applied sciences

Article

The Preliminary Development of a Friction-Based Lateral Screw-Retained Dental Crown—A Comparison between the Prototype Surface Treatment and the Retention Strength

Sugeng Supriadi [1,2,*], Yudan Whulanza [1,2], Tri Ardi Mahendra [2,3], Ratna Sari Dewi [2,3], Lindawati S. Kusdhany [2,3], Pelangi Raihan Mathar [1] and Rizki Aldila Umas [1]

1 Department of Mechanical Engineering, Faculty of Engineering, Universitas Indonesia, Depok 16424, Indonesia
2 Research Center for Biomedical Engineering, Faculty of Engineering, Universitas Indonesia, Depok 16424, Indonesia; ratnasaridewi.drg@gmail.com (R.S.D.)
3 Department of Prosthodontics, Faculty of Dentistry, Universitas Indonesia, Depok 16424, Indonesia
* Correspondence: sugeng@eng.ui.ac.id

Abstract: This study aims to develop a novel retention method combining the retrievability of the screw retention method with the ideal occlusal table and the aesthetic capability of cement retention. Coping was developed to have lateral screw access, allowing the screw to lock the coping using lateral forces from screw tightening and friction between the tip of the screw and the sandblasted surface of an abutment. Sandblasting parameters varied based on particle size. The results show a positive correlation to surface roughness and indicate a positive correlation to retention force. The highest surface roughness and retention force result was shown by groups that were sandblasted using 686 µm of aluminum oxide. Experiments on the tightening strength of 48 subjects measured in simulated conditions similar to the assembly conditions of lateral screw retention implants resulted in a mean of 69.75 Nmm with the highest and lowest values of 120.67 Nmm and 34.67 Nmm. This result became the basis of tightening torque variation. Each group's retention capability is measured and compared to cement-retained dental implants. The results show that the tightening torque correlates positively with retention force, with the highest average retention score showed by lateral screws retained under a tightening torque of 200 Nmm—317.87 N higher than cement-retained screws.

Keywords: lateral screw-retained; retrievability; retention; dental implants

check for updates

Citation: Supriadi, S.; Whulanza, Y.; Mahendra, T.A.; Dewi, R.S.; Kusdhany, L.S.; Mathar, P.R.; Umas, R.A. The Preliminary Development of a Friction-Based Lateral Screw-Retained Dental Crown—A Comparison between the Prototype Surface Treatment and the Retention Strength. *Appl. Sci.* **2024**, *14*, 660. https://doi.org/10.3390/app14020660

Academic Editor: Luca Testarelli

Received: 13 October 2023
Revised: 26 December 2023
Accepted: 27 December 2023
Published: 12 January 2024

1. Introduction

Recently, single-implant restoration has become a common practice in the field of dentistry. The biological success rate of this implant in dentistry is the highest (amounting to more than 90%), higher than any other treatments employed to treat the loss of a natural tooth [1,2]. However, as the most widely used type of retention in implant prostheses [3,4], this cement-retained type is still facing various mechanical complications, posing some serious issues such as porcelain fractures, abutment fractures, and, mainly, screw loosening [5,6]. Dr. Elyce Link-Bindo stated that about 9.3% of screw loosening occurs in the first five years [7]. Accordingly, this technical issue required that the connection between the implant and abutment be retrievable [8,9]. By using a retrievable connection/retention method, the internal screw of a two-piece dental implant can easily be retightened if needed.

The retrievability of a cement-retained dental implant is limited. Such a significant force is required to remove the crown that it can permanently damage the crown, the abutment, the internal screw, or the implant itself [10]. Although it is relatively easy to remove temporary cementations since they are designed for temporary use, most of them have a low retention capability. Veselinovic stated that the retention force of a cement implant (both temporary and permanent) decreased after being subjected to mechanical cyclic loading, which is comparable up to 12-months usage; moreover, he demonstrated that the temporary and the permanent cement retention forces decreased up to 27.7% and 44.9% from the initial values, respectively [10]. Several studies have been conducted to increase the retention level of temporary cement. Based on the results of those studies employing various methods such as laser etching, acid etching, sandblasting, oxygen plasma, and other surface treatment methods to modify the surface of the abutment which will increase the retention forces, it is found that there is a positive correlation; the increase in the retention forces ranges from 26.4% to 90.7% [11–13]. Other than studies on the surface treatment, some other studies have analyzed the effects of geometry modification on the abutment through various axial wall modifications [14–16], screw access channel modifications [17], the addition of a groove [18], the height of the abutment [19], and the shape [20]. Even though several surface treatments and geometry modifications have proven to have increased the retention significantly, most studies have shown that a cement failure mode leaves some residue in both the implant and the coping. This residue can be categorized as a rough surface to which bacteria can adhere, resulting in a higher possibility of a peri-implant disease [21–23], making this method impractical.

Another way to develop a retrievable dental implant is by using a screw-retained dental implant, which holds a dental crown by using a screw to retrieve it [24]. This screw-retained type is advantageous in that the risk of inflammation in peri-implant tissue is minimal since no cement is used in this connection type [1,25]. Although this type of crown retention is already available on the market, its price, its aesthetic limitations, and its higher clinical disadvantages than that of the cement-retained implant have made many clinicians prefer a cement-retained implant [26,27]. Since the screw-retained implant has access that is vertically placed, it compromises aesthetics, and since the access screw occupies at least 50% of the occlusal table, it is difficult to establish ideal occlusal contact (clinical disadvantages) [28,29].

Lateral screw retention has been developed to avoid occlusal access holes. The lateral screw method can help restore the excessive angulated implant while maintaining retrievability. The cross-pin retained implant-supported restoration requires modification of the abutments. It is such a complex method since the procedure starts from determining the milling direction of the abutment, continues to make the access through the abutment in the lingual-labial direction, and is followed with tapping of the abutment. This method does not require special coping or screw angulation and does not mention the torque required in the installation of the crown [30–32]. Another way to use this connection type is by employing a prefabricated part like in the Straumann system. In that system, specific components such as SynOcta TS abutment model, coping (gold or plastic coping for burnout technique), and the transversal screw are required. The lateral screw angle and position have been determined in accordance with the coping. However, in terms of its availability, the use of this connection type is limited. Since it requires a special abutment, the laboratory procedures are very sensitive and expensive; moreover, this connection type can only be exclusively used by a specific dental implant brand. The lateral screws employed in the Straumann and the cross arch pin technique are similar in that the lateral screw is required to go through the abutment. Conducting a finite element analysis study, Lasheras et al. showed that the lateral screw-retained type could be selected since it possessed the lowest mechanical risk complication in the abutment, the abutment screw, and the prosthetic screw when the loads of the inclination forces amounting to 0° and 15° are applied in the model [33].

This study offers a new approach to the achievement of lateral screw retention by employing some additional coping with several lateral screws which retains the dental crown by mainly employing friction-based retention. The set of dental implants used in this study is a widely used cement-retained dental implant subjected to any surface treatment of sandblasting with various sizes of the particle employed to increase the friction coefficient of the dental abutment. Furthermore, in this study, we also conduct an experiment with the tightening torque required in this novel friction-based lateral screw-retained dental implant. This study is aimed at developing a novel friction-based lateral screw retention method that has better aesthetics and occlusal condition than that of the vertical screw retention with a similar retention capability to that of the cement-retained method.

2. Materials and Methods

2.1. Prototype Design and Manufacturing

The main idea of a friction-based lateral screw-retained dental crown is to use coping, which has lateral access for a general headless M2 screw that locks the coping into the abutment using a lateral force generated by the tightening motion of the screw combined with the friction coefficient of the flat surface of the abutment. When both of the factors are combined, they will result in a frictional force that resists the motion of the entire crown structure. This coping then serves as the base structure for the crown structure; meanwhile, the aesthetic needs can be achieved by employing another process such as the porcelain-used-to-metal process (PFM) (see Figure 1).

