ECMS 2018

Influence of Luting Materials on the Retention of Cemented Implant-Supported Crowns

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Received: 23 April 2018; Accepted: 24 May 2018; Published: 24 May 2018

Abstract: The objectives of this study were to evaluate the retention force of cemented crowns on implant abutments with different luting materials. Cobalt-chromium crowns (n=128) were randomly divided into eight groups (n=16), and a standardized mixture was cemented onto tapered titanium abutments (Camlog) with the following types of luting materials: one eugenol-free temporary cement (RelyX TempBond NE, 3M Oral Care), one composite-based temporary cement (Bifix Temp, Voco) one zinc phosphate cement (Harvard Cement; Hoffmann), two glass-ionomer cements (Meron, Voco; Fuji I, GC), and three resin-modified glass-ionomer cements (Fuji 2, GC; Fuji Plus, GC; Ketac Cem Plus, 3M Oral Care). All specimens were aged for 14 days at 37°C in artificial saliva (S1). One half of the specimens from each group (n=8) were additionally thermocycled (5.000X, 5-55°C) (S2). Then, the crowns were vertically removed using a universal testing machine at a speed of 1 mm/min, and the force was recorded (measurement time T1). Afterwards, the crowns were recemented, aged, and removed and the force was recorded (T2, T3). A linear multiple regression analysis evaluated the influence of the luting materials and aging conditions (S1, S2) on the retention force and measurement times (T 1-3). The multiple linear regression analysis exhibited a statistically significant impact of luting materials and storage condition on the retention force. The retention forces differ statistically significant in the storage condition at T1 ($p = 0.002$) and T3 ($p = 0.0002$). The aging conditions (S1, S2) had a small significant influence ($p < 0.05$) at T3 that was not local. After aging, S1 Ketac Cem Plus had the highest retention force difference (T3 vs. T1) (-773 N) with respect to the median value, whereas RelyX TempBond NE had the smallest difference (-126 N). After aging, S2 Meron had the highest retention force difference (-783 N), whereas the RelyX TempBond NE had the smallest difference (-168 N). Recementation of implant-supported cobalt-chromium crowns decreases the retention force independent of the luting material. A material-specific ranking of the retention force of cemented implant-supported cobalt-chromium crowns was observed at T1.

Keywords: luting materials; retention; implant-supported crowns; hydrothermal stress; recementation; implant-supported cobalt-chromium crowns; retention force

PACS: J0101

1. Introduction

Dental implants have a rich and fascinating history [1]. In the last few decades, the demand for dental implantological treatment has increased steadily [2,3], and the success rates after implant insertion are high [4,5].

Oral implant science has numerous topics of interest and evolving thematic trends in clinical studies [6]. Since the 2000s, the focus of dental implantological treatment has been as a biological-driven therapy that recovers and maintains the function, long-term stability and aesthetics of soft and hard peri-implant tissues [7,8]. For biological-driven therapy, knowledge about the factors that influence dental implant's long-term functional stability and the safety of soft and hard peri-implant tissues has crucial clinical relevance and significance. These factors can be divided into two groups: biological or clinical and technical [9]. The biological or clinical factors are age, systemic health, bone support [10], occlusion [11], and hard and soft peri-implant tissue changes [12]. The technical factors refer to the amount of retention [13], devices [14] for implant-supported prosthesis retention, type of retention force applied [15], crown and implant abutment materials, geometry, height, type of the surface finishing, surface roughness [16,17], cleaning method during recementation [18], and the chemical, physical, bioactive and "remove on demand" properties of the luting material [13,14,17]. One of the actual topics of interest in the field of biological-driven implant therapy is implant restoration [8,19,20], and this topic induced the development of new methods and luting materials for implant-supported prosthesis retention [13].

There are various reasons for implant restoration. During the application of pressure on the crown occlusal surface, complications such as chipping of the alveolar bone or peri-implantitis can occur, and these complications can be the main reasons why retrieval of crowns is indicated [21]. Due the disconnection of the crown, abutment and implant damage can occur and may increase the loss of the implant [22].

