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Volumetric evaluation and three-dimensional accuracy of different elastomeric impression materials

Faruk Emir*, Simel Ayyildiz, Bulent Piskin, Cumhur Sipahi

University of Health Sciences, Gülhane Faculty of Dentistry, Department of Prosthodontics, 06010 Ankara, Turkey

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ABSTRACT

Although there is more information on the theoretical shrinkage of different elastomeric impression materials, there are insufficient number of 3-dimensional evaluations on volumetric differences and accuracy of definitive casts. The purpose of this in vitro study was to evaluate volumetric changes and the accuracy of four different impression materials using a 3-dimensional computer-aided measurement method. All definitive casts are compared with the master model by using computer-aided measurements. The 3-dimensional accuracy determined by best-fit alignment method and volumetric changes were identified by volumetric measurements. Detected changes are represented in color-coded maps and cross sections. Condensation silicon was significantly differing from polyether, polyvinyl siloxane and vinyl siloxanether. Except polyvinyl siloxane, vinyl siloxanether presented significantly lowest volumetric difference value from condensation silicon and polyether.

1. Introduction

Elastomeric impression materials are commonly used in clinical dentistry and have been subject of numerous studies [1–3]. In order to obtain clinically acceptable results, the effect of dimensional accuracy of elastomeric impression materials and impression procedures on the fabrication of prosthetic restorations should be taken into consideration [4,5]. Therefore, accurate and dimensionally stable impression materials are crucial for the production of precise definitive casts [6].

Currently, condensation silicones (CNDS), polyethers (PE), polyvinyl siloxanes (PVS) and vinyl siloxanethers (VSE) are commonly used dental impression materials. Some properties of the impression materials such as dimensional accuracy [7–12], storage time [13–16], material and tray selection [4,9,17,18], and impression techniques [19–22] were evaluated in many studies. During and upon setting, these materials exhibit dimensional changes and it is difficult to identify and evaluate complex geometrical differences with 2-dimensional measuring methods. Investigation of the dimensional changes occurred on definitive casts require accurate equipment and measurement methods [23]. Developments in digitizing systems and compatible software convert 2-dimensional measurements to 3-dimensional computer-aided techniques. In this way, the accuracy of devices and assessment quality are improved. Therefore, the identification of dimensional differences over the entire model has allowed us to make more quantitative and qualitative analysis of the accuracy of indirect restorations and to have better information [23–26].

In most of the studies, manual devices such as; analog or digital calipers, profile projectors, and microscopes were used for the accuracy measurement of definitive casts [23,27]. Although, they are easy to use and readily available, they are susceptible to operator errors, and could not show 3-dimensional differences all over the definitive casts. 2-dimensional analysis implies data loss [28] and dimensional changes in 3-dimensional measurements cannot be found in the 2-dimensional analysis [1,14]. Therefore, objective and repeatable method are crucial to detect 3-dimensional changes [23–25,29–38].

The purpose of this in vitro study was to evaluate volumetric differences and to compare the accuracy of definitive casts obtained from different impression materials. The null hypothesis was that the accuracy of definitive casts fabricated from CNDS would be lower than the other materials and that there should be volumetric differences as well as there would be no significant differences in the accuracy of the PE, PVS and VSE impression materials.

2. Materials and methods

The implementation stages of the study were as follow; fabrication of the master model, impression procedure, fabrication and digitization of the master model and definitive casts, 3-dimensional comparisons, and statistical analysis.

* Corresponding author.
E-mail address: emirfaruk@gmail.com (F. Emir).

