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The Effect on Cast Post Dimensions of Casting Investment and Airborne Particle Abrasion

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Abstract - *Cast posts can sometimes prove difficult to seat fully during fitting. This study compared two different liquid/water dilutions for phosphate bonded investment and the effect of controlled airborne particle abrasion on resulting post diameter. After measuring polymeric post patterns (n=18), 3 groups were invested using concentrated solution and 3 groups using dilute solution. After casting they were weighed and remeasured then exposed to airborne particle abrasion. Both solutions produced oversized cast posts. Mean diameter reduction during airborne particle abrasion was 8 µm/10s taking an average of 41s to reach precast size. Where a post pattern fits tightly, airborne particle abrasion for 70s should reduce the casting sufficiently to accommodate the cement lute.*

KEY WORDS: Cast posts, Phosphate bonded investments, Airborne particle abrasion

INTRODUCTION

Extensively damaged teeth with insufficient tooth structure to provide anchorage for a restoration frequently require a post retained restoration[1]. Two main types of posts are available: cast posts and prefabricated posts. Cast posts have been used for decades as a foundation restoration to support the final restoration and achieving an accurate fit is essential for its success[2]. However, an accurately fitting cast post is not always easily achieved. One of the main problems an operator may encounter is difficulty in seating the cast post during fitting due to binding with the radicular tooth structure[3]. Therefore, a slightly undersized cast post is desirable to ensure a passive fit within the prepared root canal and provide sufficient space to accommodate the cement lute. This space has been estimated to be optimally around 24-31 µm[4]. In addition this passive fit will help to avoid undesirable stress concentration and root fracture[5].

One method for producing an undersized cast post is to use a casting ring temperature of 600° C without a ring liner[3]. Posts produced using this method have been shown to require a significantly reduced time for clinical fitting and adjustment[5]. This is because the absence of a ring liner restrains the investment expansion and redirects it inward toward the mold space resulting in an undersized casting[3,5]. However, it has been found that eliminating a ring liner produced irregular expansion with possible casting distortion or cracking of the investment during expansion[6]. In addition, these studies did not explore the effects of other variables which may provide control over resulting post size. Theoretically, another way of achieving a post with a reduced diameter is by controlling the amount of investment expansion which should be designed to be slightly less than the amount of metal casting shrinkage.

Phosphate bonded investments are commonly used for investing precious, semiprecious, and nonprecious alloys that can be used for the construction of different types of restorations such as cast posts. These investments are able to withstand the high melting temperatures during casting without disintegration. In addition, they are easily removed from castings, and provide nonporous castings with minimal casting defects[7,8]. However most important of all, they are able to provide adequate expansion to compensate for the shrinkage of the alloy during solidification[7]. There are many factors which may affect the investment expansion[8-11]. One of these is the liquid/water ratio where increasing the liquid concentration increases the investment expansion[12,13,14]. Phosphate bonded investments are usually mixed with a colloidal silica liquid which should ideally be diluted with distilled water using a ratio specified by the manufacturer. The specific ratio depends on the type of alloy, restoration and material used to make the pattern. However, the optimum ratio to be used for cast posts to provide an optimum fit is not clearly defined in the literature. In addition, manufacturers often fail to specify appropriate ratios for cast posts.

Another method which has potential to produce a slightly undersized post is airborne particle abrasion. Airborne particle abrasion with aluminum oxide particles of disc shaped samples cast in a noble alloy resulted in higher volume loss than base alloys[15]. However, the practicalities of using airborne particle abrasion to reduce post diameter reliably has not yet been reported.

Hence, the first aim of this study was to compare the effect of two different liquid/water dilutions on the casting dimensions of posts invested using phosphate bonded investment. The second aim was to determine the effect of controlled airborne particle abrasion on the resulting post size and weight. The first hypothesis was "Diluting the liquid with water will reduce the expansion of the phosphate bonded investment resulting in a cast post with a smaller diameter than one made using a more concentrated solution". The second hypothesis was "Airborne particle

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abrasion of cast posts for increasing lengths of time will provide a controlled and regular reduction of post diameter and weight. It will also improve the surface morphology of cast posts."