Three types of retention of fixed dental implant-supported prosthesis-like crowns are described in the literature: screw-, cement-retention [5,10,14,23] or a combination of both [24,25]. Each type of retention has advantages and disadvantages.

Screw-retained restorations are easily retrievable [26] and have less technical and biologic complications overall but are expensive [11]. Cemented implant-supported prostheses with a screw access hole in the metal framework improve the survival rates over time and lower the cost of the implant-supported prostheses [24]. There are complications with disconnection of cement-retained implant-supported prostheses from abutments, but this retention mode is still used because it is an effective option, especially for implant-supported single crowns, short-span fixed dental prostheses [19] and for better esthetical and economic reasons [27]. There is a need for the development of new modified luting materials for implant-supported prosthesis retention [13].

Three variants and three appropriated luting agent types for cement-retention are known: temporary, permanent and semi-permanent [13,28,29]. Temporary cements with low tensile strength and high solubility help to avoid damaging the restoration and peri-implant tissues [30,31]. Permanent cements with high tensile strength and low solubility induce the opposite mechanical and clinical effects [32]. Semi-permanent retention provides adequate retention and retrievability [28]. For semi-permanent retention cements, phase change materials (PCM) were created with a phase transition behavior (solid-liquid) upon temperature or other physical factor influences [13,28]. The matrix of the conventional permanent cement can be changed with activatable microadditives and acquire new mechanical "remove on demand" properties [13,28,29].

There is still a clinical need in the guidelines regarding cement or cementation procedures and for generating accurate information about the clinical outcome of cement-retained implant-supported fixed restorations, particularly regarding the ideal type of cement that would facilitate stability and maintain retrievability [19], have biologic compatibility and lead to easy removal of excess cement using the radiographic view [33] and controlled destruction of dental cements [13]. Additionally, the alterations of the crown surfaces after multiple recementations should be studied [29]. The information regarding the retention force is very important for the implant restoration protocol [8].

Cobalt-chromium crowns have low-cost, good corrosion resistance and higher hardness, but exhibit lower detail accuracy and higher shrinkage after casting compared to gold alloys [29].

Therefore, the aim of this in vitro study was to evaluate the influence of different alternative luting materials and storage conditions (artificial aging) with hydro and hydrothermal stress (HS and HTS) on the retention force of cemented implant-supported cobalt-chromium crowns at three different measurement time points.

The null hypothesis for the present study was that the different alternative luting materials and storage conditions (artificial aging) with HS and HTS would not influence the retention force of cemented implant-supported cobalt-chromium crowns for three different measurement time points.

2. Results

2.1. Comparison of the Retention Force T1 Independent of the Storage Conditions

The luting material RelyX Temp Bond NE had the lowest retention force at T1 independent of the storage conditions (Table 2, Figure 2). Harvard was treated in the following analyses as the reference material.

At T1, Temp Bond NE showed the lowest retention force of 191.70 N (interquartile range 155.60 –224.39 N) and Meron showed the highest retention force of 902.30 N (interquartile range 848.40 – 973.90 N), as represented by the mean values. At T1, Ketac Cem Plus had the highest standard deviation (± 295.46 N) of the retention force.

2.2. Comparison of the Retention Force at T2 Independent of the Storage Conditions

At T2, RelyX Temp Bond NE was again the luting material with the lowest retention force, with a median value of 49.09 N (interquartile range 38.89 – 65.89 N). At T2, Harvard had the highest retention force median value of 258.10 N (interquartile range 225.70 – 308.70 N). Ketac Cem Plus had the highest retention force maximum value of 399.30 N (Table 3). In general, the retentions forces of all of the cements groups were reduced compared to that of T1. The graphical results are shown in Figure 2.

2.3. Comparison of the Retention Force T3 Independent of the Storage Conditions

At T3, RelyX Temp Bond NE had the lowest retention force, with a median value of 30.98 N (interquartile range 22.63 – 47.93 N), whereas Fuji Plus had the highest median value of 188.60 N (interquartile range 164.90 – 209.10 N). Fuji I had the highest retention force maximum value (279.40 N; Table 4). The retention force was continually reduced from T1 to T3. The graphical results are shown in Figure 2.