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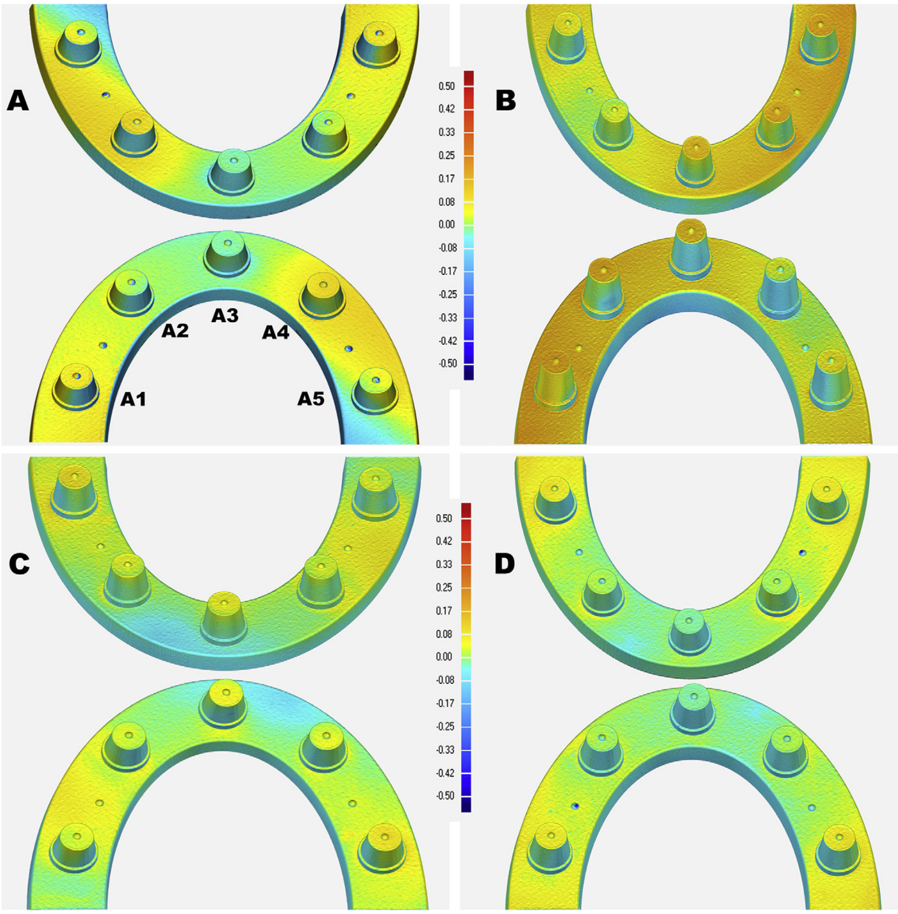

Fig. 1. Superimposition of definitive casts onto master model (the main numerical values are in Table 1). Yellow through red indicates cast is larger than master model; light blue through dark blue indicates cast is smaller than master model; green surface shows there is no difference between definitive cast and master model. A: CNDS B: PE C: PVS D: VSE. Abutments were designated as A1, A2, A3, A4 and A5.

2.1. Fabrication of the master model

Fabrication steps of the master model, custom trays and impression apparatus were carried out as detailed in our previous study [38].

2.2. Impression procedure

Auto-mixed polyether (PE, Impregum Penta; 3 M ESPE), polyvinyl siloxane (PVS, Express XT Penta Putty; 3 M ESPE), and vinyl siloxanether (VSE, Identium Heavy; Kettenbach) impression materials and light body consistency PE (ImpregumGarant Soft; 3M ESPE), PVS (Express XT Light Body; 3 M ESPE), VSE (Identium Light; Kettenbach) syringe materials for automix gun system, handmixed putty/light body condensation silicone (Optosil Comfort/Xantopren L, Heraeus Kulzer) and two-step putty/wash technique used during impression process. Metal copings were placed on each abutment and auto-mixed impression materials dispensed from an automatic dispenser (Pentamix II; 3 M ESPE) into the custom tray, and then seated on the master model, and the upper plate of the impression apparatus lowered onto the custom tray and constant force of 14.7 N applied. The same volume of impression material was used each time to standardize the study. The custom tray was removed from the master model after the setting of impression materials, and the light body was injected into the first impression with the auto-mix gun system for PE, PVS, VSE materials and a syringe was used for CNDS material. Then, the upper plate was again seated onto the correct position and impression set undisturbed twice the manufacturer's recommended time [39].

Forty impressions (n = 10 for each impression material) were taken under the same room conditions (25 °C), by the same prosthodontist. All impressions were examined visually by two prosthodontists, and impressions with bubbles or voids were excluded from study. All impressions were stored for 1 h before the pouring procedure [40].