MATERIALS AND METHODS

The Parapost XP kit was used which included polymeric impression posts, burn-out posts and drills each in 7 different nominal sizes each size color coded. Three diameters of impression post were chosen for the study: Size 4 Yellow impression posts (1.00 mm), Size 5.5 Purple impression posts (1.40mm) and Size 7 Green impression posts (1.75 mm).

The reason impression posts were chosen was because they are smooth and easier to measure with less tendency for inaccuracies which may occur with the serrated burn-out posts, particularly after the pattern has been cast.

Measuring study

The study involved measuring posts before investment, after casting and after being exposed to airborne particle abrasion using a toolmaker's microscope (accuracy 0.005mm). A Perspex jig was constructed to stabilize the post in the same place on the measuring table of the toolmaker's microscope. Measurements on the post components were conducted as follows: Ten posts of each selected size (n=30) were measured at three different locations, the top, middle and bottom part of the post. At each location two diametric measurements were taken 90 degrees from each other (X at 0 degrees and Y at 90 degrees). This provided 6 measurements for each post. Reproducibility was estimated by repeating this procedure one week after the initial reading.

Investing and casting

A constant powder to liquid ratio of 60g phosphate bonded investment powder to 14 ml diluted colloidal silica investment liquid was used at all times. Two liquid dilutions were investigated. One used routinely by our dental laboratory for all restorations including posts with a ratio of 10 ml of colloidal silica liquid to 4 ml of distilled water (1 : 0.4) representing a concentrated solution (CS). The second liquid dilution, 7.2 ml of colloidal silica liquid diluted with 6 ml of distilled water (1: 0.83) represented the most dilute solution (DS) which is the dilution recommended by the investment manufacture for inlays/onlays and partial crowns using GC Pattern Resin for semi precious alloys.

The posts were divided into 6 groups [n=18]. Three groups were invested using the CS (G1, G2, G3) and three groups were invested using the DS (G4, G5, G6). Each group consisted of 3 posts which were sizes 4, 5.5, and 7. They were attached to the crucible former by wax and placed in a size one ring with a ring liner and sprayed with a wetting agent. The phosphate bonded investment was then mixed with a vacuum mixer for one minute, poured into the ring and left to set for 20 minutes at room temperature. The vacuum mixer had been tested with a stroboscope for a consistent speed of 420 rpm. After 20 minutes the rings were placed in a preheated furnace at 750° C for 40 minutes. Then, the rings were taken out of the furnace and placed in the casting machine where the gold alloy (Yellow special, 41.0% Au, 0.4% Pt, 1.7% Pd, 44.9% Ag, 11.0% Cu, <1.0% Sn, Zn, Ru,) was melted at 900°C for 30 seconds and then cast into the ring for 60 seconds. The castings were then taken out to bench cool for an hour after which the posts were removed from the ring and cut from the sprue. All castings were then placed in 32% hydrochloric acid for 3 hours followed by an ultrasonic bath containing water for 15 minutes to remove any visible sign of investment adhering to the posts. Next, they were dried in an oven at 100°C for an hour. The posts were then weighed using an electronic balance (accuracy 0.00001g) and measured using the toolmaker's microscope to determine the "as cast" dimension prior to being exposed to airborne particle abrasion.

Airborne particle abrasion

Following weighing and measurement with the toolmaker's microscope the posts were exposed to airborne particle abrasion using 50 µm aluminum oxide particles. Airborne particle abrasion was performed in a standardized manner by controlling the pressure (45 PSI), distance (1 cm), angle (90°) and time of application (10 seconds). The post was rotated using tweezers while moving the airborne particle abrader up and down the length of the post. After 10 seconds the posts were steam cleaned and dried. The procedure was repeated up to 50 seconds, and each post was steam cleaned, reweighed and remeasured after each 10 seconds airborne particle abrasion cycle.

