

From the Klinik für Zahnärztliche Prothetik, Propädeutik und Werkstoffkunde
(Director: Prof. Dr. M. Kern)
at the University Medical Schleswig-Holstein, Campus Kiel
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**Influence of chewing force, thermal cycling and storage time on the
retrievability of cemented implant retained crowns**

Dissertation

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Presented by

Shurouk Ali

from **Brekie, Syrien**

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1st Reviewer: Priv.- Doz. Dr.Christian Johannes Mehl, Praxis für Zahnmedizin
und ImplantologieHarder/Mehl

2nd Reviewer: Prof. Dr. Katrin Hertrampf, Klinik für Mund-, Kiefer- und
Gesichtschirurgie

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Signed: Prof. Dr. Hans-Jürgen Wenz, Klinik für Zahnärztliche Prothetik, Propädeutik
und Werkstoffkunde

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List of abbreviations:

µm	micrometer
C0	no chewing simulation
C1	chewing simulation
Co-Cr	cobalt-chromium
D	day
FDP	fixed dental prosthesis
H	height
MPa	megapascal
N	Newton
Ø	diameter
S	seconds
SLS	selective laser sintering
T0	no thermal cycling
T1	thermal cycling
UTM	universal testing machine

1. Introduction

1.1 Overview

Since the introduction of osseointegrated dental implants, new surgical and prosthetic concepts and methods have been established to replace missing teeth [12, 79, 82, 136]. The long-term success shown by osseointegrated dental implants has been well-documented by a range of multiple prospective long-term studies [9, 50, 55, 71, 110]. It is, however, noteworthy that successful treatment with implant-supported restorations depends not only on osseointegration of the implant but also on maintaining the integrity of the connection of the prosthetic suprastructure to the implant [20].

In early stages implants were used to support prostheses for completely edentulous patients and particularly for edentulous mandibles [2, 8]. Later on, implant-supported restorations have been applied as an alternative treatment option for partially edentulous patients [73], i.e., dental implants were used more commonly to substitute one or more missing teeth [118]. These types of restorations are fully acknowledged by the dental profession, and their benefits are being increasingly recognized by the patients, who often particularly request them as a treatment option. This is supported by increasing numbers of placed implants [70, 135].

There are different etiologies for tooth loss; periodontal diseases [88], traumatic injuries, dental caries, or congenital missing teeth [51]. Nowadays there are four possibilities to replace the single missing tooth: 1. Conventional fixed dental prosthesis (FDP) [17], 2. Resin-bonded fixed dental prosthesis (RBFDP) [98], 3. Implant-supported crown [105] and 4. Removable partial dental prosthesis (RPDP). The importance of the third therapy option arises particularly in clinical situations, in which the neighboring teeth to the edentulous space are still intact or exhibit minimal conservative restorations [99]. Moreover, esthetically and functionally speaking, implant-retained single crowns can resemble, to a large extent, the natural teeth, which means that most of patient's demands could potentially be fulfilled [116].

Treatment with implant-supported restorations comprises of several consecutive steps; diagnosis and treatment planning, implant insertion, healing phase, exposure of the implant to the oral cavity, impressions, abutment fixation, and seating of the definitive reconstruction [17]. Implant-supported prostheses can be screw-retained, cement-retained, or a combination of both [80].

A cumulative survival rate for dental implants of 93% for an average period of 10.2 years was recorded [96]. The estimated survival rate for single implant-supported crowns reached 89.4% after a ten years observation period [94].

1.2 Manufacturing of the abutments

Several materials are available for constructing the implant abutments. These materials include titanium (mostly used), base metals, gold, and aluminum- or zirconium oxides. The employment of metallic abutments in esthetically demanding regions might be an unfavorable option, particularly, when the gingival biotype is thin. Therefore, ceramic abutments could be the most suitable option in such cases [11, 134].

Temporary restorations are of particular importance in anterior regions. Accordingly, provisional implant abutments were introduced to facilitate direct restoring procedures after implant placement [119]. These provisional abutments could be made from calcinable methacrylate, polyetheretherketon (PEEK) resin, or even titanium [5]. Implant abutments can be supplied as pre-machined abutments, or they can be constructed and customized by using press-, casting-, or CAD/CAM techniques [21, 33, 67, 100]. Even pre-machined abutments can be prepared in the same manner like natural tooth preparation for a crown [26].

1.3 Fixation of implant-retained restorations: Advantages and disadvantages

There are currently two fixation (retention) methods employed to restore fixed implant restorations — cementation and screw-retention. Both procedures have advantages and disadvantages and they are very controversially discussed [23, 45, 52, 80, 81, 109, 128]. Gervais and Wilson [45], Wood and Vermilyea [133] were of the opinion that the choice of either method should be considered carefully for each case according to the advantages/disadvantages of each situation and, whenever possible, be based on evidence-based predictions of the best long-term success and a patient centered outcome.

On the other hand, whether to screw or to cement an implant restoration usually depends on the clinician's preference, because there is no consensus established that one type of retention is superior to the other [25, 109, 111, 118, 124]. The main advantage of screw-retained prostheses is the easy retrievability of the

crowns [24, 52]. However, it is difficult to ensure a passive-fit with screw-retained implant restorations [90]. Moreover, screw-retained implant restorations proved to have disadvantages like the occlusion or esthetics due to the screw access hole [52, 133], and they are more expensive and time-consuming to produce [24, 52, 80, 117, 133] and veneering porcelain fractures are more prevalent [25, 62, 121, 137].

On the contrary, the introduction of cement-retained implant restorations has reduced some of the above mentioned problems associated with the screw-retained prostheses, such as abutment screw loosening [10, 112], wrong implant angulations [61] or occlusal fractures [85, 117, 121, 131]. Additionally, using cement-retained restorations allows obtaining enhanced esthetics [10, 25, 52, 117, 118, 133], and the development of the desired occlusal profile [25, 52, 117], since a poorly designed occlusion on implant-supported prostheses could have a deleterious impact on both, the implant-supporting bone and the respective suprastructure [19]. Additionally, cement-retained prostheses provide the clinician with a so called "passive fit", which is based on the cement space between the restoration and the abutment, which compensates for minor discrepancies in the fit of the cementable suprastructure [27, 34, 49, 63, 80, 133]. Furthermore, manufacturing cementable restoration uses preparation designs and luting techniques that resemble conventional non-implant supported-prostheses, simplifying the clinical and laboratory procedures [10, 34, 80, 133]. However, a failed cemented restoration can be unscrewed by creating an occlusal hole, thus resulting in a screw-retained crown [35]. Given that studies can be found stating the exact opposite of the advantages mentioned above [24, 38, 53, 64], the decision how to retain the implant based restorations is a decision very often left to personal preferences of the clinician and the clinical situation [27, 109, 111, 118, 124].

Two main arguments are used to oppose cemented restorations on implants: Peri-implantitis due to subgingival cement rests [32, 68] and the relative irretrievability [76, 78]. Excess cement residues, particularly in cases of deep sub-mucosal placement of implant shoulders, are a major problem that a clinician can be confronted with during employment of cement-retained restorations. These remnants might result in irritation and/or chronic inflammation of soft tissue, bone loss, and the possibility of scratching of the implant surface during removal of excess cement [3, 48, 130]. In some instances, surgical interventions can be required to remove the remaining cement [92]. However, it has been suggested that subgingival cement

rests can be reduced by minimizing the amount of cement during the luting procedure [37, 132], or by avoiding to place the margins of the customized abutments too deep into the gingival sulcus [87]. The results reported by Vigolo et al. [124] and de Brandao et al. [32] indicate that there was no evidence for a different behavior of the peri-implant marginal bone and of the peri-implant soft tissue response between cement and screw-retained restorations. Interestingly, Nissan et al. [84] have concluded that marginal bone loss and Gingival Index were significantly better for cement-retained restorations than screw-retained restorations. Contrarily, Weber et al. [128] concluded that peri-implant soft tissues responded more favorably to screw-retained crowns as compared to cement-retained crowns.