2.3. Fabrication and digitization of the master model and definitive casts

All definitive casts were poured using Type IV dental stone (Fuji Rock; GC Europe, Belgium) with a powder water ratio of 150 gr/30 mL per impression. Dental stone was mixed with hand for 15 s and with mechanical vacuum mixing device (Degussa Multivac 4; Degussa AG, Germany) for 45 s according to the manufacturer's recommendations. Each definitive cast was poured under vibration (Degussa Vibrator R2; Degussa AG, Germany) and allowed to set for 2 h at room temperature.

The master model was digitized with an optic scanner (OS) (Activity 850, Smart Optics; Bauman Sensortechnik GmbH, Germany) and virtual reference master model was obtained. Digitization process of 40 definitive casts was performed with the same OS and 40 virtual definitive casts were obtained. OS was periodically calibrated before the digitization procedure for each of the 10 definitive casts.

2.3.1. 3-dimensional comparisons and statistical analysis

The differences between definitive casts and master model were investigated with computer-aided measurement (CM). Evaluations of digitized data were performed in the following steps: (1) best-fit alignment method, (2) whole deviation process including color-coded maps and (3) calculation volumes of abutments and cross-sectional presentations of abutments.

Data of virtual reference master model and each virtual definitive cast were superimposed by a CAD software (Geomagic Verify; 3D Systems Inc, USA) using best-fit alignment method. The calculation of this method is based on the determination of the best-fit between each of the 170,000 data points per digitized definitive cast and the reference master model. Only one prosthodontist was evaluating the

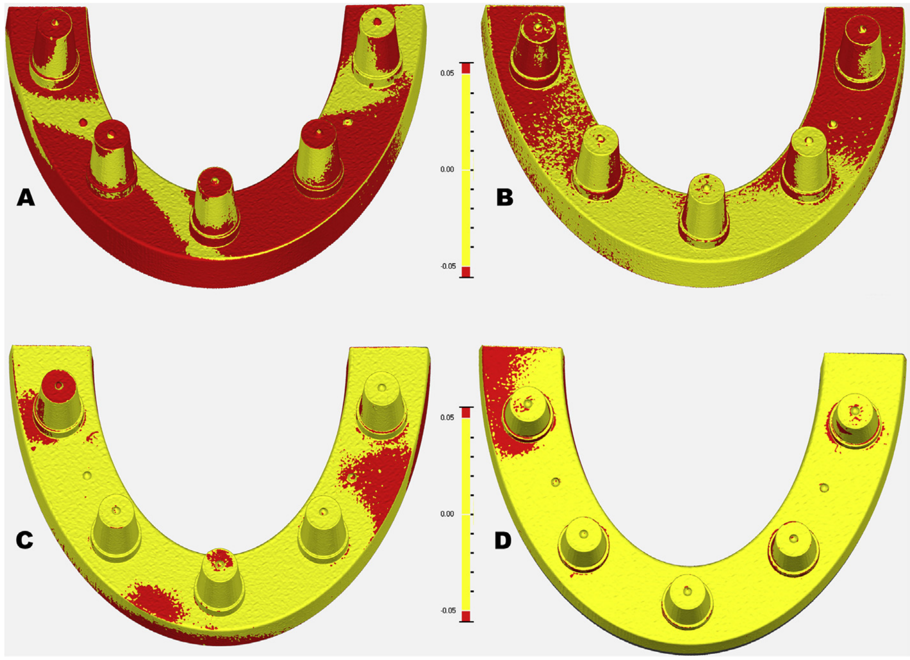

Fig. 2. Graphical presentation of deviation distribution and pass-fail scale. A: CNDS B: PE C: PVS D: VSE

superimposed data to eliminate the inter-operator variability. The results were indicated by average (Avg), average-positive (Avg+) and average-negative (Avg−) deviations. Positive values demonstrate expansions, while negative values demonstrate contraction areas on definitive casts as against the virtual reference master model.

In next stage, each virtual definitive cast was compared to the virtual reference master model to obtain a color-coded map, which showed the distribution of 3-dimensional deviations over the complete surface of each definitive cast (Fig. 1).

In the color-coded maps, yellow to red fields represent enlargements; light blue to dark blue fields represent contractions on the definitive casts. Graphical pass-fail presentation of deviations was also given. Pass value shows (yellow fields) deviations, which remain between 0 and 50 µm and fail value shows (red field) deviations higher than 50 µm (Fig. 2).