For qualitative analysis of the surface morphology of the posts before and after 10 seconds of airborne particle abrasion, three size 7 posts mounted on sticky carbon discs were evaluated using the scanning electron microscope at ≈ x45 and x180 magnification operating at 8 kV. Energy dispersive X-ray analysis EDX operating at 25 kV was also carried out to analyze the surface of the posts after devesting in 32% hydrochloric acid, to determine whether any investment remained in the posts' surface.

Statistical Analysis

A mean value of all six diameter measurements of each post was taken as a representative measure of each post. The mean change in diameter of posts following casting (cast diameter minus impression post diameter) was calculated and tabulated to determine to what extent investment solution concentration (CS and DS) affected post size. No statistical analysis was performed on this data as there was insufficient information available prior to carrying out the study to perform a power calculation. The rate of diameter reduction and weight loss per second for each post following airborne particle abrasion was calculated using linear regression analysis. The resulting times were tabulated to allow comparisons to be made on the basis investment solution concentration (CS and DS) and post size. An alpha value of $p < 0.05$ was taken to indicate statistical difference.

RESULTS

Regarding reproducibility using the toolmaker's microscope, no significant differences were found between the mean values of the first and second measurements for

Table 1. *Mean difference before and after casting calculated for three posts of each size invested with either the CS or DS.*

Post size	*Group number*	*Mean Post Diameter (mm)* *Before casting A*	 *After casting B*	*Difference B-A (mm)*	*Mean Difference for 3 posts (µm)*
		Concentrated Solution (CS)			
	G1	0.968	1.003	0.035	
4	G2	0.976	1.001	0.025	26
	G3	0.974	0.993	0.019	
	G1	1.369	1.412	0.043	
5.5	G2	1.368	1.396	0.028	31
	G3	1.368	1.390	0.022	
	G1	1.741	1.785	0.044	
7	G2	1.737	1.769	0.032	36
	G3	1.737	1.770	0.033	
		Dilute Solution (DS)			
	G4	0.979	1.018	0.039	
4	G5	0.974	1.006	0.032	33
	G6	0.974	1.001	0.027	
	G4	1.363	1.413	0.050	
5.5	G5	1.361	1.393	0.032	40
	G6	1.364	1.402	0.038	
	G4	1.739	1.802	0.063	
7	G5	1.734	1.768	0.034	47
	G6	1.733	1.776	0.043	

impression post sizes 5.5, and 7 (paired t-test, p = 0.91 and 0.064). For post size 4, a significant difference was found (paired t-test, p=0.001) however the actual size difference was at the level of the tolerance of the readings (5 microns).

To determine the change in post diameter associated with casting the mean dimension of each polymeric impression post was subtracted from the cast post measurement made prior to airborne particle abrasion. Table 1 summarizes the findings obtained using the concentrated solution (CS) and the diluted solution (DS). An average increase in diameter of 31 µm was observed using the CS compared with an average increase of 40 µm using the DS.

After exposing the posts to airborne particle abrasion up to 50 seconds, the rate of weight loss and diameter reduction per second were compared using a linear regression analysis (Figures 1, 2, 3, 4, tables 2 and 3). The mean time needed for the posts invested with the CS to return back to their original precast size during airborne particle abrasion was 39 seconds and for the posts invested with DS was 42 seconds. Table 4 shows the time needed for all the posts to return to their original size before investing and casting.

SEM images of the surface morphology of post size 7 before and after 10 seconds of airborne particle abrasion are presented in Figure 5. Before being exposed to airborne particle abrasion, the surface morphology of the post is irregular with porosities and particles of investment embedded within the post (Figure 5, A and B). By contrast, after exposure to airborne particle abrasion a smooth surface was found on the post (Figure 5, C and D). EDX of the embedded particles revealed that they were composed mainly of silicon, suggesting that they were particles of the investment material (Figure 6).