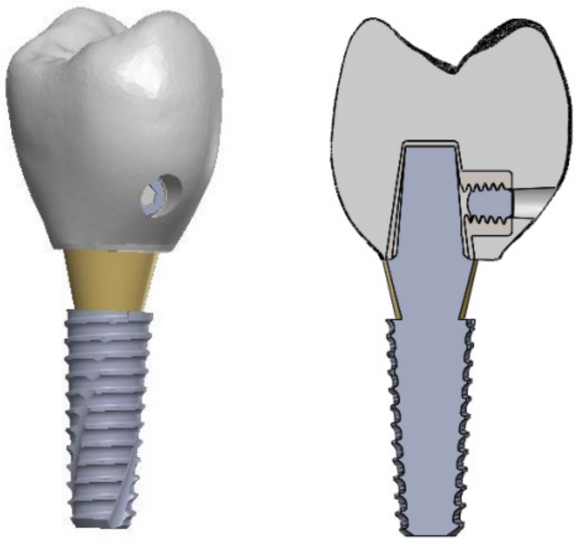
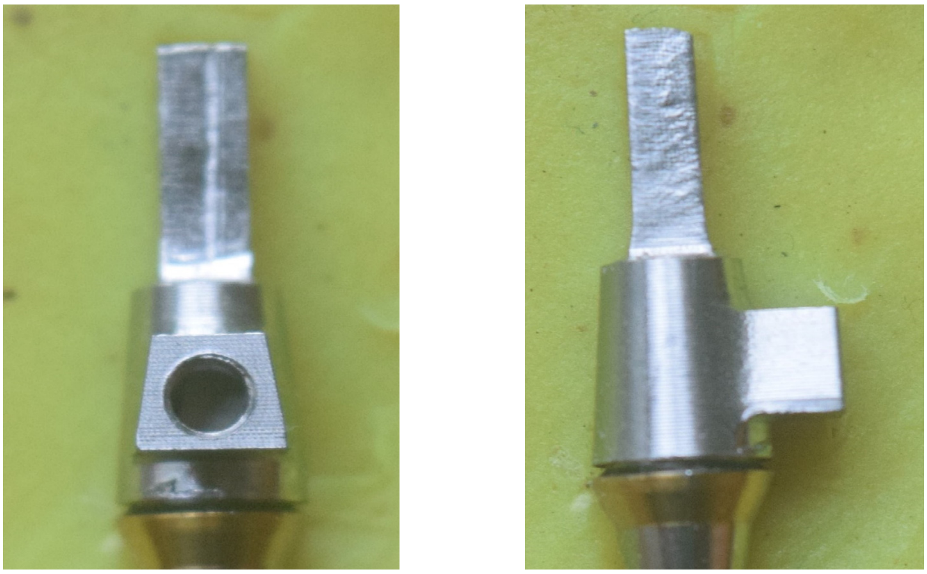


Figure 1. Usage of coping in the friction-based lateral screw-retained dental implant set.

As mentioned above, the friction coefficient is critical in this novel friction-based lateral screw-retained dental crown. Although there are many options in the surface treatment, specifically those employed to increase the friction coefficient, this study uses sandblasting. Sandblasting can create irregularity on the surface of a metal, thus increasing the surface roughness of the object [34]. Sandblasting is performed on the flat surface of the abutment serving as the contact surface between the lateral screw and the dental abutment. In a cement-retained dental crown, the flat surface of the abutment primarily serves to make the anti-rotation of the crown.

In this study, the coping design was developed by evaluating the Superline dual abutment (Dentium, Seoul, Republic of Korea) with a 4.5 mm diameter and a 5.5 mm height using an optical Nikon SMZ 1270i Type 164 microscope (Nikon, Tokyo, Japan) and XCAM1080PHA Digital Camera with Indomicroview software (Indomicro, Jakarta, Indonesia). The measurements resulting from the optical microscope served as the basis for the dental implant coping design, which was modeled using SolidWorks 2017 (Dassault Systèmes SE, Vélizy-Villacoublay, France). Since the retention test was performed by pulling the coping and the dental implant set apart in a tensile test using a universal testing machine, aside from the original coping design, each coping was designed and manufactured with a cuboid part on top (Figure 2), designed to be gripped by a universal testing machine. This coping prototype was made using NiCr (4all Ivoclar Vivadent, NY, USA), a widely used material for coping, especially in many developing countries [35].

Although we employed similar materials to that of the cement-retained coping, this coping prototype was manufactured using CNC milling instead of casting.



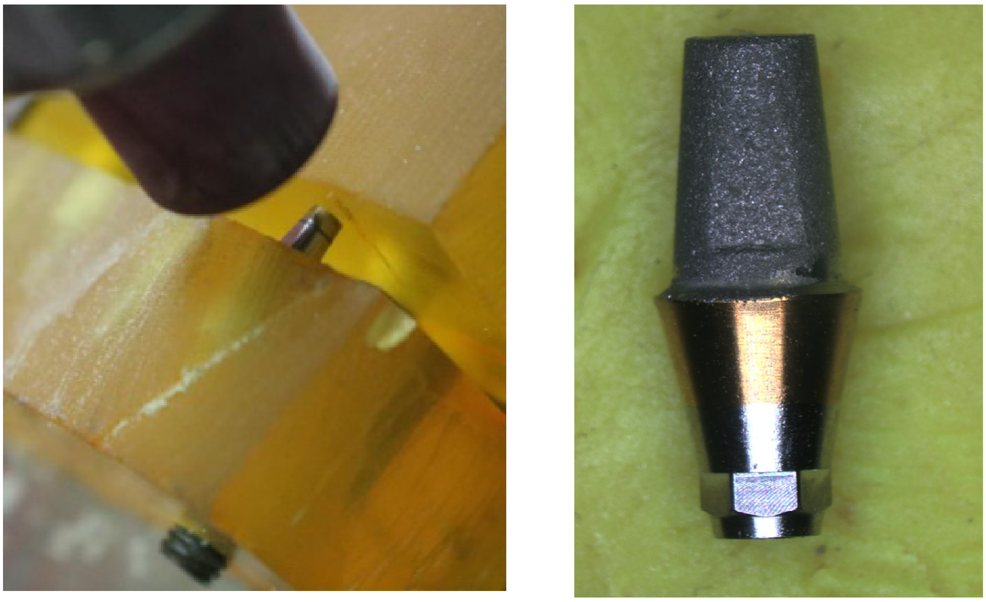
(a) (b)

Figure 2. (**a**) Front and (**b**) side view of the manufactured coping prototype for the coping retention test.

2.2. Coping Retention Test for Various Surface Roughness

In an effort to find suitable parameters for sandblasting in this novel lateral screw-retained coping method, an experiment was conducted to find the correlation between the surface roughness and the coping retention force. Several parameters in the sandblasting such as the materials, the particle size, the pressure, the distance between the nozzle and the object, the duration, and even the angle may vary [36]. Each variation of the parameter might give different results directly affecting the surface roughness of the abutment which in turn could affect the retention capability of this novel friction-based lateral screw-retained dental crown.

In this experiment, four groups of specimens sandblasted using various particle sizes of aluminum oxide (Al_2O_3) were compared to a group of untreated abutments. Each of those four groups had five specimens, and they were sandblasted using $Al_2O_3$63 amounting to 102 µm, 254 µm, and 686 µm, respectively. The sandblasting used a 0.3 MPa pressure in a 10 mm distance between the nozzle and the flat surface of the abutment for 10 s based on several previous studies [11,12] (Figure 3). In order to remove the remains of sandblasting materials in the abutment surface, the abutment was then cleaned using an ultrasonic cleaner with three steps using three different solutions, namely acetone, isopropyl alcohol (IPA), and distilled water. Each step was carried out for 5 min at 60 °C [37]. Each surface roughness of the specimen was then measured using Surfcom 2900SD3 (Tokyo Seimitsu, Tokyo, Japan) with a probe placed on the flat surface of the abutment so that the obtained measurement would have the same direction as that of the coping retention test (vertical/parallel to the axis of the dental implant). Since no information was available on the screw tightening torque for a lateral screw-retained or cross-pin retained method, as the closest approach to the lateral screw-retained method [30–32], a 200 Nmm tightening torque was used. In fact, many commercially available dental implant sets use this value for their internal screw-tightening torque [38–40]. In each of the specimens, it was ensured that the lateral screw would directly contact the sandblasted area without any angulation.