The deviation range is color-coded from −50 to +50 µm. Red surface shows differences higher than 50 µm. A: CNDS B: PE C: PVS D: VSE.

In the last stage, the volume of each abutment on definitive casts and also total volume of all abutments were calculated and compared with the abutments on reference master model to determine the volumetric differences**.** Additionally, all abutments were sectioned on XZ plane to observe the location of occurred deviations (Fig. 3).

SPSS version 20.0 (SPSS Inc., Chicago, IL, USA) was used for statistical analysis. One-way ANOVA analysis was performed to compare the groups. Post-Hoc tests were used for multiple comparisons. A value of $p < .05$ was considered statistically significant.

3. Results

Mean dimensional differences on definitive casts fabricated with CNDS, PE, PVS and VSE were −0.039 ± 0.014 mm, −0.025 ± 0.012 mm, −0.022 ± 0.009 mm, −0.015 ± 0.002 mm for Avg values, 0.061 ± 0.032 mm, 0.028 ± 0.022 mm, 0.031 ± 0.007 mm, 0.027 ± 0.014 mm for Avg + values and −0.086 ± 0.032 mm, −0.053 ± 0.053 mm, −0.047 ± 0.014 mm, −0.040 ± 0.016 mm for Avg− values. The dimensions of the definitive casts were found to be smaller than the master model.

The effect of different impression materials on the accuracy of definitive casts was analyzed with One-Way ANOVA test. ANOVA showed no significant differences between PE, PVS and VSE in terms of Avg, Avg+ and Avg− values (Table 1).

On the contrary, significant differences between CNDS and other three impression materials were observed in Avg, Avg+ and Avg− values (Fig. 4).

Volumetric differences on each abutment were analyzed with Post Hoc test. The highest deviations were observed on A2–A4. Obtained data from volumetric measurements of each abutment constructed from different impression materials are given in Fig. 5.

In terms of "Total volumetric difference" values, no significant differences were found between PVS and VSE ($p = .669$) and between PVS and PE ($p = .150$). On contrary, significant differences were found between PE and VSE ($p < .011$) (Table 2).

CNDS showed highest total volumetric difference among tested materials ($p = .688$, $p = .012$, $p < .001$) (Fig. 6).

According to the color-coded maps, on molar region, circumferential slight contraction of the abutments, and an elongation of the top surface was observed. (A1 and A5). On anterior region (A2, A3 and A4) a generalized circumferential contraction and reduction in height was observed (Fig. 1).

According to the cross sections abutments were reduced in circumference and on some abutments enlargements were found in height. Deviations mostly occurred on the shoulder finish lines and edges were rounded. Abutments of PVS and VSE were close to the master model. Some inaccurate areas where observed on the shoulder finish lines of PVS and VSE and also edges were rounded (Fig. 3).

4. Discussion

According to the best-fit alignment method the definitive casts fabricated from PE, PVS and VSE impression materials demonstrated accurate dimensional stability, except CNDS. Volumetric measurements showed significant differences were found between VSE and PE and CNDS. However, between VSE and PVS no significant differences were found. Therefore, the null hypothesis of the study was accepted.

The result of this study support the study of Nassar et al. [13] and authors reported that VSE were more accurate than PE and PVS materials. Conversely, Shah et al. [23] stated that PE was more accurate