DISCUSSION

In this study, the groups invested using the concentrated solution (CS) had a 31 µm increase in mean diameter. This increase is often desirable for crowns and other extracoronal restorations to create space for the cement lute. This finding is comparable with other studies suggesting that increasing the liquid concentration provides an increase in the setting and thermal expansion of phosphate bonded investments[8,13,14]. However, it is interesting to note that investing the groups using the dilute solution (DS) gave a 40 µm increase in diameter instead of an expected reduction in diameter resulting from a decrease in the investment expansion. This may be due to fragments of investment material embedded in the surface of the posts which may be obscuring the true diameter change. The presence of such fragments of investment material was confirmed with EDX. The acid treatment had removed visible traces of the investment which leaves the possibility that the surface of the castings has a "hybrid layer" composed of alloy with embedded investment (see Fig 6). Should a greater dilution of the solution result in a weaker investment surface this may explain the paradox of the trend to larger castings with the more dilute solution; effectively, the gold appears to penetrate further into the investment. Therefore, the first hypothesis which states that diluting the liquid with water will reduce the expansion of the phosphate bonded investment resulting in a cast post with a smaller diameter than one made using a more concentrated solution is disproved.

Airborne particle abrasion of all 6 groups up to 50 seconds showed a linear reduction in both diameter and weight as time increased. The linear regression analyses for both of these parameters (tables II and III) showed high levels of significance and correlation with the majority of values

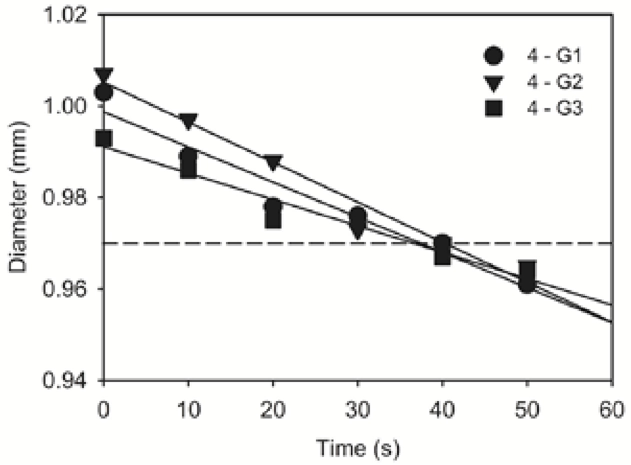

Figure 1. *Example of regression analysis of diameter reduction for post size 4 invested using the CS and exposed to airborne particle abrasion up to 50 seconds. (Dotted line is the mean diameter before investing)*

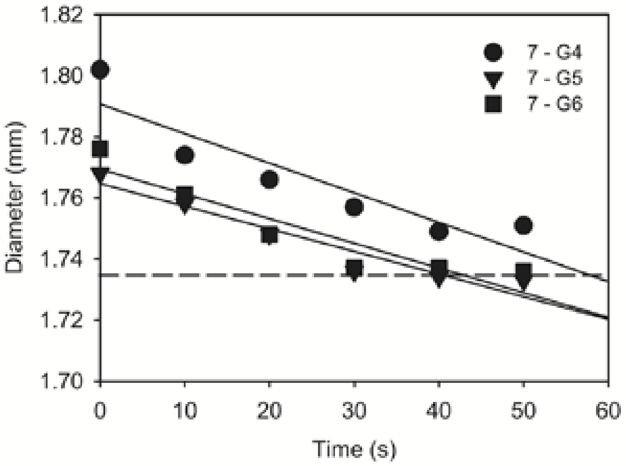

Figure 2. *Example of regression analysis of diameter reduction for post size 7 invested using the DS and exposed to airborne particle abrasion up to 50 seconds. (Dotted line is the mean diameter before investing)*

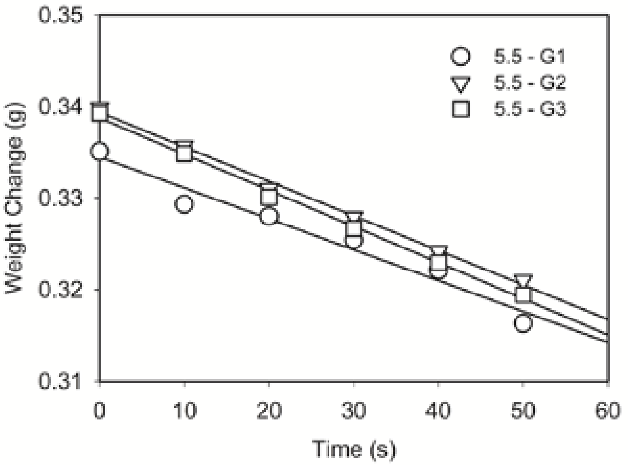

Figure 3. *Example of regression analysis of weight reduction of post size 5.5 invested using the CS and exposed to airborne particle abrasion up to 50 seconds.*