(**a**) (**b**)

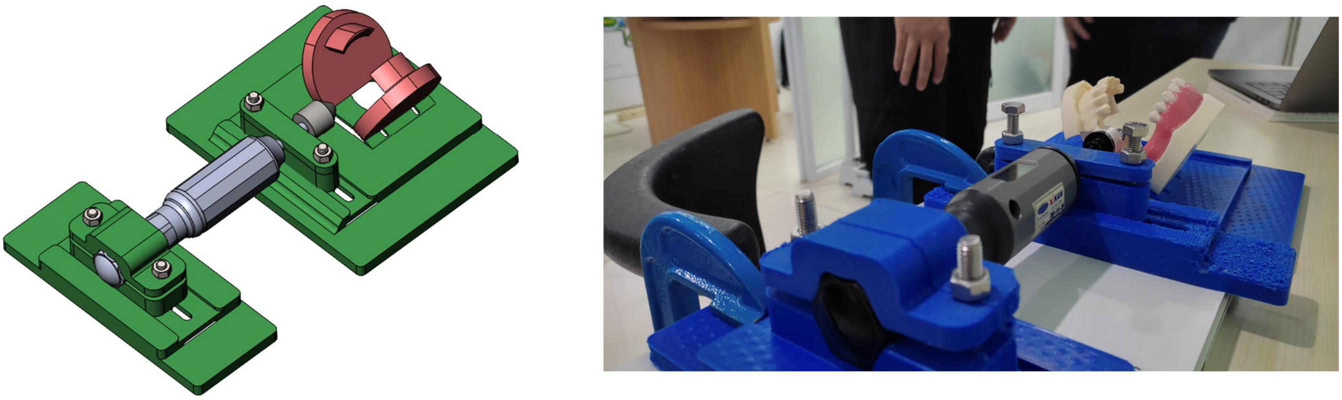
Figure 3. (**a**) Sandblasting of a dental implant abutment using Al_2O_2 and (**b**) sandblasted flat surface of an abutment.

A tensile test to determine the comparison between the retention force of the cement-retained method and the retention force of the friction-based lateral screw-retained crown was conducted using an Tensilon RTF 2350 universal testing machine (A&D Company, Tokyo, Japan) with a 1 mm/min tensile speed [41–43]. For the friction-based lateral screw-retained specimens, the cuboid space in the coping was clamped using a jig, as shown in Figure 4 below. The highest retention force was recorded in Newtons (N), the results of which were then compared among all of the groups to understand the retention capability of each assembly.

Figure 4. Tensile test setup for the lateral screw-retained dental implant.

2.3. Maximum Tightening Torque for Lateral Screw-Retained Implant

In this study, aside from the effects of the surface roughness of the abutment on the retention capability of a dental crown, we also tried to understand whether this friction-based lateral screw-retained dental crown would need some additional tools in order to easily be assembled in a patient's mouth. An experiment was conducted using a digital torque meter placed laterally to the axis of the dental implant between the phantoms to simulate various lateral screw tightening conditions with an existing Dentium screwdriver Hex Driver L/T (Dentium, Seoul, Republic of Korea). The phantom from M.tech (M.Tech, Seoul, Republic of Korea) was placed with a 40.5 mm mouth opening [44] combined with the tightening position in the second molar, chosen to purposefully restrict the subject's hand movement, which simulates the most challenging position of the lateral screw tightening condition in the patient's mouth. The jig was designed to simulate the restriction of the mouth opening and to fixate the digital torque meter. The assembly was clamped on the table, and the subjects were instructed to sit beside the assembly (Figure 5). This experiment setup mimicked the patient's actual condition on the orthodontic dental chair. This jig was 3D printed using PLA+ (eSun, Shenzhen, China) as the material. The tip of the digital torque meter was connected to Dentium's screwdriver; then, those 48 subjects, comprising 27 males and 21 females, were instructed to turn the screwdriver as hard as possible, thus simulating the assembly condition of the lateral screw-retained dental implant. Each of the subjects was asked to repeat the tightening process three times, and subsequently, the average recorded torque was used in this study.



(**a**) (**b**)

Figure 5. (**a**) The device assembly to record the maximum tightening torque of the lateral screw; (**b**) the actual implementation of the device.

2.4. Coping Retention Test for Various Tightening Torques

After revealing the effects of the surface roughness on the coping retention force and the capability of human tightening torque, this experiment divided each group based on several variations in the employed tightening torques. The tightening torque of a lateral screw resulted in the development of a lateral force, which constituted one of the main parameters in a friction-based lateral screw-retained method. Several tightening torques amounting to 69.75 Nmm (SB686 T69.75) and 120 Nmm (SB686 T120) were used, and since a 200 Nmm tightening torque (SB686 T200) was employed in the previous experiment (see Section 2.2), the results of this experiment would also be included in the analysis of this experiment. Each of these specimens was subjected to various sandblasting conditions, which showed the highest retention score based on the previous experiment. In this experiment, each variation of the friction-based lateral screw-retained groups was then compared to that of the cement-retained group (CR), serving as a benchmark in this study. Five specimens in the cement-retained group used a specially made casted coping made of the same material as that of the friction-based lateral screw-retained coping. Moreover, they were designed to have a loop used to place the hook during the tensile test (Figure 6). Before the coping was placed, all of the abutment screw access holes were filled with gutta-percha to avoid any potential chemical bonds between the materials. The coping was placed into the abutment using a GC Fuji 1 screw-retained glass ionomer cement (GC Corporation, Tokyo, Japan). Immediately after the placement, the coping was then subjected to a 50 N load for 10 min [41,45,46]. All of the samples prepared in this experiment were stored in distilled water with a temperature amounting to 37 °C for 24 h before they were tested [47]. This condition helped ensure that the cement would be fully cured under a similar condition to that of the patient's placement. These specimens were then tested in various similar settings and conditions to the coping retention test for various surface roughness.

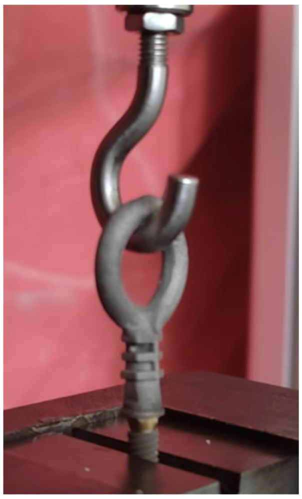


Figure 6. Tensile test for cement-retained dental implant with custom coping.

2.5. Statistical Analysis

Each gender's maximum tightening torque for the lateral screw-retained system was analyzed by using Shapiro–Wilk, and the differences were then analyzed using a *t*-test. Each group for the coping retention test in surface roughness and tightening torque variations was statistically analyzed using the Shapiro–Wilk test to check each group's normality and Levene's variance homogeneity test. Then, the one-way analysis of variance (ANOVA) and post hoc Tukey test were performed. Statistical analysis was performed using SPSS (SPSS Inc., Chicago, IL, USA). A p-value amounting to ≤ 0.05 was considered to be statistically significant.

3. Results

3.1. Coping Retention Based on Various Surface Roughness

Various sandblasting particles resulted in a variety of retention capabilities as shown in Table 1 below. Each variation was divided into several groups with specimens sandblasted by a 63 µm Al_2O_3 particle called SB63 T200, a 102 µm particle called SB102 T200, a 254 µm particle size called SB254 T200, a 686 µm particle called SB686 T200, and untreated (not sandblasted) specimens called NS.

Table 1. The retention force of each group in the sandblasting using various sizes of particles in the experiment.