2.4. Comparison of the Retention Force at Different Time Points and after the Different Storage Conditions Independent of the Luting Materials

Application of two unpaired two-sample t-tests show that the retention forces differ statistically significant (Bonferroni correction: $\alpha/3$ = 0,017) in the storage condition at T1 (p = 0.002) and T3 (p = 0.0002). The data are summarized in Table 5 and Figure 3

2.5. Comparison of the Retention Force at Different Times of Measurement Dependent on the Storage Conditions

The data showed that RelyX Temp Bond NE had the lowest retention force at every time (T1, T2, T3) and for both storage conditions (S1, S2). Harvard was used as the reference material in the following analyses (Figure 4-6).

The data of this study showed a monotonically decreasing significantly different trend ($p<0.001$) of the retention force for all materials at different times of the measurements (T2 vs.T1 and T3 vs.T1).

3. Figures, Tables and Schemes

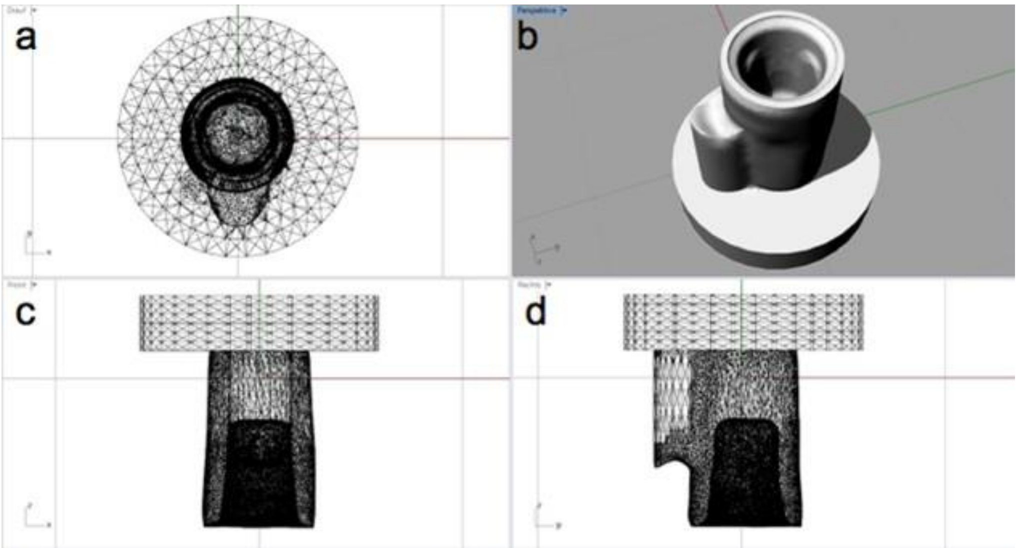

Figure 1. View of the design using the Dental-Designer software (3 shape, Copenhagen, Denmark) with crowns from above (**a**), transverse (**b**) and sidelong (**c-d**).