However, the retrievability of cemented restorations remains a key factor for the decision making. When cementation is performed on implant abutments, the varying conditions between the natural tooth dentin and abutment titanium metal, and complications (e.g. caries vs. screw loosening and screw fractures) differ significantly [78]. Moreover, single tooth restorations on implants are reported to have a higher incidence of complications in comparison to restorations on natural abutments [31, 47]. Retrievability of the restoration is desirable if interventional therapy of the implant is required [25, 26, 104]. Therefore, the retrievability of fixed implant-supported prostheses is an important consideration in delivering quality, patient oriented treatment outcomes [45].

It is well documented in the dental literature that several factors influence the retention in cement-retained restorations, whether they exist on either natural teeth or implant abutments [15, 46, 52, 58, 63, 86]. The first factor is the taper or parallelism. Previous investigations have shown a decrease in retention with increasing preparation taper [58, 72]. Bresciano et al. [21] demonstrated that the taper of implant-abutments has a bigger impact on the retention of implant-supported restorations than the height. The second factor is surface area and height. It has been demonstrated that an increase in surface area and height increases retention form and that these two factors are closely linked [15, 21, 52, 63, 76]. The third factor is surface texture. It is generally accepted that a rougher surface leads to a higher retention [41, 60, 132]. The fourth factor is cement film thickness. The effect of cement film thickness on the retention of castings cemented either onto tooth or implant abutments has been reported with a varying retention values [34, 39, 77,

123]. The fifth factor is the selected cement. This factor will be discussed in detail in the following paragraph.

1.4 Influence of the cement choice

There is wide range of commercially available luting agents [108]. Up to date, no available luting agent is ideal for all situations and clinical indications [106]. Resin based-, glass-ionomer-, zinc oxide-eugenol-, zinc polycarboxylate-, and zinc phosphate cements are widely used for fixation of single crowns and FDPs onto natural teeth [108]. Most of these cements were, automatically, employed to cement implant-supported restorations [36, 90].

The introduction of customized abutments has increased the clinical variables regarding the selection of the luting medium [21]. Accordingly, the type of cement remains a much discussed issue [52], since the retention and the retrievability of cement-retained implant restorations depends to a high degree on the cement which is used [113]. Favorable luting cements should exhibit enough strength to retain the restoration in situ, yet be weak enough to allow the retrievability of the restoration, if required [20, 75, 78, 104, 132].

A provisional luting agent can be used, as the retention values of provisional luting agents are lower than those of permanent luting agents [6, 28, 30, 74, 90, 115, 120]. These cements allow the retrievability of the restoration without damaging the restoration or the implant and its abutment [20, 54]. However, this option is accompanied by poor physical properties, like low tensile strength and high solubility. Marginal leakage caused by wash-out of temporary luting cements can lead to dead spaces, the accumulation of bacteria, and inducing the inflammation of the soft tissues, especially if the margins are located sub-gingival [65, 89, 91]. This restricts the use of temporary luting materials for cementing implant-retained restorations for an extended period of time [91].

The retentive strength of resin, glass-ionomer-, zinc phosphate- and eugenol-free zinc oxide cements used for retaining implant-supported restorations, was the subject of several investigations [75, 132]. Clayton et al. [28] found that zinc phosphate cement produced a stronger retentive bond than either glass-ionomer or composite resin cements. In contrast, Squier et al. [115] found that resin cement showed the highest mean retentive strength when compared to zinc phosphate

cement and resin-reinforced glass-ionomer cement. Similarly, Pan and co-workers [90] demonstrated that the evaluated resin cements exhibited greater retention than the zinc phosphate cement which coincided with results of previous studies [115, 120].

However, although crowns and FDPs cemented on implant abutments with such kind of cements would have a lower risk of retention loss, their retrievability is questionable [75]. Nevertheless, a method of “semipermanent” fixation that provides adequate retention of the restoration and still allows retrievability would be desirable [132]. Accordingly, regardless of the retentive forces inherent to the type of cement, an effort was made to reduce the retention by employing petroleum jelly [21]. The addition of petroleum jelly to zinc phosphate cement lowered the retention values significantly without showing an increase in marginal leakage [91]. Another approach was carried out to decrease retention values of permanent cements by reducing the amount of applied cement, but no difference in half-coating or complete coating of the inner surfaces of the implant-retained crowns could be found, whereas, using the half-coating technique tended to result in improved marginal fit and a better occlusal discrepancy [132].

1.5 Complications (biological and technical)

Intraosseous dental implants have gained wide acceptance and adoption by dentists for application in prosthetic dentistry; however, complications are still a matter of concern for clinicians [18]. Complications associated with implant-supported suprastructures can be divided into technical and biological aspects [40]. Veneering ceramic fractures, screw loosening, and loss of the reconstructions retention were reported to be the most common technical complications [59, 94]. The incidence of these events after an observation period of at least 5 years recorded was 10.3%, 8.2%, and 5.7%, respectively [4]. In this context, however, it can be stated that the etiologies of technical events can be eliminated with technical amendments and enhancing the materials and components utilized in implant-retained reconstructions [95].

On the other hand, peri-implantitis and bone loss were reported to have the highest incidence among other biological complications [59, 97]. Biological events are mostly multi-factorial, i.e., patient’s susceptibility accompanied by biologic

interactions with the inserted materials [131] or other incidental inducing factors, e.g. excess cement [92], and/or the presence of an overload applied to the delivered suprastructure [57, 83]. It has been reported that residual excess cement was mostly responsible for the development of peri-implant diseases [125]. Furthermore, the presence of micro-gaps between the implant shoulder/abutment and implant abutment/suprastructure facilitates bacterial colonization formation [29, 65, 102], which in turn can induce peri-implant inflammations and peri-implantitis [83]. Nevertheless, biological complications are still one of the predominant issues studied in the field of implant research [40].

1.6 How to remove suprastructures

The retrievability of implant-supported restorations is of particular importance in terms of maintenance and repair procedures [26]. While this is easily performed in screw-retained suprastructures, recovery of cement-retained reconstructions without damaging them or/and implant-system components might pose a great challenge to clinicians [26, 132]. Several methods have been applied to facilitate this procedure. Preparation of an access hole through the veneering ceramic and metal coping to attain the abutment screw is well described [35, 129]. Another method includes incorporating a retrieval screw into the definitive restoration during the fabrication process [26]. An alternative to the previous methods was to prepare a lingual groove and using connectors (in FDPs) in conjunction with a clinical removal device (e.g. Coronaflex), which applies high-impact and short duration forces [75].

In clinical situations, mostly masticatory forces and more seldom vertical tensile forces can contribute to crown de-cementation [61, 75]. However, most in-vitro studies utilize uniaxial tensile tests to evaluate the retentive strength of cemented implant crowns or FDPs [15, 20, 21, 34, 90, 114, 132]. This enables a direct comparison with investigations of a similar nature [36]. However, a constant force of long duration; e.g. tensile forces, are clinically not applicable and only instruments with high pressure, high-impact, and short duration force can be used intraoral to retrieve crowns or FDPs [75, 132]. Little data is available on the retrievability of cemented implant crowns using clinical removal devices and whether the retrievability correlates to crown retention.

1.7 Aim of study – evolving the research question

Till now there are only few reports with regard to a predictable retrievability behavior of luting cements used with implant-supported restorations under oral environment-simulating conditions. In this study four commercially available cements were evaluated for their suitability to provide a durable, but retrievable cementation of fixed implant-supported restorations. The effect of chewing simulation and thermal cycling on tensile strength and removal attempts of the investigated cements was evaluated.

The null-hypotheses of this study to be tested were:

1. There is no difference regarding retention and removal attempts between the cements.
2. Thermal cycling and chewing simulation does not influence retention and removal attempts of the cements.
3. There is no correlation between tensile strength and removal attempts for any of the cements.

2. Materials and methods

2.1 Abutments

Hundred and twenty-eight titanium universal abutments of the Camlog implant system with a diameter of 4.3 mm, a height of 8.5 mm and a taper of 6 degrees (Camlog Biotechnologies, Basel, Switzerland) were used. The abutments were shortened standardized to a height of 4 mm (Isomet 1000 precision saw; Buehler, Lake Bluff, IL, USA). Each screw-retained abutment was attached to an implant analog with 20 Ncm torque using a manual torque controller (Camlog, Fig.1). The abutments were retightened with 20 Ncm after 10 minutes to impede screw loosening.