Group	Sample	R_a (µm)	Retention (N)
Not Sandblasted (NS)	Sample 1	0.04	153.82
	Sample 2	0.04	129.28
	Sample 3	0.04	191.93
	Sample 4	0.04	177.05
	Sample 5	0.04	165.02
Sandblasted 63 µm (SB63 T200)	Sample 1	0.35	135.36
	Sample 2	0.44	102.20
	Sample 3	0.49	209.68
	Sample 4	0.47	179.87
	Sample 5	0.44	168.42

Table 1. *Cont.*

Group	Sample	R_a (µm)	Retention (N)
Sandblasted 102 µm (SB102 T200)	Sample 1	0.55	251.86
	Sample 2	0.59	259.77
	Sample 3	0.51	237.29
	Sample 4	0.59	249.85
	Sample 5	0.54	250.13
Sandblasted 254 µm (SB254 T200)	Sample 1	0.51	305.06
	Sample 2	0.62	307.08
	Sample 3	0.58	350.70
	Sample 4	0.60	253.86
	Sample 5	0.57	305,18
Sandblasted 686 µm (SB686 T200)	Sample 1	0.73	320.07
	Sample 2	0.68	327.69
	Sample 3	0.67	287.07
	Sample 4	0.62	343.86
	Sample 5	0.67	310.67

Figure 7 shows the comparison of R_a among the groups based on the particle sizes used in the sandblasting. It shows that the average R_a from the highest to the lowest is shown by SB686 T200 with 0.67 ± 0.04 µm, SB254 T200 with 0.58 ± 0.04 µm, SB102 T200 with 0.56 ± 0.03 µm, SB63 T200 with 0.44 ± 0.05 µm, and NS with 0.04 ± 0.002 µm.

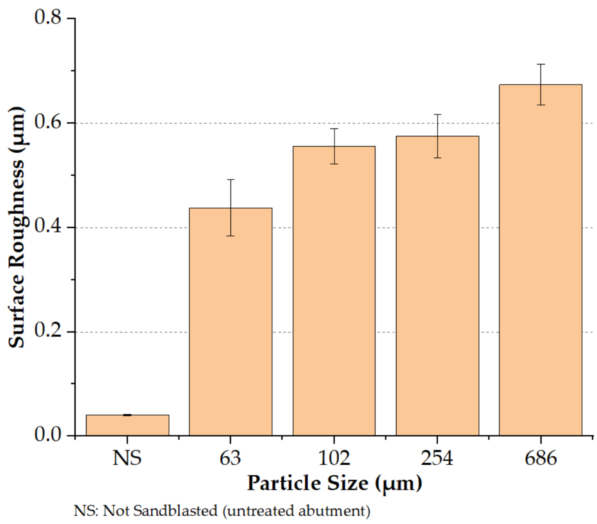


Figure 7. Surface roughness comparison among various sandblasted particle sizes.

Figure 8 shows the retention force of each group, with the highest retention force being SB686 T200 with 317.87 ± 21.08 N, followed by SB254 T200 with 304.38 ± 34.30 N, SB102 T200 with 249.78 ± 8.06 N, and NS with 163.420 ± 23.76 N. Moreover, the lowest retention force on average was SB63 T200 with 159.106 ± 41.47 N. The one-way analysis of variance (ANOVA) shows a p-value < 0.05, in which all of the groups were significantly different, with an exception for SB686 T200 compared to SB254 T200 and NS compared to SB63 T200, where both pairs have a p-value > 0.05.

3.2. Hand Tightening Torque

Table 2 shows the summary of the data for the hand tightening torque, and Appendix A shows the detailed data. Figure 9 shows the histogram of the overall data of the tightening torque capability.

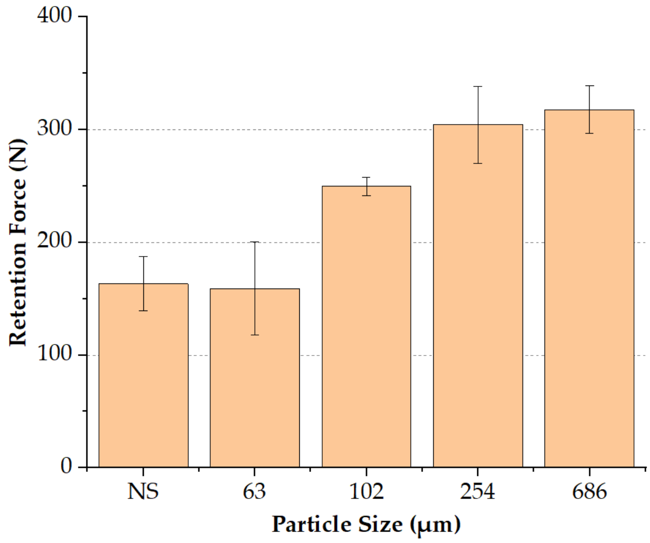


Figure 8. Coping retention force comparison among various sandblasted particle sizes.

Table 2. Summary of the hand tightening torque data based on gender and the overall data.

Gender	Mean	Standard Deviation	Minimum	Maximum
Male	75.28	24.94	34.67	120.67
Female	62.92	18.47	35.67	100.33
Overall	69.75	22.91	34.67	120.67

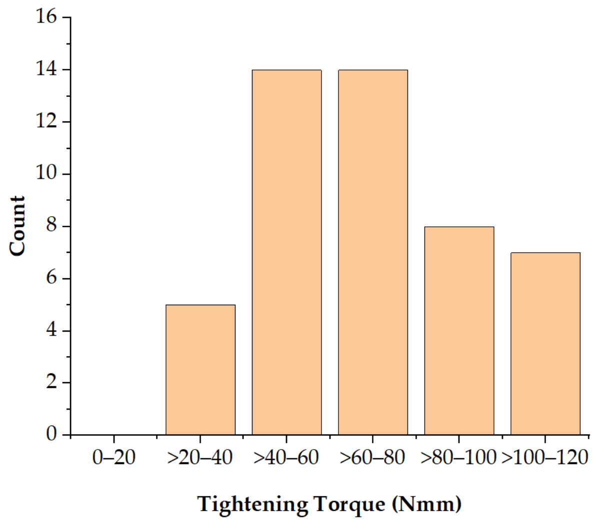


Figure 9. Histogram of tightening torque capability of all subjects.

The Shapiro–Wilk test shows that each group of male, female, and overall data has a normal data distribution with a p-value > 0.05. As such, a comparison between the male and the female data for the tightening torque in this experiment was made using the t-test, resulting in significant differences between the groups with the male data showing a higher tightening torque ($p < 0.05$).

3.3. Coping Retention Based on the Tightening Torque

Table 3 shows the dental implant retention for each group, with cement retained (CR) serving as the standard/benchmark and three groups of lateral screw with the tightening torque amounting to 69.75 Nmm (SB686 T69.75) and 120 Nmm (SB686 T120).

Table 3. Retention force of each group.

Group	Sample	Retention (N)
Cement Retained (CR)	Sample 1	153.33
	Sample 2	145.181
	Sample 3	186.66
	Sample 4	160.19
	Sample 5	133.78
Lateral Screw (Tightening Torque 69.75 Nmm) (SB686 T69.75)	Sample 1	100.33
	Sample 2	108.14
	Sample 3	110.66
	Sample 4	95.23
	Sample 5	68.97
Lateral Screw (Tightening Torque 120 Nmm) (SB686 T120)	Sample 1	161.828
	Sample 2	187.31
	Sample 3	149.676
	Sample 4	124.51
	Sample 5	169.07

Figure 10 shows the comparison among the groups including SB686 T200 in which the specimens were tightened with a 200 Nmm tightening torque. It shows that the average coping retention of the lateral screw retention with a 200 Nmm tightening torque (SB686 T200) has the highest retention, amounting to 317.87 ± 21.08 N, followed by a 120 Nmm tightening torque (SB686 T120), amounting to 158.48 ± 23.37 N, and cement retention (CR), amounting to 155.83 ± 19.85 N. Moreover, the lateral screw retention with a 69.75 Nmm tightening torque (SB686 T69.75) has the lowest retention, amounting to 96.67 ± 16.66 N.