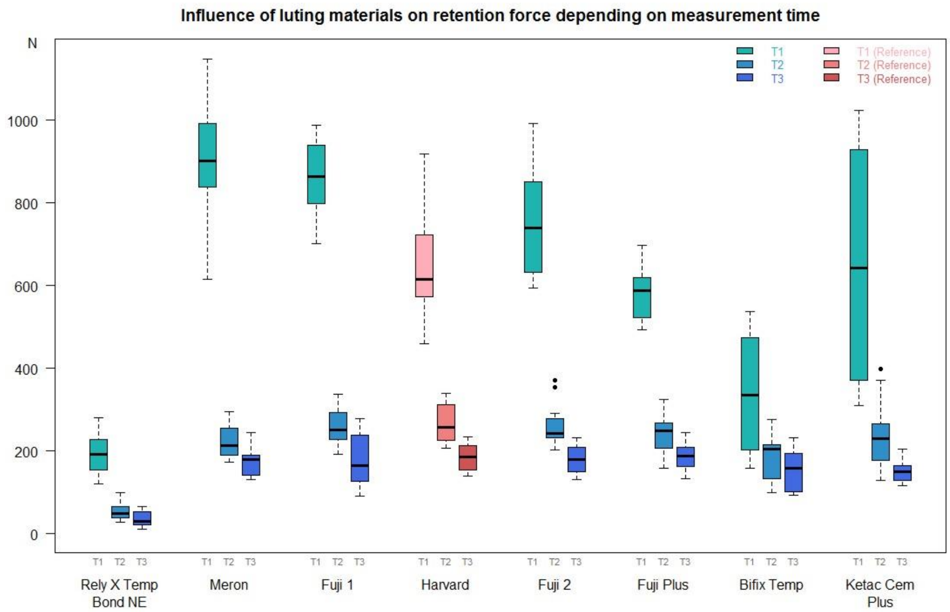

Figure 2. Comparison of the retention force at T1 – T3 independent of the storage conditions. Boxes indicate the data's location and variation. One box includes 50% of the analyzed data, the line within the box indicates the median.

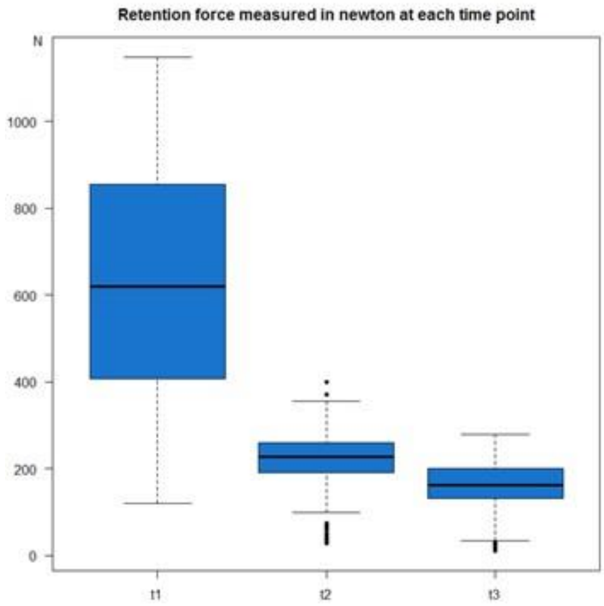

Figure 3. Comparison of the retention forces at the different time points independent of the luting materials. For a description of the boxplot, see Figure 2. Circles indicate outliers and extreme values.

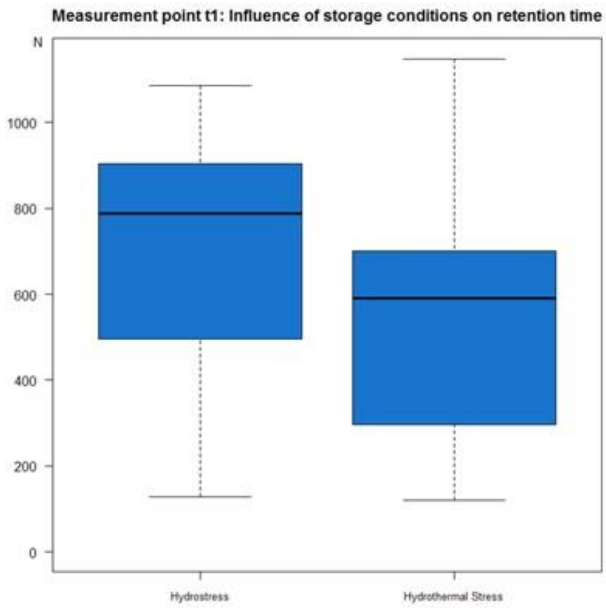

Figure 4. Comparison of the retention force at T1 after the different storage conditions independent of the luting materials. For a description of the boxplot, see Figure 2.

