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Research article

An auxiliary factor for increasing the retention of short abutments

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ABSTRACT

Background: Retention is an essential factor in the sustainability of the prosthesis, especially for short abutment. Despite, the availability of several auxiliary applications, achieving a clinically good retention for cast crowns in prepared short teeth remains a major challenge for the practicing dentist.

Objectives: This study tests a new method for applying frustum-shaped grooves on short prepared abutments and compares them with traditional setting grooves.

Methods: Forty-eight copper machine-milled short dies with 3.5 mm length and 12^{o} conversion with a chamfer finish line of 0.7 mm were prepared to mimic short prepared molars and distributed into 4 groups. A control group with two opposing setting grooves and two groups with dual opposing frustums, one of which was prepared to receive two integrated metal protrusions inside the casting that fit the frustums. Frustums were prepared with Komet bur No. 807 with dimensions 0.9 mm at the base and 0.7 mm at the occlusal surface. A direct wax-up was carried out on all dies and all castings were cemented with zinc phosphate cement. A pull-off test was applied until separation. Data were analysed to compare the correlation of the four groups using one-way ANOVA and Bonferroni test ($p \leq 0.05$).

Results: The mean retentive values in Newton were as follows: the control group, 457.80; the setting grooves group, 461.07; the frustum group, 597.59; and the frustum group with the two metal protrusions, 919.80. The retention was increased by 65% in frustum group and doubled in frustum group with the metal protrusions.

Conclusions: The results showed a statistical significance in retention in the frustum groups with and without metal protrusion over the retention of the control and the setting grooves groups.

1. Introduction

In the last decade, the remarkable development in chemical dental products (i.e. disinfectants, bleaching preparations, nanomaterials, filling materials, etchants, dental alloys, dental ceramic compounds, sealants, luting agents…etc.) for enhancing their mechanical and physicochemical properties has created recent challenges [1, 2, 3, 4, 5]. In spite of that, the ideal restoration, the best cement and the most effective technique for increasing the retention in short abutments are still controversial [6].

The success of the cast restorations depends on the combination of various factors such as the dentist, the dental technician, and the patient [6, 7, 8]. For the restoration to function for a long time, the principles of biomechanics, the choice of the correct cement, and the rational of tooth preparation must be adhered to realise the concept of retention and resistance [9, 10, 11, 12].

The term "retention" was described as the physical factor that prevents the failure of the cast restoration along the long axis of the preparation, while the term "resistance" was considered casting's ability to oppose lateral dislodging forces [13, 14]. The two terms were assumed to be inseparable, but the term resistance has a wider spectrum than retention [14, 15].

Walton and associated [16] stated that 69.5% of the failures of fixed cast restorations were due to mechanical reasons, while 28.5% of failures were due to biological factors such as caries and the involvement of the soft and hard supporting tissues and backed-up by other teams [17, 18]. Inadequate clinical crown length and the degree of the tooth destruction prior to treatment and debonding were suggested as the main reasons for failures of restorations [19, 20]. A new generation of resin cements was

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added to improve the rate of retention of traditional cement [21, 22, 23, 24, 25].

Many auxiliary retentive ways were suggested by many workers and researchers and used by dental professionals to overcome the lack of retention in short teeth [26, 27, 28, 29, 30, 31, 32].

Auxiliary retentive methods are used for molars prepared as abutment for bridges, abutments with more than 20^{o} conversion, teeth less than 3 mm in length to anterior teeth and 4 mm in length to molars, or length-to-diameter ratio of $\leq$0.4 [30,33-38].

Researchers showed that there was no statistical difference in retention when setting grooves or boxes were added to preparations with 20^{o} or more of conversion, and the increase in surface contact offered by the grooves was too small statistically to show any improvement in retention [29, 38].

Tjan et al. [21] also suggested that the setting grooves make the casting more difficult to fit and will subject the tooth to hydraulic pressure by the cement.

Several publications described an old method to improve the retention of castings on short abutments by using cement keys and opposing grooves on the outer surface of the abutment and the inner surface of the casting; a cement lock was assumed to increase the retention. However, there are variations to this method wherein several grooves were added [28, 39, 40]. This method has not been studied enough.