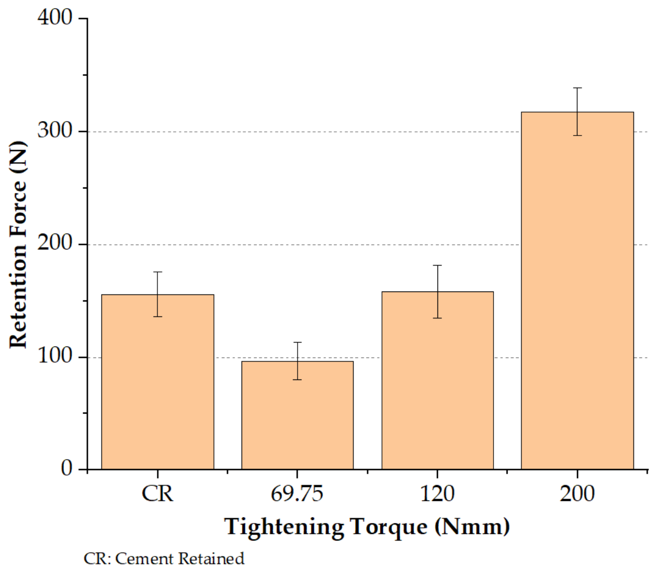
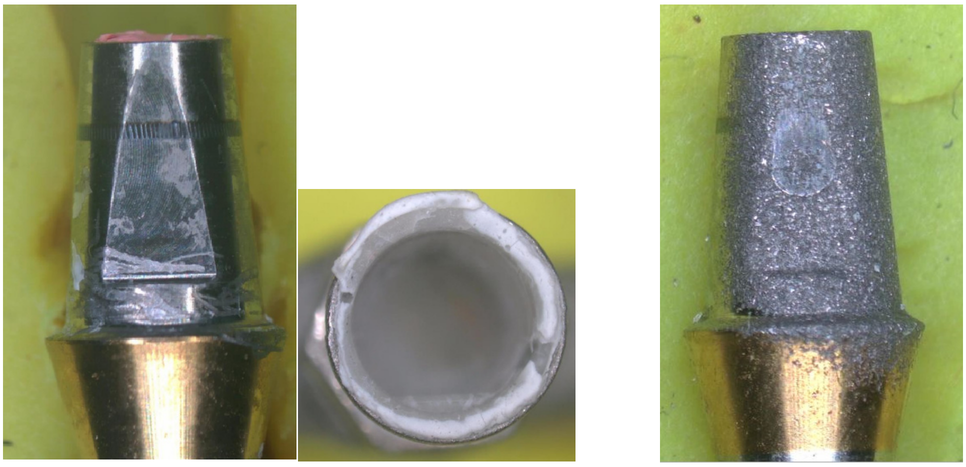


Figure 10. Coping retention force comparison among various tightening torque groups.

The one-way analysis of variance (ANOVA) shows a p-value < 0.05; the comparison between each group shows the comparison to the cement-retained group. The SB686 T69.75 is significantly lower ($p < 0.01$), SB686 T120 has a higher average but is statistically insignificant, and SB686 T200 is significantly higher ($p < 0.01$). Among screw-retained groups, compared to SB686 T200, both SB686 T69.75 and SB686 T120 are significantly lower ($p < 0.01$).

The failure mode of the cement-retained group under the tensile test shows residue of cement in the abutment and coping, and the lateral screw-retained (SB686 T69.75, SB686

T120, and SB686 T200) shows a mark that resulted from friction between the screw and the sandblasted surface of the abutment (see Figure 11).



(**a**) (**b**)

Figure 11. (**a**) Cement-retained and (**b**) lateral screw-retained failure mode.

4. Discussion

This study developed a novel friction-based lateral screw-retained method approach by designing a universal coping and surface treatment for an existing abutment. This approach to the novel retention method can be used on most single-implant restorations with a flat surface (in this case, an anti-rotation feature for Dentium), with a simple manufacturing procedure carried out on the coping to give access to the lateral screw and surface treatment performed on the flat surface of the abutment to increase the surface roughness. With this coping, the retrievability of screw-retained implants can be achieved at the same time. Although, currently, this coping design is limited, this design structure can be further developed to provide better support. A study by Wang et al. shows that the maximum fracture resistance strength of porcelain in porcelain-fused-to-metal (PFM) crowns highly depends on its metal structure/substructure design [48].

Sandblasting is carried out in order to increase static friction, which can lead to stronger retention. Sandblasting is performed to create irregularity in the titanium surface of the abutment, which increases the surface roughness [49]. Surface roughness is related to the friction coefficient, and a higher friction coefficient could increase the retention capability of this retention method. Sandblasting was chosen because it is one of the easiest and most inexpensive methods of surface treatment [50], which increases the possibility of this method being replicated and used around the world since it does not need any specific abutment or implant that is manufactured. The result of this study also demonstrates that it can be implemented by modifying the existing surface of the abutment.

The results of sandblasting using various particle sizes show a positive correlation between the particle size and the surface roughness. A larger particle size results in a higher surface roughness of the object's surface. This correlation is similar to that of a study by Hasan and Abood, which also uses various Al_2O_3 particle sizes [34]. In this study, the highest surface roughness was shown by SB686 T200 (0.67 ± 0.04 µm), which was also significantly higher compared to other groups ($p < 0.01$), and the untreated surface of the abutment (0.04 ± 0.002 µm) had the lowest surface roughness (R_a), which was also significantly lower compared to other groups ($p < 0.01$). However, the result also shows that groups SB102 T200 and SB254 T200 are insignificantly different from each other, but SB254 T200, which has a larger particle size, shows a higher average of surface roughness. The result of this experiment also shows that surface roughness mainly has a positive correlation with the retention force, which confirms the positive correlation between the surface roughness and the static friction coefficient. Though NS groups show a higher retention force than that of SB63 T200, it is insignificant, and it shows that within that surface roughness conditions, the retention is mainly affected by the tightening torque instead of friction between the lateral screw and abutment. In this study, the highest retention force was also shown by groups with the highest surface roughness (SB686 T200), and the lowest retention force was shown by both SB63 T200 and NS groups, which also have low surface roughness. A positive correlation between the surface roughness and static friction opens the possibility of using other surface treatment options to increase the surface roughness in the abutment's flat surface, thus increasing the versatility of this method. Other surface treatments that can be used as a strategy to increase the surface roughness are laser etching, acid etching, ion implantation, sputtering, and other combinations of several surface treatment methods such as SLA, which combines sandblasting using large grit and acid etching [51]. Aside from that, geometry alteration, like making a groove in an abutment, is worth trying since the study by de Campos et al. shows that the surface roughness (R_a) of a grooved abutment can reach up to 8.38 μm [52]. As the SB686 T200 group shows the highest surface roughness and retention score, Al_2O_3 with a particle size of 686 μm was then used as a parameter for sandblasting for retention force based on the tightening torque experiment. The result of this group was also then compared to other variations in the tightening torque experiment since the parameters were already similar.

In the case of the coping retention under different tightening torque experiments, the lowest retention was shown by the SB686 T69.75 group with 96.67 ± 16.66 N, and the highest was shown by the SB686 T200 group, with force retention amounting to 317.87 ± 21.08 N, which was significantly different ($p < 0.01$). This shows that the tightening torque is one of the crucial aspects to be considered in which the value groups subjected to lower tightening torque show significantly lower strength than those subjected to the higher torque. Considering the wide range of tightening capabilities shown in the hand tightening torque experiment (lowest value in 34.67 Nmm and highest value in 120.67 Nmm), the importance of a standardized tightening torque is imminent and could be achieved by developing tools. Various studies show that the current torque wrenches readily available on the market have excellent accuracy [38,53,54]. One of the factors is the angle at which the examiner reads the torque value, with 90° being the best [55]. One of the approaches for lateral screw-retained implant assembly, as shown in a study by Lee et al. [56], uses a lateral screwdriver with a contra-angle attachment, which is easily managed within the oral cavity, with the torque ranging from 500 to 1000 Nmm, which is a lot higher than the highest tightening torque used in this study. For this friction-based lateral screw-retained crown, the use of a similar lateral screwdriver with a contra-angle attachment can easily surpass the highest tightening torque value used in this study. It might give a more accurate value taking into account that different tightening torques resulted in a significantly different retention force.

Cement-retained implants have become the benchmark/standard in this study because they have proven to be able to perform adequate retention during the daily usage of a dental implant. Various studies show that the biggest mechanical complications are the results of dynamic compression forces on the dental implants such as screw loosening, porcelain fractures, and abutment fractures [5–7]. The tensile test was conducted using five samples to obtain the coping retention force for each group; moreover, the result from the cement-retained group shows an average of 155.83 ± 19.85 N. Various studies with a similar condition intended to calculate retention force show the difference between one type and another varied by types of cement, abutment used, and even thickness of the cement used. A study by El-Helbawy shows an average retention force of 138.8 ± 10.2 N for the assembly of cast coping with titanium abutment (dentist) using Temp-Bond Non-Eugenol (Kerr) as the cement [11]. Another study by Reddy et al. involving three brands of cement widely available on the market shows various average retention forces ranging from 138.41 N to 258.28 N [57]. The thickness of the cement has also been shown to influence the retention of dental implant coping. A study by Abou-Obaid and Al-Khudairy comparing different cement thicknesses shows that the optimum thickness recorded in this study is 20 μm, which has the highest retention force compared to groups with 35 and 50 μm cement thickness; it is also demonstrated that in cement-retained dental implant, abutment height also affects retention strength, which related to the different surface area [58].