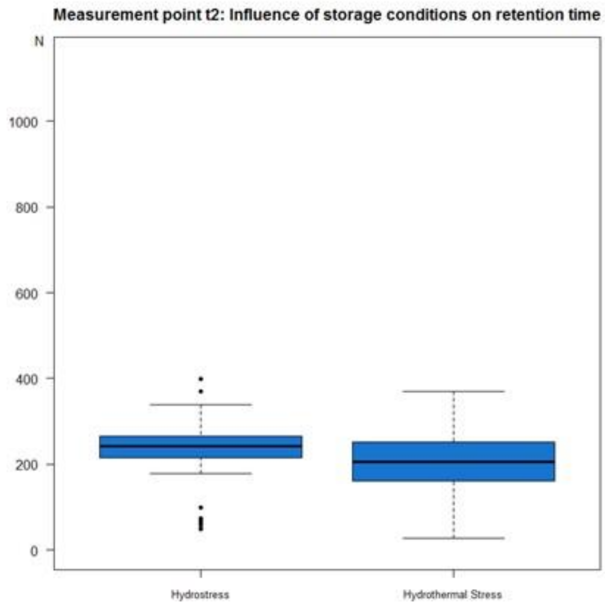

Figure 5. Comparison of the retention force at T2 after the different storage conditions independent of the luting materials. For a description of the boxplot, see Figure 2. Circles indicate outliers and extreme values.

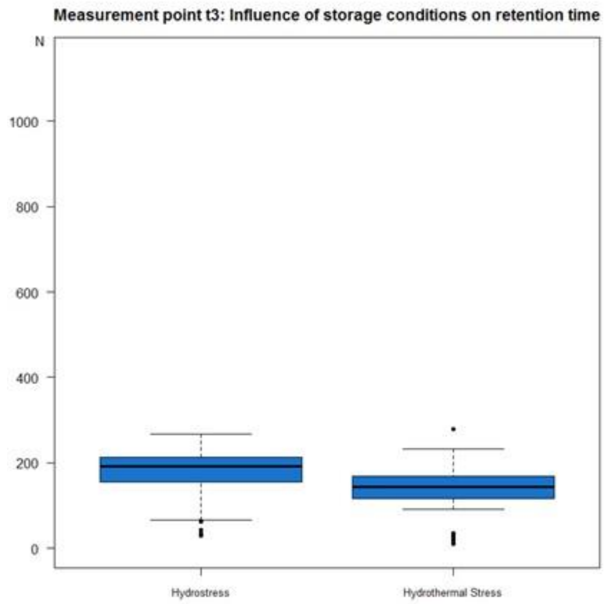

Figure 6. Comparison of the retention force at T3 after the different storage conditions independent of the luting materials. For a description of the boxplot, see Figure 2. Circles indicate outliers and extreme values.

Table 1. Description of the luting materials used in this study.

Material	Type	Chemical Composition [a]	Application	Manufacturer
RelyX TempBond NE	eugenol-free temporary cement	P: zinc oxide L: White Mineral Oil (Petroleum)	paste/paste	3M Oral Care, Seefeld, Germany
Meron	glass ionomer cement	P: Fluoraluminosilicate glass L: polyacrylic acid	capsule	VOCO, Cuxhaven, Germany
Harvard Cement	zinc phosphate cement	P: Zinc oxide, magnesia L: phosphoric acid	powder/liquid	Hoffmann Dental, Hoppegarten, Germany
Fuji I	glass ionomer cement	P: Fluoroaluminosilicate glass L: polyacrylic acid	powder/liquid	GJ, Tokyo, Japan
Fuji II	resin-modified glass ionomer cement	P: Fluoroaluminosilicate glass L: methacrylated polyacrylic acid	paste/paste syringe	GJ, Tokyo, Japan
Fuji Plus	resin-modified glass ionomer cement	P: Fluoraluminosilicate glass L: methacrylated polyacrylic acid	capsule	GJ, Tokyo, Japan
Bifix Temp	composite-based temporary cement	B: Triethylene glycol dimethacrylate C: benzolperoxid	paste/paste	VOCO, Cuxhaven, Germany
Ketac Cem Plus	resin-modified glass ionomer cement	P: Fluoroaluminosilicate glass L: Methacrylated polyacrylic acid	paste/paste syringe	3M Oral Care, Seefeld, Germany

a: according to the information provided by the manufacturers. Abbreviations: P = Powder;

L = liquid; B = Base; C = Catalyyst

Table 2. Descriptive data of the statistical evaluation of the retention force at T1 independent of the storage conditions (in N).