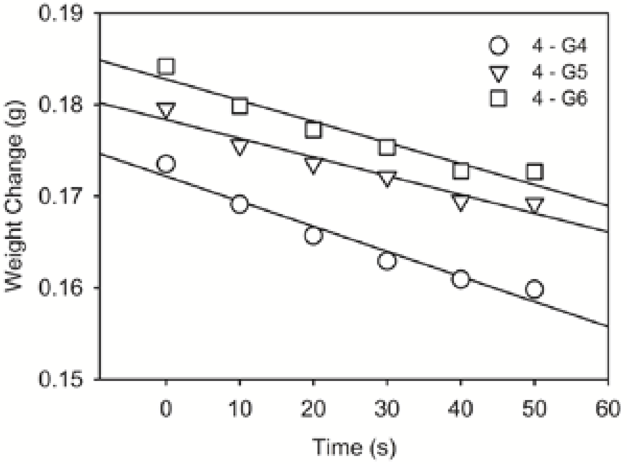

Figure 4. *Example of regression analysis of weight reduction of post size 4 invested using the DS and exposed to airborne particle abrasion up to 50 seconds.*

having an $r^2 > 0.9$. The mean rates of diameter reduction ranged from 7 to 8 µm per 10 seconds of exposure to airborne particle abrasion (table 2) and appeared not to be affected by post size. This finding is similar to another study where 6-8 µm of substance loss was found when exposing a noble alloy to airborne particle abrasion for 14 seconds using 110 µm aluminum oxide particles[15]. On the other hand, a trend emerged for the rate of weight reduction associated with post size (table 3). With both solution concentrations the rates of weight reduction for post sizes 4, 5.5 and 7 were 2, 4 and 5 mg per 10 seconds of exposure to airborne particle abrasion respectively. Clearly, if the airborne particles abraded the surface at a constant rate (as determined by the change in diameter) then a greater volume of alloy (as determined by the change in weight) would be removed with the larger diameter posts. For the current study the weight loss measurements provide helpful data to back-up the linear measurements which although sampled at six locations do not include possible variations in diameter between the measurement points. Therefore, the second hypothesis which states that airborne particle abrasion of cast posts for increasing lengths of time will provide a controlled and regular reduction of post diameter and weight and will also improve the surface morphology of cast posts is proved.

Although not attempted in this study it would be interesting to calculate the diameter change associated with the various rates of weight loss. If there is a good correlation with measured diameter change then weight loss may prove to be an efficient way of measuring changes resulting from airborne particle abrasion for future studies.

The posts needed an average of 41 seconds of exposure to airborne particle abrasion to reach their precast size. However to accommodate the cement lute, which has been estimated as an optimum to be between 24 and 31 µm[4],

Table 2. *Mean rate of diameter reduction of three posts of each size invested with either CS or DS (derived from gradient of regression analysis).*

Post size	*Group number*	*Regression Gradient (mms^{-1})*	*Squared Correlation coefficient (r^2)*	*P*	*Mean rate of diameter reduction (μm per 10 sec for 3 posts)*
Concentrated Solution (CS)					
4	G1	0.8	0.949	.001	8
	G2	0.9	0.963	.001	
	G3	0.6	0.950	.001	
5.5	G1	0.8	0.910	.003	7
	G2	0.7	0.927	.002	
	G3	0.6	0.993	<.001	
7	G1	0.7	0.770	.021	8
	G2	1.0	0.923	.002	
	G3	0.8	0.965	<.001	
Dilute Solution (DS)					
4	G4	0.8	0.929	0.001	7
	G5	0.6	0.941	0.001	
	G6	0.7	0.980	<.001	
5.5	G4	1.0	0.906	0.003	8
	G5	0.7	0.970	<.001	
	G6	0.8	0.888	0.004	
7	G4	1.0	0.840	0.010	8
	G5	0.7	0.917	0.002	
	G6	0.8	0.860	0.007	