Among the lateral screw-retained group, SB686 T200 has the highest coping retention force, followed by SB686 T120, and SB686 T69.75 has the lowest. This demonstrates that tightening torque affects coping's retention capability (positive correlation), with higher tightening torque resulting in a higher coping retention force. Compared to cement-retained implants, the SB686 T69.75′s retention is significantly lower ($p < 0.01$). Compared to a study by Nagasawa et al., the average coping retention force of SB686 T69.75, which is 96.67 ± 16.66 N, is higher compared to five of six commercially available temporary cements tested after 7 days of seating and higher than all of them when compared to 28-day-old specimens [43]. The coping retention force of cement-retained implants compared to SB686 T120 is insignificantly different, which shows that with the right tightening torque, the retention performance of friction-based lateral screw-retained implants is comparable to various cement-retained groups. Compared to SB686 T200, the coping retention force of cement-retained implants is significantly lower ($p < 0.01$).

There are no known standards regarding the retention force of dental implant coping. However, there are studies regarding the pull-out strength of dental implants. One of them is a study by Seong et al. investigating the pull-out strength of a dental implant implanted in a rabbit tibia for 1 to 12 weeks of healing time. This study shows that healing time affects pull-out strength, which is similar to human bone [59]; it shows that after one week, the pull-out force is 187.9 ± 69.2 N. After twelve weeks, the pull-out force is 351.8 ± 69.2 N, and this value is also shown in a study by Oliscovicz et al. for pull-out force on Synbone (Synbone AG, Malans, Switzerland), which simulates the artificial bone of the human femur [60]. The pull-out force shown in both studies shows a value close to SB686 T200, demonstrating that based on pull-out force setup conditions (sandblasting and tightening torque), SB686T200 groups show promising results since it is expected that the dental crown has a lower pull-out force compared to dental implants in a failure condition.

The lateral screw-retained failure mode shows tracks from friction between the lateral screw and the abutment's surface, but the overall abutment did not show any damage. As shown in previous studies, the assembly and failure mode of cement-retained implants leave residue in the abutment and coping, which could result in peri-implantitis diseases [21–23]. The failure mode in lateral screw needs further investigations to understand whether its condition after failure affects the retention capability, as the surface roughness may decrease due to friction between the screw and the abutment's surface. If this type of failure affects retention performance, then the abutment needs to be replaced or re-sandblasted, and since there is no damage inflicted on the overall abutment, it can just be removed without any further disturbance to the implant and surrounding bones. This phenomenon also needs to be one of the considerations of using a one-piece implant for friction-based later screw-retained dental crowns, since any damage inflicted on the abutment area may need further invasive surgery.

From this preliminary study, it is found that there needs to be further study into the preparation and assembly method for this novel friction-based lateral screw-retained method. As part of the preparation, sandblasting of the abutment as the primary surface treatment within this method will need to be performed in a laboratory environment with a proper cleaning method to remove debris and possible contamination from the sandblasting procedure. The lateral screw-retained coping also needed to be appropriately assembled using porcelain-fused-to-metal (PFM) for the crown but still provide enough access to the lateral screw access. Both the sandblasted abutment and crown need proper sterilization inside the patient's mouth before the assembly process, which requires further study. For the crown assembly, there are two possible options regarding the access for the lateral screw (lingual and facial). A study by Lee et al. uses the lingual side for the lateral screw access, giving clinicians more flexibility [56]. However, in that study, the metal part of the crown was exposed, which highly affected the aesthetics. One of the possible ways to overcome this is by minimizing the access hole for the lateral screw and, once the lateral screw is properly tightened, blocking the access hole using resin fillings which are usually used to fill the cavity.

This study has its limitations regarding sample size, available abutment type, and surface treatment procedure performed. But it shows the prospect of friction-based lateral screw retention to be one of the methods that could gain the advantage over cement and screw retention, which is easy to replicate and use with limited resources.

5. Conclusions

Within the limitation of this study, conducted tests show the potential of a novel friction-based lateral screw retention method. The coping design in this study combined the advantage of the cement-retained and vertical screw retention method. This design gives an ideal occlusal advantage, better aesthetics, and is retrievable. This study shows that particle size positively correlates with surface roughness in the sandblasting process of titanium dental abutments. Aside from that, surface roughness was also found to be a critical factor that positively correlates with retention force. Sandblasting on titanium dental abutments using Al_2O_3 with 686 μm particle size (highest particle size used in this study) under 0.3 MPa pressure from a 10 mm distance in 10 s resulted in the highest surface roughness (R_a) of 0.67 ± 0.04 μm and a retention force of 317.87 ± 21.08 N; these sandblasting conditions were then used in the following experiment as the standard sandblasting conditions.

In order to understand the human capability to produce tightening torque for this novel friction-based lateral screw retention, an experiment was conducted under simulated conditions. The jig with a 40.5 mm mouth opening and conditions similar to lateral screw tightening in the second molar shows an average of 69.75 Nmm with a standard deviation of 22.91 Nmm.

Using sandblasting parameters and considering variations of tightening torque from the previous experiment, the novel friction-based lateral screw retention was tested under variations of tightening torque, namely 69.75, 120, and 200 Nmm. The result of this experiment is promising for the possibility of this novel crown retention method. The retention force of SB686 T69.75 gives the lowest value of 96.67 ± 16.66 N, which is significantly lower compared to CR groups ($p < 0.01$). The SB686 T120 average is 158.48 ± 23.37 N, which is insignificantly different compared to CR with 155.83 ± 19.85 N. Lastly, SB686 T200 shows a significantly higher result of 317.87 ± 21.08 N compared to CR ($p < 0.01$). This phenomenon, combined with the tightening capability of this study's subject, proved that tightening torque can have a significant impact on coping retention in this method.

Even though the result of this study shows it can be one of the solutions to today's crown retention methods, there is still much room for improvement, and studies need to be conducted to explore the full potential of this novel retention method.

6. Patents

This work's prototype design and results are intended to be filed as a patent.

Author Contributions: Conceptualization, S.S., Y.W., T.A.M., R.S.D. and L.S.K.; methodology, T.A.M., P.R.M. and R.A.U.; formal analysis, S.S., T.A.M., P.R.M. and R.A.U.; data curation, T.A.M., P.R.M. and R.A.U.; writing—original draft preparation, T.A.M. and R.A.U.; writing—review and editing, S.S., T.A.M. and R.A.U.; visualization, R.A.U.; supervision, S.S., Y.W., T.A.M., R.S.D. and L.S.K. All authors have read and agreed to the published version of the manuscript.

Funding: This research is funded by the Directorate of Research and Development, Universitas Indonesia, under Hibah PUTI 2023, grant number NKB-837/UN2.RST/HKP.05.00/2023.

Institutional Review Board Statement: The study was conducted according to the guidelines of the Declaration of Helsinki, and approved by the Institutional Review Board of Komisi Etik Penelitian Kedokteran Gigi Fakultas Kedokteran Gigi Universitas Indonesia (protocol code 071421022; date of approval 2 November 2022).

Informed Consent Statement: Informed consent was obtained from all subjects involved in the study.

Data Availability Statement: Data are contained within the article and available on request from the corresponding author. The data are not publicly available due to privacy.

Conflicts of Interest: The authors declare no conflict of interest.

Appendix A

Table A1. Overall Subjects Hand Tightening Torque Data.