Fig. 1 – Camlog laboratory analog, abutment, and abutment screw

2.2 Suprastructures

The implant-supported crowns were designed computer-aided with a software program (CAD, Autodesk Inventor, Autodesk, USA). Computer-aided manufacturing (CAM, BEGO Medifactory-System, BEGO, Bremen, Germany) and selective laser sintering (SLS) using a cobalt-chromium alloy (Wirobond C, BEGO Medical) was employed to produce the crowns (Fig. 2). Hereby, a high-energy focused laser beam directly fuses a localized region of a thin layer of a cobalt-chromium powder to build up the crowns gradually. Results with regards to fit and survival rates of two in vivo studies showed that crowns produced with SLS technology exhibit a marginal and internal accuracy that is comparable to conventional production procedures [1, 101].



Fig. 2 – Example of a single crown ready to be cemented on the abutment. The occlusal loop was used to remove the crowns with the universal testing machine. The wider of the occlusal loops enabled chewing simulation testing.

A loop was added to the occlusal surface (Fig. 2) to allow tensile testing with a universal testing machine (UTM, Zwick BZD10/TNZA, Ulm, Germany). The internal surfaces of the crowns were machined, using high performance hard metal burs capable of milling cobalt-chromium alloy to precisely mirror the corresponding abutment shape (Komet, Gebr. Brasseler, Lemgo, Germany). These burs were specially designed using computer software (Autodesk Inventor). For grinding the inner crown surfaces, the burs were mounted in a milling machine to reduce vibration induced tolerances (Emcomat, Emco, Vienna, Austria) [77].

2.3 Inspection of the fit of the suprastructures

The fit of the resulting crowns was checked randomly for 25 percent of the abutment/crown assemblies. The crowns were filled with a black disclosing silicone (Fit-checker black, GC, Tokyo, Japan) and the abutment was placed under a 50 N load (5 kg) for 5 minutes. After removal of the abutment, the remaining thin layer of the black disclosing silicone in the crown was filled with a yellow silicone light body (Aquasil Ultra, Dentsply DeTrey, Constance, Germany). After 7 minutes, the fused silicone bi-layers were taken out and embedded again in the yellow silicone light body which was put in a brass ring ($\varnothing = 1$ cm, H = 1 cm). The resulting cylindrical silicone masses were cut twice in the horizontal dimension. Thereafter, slices of the disclosing silicone were photographed by means of a digital camera (Canon EOS

D60, Japan) mounted on light microscope (Wild Makroskop M420, Heerbrugg, Switzerland) at 70× magnification to obtain the required digital images.

Photoshop software (Adobe CS4, San Jose, CA, USA) was employed to measure the thickness of the disclosing silicone at eight different spots on exactly opposing sites on the digital images for each implant specimen. For this purpose, the measuring scale of the software was firstly calibrated as follows: A 2 mm optical microscope stage micrometer reading at 0.01 mm intervals (Leitz, Wetzlar, Germany) was photographed by the same camera (Canon EOS D60, Japan) and the light microscope (Wild Makroskop M420, Heerbrugg, Switzerland) at the same magnification (70×). Later on, this digital image was used to identify the equivalent of pixel units in micrometer units on the digital image. Hereafter, the thickness of the disclosing silicone circle was measured at the predetermined sites using the software's ruler tool. Four measurements were conducted per disc (slice), and overall eight measurements per implant specimen were taken [76-78] (Fig. 3).

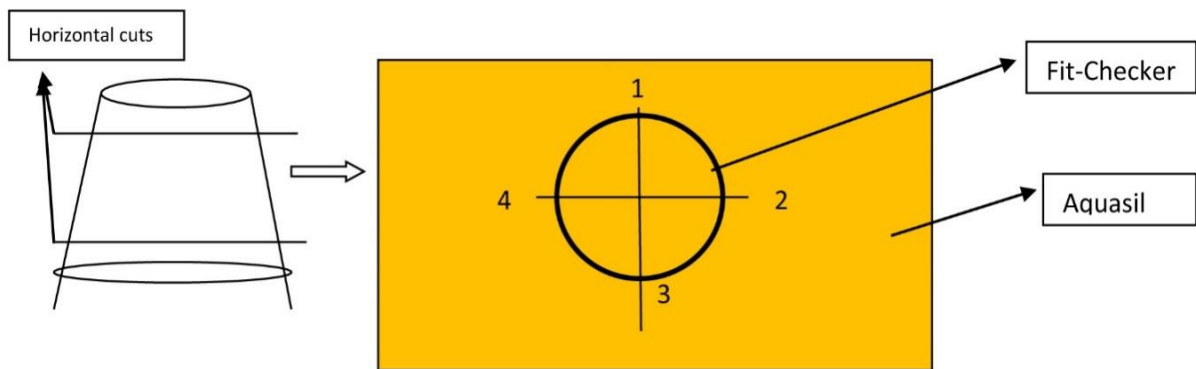


Fig. 3 – The schematic view demonstrates the appropriate sites for determining the disclosing silicone (Fit-Checker) thicknesses by using a silicone (Aquasil Ultra, Dentsply DeTrey, Constance, Germany)

2.4 Employed materials and cementation procedures

The crowns and their corresponding implant-abutment assemblies were numbered for the purpose of identification during cementation procedures. Four cements were evaluated in the present study – Glass-ionomer cement (Ketac Cem) and three composite resin cements (Multilink Implant, Telio CS Cem and Retrieve). The materials used in this study are listed in Table 1 and were used according to the manufacturers' instructions. Prior to cementing the crowns, the occlusal screw

access of the abutments was closed with white gutta-percha (gutta-percha in sticks, Dentsply DeTrey, Constance, Germany) before cementation [75, 132] (Fig. 4).

Table1. Materials used in this study. The data as provided by the manufacturers.

Proprietary material	Lot no.	Type	Manufacturer
Ketac Cem, Aplicap	427254	Glass ionomer cement	3M Espe, Seefeld, Germany
Multilink Implant	R25959	Resin cement	Ivoclar Vivadent, Schaan, Liechtenstein
Telio CS Cem	P69516	Resin cement	Ivoclar Vivadent
Retrieve	11326- 11326	Resin cement	Parkell, NY , USA
Liquid Strip	R08837	Oxygen inhibitor	Ivoclar Vivadent
Fit-Checker Black	1107051	Silicone	Kuraray, GC Corp., Tokyo, Japan
Aquasil Ultra	120216	Silicone light body	Dentsply DeTrey, Constance, Germany



Fig. 4 – Implant abutment on the left closed with gutta-percha

Before cementation the inner surfaces of the crowns were air-abraded with 50 μm aluminum oxide particles at a pressure of 0.2 MPa (2 bar) for 10 seconds. All abutments were pearl blasted for 10 s at 0.2 MPa. Prior cementation the crowns and abutments were ultrasonically cleaned in 99% Isopropanol for three minutes. Components were allowed to air-dry and were visually inspected for surface cleanliness.

As Multilink Implant specimens in a comparable study [76] provided excessive retention values when using a primer (Monobond plus, Ivoclar Vivadent), Multilink Implant specimens in this study were bonded without using a primer. The cements were applied with a band of 1 mm to the cervical margin of the inner surface of the crowns. Then, by using a micro-brush, luting agents were painted to a thin film on the inner surface of the castings. Each micro-brush was used once, and then discarded. The crowns were cemented under a load of ≈ 50 N (5 kg) for 10 minutes at 20 °C using air-conditioning [74, 76, 77] (Fig. 5).