Table 3. *Mean rate of weight reduction of three posts of each size invested with either CS or DS (derived from gradient of regression analysis).*

Post size	*Group number*	*Regression Gradient (mms^{-1})*	*Squared Correlation coefficient (r^2)*	*P*	*Mean rate of weight reduction (mg) per 10 sec for 3 posts*
Concentrated Solution (CS)					
4	G1	2.0	0.993	<.001	2
	G2	3.0	0.990	<.001	
	G3	2.0	0.989	<.001	
5.5	G1	3.0	0.962	0.001	4
	G2	4.0	0.995	<.001	
	G3	4.0	0.996	<.001	
7	G1	4.0	0.992	<.001	5
	G2	6.0	0.969	<.001	
	G3	5.0	0.993	<.000	
Dilute Solution (DS)					
4	G4	3.0	0.957	0.001	2
	G5	2.0	0.946	0.001	
	G6	2.0	0.938	0.001	
5.5	G4	4.0	0.980	<.001	4
	G5	4.0	0.962	0.001	
	G6	4.0	0.932	0.001	
7	G4	5.0	0.955	0.001	5
	G5	5.0	0.922	0.002	
	G6	4.0	0.852	0.008	

Table 4. *The time taken for all posts to reach their original size (before investing and casting) by airborne particle abrasion.*

Post size	*Group number*	*Time taken for the posts to reach their original size in seconds*	*Mean Time (s)*
		Concentrated Solution (CS)	
4	G1	35	39
	G2	40	
	G3	35	
5.5	G1	50	
	G2	35	
	G3	40	
7	G1	50	
	G2	25	
	G3	45	
		Dilute Solution (DS)	
4	G4	45	42
	G5	50	
	G6	40	
5.5	G4	40	
	G5	35	
	G6	35	
7	G4	50	
	G5	35	
	G6	50	

even more airborne particle abrasion is needed if the post has a tight fit within the canal. The results suggest approximately 30 more seconds would be needed in order to gain an undersize of about 24 µm. It is important to emphasize that manufacturers produce the components of their cast post systems to give tolerance for the casting to be a passive fit with space for the cement lute. Clinically, this means that some parts of the cast post will be potentially tighter than others within the canal (e.g. where the pattern resin or wax is well adapted) with a commensurate need for longer airborne particle abrasion. In addition, sometimes the manufacturing tolerances would occasionally allow for the post to be slightly larger than the drill. This variation makes airborne particle abrasion an important process to ensure a passive fit.

There are numerous studies on the expansion of phosphate bonded investments[8-11, 13,14], but very few of these have been on the effect of investment expansion on resulting cast post size[3, 5], Although this study has involved a small sample size, 6 measurements were taken for each post which improved measurement consistency.

A formal statistical analysis comparing the diameter of posts resulting from the two investment solution concentrations was not carried out for this study as the mean difference was only 9 microns. This difference was not judged to be of clinical significance but would have required an