Luting Material	T1						
	Minimum	1st quartile	Median	Mean value	SD	3rd quartile	Maximum
RelyX Temp Bond NE	119.70	155.60	191.70	189,30	47.47	224.39	280.90
Meron	615.20	848.30	902.30	914.60	130.90	973.90	1148.00
Fuji I	702.30	800.50	863.60	865.10	87.44	936.20	987.90
Harvard	459.10	575.90	615.80	651.60	129.90	711.30	919.00
Fuji II	593.30	636.60	740.10	752.70	135.13	829.50	991.70
Fuji Plus	492.50	528.40	588.50	583.10	62.66	617.80	698.20
Bifix Temp	158.30	204.00	334.50	337.60	137.92	466.40	538.30
Ketac Cem Plus	310.00	370.80	642.20	647.50	295.46	899.80	1024.00

Table 3. Descriptive data of the statistical evaluation of the retention force at T2 independent of the storage conditions (in N).

Luting Material	T2						
	Minimum	1st quartile	Median	Mean value	SD	3rd quartile	Maximum
RelyX Temp Bond NE	27.28	38.89	49.09	52.21	19.11	65.85	98.55
Meron	172.90	190.90	213.60	223.30	36.64	253.90	295.50
Fuji I	192.30	232.20	251.40	258.20	44.51	292.50	338.30
Harvard	206.70	225.70	258.10	270.80	46.68	308.70	340.30
Fuji 2	203.20	231.50	242.40	259.90	46.07	272.00	370.60
Fuji Plus	159.40	209.10	249.20	242.70	42.93	265.10	325.30
Bifix Temp	99.47	137.70	205.00	186.10	53.69	214.70	275.90
Ketac Cem Plus	128.90	180.00	229.10	236.60	75.84	255.30	399.30

Table 4. Descriptive data of the statistical evaluation of the retention force at T3 independent of the storage conditions (in N).

Luting Material	T3						
	Minimum	quartile	Median	Mean value	SD	3rd quartile	Maximum
RelyX Temp Bond NE	10.45	22.63	30.98	35.64	19.15	47.93	66.78
Meron	131.90	142.40	179.30	173.30	31.27	190.10	244.50
Fuji I	91.93	129.40	165.30	182.10	61.05	237.30	279.40
Harvard	140.20	153.50	185.30	185.30	30.48	211.60	234.00
Fuji 2	131.20	154.80	178.80	180.00	34.37	207.50	231.70
Fuji Plus	132.80	164.90	188.60	187.30	31.77	209.10	244.20
Bifix Temp	92.92	102.40	158.90	155.70	48.12	194.60	232.40
Ketac Cem Plus	116.20	132.10	150.60	150.70	26.52	164.10	204.10

Table 5. Differences at the various time points T1, T2 and T3 (t-test).

	Difference of mean	Lower 95% CI	Upper 95% CI	p-Wert
T1	150.817	57.457	243.177	0.002
T2	29.589	1.379	57.798	0.040
T3	38.183	18.275	58.091	0.0002

4. Discussion

The success rates after dental implantological treatment are high [4,5], and the need for future removal and reparation of implant-fixed restorations will increase [13]. The choice of cement for implant-fixed restorations can influence the implant stability after restoration removal. Thus, the aim of this in vitro study was to evaluate the influence of different luting materials on the cemented implant-supported cobalt-chromium crowns' retention force after artificial aging with hydro and hydrothermal stress. The data were assessed using a universal testing machine.