As there are several encouraging and controversial publications related to managing castings on short clinical crowns by incorporating auxiliary retentive features, it was decided to explore a new and original method by preparing grooves in the shape of frustum parallel to the long axis of a short crown. The current in vitro study was carried out to evaluate frustum grooves and the retentive values of castings with or without internal protrusion on the inner surfaces of the castings were compared with the conventional setting grooves using zinc phosphate cement.

2. Materials and methods

2.1. Spacimen preparation

Forty-eight copper dies were cut from a 11-mm diameter circular rod at a total length of 15 mm and machined to 3.5 mm in length and 12^{o} conversion with a chamfer finish line of 0.7 mm deep with flat occlusal surfaces; all line occlusal angles were bevelled at 45^{o} to mimic a prepared short molar. The butt ends of each die were prepared to fit the test apparatus (Fig. 1A-C).

2.2. Samples categorisations

Four equal groups of 12 dies each were divided as follows:

Group 1 (Gr. 1; CG) - as a control set.

Gr. 2 (SG) – two opposing setting grooves were prepared with a conical flat rounded end diamond bur of 1.4 mm in diameter at the tip and 1.8 mm at the shank end. The base of the grooves was located at 0.5 mm from the finish line. The depth of finished groove was 0.7 mm at the base and 0.9 mm at the occlusal surface (Fig. 2A&B).

Gr. 3 (F) - two opposing frustum grooves were prepared with a Komet bur No. 807 with a diameter of 1.8 mm at the tip and 1.4 mm at the shank end. The finished groove measured 0.9 mm at the base and 0.7 mm at the occlusal surface (Supplementary Material (SM) – Figs. S1–S6).

Gr. 4 (FM) - as in Gr. 3 (F), but the castings were to have two metal protrusions of 6 mm in length and width on the inner surface of the casting at 1 mm from the finish line, each to fit into the opposing groove (Fig. 3A&B).

All samples had a small reference notch to indicate later the casting consistently. The cutting burs for all preparations were discarded after 6 cuts.