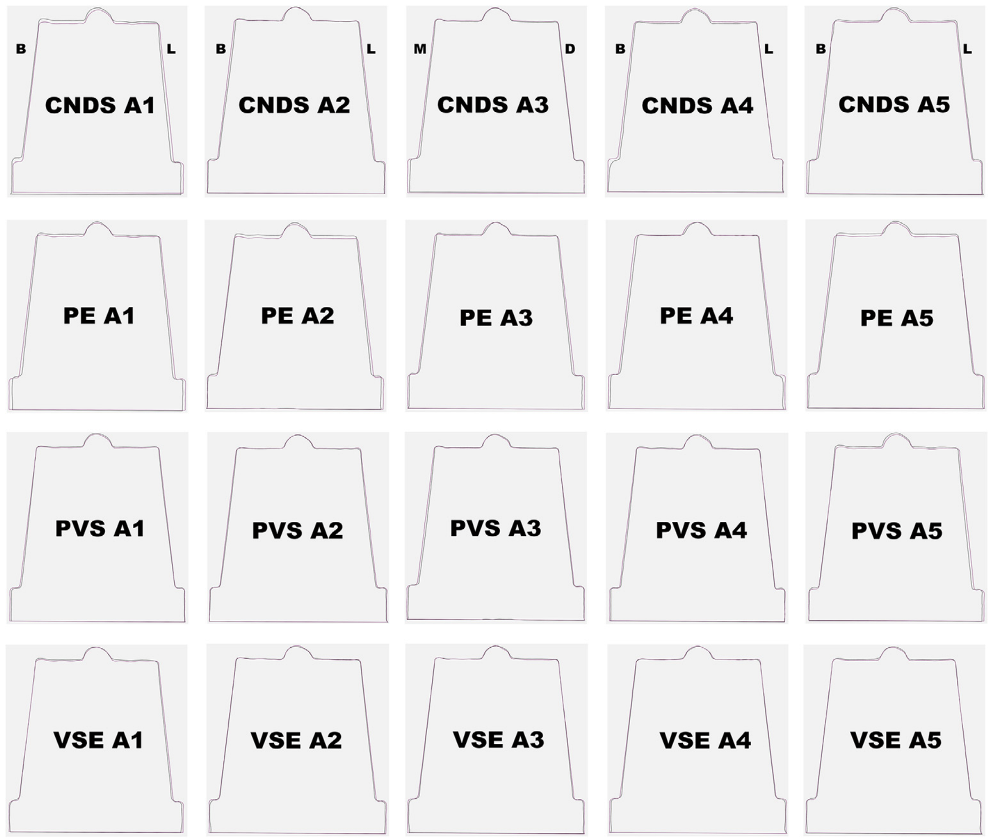

Fig.3. Cross-sections on XZ plane. Red lines represent master model and black lines represent definitive casts.

than PVS. This difference might be the lower elastic recovery capability of PE than PVS [41]. According to Stober et al. [7] PE, PVS and VSE showed clinically acceptable results. Marković et al. [40] reported that between PVS and CNDS significant differences were found and PVS was more accurate. According to the studies above accuracy of impression materials were related to many factors, such as the type of impression materials and trays, various impression techniques and the geometry of the master model.

In previous studies, the master models used for assessment of impression materials were designed linear [2,3], or arch form [27,42]. It was stated that arch shaped master models would be more relevant to clinical conditions in the evaluation of impression materials [23]. Also, some authors suggested using custom acrylic impression trays to reduce the amount of the dimensional changes [3,27]. In terms of impression technique, some authors reported that more accurate casts were fabricated with two-step putty/wash technique [2,8]. In this study arch shaped metal master model, custom trays and two-step putty/wash technique were used.

CM has been used as a reference method in some recent studies for high precision analyzes [23,27,38]. In this study, 3-D analyze software was used to assess dimensional accuracy of definitive casts. Shah et al. [23] evaluated the accuracy of PVS and PE impressions with software to analyze differences between the master model and definitive casts. Best-fit alignment method was used in other studies to evaluate the full arch 3-D accuracy of definitive casts and investigate dimensional discrepancies [10,29,37,43]. Moreover, some authors also used the CM and analyzed the distribution of the 3-D differences and showed on the color-coded maps [31,37,38].

In some studies, the accuracy of full-arch definitive casts was ranging from 0.01 mm to 0.06 mm [29,32,33,35,42,43]. However, the varying differences might be related to different impression materials, techniques and trays. In this study, accuracy of the definitive casts for complete arch was ranged between 0.01 mm and 0.03 mm for Avg values. In the fabrication of fixed prosthesis, marginal gaps smaller than 100 µm considered clinically acceptable [7,44,45]. In this study, results were lower than the acceptable marginal fit values. Another finding of the current study was the smaller size of definitive casts when compared to master model. There are a number of reasons that could cause definitive casts to be smaller in size of the master model. The factors responsible for the dimensional changes in elastomeric materials could be setting shrinkage [7,12,17] and loss of volatile components [13,46]. The reason of the smaller abutments might be the shrinkage of the elastomeric impression materials towards the center of the bulk material during setting [38,47]. Hence, reduced size of the abutments could result in small or tight restorations.