Gender	Age	Height (cm)	Weight (kg)	Average Tightening Torque (Nmm)
Male	25	169	55	109.33
Male	25	185	81	34.67
Male	26	180	82	75.00
Male	26	183	68	92.33
Male	26	170	100	71.00
Male	26	165	65	86.67
Male	26	171	64	50.00
Male	27	177	78	56.00
Male	28	173	66	53.00
Male	28	165	77	46.00
Male	29	178	85	101.67
Male	29	173	85	58.67
Male	30	180	92	61.00
Male	30	168	76	70.67
Male	30	168	70	67.33
Male	30	175	95	69.00
Male	31	168	72	88.67
Male	31	168	63	49.67
Male	31	167	82	118.00
Male	32	158	61	112.67
Male	32	168	84	55.00
Male	35	170	90	105.00
Male	35	186	100	90.67
Male	35	180	75	120.67
Male	36	198	112	70.33
Male	36	169	70	44.33
Female	26	148	45	55.67
Female	27	165	53	37.67
Female	27	163	49	71.00
Female	28	164	66	35.67
Female	29	164	48	52.00
Female	29	159	60	63.00
Female	30	162	58	87.33
Female	30	155	54	81.00
Female	30	155	50	73.67
Female	30	167	75	77.00
Female	30	167	78	36.67
Female	31	155	52	39.00
Female	34	158	70	50.00
Female	36	165	48	59.67
Female	36	165	58	50.67
Female	36	158	52	76.67
Female	36	173	90	100.33
Female	37	170	56	89.33
Female	38	153	60	66.33
Female	40	156	67	54.00
Female	42	158	62	64.67

References

1. Pjetursson, B.; Asgeirsson, A.; Zwahlen, M.; Sailer, I. Improvements in Implant Dentistry over the Last Decade: Comparison of Survival and Complication Rates in Older and Newer Publications. *Int. J. Oral Maxillofac. Implant.* **2014**, *29*, 308–324. [CrossRef] [PubMed]
2. Resnik, R. *Misch's Contemporary Implant Dentistry*, 4th ed.; Elsevier: Amsterdam, The Netherlands, 2019.
3. Reda, R.; Zanza, A.; Cicconetti, A.; Bhandi, S.; Guarnieri, R.; Testarelli, L.; Di Nardo, D. A Systematic Review of Cementation Techniques to Minimize Cement Excess in Cement-Retained Implant Restorations. *Methods Protoc.* **2022**, *5*, 9. [CrossRef] [PubMed]
4. Makke, A.; Homsi, A.; Guzaiz, M.; Almalki, A. Survey of Screw-Retained versus Cement-Retained Implant Restorations in Saudi Arabia. *Int. J. Dent.* **2017**, *2017*, 5478371. [CrossRef] [PubMed]
5. Caricasulo, R.; Malchiodi, L.; Ghensi, P.; Fantozzi, G.; Cucchi, A. The influence of implant-abutment connection to peri-implant bone loss: A systematic review and meta-analysis. *Clin. Implant. Dent. Relat. Res.* **2018**, *20*, 653–664. [CrossRef] [PubMed]
6. Kim, J.C.; Lee, J.; Kim, S.; Koo, K.T.; Kim, H.Y.; Yeo, I.S.L. Influence of implant-abutment connection structure on peri-implant bone level in a second molar: A 1-year randomized controlled trial. *J. Adv. Prosthodont.* **2019**, *11*, 147–154. [CrossRef] [PubMed]
7. Link-Bindo, E.E.; Soltys, J.; Donatelli, D.; Cavanaugh, R. Common Prosthetic Implant Complications in Fixed Restorations. *Compend. Contin. Educ. Dent.* **2016**, *37*, 431.
8. Wittneben, J.G.; Joda, T.; Weber, H.P.; Brägger, U. Screw retained vs. cement retained implant-supported fixed dental prosthesis. *Periodontology 2000* **2017**, *73*, 141–151. [CrossRef]
9. Ma, S.; Fenton, A. Screw- Versus Cement-Retained Implant Prostheses: A Systematic Review of Prosthodontic Maintenance and Complications. *Int. J. Prosthodont.* **2015**, *28*, 127–145. [CrossRef]
10. Veselinović, V.; Marin, S.; Trtić, Z.; Trtić, N.; Dolić, O.; Adamović, T.; Arbutina, R.; Šćepanović, M.; Todorović, A. Application of Semipermanent Cements and Conventional Cement with Modified Cementing Technique in Dental Implantology. *Acta Stomatol. Croat.* **2021**, *55*, 367–379. [CrossRef]
11. El-Helbawy, N.; El-Hatery, A.; Ahmed, M. Comparison of Oxygen Plasma Treatment and Sandblasting of Titanium Implant-Abutment Surface on Bond Strength and Surface Topography. *Int. J. Oral Maxillofac. Implant.* **2016**, *31*, 555–562. [CrossRef]
12. Kurt, M.; Külünk, T.; Ural, Ç.; Külünk, Ş.; Danişman, Ş.; Savaş, S. The Effect of Different Surface Treatments on Cement-Retained Implant-Supported Restorations. *J. Oral Implant.* **2013**, *39*, 44–51. [CrossRef] [PubMed]
13. Drummond, L.G.R.; Segundo, R.M.H.; Oshima, H.M.S.; Shinkai, R.S.A. The effect of surface texture on the retention of single implant-supported crowns cemented on wide-platform abutments. *Rev. Odonto Cienc.* **2017**, *32*, 169–173. [CrossRef]
14. Tan, K.M.; Masri, R.; Driscoll, C.F.; Limkangwalmongkol, P.; Romberg, E. Effect of axial wall modification on the retention of cement-retained, implant-supported crowns. *J. Prosthet. Dent.* **2012**, *107*, 80–85. [CrossRef] [PubMed]
15. Derafshi, R.; Ahangari, A.H.; Torabi, K.; Farzin, M. Evaluation of the Effect of Axial Wall Modification and Coping Design on the Retention of Cement-retained Implant-supported Crowns. *J. Dent. Res. Dent. Clin. Dent. Prospects* **2015**, *9*, 35–39. [PubMed]
16. Farzin, M.; Torabi, K.; Ahangari, A.H.; Derafshi, R. Effect of abutment modification and cement type on retention of cement-retained implant supported crowns. *J. Dent.* **2014**, *11*, 256.
17. Wadhwani, C.; Hess, T.; Piñeyro, A.; Chung, K.-H. Effects of Abutment and Screw Access Channel Modification on Dislodgement of Cement-Retained Implant-Supported Restorations. *Int. J. Prosthodont.* **2013**, *26*, 54–56. [CrossRef] [PubMed]
18. Lewinstein, I.; Block, L.; Lehr, Z.; Ormianer, Z.; Matalon, S. An in vitro assessment of circumferential grooves on the retention of cement-retained implant-supported crowns. *J. Prosthet. Dent.* **2011**, *106*, 367–372. [CrossRef]
19. Biyani, R.; Ali, M.; Belles, D.; Powers, J.M. Effect of Metal Extension of Crown in the Screw Access Channel of a Posterior Implant Abutment on the Retention of Cement Retained Prosthesis. *J. Oral Implant.* **2015**, *41*, 537–541. [CrossRef]
20. Bresciano, M.; Schierano, G.; Manzella, C.; Screti, A.; Bignardi, C.; Preti, G. Retention of luting agents on implant abutments of different height and taper. *Clin. Oral Implants Res.* **2005**, *16*, 594–598. [CrossRef]
21. Nematollahi, F.; Beyabanaki, E.; Alikhasi, M. Cement Selection for Cement-Retained Implant-Supported Prostheses: A Literature Review. *J. Prosthodont.* **2016**, *25*, 599–606. [CrossRef]
22. Linkevicius, T.; Puisys, A.; Vindasiute, E.; Linkeviciene, L.; Apse, P. Does residual cement around implant-supported restorations cause peri-implant disease? A retrospective case analysis. *Clin. Oral Implants Res.* **2013**, *24*, 1179–1184. [CrossRef] [PubMed]
23. Scarano, A.; Inchingolo, F.; Scogna, S.; Leo, L.; Greco Lucchina, A.; Mavriqi, L. Peri-implant disease caused by residual cement around implant-supported restorations: A clinical report. *J. Biol. Regul. Homeost. Agents* **2021**, *35*, 211–216. [CrossRef] [PubMed]
24. Da Rocha, P.V.B.; Freitas, M.A.; De Morais Alves Da Cunha, T. Influence of screw access on the retention of cement-retained implant prostheses. *J. Prosthet. Dent.* **2013**, *109*, 264–268. [CrossRef] [PubMed]
25. Sailer, I.; Karasan, D.; Todorovic, A.; Ligoutsikou, M.; Pjetursson, B.E. Prosthetic failures in dental implant therapy. *Periodontology 2000* **2022**, *88*, 130–144. [CrossRef] [PubMed]
26. Hamed, M.T.; Abdullah Mously, H.; Khalid Alamoudi, S.; Hossam Hashem, A.B.; Hussein Naguib, G. A Systematic Review of Screw versus Cement-Retained Fixed Implant Supported Reconstructions. *Clin. Cosmet. Investig. Dent.* **2020**, *12*, 9–16. [CrossRef]
27. Shadid, R.; Sadaqah, N.; Shadid, B.R.; Rayyan, M.M.; Makarem, H.A.; Oh, K.C.; Moon, H.S.; Pera, F.; Pesce, P.; Bevilacqua, M.; et al. A Comparison Between Screw- and Cement-Retained Implant Prostheses. A Literature Review. *J. Oral Implant.* **2012**, *38*, 298–307. [CrossRef]
28. Kenneth, H.; Reena, G.C. Cement-retained versus screw-retained implant restorations: Achieving optimal occlusion and esthetics in implant dentistry. *J. Prosthet. Dent.* **1997**, *77*, 28–35.