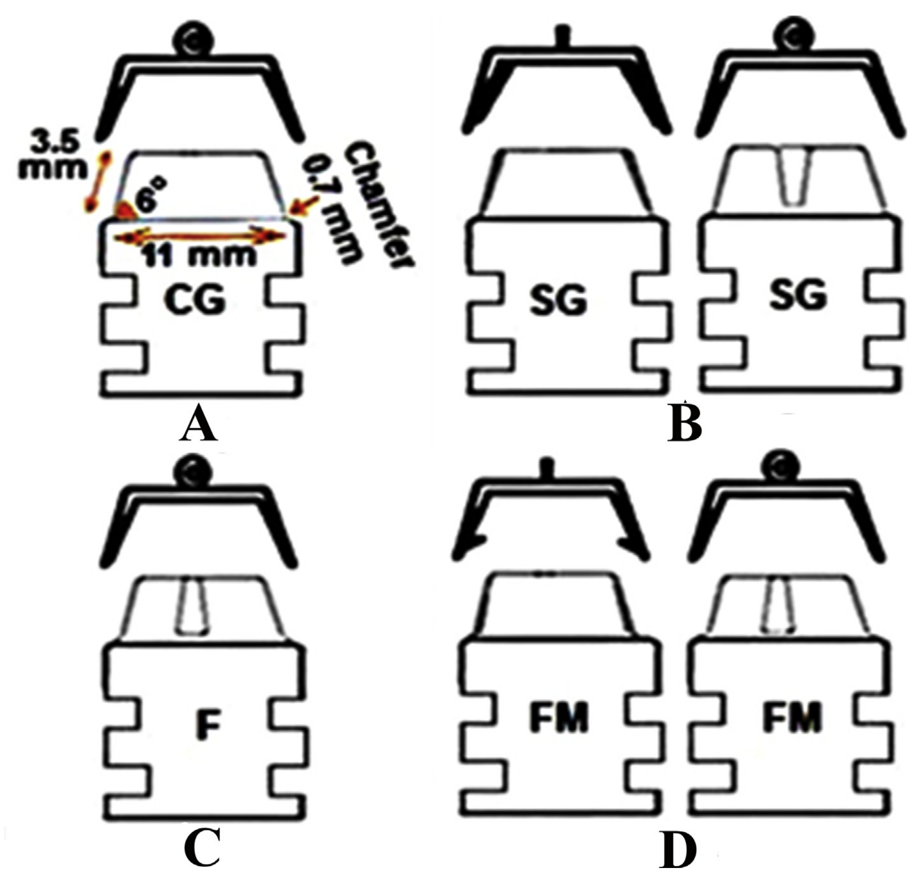

Fig. 1. Schematic illustration of the Dies. A: Group (Gr. 1), CG; B: Gr. 2, SG; C: Gr. 3, F; D: Gr. 4, FM.

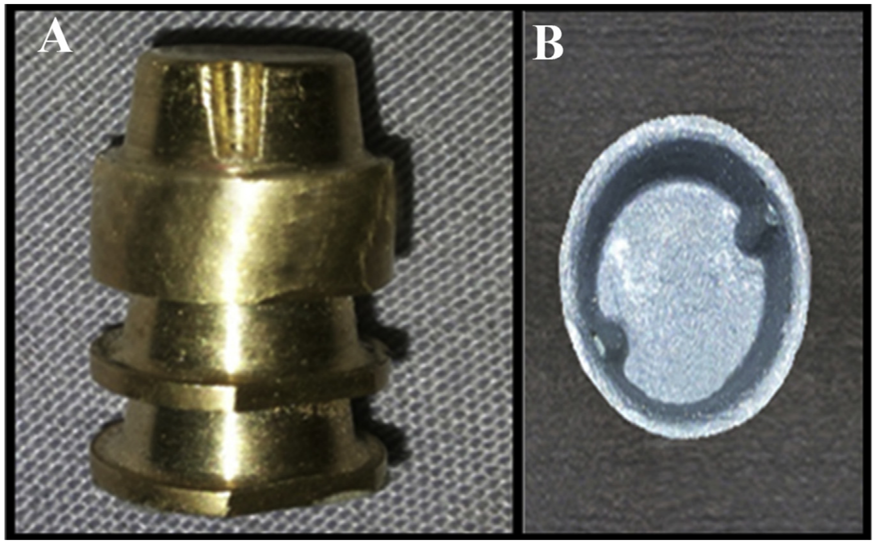

Fig. 2. An abutment and a casting from Gr. 2, SG. A: The copper abutment with the prepared setting grove, and B: The casting.