In the results section, Avg+ and Avg− values were given in addition to Avg values. It defines the negative and positive deviations separately in order to evaluate enlargements and contractions on definitive casts. In the quantitative inspection, if the positive and negative deviations show an equal distribution, total deviation values will be close to zero. For this reason, qualitative inspection on color-coded maps was a necessity to evaluate distribution of deviations [1,5,21,22,24,25,31,34,36,48].

Color-coded maps show irregularly occurring deviations entire definitive cast. According to the color-coded maps, generally the size of abutments reduced and the highest differences were occurred on CNDS. The reason of this might be the inadequate elastic recovery of CNDS that cannot compensate the distortion while repositioning the tray with putty/wash material. Cross sections also showed similar results with color-coded maps. Additionally, the highest volumetric differences were observed on A2–A4. These abutments are located on the curvatures which are vulnerable to the digitization. This may be the result of optical errors due to the overlapping scans during digitization [25].

Table 1
Avg, Avg + and Avg − differences of the impression materials compared with the reference master model.

	Group		Mean (μm)	SE	*P*-value
Avg	CNDS	PE	−13.31[a]	4.8	0.047
		PVS	−16.24[a]	4.8	0.011
		VSE	−24.00[a]	4.8	< .001
	PE	CNDS	13.31[a]	4.8	0.047
		PVS	−2.93[b]	4.8	0.932
		VSE	−10.69[b]	4.8	0.147
	PVS	CNDS	16.24[a]	4.8	0.011
		PE	2.93[b]	4.8	0.932
		VSE	−7.76[b]	4.8	0.400
	VSE	CNDS	24.00[a]	4.8	< .001
		PE	10.69[b]	4.8	0.147
		PVS	7.76[b]	4.8	0.400
Avg +	CNDS	PE	32.69[a]	9.5	0.008
		PVS	30.17[a]	9.5	0.017
		VSE	33.88[a]	9.5	0.006
	PE	CNDS	−32.69[a]	9.5	0.008
		PVS	−2.52[b]	9.5	0.994
		VSE	1.19[b]	9.5	0.999
	PVS	CNDS	−30.17[a]	9.5	0.017
		PE	2.52[b]	9.5	0.994
		VSE	3.71[b]	9.5	0.980
	VSE	CNDS	−33.88[a]	9.5	0.006
		PE	−1.19[b]	9.5	0.999
		PVS	−3.71[b]	9.5	0.980
	CNDS	PE	33.03[a]	11.4	0.032
		PVS	−38.88[a]	11.4	0.009
		VSE	−45.12[a]	11.4	0.002
Avg −	PE	CNDS	33.03[a]	11.4	0.032
		PVS	−5.85[b]	11.4	0.956
		VSE	−12.09[b]	11.4	0.720
	PVS	CNDS	38.88[a]	11.4	0.009
		PE	5.85[b]	11.4	0.956
		VSE	−6.24[b]	11.4	0.948
	VSE	CNDS	45.12[a]	11.4	0.002
		PE	12.09[b]	11.4	0.720
		PVS	6.24[b]	11.4	0.948

*Different alphabets mean significantly different differences at an experiment-wise alpha level 0.05.

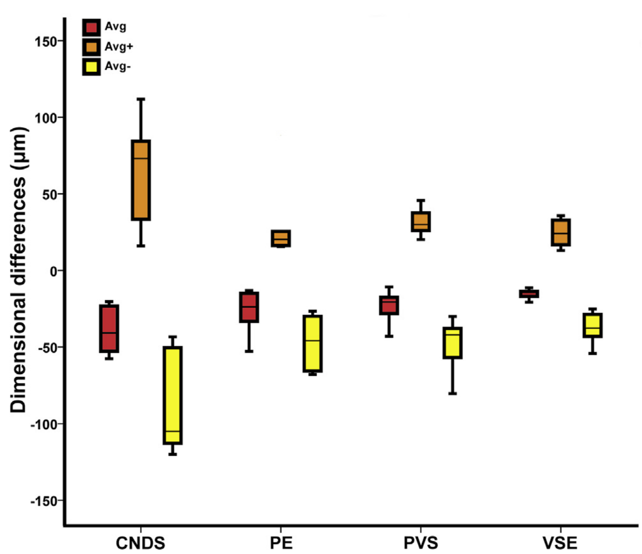

Fig.4. Avg, Avg + and Avg − values in μm. Differences between CNDS and other three impression materials were significant ($p < .008$, $p < .017$, $p < .006$). Differences between PE, PVS and VSE were not statistically significant ($p = .09$, $p = .9$, $p = .9$).