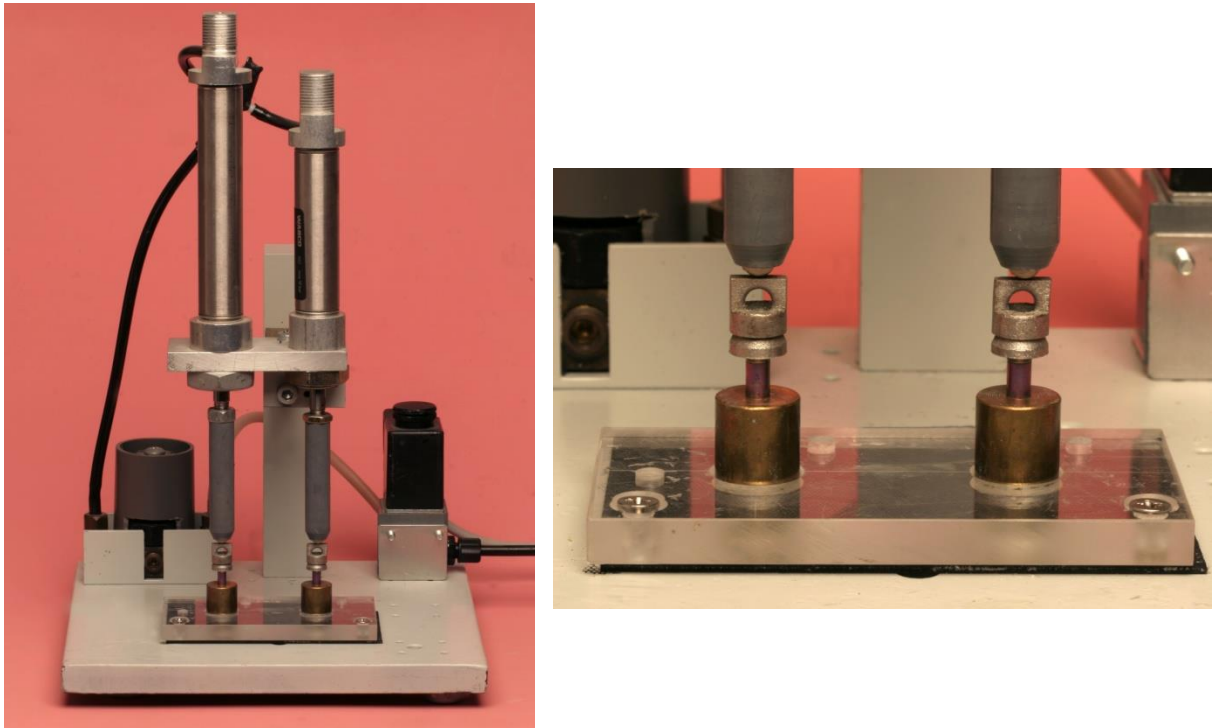


Fig. 5 – Cementation of the crowns

Directly after seating the crowns on the abutments and removal of the excess cement using foam pellets, brushes and a plastic curette (Universal implant deplaqueur; Kerr Hawe, Bioggio, Switzerland) an oxygen inhibiting layer (Liquid Strip,

Ivoclar Vivadent) was placed to ensure complete chemical curing of resin-based cements.

2.5 Study design

After cementation specimens were stored in de-ionized water at a temperature of 37 °C for three days. After three days storage specimens were subjected to the treatment proposed by each experimental subgroup, see Fig. 6.

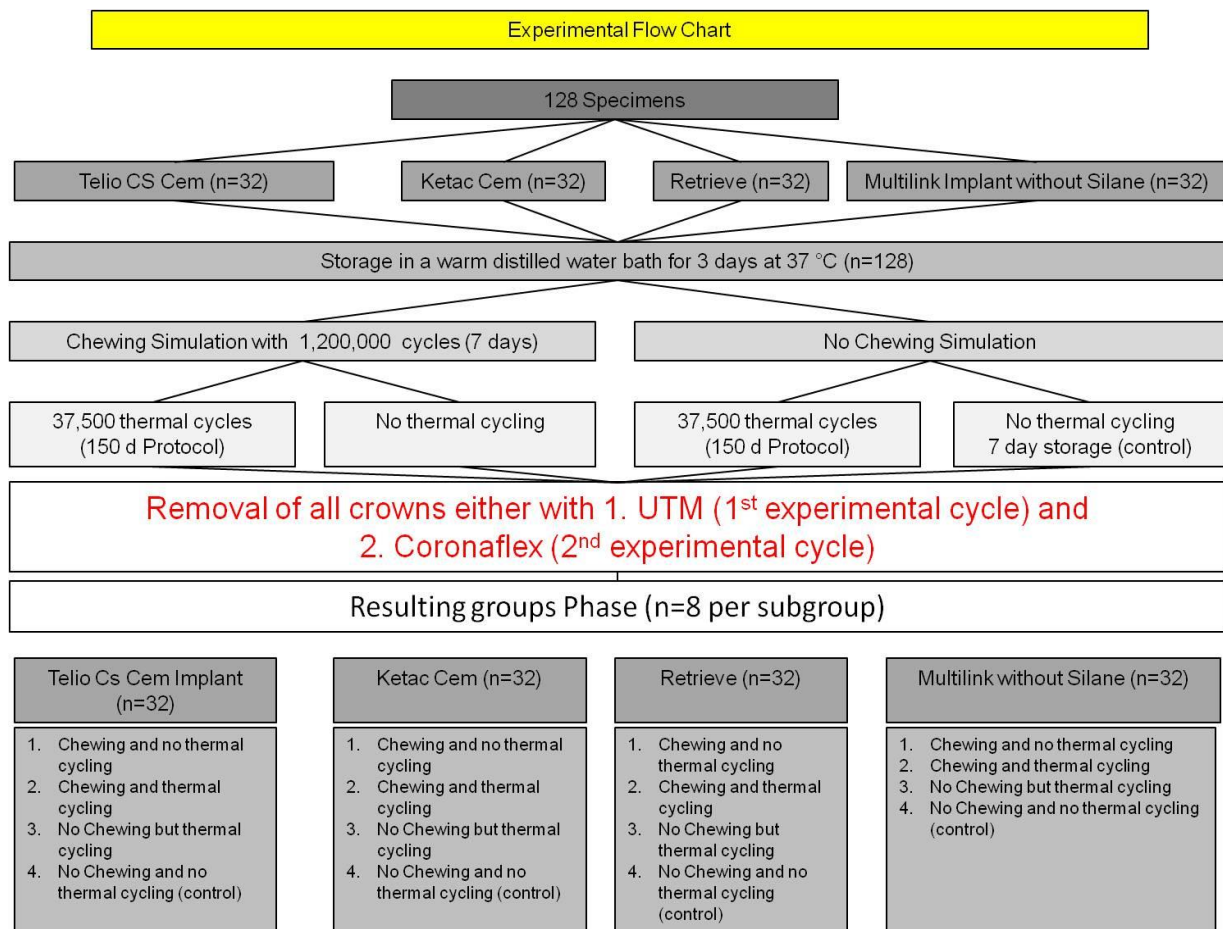


Fig. 6 – Experimental flow chart

The control group specimens were stored in de-ionized water for 10 days. Thermocycling was performed with the specimens being subjected to 37,500 cycles from 5 to 55 °C with a dwell time of 30 s (150 D storage protocol). The specimens who were assigned to be dynamically fatigued in the chewing simulator (Willytec, Munich, Germany) were subjected to dynamic loading with 1,200,000 cycles. Dynamic loading procedures were carried out as follows: implant-analogs of all

specimens were fastened firmly in special cylindrical-shape brass holders and it was ensured that all of them were level. Then, each two holders were attached firmly in specially designed cylindrical-shape Teflon holders. Each two specimens were joined together by means of a brass bar. This bar was machined and had a groove cut into its lower side, which facilitated a firm combining and attaching the loops of the respective two specimens at equal distances from the middle of the bar. The upper side was a 30° angled surface which included a 2-mm thick centrally incorporated Co-Cr alloy disc, which received later the simulating chewing load. Later on, these Teflon holders were placed into the water chambers of the chewing simulator and screwed tightly into position. The parameters chosen for the testing in the chewing machine were: 1. 10 kg load for each paired specimens; 5 kg load per specimen, 2. A two dimensional movement with a speed of 30 mm/s (3 mm eccentric seating and then 2 mm sliding movement towards the middle of the Co-Cr disc), 3. No thermal cycling; only de-ionized water (see Fig. 7).



Fig. 7 – Specimens ready to be dynamically fatigued (left). Specimens inside the chewing simulator (right)

Altogether 32 subgroups (4 cements with: 1. control, 2. thermal cycling, 3. chewing simulation, 4. combination chewing simulation and thermal cycling), retrieval with UTM or Coronaflex (see Fig. 6) with eight specimens each were tested.