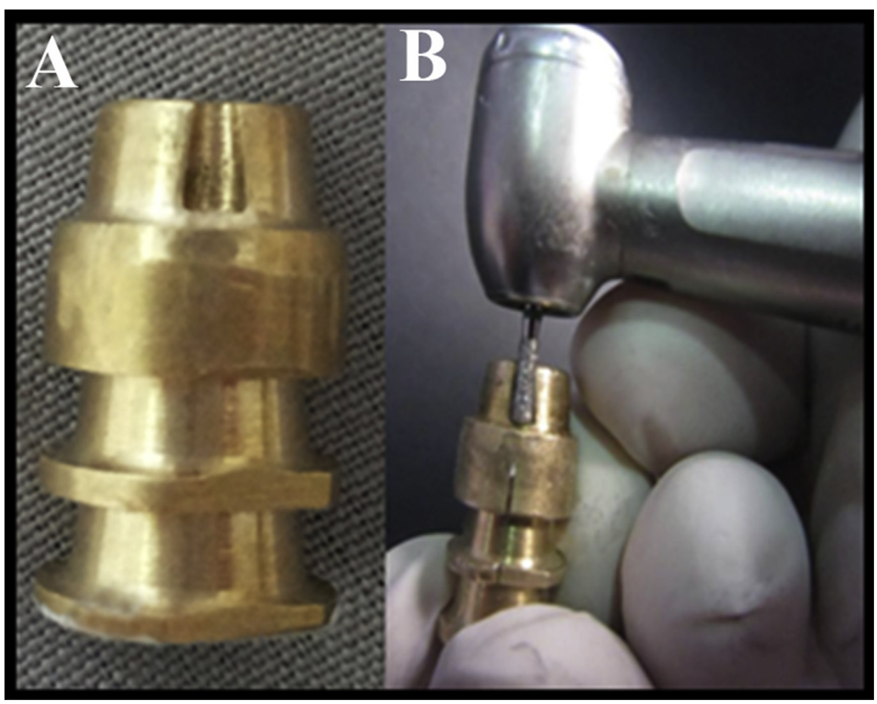

Fig. 3. The preparation of the frustum. A: The prepared frustum on the abutment, and B: Frustum preparation.

2.3. Laboratory construction of the castings

All grooves in Grs. (F and FM) were blocked with wax. A die spacer was applied to all samples of all groups to 0.5 mm from the finish line, and the standard laboratory methods for waxing up were used (Video 1). A small ring of wax with 2 mm diameter was attached to the occlusal surface of the castings to attach it to the testing apparatus. All waxed shells were carefully checked prior to casting to ascertain that the reference notch on the die was printed onto the wax shell in order to locate the castings correctly on the die.

Prior to casting, the wax in the frustum was removed from the dies in Grs. 3 (F) and 4 (FM). The technician laboratory made triangular-shaped pins composed of Duralay of a base and length of 0.6 mm, which were inserted through the wax pattern into the frustums at 1 mm from the finish line. The bases of the triangular pins were parallel to the occlusal surfaces of the dies. The wax patterns were removed and re-inserted to confirm that the pins passed freely in the grooves (Fig. 4A&B; Video 2).

All wax patterns were cast in the lost wax method, sand blasted, ultrasonically cleaned, and visually inspected. Unsatisfactory castings were redone.

The castings were cemented with zinc phosphate cement mixed according to manufacturer's instructions and subjected to a pressure of 7 kg for 10 min.

The cementation of Grs. (3 and 4) was completed by filling the frustums first with the cement prior to inserting the castings on the dies.

Instron universal testing machine was used to apply a pull off test. The upper rig of the machine was connected to the metal ring of the occlusal surface of each crown. The test was carried on till separation was achieved and values of test were collected.

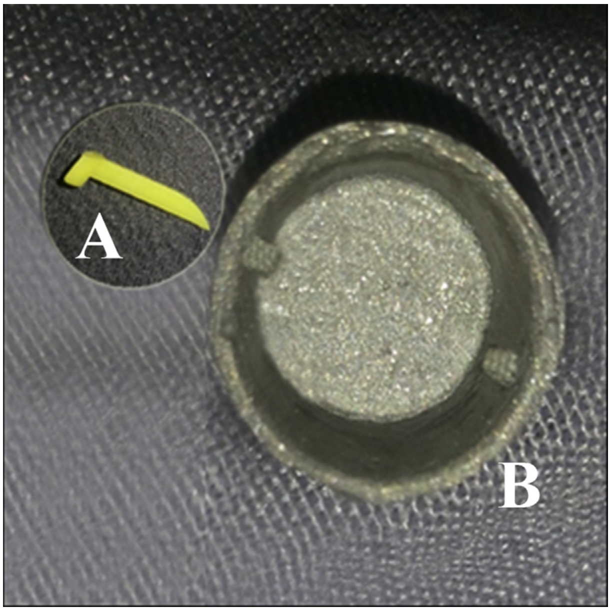

Fig. 4. The Duralay pin and the protrusion inside the casting. A: The Duraly pin, and B: The two metal protrusions inside the casting from (Gr. 4; FM).

2.4. Statistical study

Excel and SPSS (V13) were used to tabulate and analyse the survey data. This involved the use of the one-way analysis of variance to study the significance of variance/difference in the average tensile forces between the studied groups. Bilateral comparison was then carried out between each pair of groups using the Bonferroni correction method. The confidence factor was 95 % with $p < 0.05$ for all the tests.