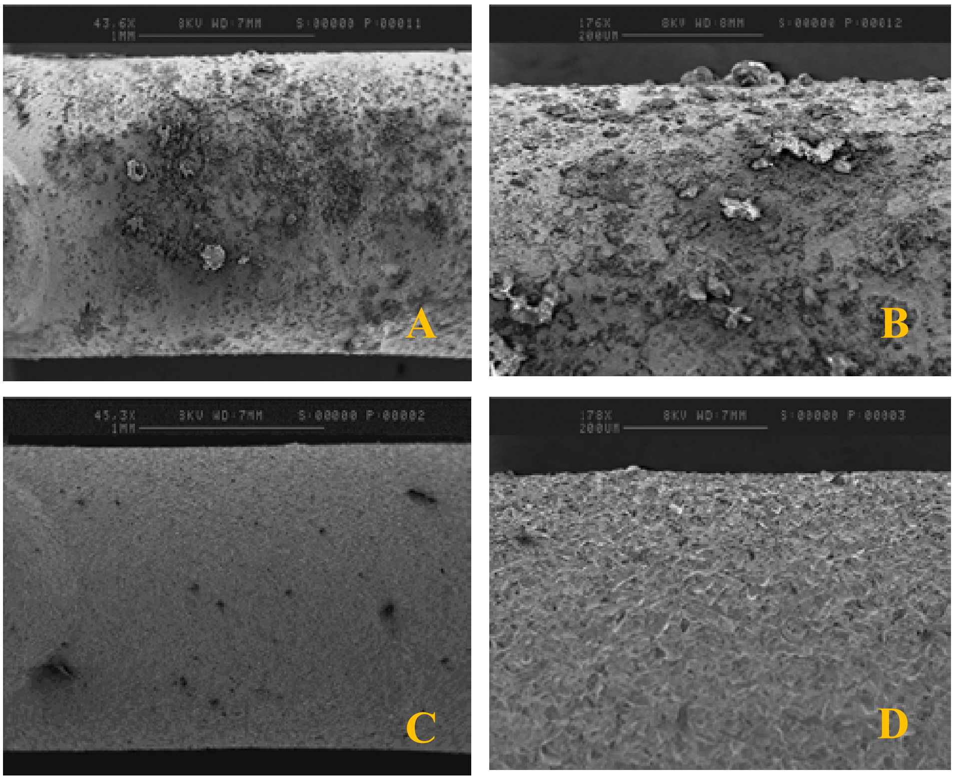

Figure 5. *SEM photomicrograph of the surface morphology of size 7 post at low (45X) and high magnification (180X). Before exposure to airborne particle abrasion (A and B) and after exposure to airborne particle abrasion (C and D).*