The recementation protocol analysis at T1 showed some peculiarities for different luting materials: the highest retention forces independent of the storage conditions was found for the permanent glass-ionomer cements Meron and Fuji I, , with median values of 902.30 N and 863.60 N, respectively; the lowest retention forces were found for the temporary cements eugenol-free RelyX TempBond NE and composite-based Bifix Temp, with median values of 191.70 N and 334,50 N, respectively. Permanent zinc phosphate Harvard cement and permanent resin-modified glass-ionomer cements,(RMGI) including Fuji II Fuji Plus and Ketac Cem Plus (3M Oral Care, Seefeld, Germany), showed an interjacent retention force, with the highest median value of 740.10 N for Fuji II and lowest value of 588.50 N for Fuji Plus. Permanent zinc phosphate Harvard cement and resin-modified glass-ionomer cement Ketac Cem Plus did not have very different median values: 615.80 N and 642.20N, respectively. This result is in concordance with the data of Safari et al., 2018, where after the first cementation with resin-modified glass-ionomer cements, a medium retention force between the resin cements (highest) and zinc-oxide-eugenol cement (lowest) was shown [34].

The superstructure geometry and related surface peculiarities influenced the mechanical behavior of the different dental implant-abutment connections [35].

The date of the present study clearly demonstrated that the bonding capacities of the different luting materials had a remarkable influence on the retention force only for the first cementation, and the material-specific ranking of the cemented implant-supported cobalt-chromium crowns' retention force was observed only at T1. Another aspect of this study merits consideration. The specimens, after recementation (T2 and T3), presented with lower retention force values independent of the storage conditions (in both HS and HTS groups).

The results of the present study also show that crown removal, following sandblasting and recementation of implant-supported cobalt-chromium crowns, decreased the retention force values in all of the cement groups independent of the luting materials. It was observed that a significant retention force decrease occurred during the second and third crown removal in all of the cement groups. Mundt et al., 2010 used a similar sandblasting model of the cobalt-chromium crowns' inner surface with a 50 mm aluminum oxide particle size at a pressure of 2.5 bar, followed by rinsing and dryness, and reported similar observations [29]. Unfortunately, there is not much information regarding the varied conditions and surface peculiarities for cemented implant-supported cobalt-chromium crowns' internal surface and abutment surface after retrieval and following cementation.

Obviously, the characteristics of cemented implant-supported cobalt-chromium crowns' internal surface were changed after the retention and surface conditioning with sandblasting, which significantly reduce the crown-cement-abutment bonding interaction and, consequently, the retention force during the second and third retention.

Most likely, for future cementations, special alternative methods or condition agents for preserving the cobalt-chromium crowns' internal surface conditions have to be developed, which may be an alternative to sandblasting.

The limits of this study are that only HS and HTS for inducing artificial aging were performed, and the forces were always applied along the vertical prosthetic axis, which is not always possible in clinical practice [14].

The null hypothesis for the present study, which was that the eight different luting materials will not differ in their influence on the cemented implant-supported cobalt-chromium crowns' retention force after artificial hydro and hydrothermal aging, was partly confirmed.

5. Materials and Methods

5.1. Cobalt-Chromium Crowns and Luting Materials

Cobalt-chromium crowns (n=128) were randomly divided into eight groups (n=16) for standardized cementation onto the corresponding abutments with the following luting materials: one eugenol-free temporary RelyX TempBond NE cement (3M Oral Care, Seefeld, Germany); one composite-based temporary Bifix Temp cement (Voco, Cuxhaven, Germany); one zinc phosphate Harvard cement (Hoffmann Dental, Hoppegarten, Germany); two glass-ionomer cements, Meron (Voco, Cuxhaven, Germany) and Fuji I (GC, Tokyo, Japan); and three resin-modified glass-ionomer cements, Fuji II (GC, Tokyo, Japan), Fuji Plus (GC, Tokyo, Japan), and Ketac Cem Plus (3M Oral Care, Seefeld, Germany) (Table 1).