3. Results

The test samples were divided into four equal groups of 12 specimens each and the results of the pull-off test are presented in (Table 1).

Table 2 shows the arithmetic mean, standard deviation, standard error (SE) and the minimum and maximum amount of tensile strength (TS, Newton (N)) for the test samples of each studied group.

3.1. Results of the one-way ANOVA analysis

Table 3 shows the results of the one-way ANOVA analysis of the significance of variance in the mean amount of TS between the four studied group samples (CG, SG, F, and FM).

This Table shows that the significance level is much lower than 0.05, which means that with a 95% confidence level, there is a significant variation in the difference of the mean TS (N) between at least two of the four studied groups. To establish which group has the most substantial variation of mean TS from the others, One-Way comparison was performed between the four studied groups in accordance with the Bonferroni method.

Table 1
Results of pull-off test (Newton).

Abutment number	Group FM	Group F	Group SG	Group CG
1	824.04	578.79	407.115	451.26
2	804.42	593.505	304.11	515.025
3	946.665	598.41	510.12	568.98
4	809.325	559.17	446.355	372.78
5	907.425	549.36	505.215	529.74
6	789.705	573.885	568.98	593.505
7	961.38	622.935	500.31	304.11
8	1142.865	618.03	465.975	534.645
9	1167.39	671.985	667.08	382.59
10	735.75	529.74	426.735	309.015
11	1177.2	686.7	362.97	608.22
12	770.085	588.6	367.875	323.73

Table 2
Descriptive statistics of data (Tensile strength (TS), Newtown).

Gr.	Number of copper stents/ plates	Arithmetic mean (μ) ± Standard deviation (std. dev.)	Standard error (SE)	Lower bound	Upper bound
Setting grooves (SG)	12	461.07 ± 98.37	28.40	304.11	667.08
Frustum (F)	12	597.59 ± 47.96	13.84	529.74	686–.7
Frustum with metal protrusion (FM)	12	919.69 ± 161.91	46.74	735.75	1177.2
Control group (CG)	12	457.80 ± 114.05	32.92	304.11	608.22

3.2. Results of the one-way comparisons according to the Bonferroni method

Table 4 shows the results of bilateral comparisons according to the Bonferroni method, which was used in studying the significance of bilateral differences in the average amount of TS among the four groups studied.

4. Discussion

This work was designed to explore the validity of new frustum-shaped grooves in retaining castings made to fit short crowns with and without protrusion incorporated into the inner walls of the metal casting, and compare the retention values of this system with those of the traditional setting groove technique, because the lack of retention of short clinical crowns has been of great concern to the practicing dentist [41, 42, 43, 44].

Zinc phosphate cement was chosen, as it is widely researched, used and has favourable properties [13, 45, 46, 47, 48, 49]. Chan et al. [26] used phosphate cement in studies similar to the present research.

The current method for waxing up directly on the machined abutments provides a better fit and avoids the difficulties that might occur from utilising the indirect methods [50]. O'kray and his team [40] adopted similar methods in all their works.

All castings were cleaned with aluminium oxide (Al_2O_3) of 50 μm (diameter) as stipulated by Proussaefs et al. [34] and other works [50, 51].

Metal abutments were used for their resistance to abrasion during the fabrication of the castings and to standardise the geometrical shape of the abutments [33, 40].

The abutments in this study were 3.5 mm (height), 11 mm (diameter) at the finish line, had 12^o of conversion, and the occlusal surface was bevelled at 45^o. These measurements were modified from the works of Goodacre et al. [27] and Parker et al. [52] who suggested a height of 3 mm for premolars and 4 mm for molars and 23.5^o of conversion and stated that the occlusocervical/incisocervical dimension to faciolingual dimension should be ≤ 0.4.

Our work did not follow the recommendations of Goodacre et al. [27], as the occlusocervical/incisocervical dimension to faciolingual dimension was 3.6 mm.

All grooves and frustums were prepared manually by the corresponding author after preparing several units prior to the use of the experiment samples. This approach was used previously by many

Table 3
Results of ANOVA analysis.