2.6 Retrieval of suprastructures and data collection

Following the experimental test arrangements the crowns were removed with the UTM mentioned above with a crosshead speed of 2 mm/min (Fig. 8) or the Coronaflex (KaVo, Biberach, Germany), (Fig. 9). For this purpose a specially

designed assembly to hold the Coronaflex in constant position was fabricated. A brass holder to retain the specimen (the implant analog) was attached firmly at an appropriate location to the base of the assembly. A centrally perforated 2 mm thick stainless steel plate provided with an attached stainless steel loop was constructed. Each specimen's analog was inserted through the plate's central hole and fixed tightly into the brass holder. Then, the loop was held lightly, and the tip of the Coronaflex was hooked into the loop and the specimens were aimed to be removed with the dynamically applied impact with a preload of 400 cN [76, 78]. The bottom side of the cemented crown was in intimate contact with the metal plate (Fig. 9). The force applied for the retrieval force preload was evaluated in earlier studies [76, 78]. Coronaflex was supplied with 3.5 bar air pressure, which is in accordance with the manufacturers' instructions. The number of attempts needed to retrieve each crown using the Coronaflex was recorded, but was stopped after a maximum of 300 removal attempts [76].



Fig. 8 – Crowns ready to be retrieved by the universal testing machine

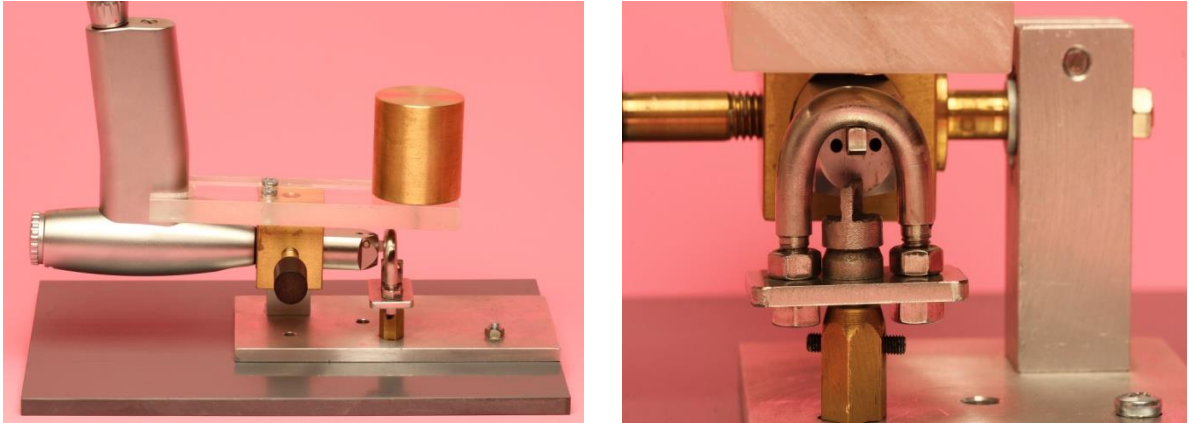


Fig. 9 – Crowns ready to be retrieved by the Coronaflex

2.7 Statistical analysis

The data were statistically analyzed using “SPSS for Windows” (Version 18.0; SPSS Inc., Chicago, USA) at a level of significance of $P \leq 0.05$. Since data were not distributed normally (Kolmogorov-Smirnov-Test and Shapiro-Wilks tests) Kruskal-Wallis tests followed by Dunn’s post-hoc tests and Mann-Whitney U tests were used. To statistically calculate the correlation between the tensile testing with the UTM and the Coronaflex the Spearman rank correlation coefficient test was used. All multiple testing was adjusted according to Bonferroni-Holm for multiple comparisons [56].

3. Results

The average misfit of the crowns measured with the disclosing silicone and the light microscope was $8.6 \pm 2.4 \mu\text{m}$. The results and statistical evaluation of tensile strength and retrievability can be found in Tables 2-4.

Table 2 Tensile strength values (in *N*, median, 25th, 75th percentile) when removing the crowns with the universal testing machine are shown (n = 8 per group). Statistical analysis was performed using Kruskal-Wallis tests followed by Dunn's post-hoc tests for pair-wise comparisons adjusted according to Bonferroni-Holm. [C0 = no chewing simulation, C1 = 1,200,000 chewing cycles; T0 = no thermal cycling, T1 = 37,500 thermal cycles]

Removal with universal testing machine						
	Ketac Cem Median (25th, 75th percentile)	Multilink Implant Median (25th, 75th percentile)	Retrieve Median (25th, 75th percentile)	Telio CS Cem Median (25th, 75th percentile)	Kruskal-Wallis tests (comparing the cements at constant factors)	
C0 T0	244 (230;258)	307 (260;330)	154 (138;175)	107 (105;118)	P ≤ 0.0001	
C0 T1	264 (243;340)	311 (288;366)	93 (74;108)	81 (73;90)	P ≤ 0.0001	
C1 T0	225 (119;251)	275 (253;371)	123 (111;145)	81 (68;91)	P ≤ 0.0001	
C1 T1	235 (289;301)	303 (268;332)	102 (73;118)	86 (73;93)	P ≤ 0.0001	
Pair-wise comparisons (Dunns post-hoc tests)						
	Ketac Cem vs. Multilink Implant	Ketac Cem vs. Retrieve	Ketac Cem vs. Telio CS Cem	Multilink Implant vs. Retrieve	Multilink Implant vs. Telio CS Cem	Retrieve vs. Telio CS Cem
C0 T0	0.3	0.1	0.001	0.008	<0.0001	0.2
C0 T1	0.8	0.02	0.004	0.002	0.0002	0.8
C1 T0	0.1	0.3	0.03	0.01	<0.0001	0.2
C1 T1	1	0.01	0.005	0.002	0.0006	1

Table 3 Attempts (decimals were rounded, median, 25th, 75th Percentile) to remove the implant-supported crowns with the Coronaflex are shown (n = 8 per group). Statistical analysis was performed using Kruskal-Wallis tests followed by Dunn's post-hoc tests for pair-wise comparisons adjusted according to Bonferroni-Holm. [C0 = no chewing simulation, C1 = 1,200,000 chewing cycles; T0 = no thermal cycling, T1 = 37,500 thermal cycles]

Removal with Coronaflex						
	Ketac Cem Median (25th, 75th percentile)	Multilink Implant Median (25th, 75th percentile)	Retrieve Median (25th, 75th percentile)	Telio CS Cem Median (25th, 75th percentile)	Kruskal-Wallis tests (comparing the cements at constant factors)	
C0 T0	5 (3;6)	6 (2;9)	3 (2;7)	3 (2;3)	P = 0.2	
C0 T1	3 (2;4)	3 (2;4)	3 (2;12)	1 (1;2)	P = 0.01	
C1 T0	2 (1;2)	4 (2;12)	4 (2;7)	2 (1;4)	P = 0.07	
C1 T1	3 (2;4)	6 (4;28)	3 (1;11)	2 (1;2)	P = 0.06	
Pair-wise comparisons (Dunns post-hoc tests)						
	Ketac Cem vs. Multilink Implant	Ketac Cem vs. Retrieve	Ketac Cem vs. Telio CS Cem	Multilink Implant vs. Retrieve	Multilink Implant vs. Telio CS Cem	Retrieve vs. Telio CS Cem
C0 T1	1	1	0.04	1	0.1	0.04

Table 4 Evaluating the influence of thermal cycling and chewing simulation on the tensile strength and retrievability of the cemented crowns using Mann-Whitney *U* tests (*P*=level of significance) and the correlation between the removal with the universal testing machine and the Coronaflex tested with the Spearman rank correlation (*r*=correlation co-efficient).