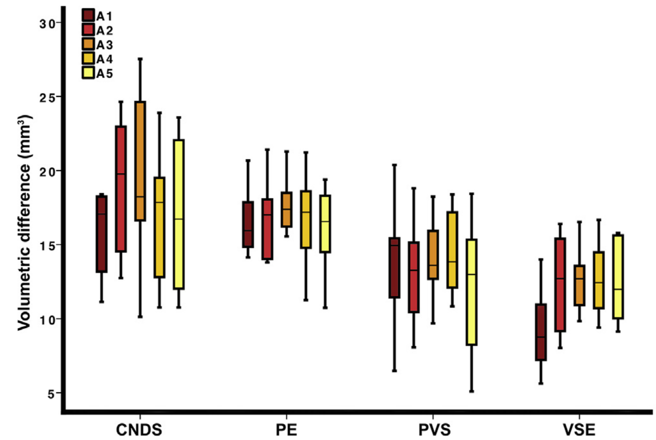

Fig. 5. Mean volumetric difference values (mm^3) of each abutment and standard deviation after superimposition of reference master model.

Table 2
Comparison of total abutment volume differences in digitized models of the 4 types of impressions.

		Mean difference (mm^3)	SE	*P*-Value
CNDS	PE	7.528[a]	6.8	0.688
	PVS	22.308[b]	6.8	0.012
	VSE	30.045[b]	6.8	< .0010.68
PE	CNDS	−7.528[a]	6.8	8
	PVS	14.780[a]	6.8	0.150
	VSE	22.517[b]	6.8	0.011
PVS	CNDS	−22.308[a]	6.8	0.012
	PE	−14.780[b]	6.8	0.150
	VSE	7.737[b]	6.8	0.669
VSE	CNDS	30.045[a]	6.8	< .001
	PE	22.517[a]	6.8	0.011
	PVS	−7.737[b]	6.8	0.669

*Different alphabets mean significantly different differences at an experiment-wise alpha level 0.05.

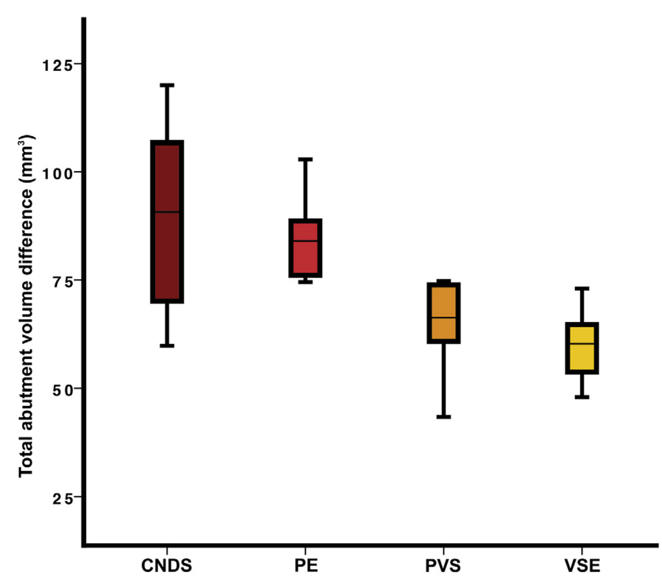

Fig. 6. Total volumetric differences of all abutments on definitive casts made of different impression materials.

5. Conclusion

1. The accuracy of PE, PVS and VSE impression materials were close to each other and display acceptable accuracy for clinical use.
2. The smallest variation range of deviations was obtained with VSE material.
3. According to the total volumetric difference measurements PVS was as dimensionally accurate as VSE. Also, VSE was more accurate than PE (p = .011) and CNDS (p < .001).
4. The highest dimensional changes occurred in the anterior region and abutments were observed to be mostly smaller than the master model.

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