Studied variable	Time	Sum of squares (SS)	Degrees of freedom	Var. (mean square discrepancy)	Calculated F-value	Significance level	Significance variance
TS	Between groups	1696818.88	3	565606.29	44.191	0.0000	+[a]
	Within groups	563157.62	44	12799.04			
	Total	2259976.49	47				

[a] Significant difference: +.

Table 4
Results of Bonferroni test (TS, Newtown).

Set (I)	Set (II)	Mean difference (I-II)	SE	Significance level	Significance of variance
Setting grooves (SG)	Frustum (F)	-136.52	46.19	0.030	+[b]
	F	-458.62	46.19	0.000	+[b]
	CG	3.27	4.19	1.000	-[c]
Frustum (FM)	F	12–322.10	46.19	0.000	+[b]
	CG	139.79	46.19	0.025	+[b]
Control group (CG)	CG	461.89	46.19	0.000	+[b]

[b] Significance difference: +.
[c] Significance difference: -.

researchers [35, 40]. This type of study involving the use of frustum has not previously been mentioned in the literature as described in this study. Therefore, two groups of frustum (with/without metal protrusion) were chosen to test which design is better. Also, the dimensions of the frustums (which (the frustum) is the portion of a pyramid that remains after its upper part has been cut off by a plane parallel to its base) were chosen at random and for this purpose, the Komet bur No. 807 was selected to prepare grooves of 0.9 mm in depth at the finish line, 0.7 mm at the occlusal end, 3.5 mm length, with the inclination of 10^{o} representing the conical conversion of 20^{o} of the bur. This shape has not previously been mentioned in the literature. In contrast, the conventional grooves were prepared to measure in depth 0.7 mm at the finish line and 0.9 mm at the occlusal end.

The average retention (N) was measured as 457.80 for the CG, 461.07 for the setting groove group, 597.59 for the FG, and 919.69 for the FG with the two protrusions.

The retention values of the CG were similar to the results of Chan et al. [26] who recorded 47 kg (412.02 N) with 7^{o} inclination using extracted teeth, while in this study, a value of (425.88 N) with an inclination of 6^{o} was recorded.

The increase in retention in the FGs where the grooves were reversed and filled with cement key was statistically viable at $p < 0.05$ which represents 65% incremental in retention compared to the CG, while with addition of two protrusions to the inner side of the casting in retention attained 100%.

The hypothesis behind this increase in retention is that the shear strength of the cement on the contacting walls was reversed into compressive strength within the frustums. According to the literature, the compressive strength of the zinc phosphate cement is 110 Mpa while the shear strength is 13 Mpa [14, 53, 54, 55, 56, 57, 58, 59].

In Grs. (1 and 2), the cement (mainly) remained attached to the inner walls of the castings (Fig. 5), while in Gr. 3, the retentive shape of the frustum prevented the release of the cement from the grooves and the cement remained inside the inner walls in the casting except the part opposing grooves (Fig. 6).

With the presence of this metal protrusion, the crown cannot dislodge unless cement trapped by the frustum is crashed or the protrusion itself fractures (Fig. 7).

No cement was found in the frustum in the protrusion group. This could explain the greater force required to dislodge the cement from the grooves.

Fig. 5. The cement inside the castings in Gr. 1, CG.

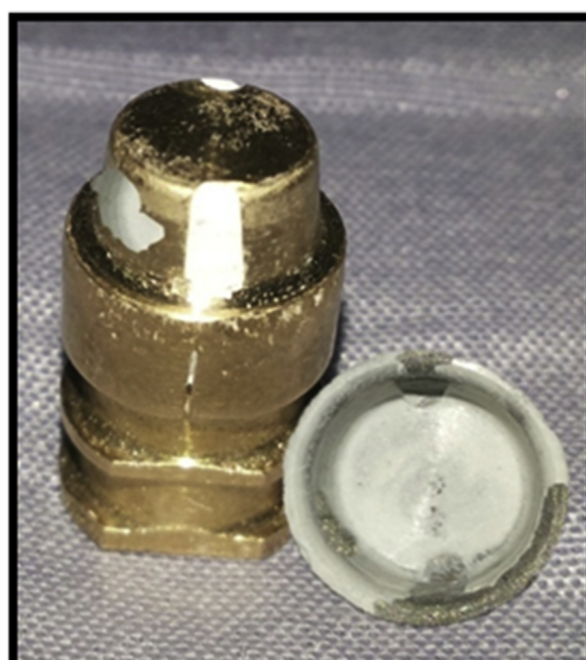

Fig. 6. The retained cement inside the frustum (Gr. F).

