et al.*[34] However, heavy bodies only showed a very weak or no correlation (R = 0.1162) between tensile strength and elongation at break. The degree of correlation between tensile strength and elongation depends on material categorization or type (such as vinyl polysiloxane or PE, LB, or HB under the same category) and composition (such as filler loading).[16,17,35,36]

This study investigated three major mechanical properties of a newly formulated VPS and eight other commercially available VPS impression materials to ensure that the impression materials can withstand stress under various situations and have an accurate impression for restoration. However, this study did not consider other properties like hydrophilicity, dimensional accuracy, and stability, which also affect the accuracy impression. Future work on other properties like hydrophilicity and dimensional accuracy is ongoing and will be reported later.

Conclusions

The Glidewell Exp VPS impression material exhibited a significantly higher tear strength and adequate tensile strength with higher elongation at break compared to other commercially available VPS impression materials. Based on all impression materials tested, there is a very weak or no correlation for light bodies and a weak or moderate correlation for heavy bodies between tear strength and tensile strength. A moderate correlation on light bodies and a very weak or no correlation on heavy bodies was observed between tensile strength and elongation at break.

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Conflicts of interest

The authors declare no conflicts of interest.

Authors contributions

LL: Conceptualization, methodology, writing—original draft preparation, writing—review and editing, formal analysis, investigation, data curation; TL: investigation, data curation, resources; RM: project administration, funding acquisition.

Ethical policy and Institutional Review board statement

Not applicable.

Patient declaration of consent

Not applicable.

Data availability statement

The data are contained in the article.

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