[**C0** = no **c**hewing simulation, **C1** = 1,200,000 **c**hewing cycles; **T0** = no **t**hermal cycling, **T1** = 37,500 **t**hermal cycles, UTM = universal testing machine]

Influence of thermal cycling									
		Ketac Cem		Multilink Implant		Retrieve		Telio CS Cem	
		UTM	Coronaflex	UTM	Coronaflex	UTM	Coronaflex	UTM	Coronaflex
C0	T0 vs. T1	0.06	0.03	0.3	0.3	0.0003	0.8	0.0002	0.003
C1	T0 vs. T1	0.05	0.04	0.9	0.4	0.04	1	0.4	0.4
Influence of chewing simulation									
		Ketac Cem		Multilink Implant		Retrieve		Telio CS Cem	
		UTM	Coronaflex	UTM	Coronaflex	UTM	Coronaflex	UTM	Coronaflex
T0	C0 vs. C1	0.2	≤ 0.0001	1	0.9	0.02	0.8	≤ 0.0001	0.2
T1	C0 vs. C1	0.7	1	0.5	0.07	0.7	0.8	0.6	0.7
Correlation between the UTM removal and Coronaflex removal									
Overall		Ketac Cem		Multilink Implant		Retrieve		Telio CS Cem	
r	P	r	P	r	P	r	P	r	P
0.5	≤ 0.0001	0.3	0.1	0.7	≤ 0.0001	0.2	0.2	0.6	= 0.0007

Retention values were recorded between 225 N (25th percentile) and 264 N (75th percentile) for Ketac Cem, between 275 N (25th percentile) and 311 N (75th percentile) for Multilink Implant, between 93 N (25th percentile) and 154 N (75th percentile) for Retrieve and between 81 N (25th percentile) and 107 N (75th percentile) for Telio CS Cem. Telio CS Cem showed the lowest retention values followed by Retrieve, Ketac Cem and Multilink Implant.

The number of removal attempts with the Coronaflex recorded between 2 and 5 for Ketac Cem, between 3 and 6 for Multilink Implant, between 3 and 4 for Retrieve and between 1 and 3 for Telio CS Cem. The number of removal attempts was not significantly different between the cements (*P*>0.05), with the exception of the

following comparisons: Ketac Cem and Telio CS Cem ($P = 0.04$; 37,500 thermal cycles, no chewing simulation), and Retrieve and Telio CS Cem ($P = 0.04$; 37,500 thermal cycles, no chewing simulation). Thermal cycling and chewing simulation influenced the retrieval of the cements partly ($P \leq 0.05$, see Table 4), with the exception of Multilink Implant ($P > 0.05$). For Multilink Implant and Telio CS Cem correlations between removal with the universal testing machine and the Coronaflex could be found ($r > 0.6$, $P \leq 0.0001$).

4. Discussion

In this in-vitro study the influence of thermal cycling and chewing simulation on tensile strength and removal attempts of implant-retained crowns was evaluated. All null-hypotheses had to be rejected, since the choice of cement influenced crown retention and removal attempts. Moreover, thermal cycling and/or chewing simulation influenced the retention for all cements, except for Multilink Implant. A correlation between tensile strength and number of removal attempts could be found for Multilink Implant and Telio CS Cem.

4.1 Discussion of the study design

There are multiple factors in the oral cavity including temperature changes, masticatory forces, and water degradation that likely cause fatigue of the cement of the implant-retained crowns and might adversely affect the properties and retention of luting cements [61, 89, 90]. Therefore, in-vitro conditions should ideally be established to imitate some influential oral aspects to obtain an evidence of the potential clinical performance of the materials [36]. It has been demonstrated that variations exist in the amount of retention exhibited by the same types of cements used under different in-vitro conditions [28, 60, 61, 89, 90]. Previous investigators have reported conflicting results regarding the impact of cyclic loading and thermal cycling on the retention values of cements [44, 60, 76, 89, 93].

The experimental restorations in our investigation were fabricated from a Co-Cr alloy, which exhibits only a minimal substance loss caused by air-abrasion [66]. In other studies, the wear of the inner crown surfaces was found to be insignificant; however, it should be kept in mind that it might possibly reduce the fit and therefore the retention of the crowns on the abutments [75, 132]. Similar to previous studies [76-78] the crowns were initially randomly chosen for their respective experimental group, to ensure that changes caused by the initial cleaning procedures and air-abrasion prior to the first test cycle were equal for all tested groups. The same procedure was undertaken with the titanium implant-abutments, as their surfaces were pearl blasted. However after the initial selection process all crowns were numbered to allow correlation tests between the Coronaflex and the UTM.

4.2 Discussion of the results

The low number of removal attempts might not be directly transferrable to the clinical situation, as laboratory conditions may differ to a large extent from clinical conditions [75]. Clinical aspects that might increase the number of the needed removal attempts encompass the following: 1. The removal force might be partially absorbed by the elastic bone [78]; 2. The mobility of the mandible and the patient's head, and the limited accessibility at the point of loading, might result in an angled application of the removal forces [75]; 3. In this study all connections and parts of the metal set-up were firmly attached and the applied forces were strictly vertically oriented, which means that no attenuation was possible and, consequently, the force was almost completely transferred to the cement interface thus testing the adhesive and cohesive qualities of the cements [78].

The significant differences in crown retention obtained by the different cements might be explained by their respective cohesive strength and their ability to establish chemical bonds to the metal surfaces of the titanium abutment and the cobalt-chromium crown. After visual inspection of the abutment surfaces none of the cements left any residual cement on the abutment surface, leaving almost 100% of the residual cement attached to the inner surface of the crown, which could be attributed to the fact that the rough air-abraded inner surface of the crown provided greater micromechanical retention than the smooth abutment surface [36].

The tensile strength of the cements and their resistance to removal attempts is based on their cohesive and adhesive properties. Ketac Cem provides good physical properties, but has a limited adhesion to titanium (around 3 MPa) [103]. In previous studies tensile values were comparable to this study with regards to the minimal influence of chewing simulation and thermal cycling [75, 76]. This cement's stability mainly derives from its cohesive strength and the micromechanical interlocking between the roughened walls at a minimal cement film thickness of around 9 μm [77]. If the cement film thickness is increased to 50 μm the tensile values drop significantly [77].

Multilink Implant was used in this study without any preconditioning with primer neither at the titanium surfaces nor at the Co-Cr crown surfaces, unlike in previous studies [14]. In a comparable study [77] tensile test values using silane (primer) averaged 1200 N, which was contrary to the aim of this study, finding cements for a "semipermanent cementation". Multilink Implant's physical properties, i.e. Vickers'

hardness, E-modulus and cohesive strength are superior to the other cements used in this study (Data provided by the manufacturers [77]). This could explain the negligent effect of thermal cycling and chewing simulation and the higher tensile test values in comparison to the other cements.

Most of the cements used for cementing implant-supported prostheses were originally designed to bond restorations to natural tooth surfaces [90]. Telio CS Cem and Retrieve were especially designed to provide durable temporary cementation for implant restorations, but allow retrievability if necessary. Both cements have weaker physical properties compared to Ketac Cem and Multilink Implant. This can be attributed to a higher matrix/filler ratio (around 45 % both) and additional softeners (Data provided by the manufacturers). In comparison Multilink Implant contains around 30 % matrix and 60 % inorganic fillers. Another important aspect could be the minimal cement film thicknesses for the cements, as a higher cement film thickness leads mostly to reduced cement retention values [132].

Cement film thickness in our study has been verified by means of a disclosing silicone media, which appeared to be a reliable method to check the discrepancies between crown and abutment [76]. The discrepancies between crown and abutment assessed in the present study are smaller than in other in vitro [7, 16] or in vivo [42] studies. Although retention forces of zinc phosphate cement, resin cement and glass ionomer cement were not significantly affected by a cement film thickness ranging from 25 μm to 100 μm [20, 60] it is likely that a more precise fit results in higher retention values, since more of the cement particles can ensure mechanical micro retention in a greater surface area [22]. The cement film thickness results reported for glass ionomer cement (Ketac Cem) vary in the literature with a range from 7.2 μm [69] to 58 μm [103]. In the current study cementing loads of 50 N have been used, the computer-aided design and manufacturing of the crowns resulted in precisely fitting abutment-crown assemblies. Furthermore, the conical shape of the abutment without a shoulder and the design of the crowns without an occlusal cover allowed the cements to be pressed until minimal film thickness was achieved [76]. Accordingly, it can be assumed that the cement thicknesses were closer to the lower end of this range as higher cementing loads result in smaller seating discrepancies [103]. For the composite resin cements varying data ranging from 9 μm to 409 μm can be found largely depending on the resin cement used [103, 122].