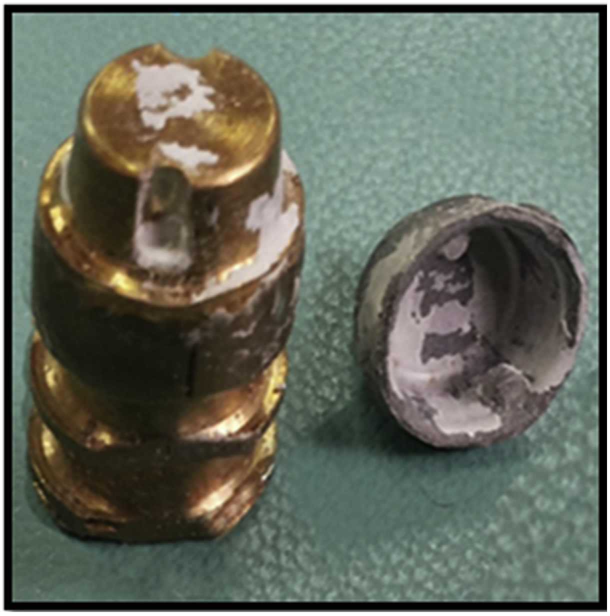

Fig. 7. An abutment and a casting from Gr. 4 (FM) after pull-off test.

The outcomes of this study concurred with the findings of O'kray et al. [40] who achieved 56% growing in retention when two circumferential grooves were incorporated and 62% when there were single opposing grooves on the surface of the preparation and the other on the inner wall of the casting using modified resin glass ionomer cement.

Furthermore, our results concurred with the study of Lewinstein and associates [39], who achieved 60% increase in retention when circumferential grooves were added to an implant abutment cemented with zinc phosphate cement, as well as with the work of Arcoria et al. [50] who reported that the addition of auxiliary retentive means either on the surfaces of the preparation or inside the casting will be statistically viable.

Our results disagreed with other works [26, 28, 29, 30], whose their outcomes were related to different abutment design, use of different cements and different locations, and sizes of grooves. The frustum design yielded unequivocal results that were statistically viable.

In spite of the encouraging results of the current research, this *in-vitro* study must be followed by a clinical study of the Frustum preparation technique. In addition, Frustum preparation is not indicated for big, young or sensitive vital pulps. So, the current technique can be indicated for short abutments which meet the following conditions:

A. Endodontically treated abutments,
B. Abutments with small or retrograde pulps, and
C. Abutments restored with post and core.

5. Conclusions

Within the limitations of this *in-vitro* study, the following conclusions were drawn:

a) With the use of the frustum grooves, an increase of 65% in retention was achieved in conventional castings.
b) The inclusion of two protrusions in the inner side of castings on short abutments increased the retention by 100% (Video 3).

The researchers of this article recommend further works on:

I. Longitudinal clinical study to evaluate the retention and sensitivity.
II. Applying this technique on bridges (in vivo and in vitro studies).
III. Evaluating the retention with different frustum dimensions or locations.
IV. Studying the effect of the frustum preparation on “resistance”.

Declarations

Author contribution statement

Fendi AlShaarani: Conceived and designed the experiments; Contributed reagents, materials, analysis tools or data; Wrote the paper.

Rami M Alaisami: Performed the experiments; Analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data; Wrote the paper.

Loai Aljerf, Issam A Jamous, Kanaan Elias & Anas Jaber: Conceived and designed the experiments; Analyzed and interpreted the data; Wrote the paper.

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Competing interest statement

The authors declare no conflict of interest.

Additional information

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