5.2. Preparation of Test-Bodies

Camlog logfit abutments (6° tapered, 4.3 mm diameter, and 5.8 mm height) were screwed with Camlog model implants (Camlog, Altatec Winsheim). One Camlog logfit abutment (LOT 000034680) was scanned with a model scanner D800 (3shape, Copenhagen, Denmark), and a stereolithographic (STL) file was produced. Using the Dental Designer (3Shape, Copenhagen, Denmark) software, the STL file of the abutment was used for the crown design for the following standardized decementation (Figure 1). Cobalt-chromium crowns were produced by using laser-sintering from a cobalt-chromium-alloy (Compartis Co-Cr; Degudent, Hanau, Germany).

The produced cobalt-chromium crowns in all eight groups (n=16) were prepared using standardized cementing with a weight of 6 kg on the abutments.

5.3. Artificial Aging after Hydro- and Hydrothermal Stress

To simulate the oral cavity medium and its impact on the luting characteristics of the tested materials immediately after cementation, all specimens were divided, according to the storage conditions, into two groups (S1 and S2): one half of the specimens (S1) (n=8 from every material group) were subjected to hydro stress (HS) due the storage at 37°C for 14 days in 100 ml of artificial saliva (Dental center, Erfurt, Germany) [16]. The other half of the specimens (S2) (n=8 from every material group) were subjected first to hydro stress (HS) and then to hydrothermal stress (HTS), which was accomplished using thermocycling in a Thermocycler THE1000 (SD Mechatronics, Feldkirchen-Westerham, Germany) with 5.000 cycles in water baths at temperatures of 5°C and 55°C (resistance time 30 s, dripping time 15 s), followed by evaluation of the retention force of the cemented crowns on the implant abutments with the different luting materials.

5.4. Retention Force Measurement

After HS (group S1) or HS and following HTS (group S2), the cobalt-chromium crowns were vertically removed using a universal testing machine Texture Analyser HD (Stable Micro Systems, Goldalming, UK) at a constant speed of 1 mm/min, and the force in Newtons (N) was recorded (first time of measurement (T1)). The blasting agent used for sandblasting with the Basic quattro IS (Renfert, Hilzingen, Germany) was aluminum oxide $Al2O3$ (Orbis, Muenster, Germany) with a particle size of 50 µm and pressure of 1.0 bar. The plate or the model analogue was manually fixed on the bottom of the blasting basket and blasted at a 45 ° angle at a distance of 3 cm for approximately10 s. These values were constantly checked with a set square. After sandblasting, the cobalt-chromium crowns were cemented with the same luting material; groups S1 and S2 were aged after storage at the abovementioned storage conditions and removed, and the force (N) was recorded at the next two time-points (T2, T3).

5.5. Statistics

A multiple linear regression analysis evaluated the impact of each luting material and storage condition on the retention force at each measurement time. The statistical software package SPSS (Statistical Package for Social Sciences, IBM, Amronk, NJ, USA) Vers. 23 and R (R Core Team, Vienna, Austria) Vers. 3.3.2 was used

6. Conclusions

The obtained data showed that sandblasting and recementation of implant-supported cobalt-chromium crowns resulted in a reduction of the retention force independent of the luting material. Within the limitations of this study, it can be concluded that a material-specific ranking of the cemented implant-supported cobalt-chromium crowns' retention force was observed at T1. Clinical research is needed to confirm these findings.

Acknowledgments: The authors thank to Mr. J. Hannibal from Winnopal, Elze, Germany, for his technical support, 3M Oral Care, Seefeld, Germany and Voco, Cuxhaven, Germany for the materials provided of this study.

Author Contributions: EAN: wrote the paper; FR: performed the experiments, measurements and date assessment; CB: performed statistical data analysis; WHA: planned and supervised the experimental procedure and corrected the manuscript AP: designed, conceived and planned the experiments; supervised the experimental procedure and the entire project; and corrected the final manuscript correction. All of the authors read and approved the final manuscript.

Conflicts of Interest: The authors declare that they have no conflict of interests.

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