A correlation between tensile strength and number of removal attempts could be found only for Multilink Implant and Telio CS Cem. However, these results should not be over interpreted as the removal attempts averaged only between 1 and 6, which in turn contrasts with results from a previous study with an abutment length of 6 mm and cast gold crowns [75].

4.3 Clinical implications

Implant related complications occurring in the first year occupying 1-2 hours of treatment time and around \$170 (Canadian Dollar) average repair costs [13, 127]. In the following years implants still have a higher complication rate than restorations on natural abutments [48, 107]. The thermal cycling and chewing simulation regime employed in this study represents around 4-5 service years in vivo [43]. Although Ketac Cem, Retrieve and Telio CS Cem, showed some susceptibility to chewing simulation and thermal cycling, it seems questionable whether these differences have a clinical relevance. More importantly, none of the abutment-crown assemblies debonded prematurely, making them suitable for cementing fixed implant restorations. Since the practice of permanently cementing implant-based prostheses often appears to be at odds with the likelihood of biological and technical failures occurrence, retrievability is still an important aspect of delivering patient-based treatment outcomes [45, 126]. Additional economic considerations make the choice of the cement of vital importance for cemented implant supported restorations [126, 127].

5. Conclusions

On the basis of the results and the limitations of this study, the following conclusions can be drawn:

1. Ketac Cem and Multilink Implant (without silane) can be used when a “semipermanent” cementation is preferred.
2. Cementation with Retrieve and Telio CS Cem is indicated when a temporary cementation is preferred.
3. Thermal cycling and/or chewing simulation, influences the retention of luting cements with the exception of Multilink Implant cement.
4. A correlation between tensile strength and number of removal attempts could be found for Multilink Implant and Telio CS Cem.

6. Summary

The main goal of this in-vitro study was to evaluate whether tensile strength and retrievability of cemented implant-retained crowns correlate when using artificial ageing. Hundred and twenty-eight crowns were fabricated from a Co-Cr alloy for 128 tapered titanium abutments (6° taper, 4.3 mm diameter, 4 mm length, Camlog, Germany). The crowns were cemented with glass-ionomer (Ketac Cem) or resin cements (Multilink Implant, Telio CS Cem, and Retrieve). Multilink Implant was used without priming. The experimental groups were subjected to either 37,500 thermal cycles between 5 °C and 55 °C or 1,200,000 chewing cycles or a combination of both. Control groups were stored for 10 days in deionized water. The crowns were removed with a universal testing machine or a clinically used removal device (Coronaflex). Data were statistically analyzed using non-parametrical tests.

Retention values ranged between 31 N and 425 N. Telio CS Cem showed the lowest retention values followed by Retrieve, Ketac Cem and Multilink Implant. The number of removal attempts with the Coronaflex were not significantly different between the cements ($P > 0.05$). Thermal cycling and/or chewing simulation significantly influenced the retrieval of Ketac Cem, Retrieve and Telio CS Cem specimens ($P \leq 0.05$). Only for Multilink Implant and Telio CS Cem correlations between removal with the universal testing machine and the Coronaflex could be revealed ($P \leq 0.0001$). Under the conditions of this in-vitro study, Ketac Cem and Multilink implant (without silane) can be used for a “semipermanent” cementation. Retrieve and Telio CS Cem are recommendable for a temporary cementation of implant-retained crowns.

7. Zusammenfassung

Das Ziel der vorliegenden In-vitro-Studie war es, zu evaluieren, ob die Zugfestigkeit und die Abnehmbarkeit der zementierten implantatgetragenen Kronen korrelieren, wenn die Zemente einer künstlichen Alterung unterzogen werden. Hundertundachtundzwanzig Kronen wurden aus einer Co-Cr-Legierung für 128 konische Titanabutments mit einem Neigungswinkel von 6° , 4,3 mm Durchmesser und 4 mm Länge (Camlog, Deutschland) hergestellt. Die Kronen wurden mit Glasionomerezement (Ketac Cem) oder Kunststoffzementen zementiert (Multilink Implant, Telio CS Cem, Retrieve). Multilink Implant wurde ohne einen Primer verwendet. Die Versuchsgruppen wurden entweder mit 37.500 Temperaturwechsellastzyklen zwischen 5°C und 55°C oder 1.200.000 Kauzyklen oder einer Kombination von beidem künstlich gealtert. Die Kontrollgruppen wurden 10 Tage lang in entionisiertem Wasser aufbewahrt. Die Kronen wurden mit einer Universalprüfmaschine oder einem klinisch verwendeten Kronenentfernungsgerät (Coronaflex) gelöst. Die Daten wurden statistisch unter Verwendung von nicht-parametrischen Tests analysiert.

Die Retentionswerte lagen zwischen 31 N und 425 N. Telio CS Cem wies die niedrigsten Retentionswerte auf, gefolgt von Retrieve, Ketac Cem und Multilink Implant. Die Abklopfversuche mit dem Coronaflex-Gerät unterschieden sich nicht signifikant zwischen den Zementen ($P > 0,05$). Thermische Wechselbelastung und/oder Kausimulation beeinflussten die Abnehmbarkeit von Ketac Cem, Retrieve und Telio CS Cem Proben signifikant ($P \leq 0,05$). Nur für Multilink Implant und Telio CS Cem konnten Korrelationen zwischen der Entfernung mit der Universalprüfmaschine und dem Coronaflex-Gerät nachgewiesen werden ($P \leq 0,0001$). Unter den Bedingungen dieser In-vitro-Studie kann Ketac Cem und Multilink-Implantat (ohne Silan) für eine "semi-permanente" Zementierung empfohlen werden. Retrieve und Telio CS Cem eignen sich nur für eine provisorische Befestigung von Implantatkronen.

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10. Dedication

Finally, I dedicate this thesis to:

The memory of my father.....Hneid

My mother.....Maha

My husband.....Shadi

My children.....Fadi and Rami

My brothers.....Mazen, Kareem, and Mossab

Thank you all for your comprehension, love, and encouragement.

11. Curriculum Vitae



LEBENS LAUF

Shurouk Ali geboren
am 1976 in Brekie,
Syrien

Schulbildung

September 1988 – Juli 1994

Anwar-al-Jundi-Schule in
Tartous (Syrien), Abschluss:
Abitur

September 1982 – Juli 1988

Brekie-Grundschule bei Tartous

Studium

seit Februar 2012

Doktorarbeit zum Thema
„Influence of chewing force,
thermal cycling and storage
time on the retrievability of

cemented implant retained
crowns“

September 1994 – August 2000

Studium der Zahnmedizin an
der Universität Tishreen in
Syrien
Abschluss: Diplom

Berufliche Erfahrung

seit Dezember 2012

Beteiligung an DFG-Studie
(Einzelimplantatstudie für
zahnlose Patienten) in Kiel

April 2003 bis September 2010

Zahnarztpraxis in Damaskus

Januar 2001 bis März 2003

Leitung einer Privat-
Zahnarztpraxis bei Tartous,
Syrien

Sprachkenntnisse

Arabisch

Muttersprache

Deutsch

gute Kenntnisse

Englisch

gute Kenntnisse

Sonstiges

Oktober 2008

Teilnahme an der
gemeinsamen

	wissenschaftlichen Tagung der Zahnmedizin in Damaskus
Winter 2005	zahnärztliche Vorsorgeuntersuchungen in Kindergärten (Syrien)
seit 2000	Mitglied der syrischen Zahnärztekammer
1994 – 2001	ehrenamtlicher Unterricht für Kinder im Alter 5-8 Jahre (Lesen und Schreiben, Heimat- und Sachunterricht, Kunst)

12. Appendixes

Material/ Tensile	Code	X	Code	CS	Code	TC	Code	CS+TC
	25	237	9	259	17	274	1	296
	26	231	10	208	18	342	2	245
	27	217	11	249	19	332	3	303
Ketac Cem	28	266	12	90	20	355	4	307
	29	229	13	241	21	245	5	162
	30	251	14	71	22	254	6	296
	31	252	15	207	23	242	7	281
	32	260	16	252	24	242	8	232