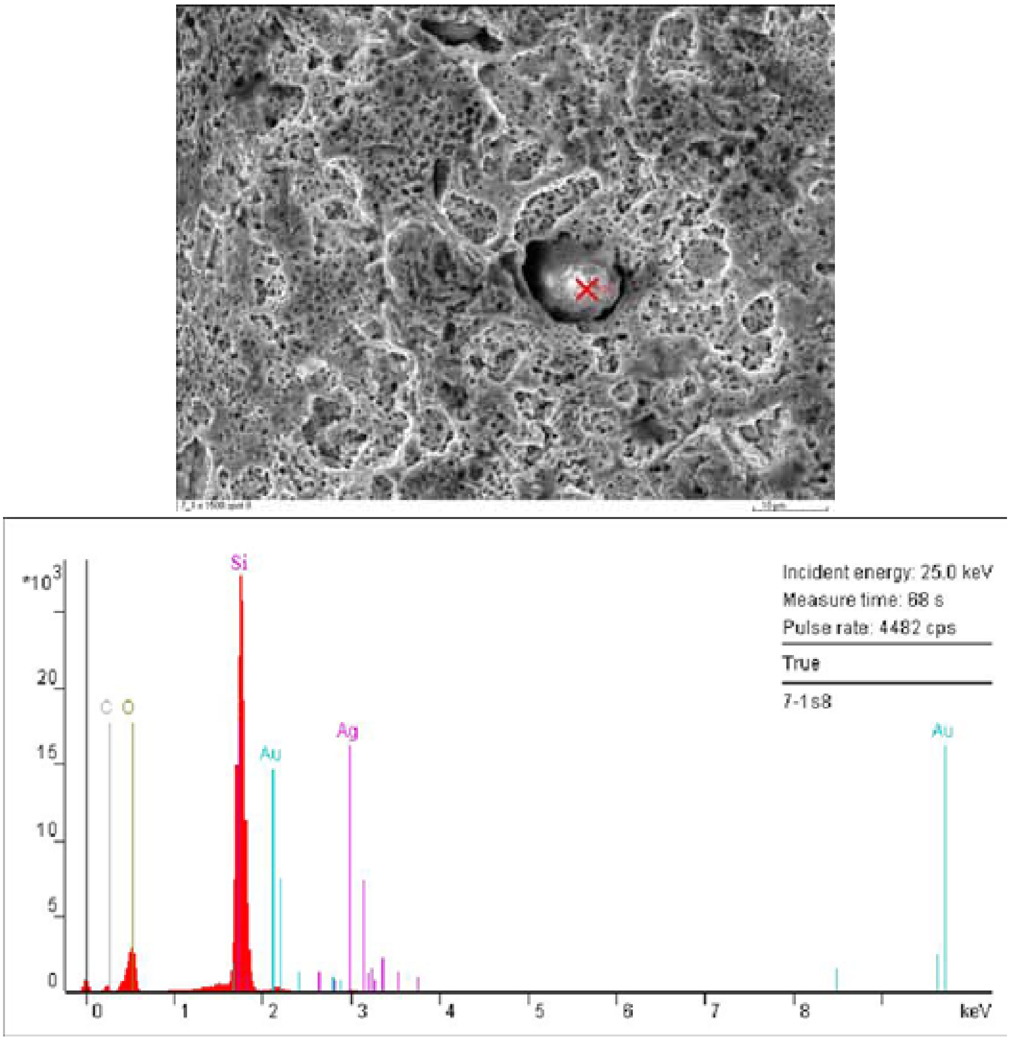

Figure 6.

A. Photomicrograph of the surface morphology of post size 7 at x1500 magnification before exposure to airborne particle abrasion with X denoting the chosen spot for analysis.

B. graph showing constituents of the surface of the post showing a high concentration of silicon, indicating an investment inclusion.

unmanageably large number of specimens to have sufficient statistical power to avoid a type II error. However, we would recommend that if this type of investigation is extended to other investment materials and alloys it would be essential to pilot the extent of any resulting differences before selecting an appropriate sample size for statistical hypothesis testing.

Further investigation is indicated to determine the effect of other liquid concentrations, alloys, and investments on the cast post size. Investigating different airborne particle abrasion parameters such as the distance, pressure and particle size is also indicated. To overcome any variance due to operator technique a mechanical means of airborne particle abrasion could be developed to control the above variables plus the relative rate of movement between airborne particle abrader nozzle and specimen surface. As mentioned above the relationship between diameter changes and weight changes may also help to provide greater understanding of a technique used daily in almost every dental laboratory.

CONCLUSIONS

Within the limitations of this study, casting dimensions were not dependent on the concentration of the phosphate bonded investment solution. Airborne particle abrasion with 50 µm aluminum oxide particles for just over a minute is needed in post patterns with a tight fit to ensure a passive fit with sufficient space to accommodate the cement lute.

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MANUFACTURERS' DETAILS

- Parapost XP kit: Coltene, Whaledent, Switzerland
- Toolmaker's microscope: TM-111, Mitutoyo, Japan
- Perspex jig: Bay Plastics, Newcastle, UK
- Phosphate bonded investment, Colloidal silica investment liquid: GC Fujivest Super, Belgium
- Ring liner: New casting liner, GC, Belgium
- Wetting agent: Waxit, Degudent, Germany
- Vacuum mixer: Smart-mix, Ammangirrbach, Germany
- Furnace: Cestradent MF1, England
- Casting machine: Heracast IQ, Heraeus Kulzer, Germany
- Gold alloy: Yellow special, Metalordental, Switzerland
- Oven: Memmert, West Germany
- Electronic balance: AE 240S , Mettler-Toledo, Switzerland
- Airborne particle abrasion: Renfert, Basic Master, Germany
- Steam cleaner: Aquaclean3, Degussa, Germany
- Carbon discs: Agar Scientific, Stansted Essex
- Scanning electron microscope: Stereoscan S40, UK
- EDX analysis: Rontec, Germany
- Statistical software: Minitab 15, Minitab Inc. Pennsylvania

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