Material/ Tensile	Code	X	Code	CS	Code	TC	Code	CS+TC
	57	151	41	165	49	123	33	68
	58	200	42	149	50	93	34	121
	59	118	43	111	51	108	35	125
Retrieve	60	140	44	111	52	82	36	110
	61	137	45	131	53	67	37	86
	62	156	46	130	54	107	38	107
	63	176	47	79	55	71	39	31
	64	172	48	115	56	92	40	97

Material/ Tensile	Code	X	Code	CS	Code	TC	Code	CS+TC
	89	298	73	278	81	374	65	316
	90	362	74	381	82	343	66	350
	91	319	75	342	83	390	67	287
Multilink Implant	92	316	76	425	84	305	68	322
	93	175	77	271	85	283	69	262
	94	334	78	255	86	316	70	335
	95	274	79	250	87	276	71	289
	96	255	80	252	88	302	72	221

Material/ Tensile	Code	X	Code	CS	Code	TC	Code	CS+TC
	121	124	105	74	113	90	97	87
	122	120	106	98	114	57	98	93
	123	107	107	87	115	89	99	72
Telio CS	124	107	108	89	116	76	100	92
	125	106	109	92	117	85	101	84
	126	104	110	40	118	100	102	77
	127	111	111	70	119	76	103	190
	128	105	112	67	120	72	104	71

Material/ Impact	Code	X	Code	CS	Code	TC	Code	CS+TC
	25	10	9	1	17	4	1	4
	26	4	10	2	18	4	2	3
	27	6	11	2	19	2	3	5
Ketac Cem	28	6	12	2	20	3	4	3
	29	4	13	2	21	3	5	1
	30	3	14	1	22	2	6	2
	31	6	15	2	23	4	7	4
	32	3	16	2	24	2	8	2

Material/ Impact	Code	X	Code	CS	Code	TC	Code	CS+TC
	57	13	41	>300	49	19	33	4
	58	8	42	2	50	>300	34	22
	59	4	43	7	51	5	35	11
Retrieve	60	3	44	4	52	12	36	10
	61	2	45	13	53	1	37	2
	62	2	46	4	54	3	38	2
	63	2	47	2	55	2	39	1
	64	1	48	1	56	2	40	1

Material/ Impact	Code	X	Code	CS	Code	TC	Code	CS+TC
	89	7	73	5	81	3	65	>300
	90	>300	74	20	82	6	66	28
	91	18	75	>300	83	>300	67	6
Multilink Implant	92	6	76	>300	84	3	68	29
	93	2	77	9	85	2	69	4
	94	9	78	2	86	4	70	12
	95	2	79	2	87	1	71	4
	96	2	80	2	88	2	72	1

Material/ Impact	Code	X	Code	CS	Code	TC	Code	CS+TC
	121	4	105	2	113	2	97	1
	122	3	106	2	114	1	98	2
	123	3	107	4	115	2	99	1
Telio CS	124	2	108	4	116	2	100	1
	125	3	109	1	117	1	101	2
	126	3	110	1	118	1	102	2
	127	2	111	2	119	1	103	8
	128	2	112	2	120	1	104	1

Discrepancies displayed between the crown and the respective abutment by using Fit Checker														
Sample	A1	A2	A3	A4	Mean A	S.D. A	B1	B2	B3	B4	Mean B	S.D. B	Mean A,B	S.D. A,B
1	4.5	5.4	5.4	5.0	5.1	0.4	5.4	5.5	7.6	11.4	7.5	2.8	6.3	2.3
3	7.8	4.9	5.8	6.4	6.2	1.2	8.7	8.9	7.7	7.6	8.2	0.7	7.2	1.4
11	8.0	12.1	13.2	17.2	12.6	3.8	15.4	7.7	16.6	11.2	12.7	4.1	12.7	3.6
14	5.4	5.8	9.0	6.2	6.6	1.6	9.5	14.6	12.2	12.3	12.2	2.1	9.4	3.5
18	6.0	5.9	6.3	4.7	5.7	0.7	8.3	7.1	6.8	5.9	7.0	1.0	6.4	1.1
21	5.6	6.0	5.6	5.8	5.8	0.2	8.9	9.4	8.0	8.9	8.8	0.6	7.3	1.6
25	13.7	13.0	5.3	6.5	9.6	4.3	5.6	12.8	13.1	11.4	10.7	3.5	10.2	3.7
29	6.9	10.3	8.2	10.7	9.0	1.8	9.2	3.0	6.7	10.7	7.4	3.4	8.2	2.6
33	10.8	12.1	9.9	8.3	10.3	1.6	9.0	11.7	10.8	10.0	10.4	1.1	10.3	1.3
36	6.3	6.5	10.0	6.7	7.4	1.8	10.0	7.4	8.5	6.2	8.0	1.6	7.7	1.6
42	8.1	9.0	8.7	9.1	8.7	0.5	8.1	9.5	9.2	9.0	9.0	0.6	8.8	0.5
44	11.0	9.0	9.4	10.3	9.9	0.9	7.3	6.7	7.6	6.5	7.0	0.5	8.5	1.7
49	7.8	5.5	8.2	6.3	7.0	1.3	8.6	5.9	7.3	5.9	6.9	1.3	6.9	1.2
54	6.9	7.6	6.0	6.3	6.7	0.7	5.9	8.3	6.2	6.8	6.8	1.1	6.8	0.8
58	6.7	5.3	5.3	4.9	5.5	0.8	5.4	3.7	6.2	5.0	5.1	1.0	5.3	0.9
62	8.7	8.9	7.4	9.1	8.5	0.7	8.2	7.1	7.6	8.0	7.7	0.5	8.1	0.7
65	9.8	8.0	6.3	7.2	7.8	1.5	7.6	7.4	8.1	6.2	7.3	0.8	7.6	1.1
70	6.3	6.2	5.1	3.6	5.3	1.2	5.1	5.8	5.9	4.7	5.4	0.5	5.3	0.9
73	9.2	13.0	11.7	12.3	11.5	1.6	12.7	11.3	12.2	11.4	11.9	0.7	11.7	1.2
75	9.6	10.8	13.0	9.8	10.8	1.5	11.7	7.1	8.0	6.4	8.3	2.4	9.5	2.3
83	6.3	5.3	5.4	5.9	5.7	0.5	6.3	5.1	6.5	6.2	6.0	0.6	5.9	0.5
88	6.4	7.3	10.5	6.0	7.6	2.0	9.2	10.1	8.5	7.6	8.9	1.1	8.2	1.7
90	9.6	8.2	6.0	6.7	7.6	1.6	5.0	8.1	10.1	9.0	8.1	2.2	7.8	1.8
94	8.3	8.1	8.5	7.3	8.1	0.5	9.1	8.3	6.9	6.5	7.7	1.2	7.9	0.9
98	8.1	7.1	7.6	9.0	7.9	0.8	9.6	6.2	6.4	7.6	7.4	1.6	7.7	1.2
101	6.8	6.5	6.9	7.3	6.9	0.3	6.2	8.2	6.3	6.4	6.8	1.0	6.8	0.7
105	13.1	16.4	16.8	19.2	16.4	2.5	17.2	19.6	16.7	16.3	17.5	1.5	16.9	2.0
108	7.3	8.0	6.0	6.3	6.9	0.9	6.3	9.4	8.5	6.8	7.7	1.4	7.3	1.2
114	11.8	13.6	15.9	13.5	13.7	1.7	11.3	9.2	13.2	10.9	11.2	1.6	12.4	2.0
119	9.9	11.9	11.2	6.5	9.9	2.4	10.4	14.2	7.1	9.0	10.2	3.0	10.0	2.5

121	8.0	8.3	8.0	8.0	8.1	0.2	8.9	15.8	16.7	10.7	13.0	3.8	10.5	3.6
127	9.4	10.8	8.2	8.9	9.3	1.1	13.2	8.7	10.3	11.2	10.8	1.9	10.1	1.6
Total					8.4	2.6					8.9	2.6	8.6	2.4