29. Andersson, B.; Odman, P.; Lindvall, A.M.; I Brånemark, P. Cemented single crowns on osseointegrated implants after 5 years: Results from a prospective study on CeraOne. *Int. J. Prosthodont.* **1998**, *11*, 212–218.
30. Gervais, M.; Hatzipanagiotis, P.; Wilson, P. Cross-pinning: The philosophy of retrievability applied practically to fixed, implant-supported prostheses. *Aust. Dent. J.* **2008**, *53*, 74–82. [CrossRef]
31. Sambrook, R.; Judge, R.; Abuzaar, M. Strategies for restoration of single implants and use of cross-pin retained restorations by Australian prosthodontists. *Aust. Dent. J.* **2012**, *57*, 409–414. [CrossRef]
32. Sambrook, R.J.; Judge, R.B. The cross-pin retained implant supported restoration: A study of gasket placement and leakage. *Aust. Dent. J.* **2012**, *57*, 415–420. [CrossRef] [PubMed]
33. Sánchez Lasheras, F.; Rodríguez, J.G.; Mauvezín-Quevedo, M.; Martín-Fernández, E.; Bobes-Bascarán, J.; de Llanos-Lanchares, H.; Álvarez-Arenal, Á. Does the transversal screw design increase the risk of mechanical complications in dental implants? A finite elements analysis. *Int. J. Numer. Methods Biomed. Eng.* **2019**, *35*, e3205. [CrossRef] [PubMed]
34. Hasan, S.F.; Abood, A.Z. Effect of Various Particle Size of Sand-blast on Roughness and Shear Bond Strength of Ips E.max Press With Ceramic Veneer Materials (An in Vitro Study). *Malays. J. Med. Health Sci.* **2022**, *18*, 45–52.
35. Haider, A.; Jaffery, S.H.I.; Khan, A.N.; Qadir, N.; Jing, X. Effect of Cerium on Mechanical, Metallurgical and Biomedical Properties of NiCrMoB Dental Alloy. *SSRN Electron. J.* **2023**, *24*, 5082–5093. [CrossRef]
36. Finger, C.; Stiesch, M.; Eisenburger, M.; Breidenstein, B.; Busemann, S.; Greuling, A. Effect of sandblasting on the surface roughness and residual stress of 3Y-TZP (zirconia). *SN Appl. Sci.* **2020**, *2*, 1700. [CrossRef]
37. Yuda, A.W.; Supriadi, S.; Saragih, A.S. Surface modification of Ti-alloy based bone implant by sandblasting. In Proceedings of the International Symposium of Biomedical Engineering (ISBE), Padang, Indonesia, 13–14 July 2019; Volume 2193. [CrossRef]
38. Sameera, Y.; Rai, R. Tightening torque of implant abutment using hand drivers against torque wrench and its effect on the internal surface of implant. *J. Indian Prosthodont. Soc.* **2020**, *20*, 180–185. [CrossRef]
39. Haack, J.E.; Sakaguchi, R.L.; Sun, T.; Coffey, J.P. Elongation and preload stress in dental implant abutment screws. *Int. J. Oral Maxillofac. Implant.* **1995**, *10*, 529–536.
40. Mohammed, H.H.; Lee, J.-H.; Bae, J.-M.; Cho, H.-W. Effect of abutment screw length and cyclic loading on removal torque in external and internal hex implants. *J. Adv. Prosthodont.* **2016**, *8*, 62–69. [CrossRef]
41. Bishti, S.; Siouri, J.; Wolfart, S.; Tuna, T. Retention Forces of Implant-Supported Single Crowns and Fixed Dental Prostheses after Cementation: An In-Vitro Study. *Oral* **2022**, *2*, 29–40. [CrossRef]
42. Sarfaraz, H.; Hassan, A.; Kamalakanth Shenoy, K.; Shetty, M. An in vitro study to compare the influence of newer luting cements on retention of cement-retained implant-supported prosthesis. *J. Indian Prosthodont. Soc.* **2019**, *19*, 166–172. [CrossRef]
43. Nagasawa, Y.; Hibino, Y.; Nakajima, H. Retention of crowns cemented on implant abutments with temporary cements. *Dent. Mater. J.* **2014**, *33*, 835–844. [CrossRef] [PubMed]
44. Rahmania, A.; Tanti, I.; Gita, F. The association of normal mouth opening with gender and height. *J. Int. Dent. Med. Res.* **2017**, *10*, 406–409.
45. Anilkumar, P.; Chokhani, D.S.; Mangrulkar, S.K.; Gupta, I.; Singh, R.; Kumar, S. A comparative study of retention of cement retained implant prosthesis cemented with different luting cements. *Int. J. Health Sci.* **2022**, *III*, 9136–9144. [CrossRef]
46. Keum, E.C.; Shin, S.Y. A comparison of retentive strength of implant cement depending on various methods of removing provisional cement from implant abutment. *J. Adv. Prosthodont.* **2013**, *5*, 234–240. [CrossRef]
47. Dähne, F.; Meißner, H.; Böning, K.; Arnold, C.; Gutwald, R.; Prause, E. Retention of different temporary cements tested on zirconia crowns and titanium abutments in vitro. *Int. J. Implant. Dent.* **2021**, *7*, 62. [CrossRef] [PubMed]
48. Wang, C.H.; Wu, J.H.; Li, H.Y.; Wang, P.-P.; Lee, H.E.; Du, J.K. Fracture resistance of different metal substructure designs for implant-supported porcelain-fused-to-metal (PFM) crowns. *J. Dent. Sci.* **2013**, *8*, 314–320. [CrossRef]
49. Osak, P.; Maszybrocka, J.; Zubko, M.; Rak, J.; Bogunia, S.; Łosiewicz, B. Influence of Sandblasting Process on Tribological Properties of Titanium Grade 4 in Artificial Saliva for Dentistry Applications. *Materials* **2021**, *14*, 7536. [CrossRef]
50. Kunt, G.E.; Ceylon, G.; Yilmaz, N. Effect of surface treatments on implant crown retention. *J. Dent. Sci.* **2010**, *5*, 131–135. [CrossRef]
51. Jemat, A.; Ghazali, M.J.; Razali, M.; Otsuka, Y. Surface Modifications and Their Effects on Titanium Dental Implants. *BioMed Res. Int.* **2015**, *2015*, 791725. [CrossRef]
52. De Campos, T.N.; Adachi, L.K.; Miashiro, K.; Yoshida, H.; Shinkai, R.S.; Neto, P.T.; Moreira Arantes Frigerio, M.L. Effect of surface topography of implant abutments on retention of cemented single-tooth crowns. *Int. J. Periodontics Restor. Dent.* **2010**, *30*, 409–413.
53. Erdem, M.A.; Karatasli, B.; Kose, O.D.; Kose, T.E.; Çene, E.; Aya, S.A.; Cankaya, A.B. The Accuracy of New and Aged Mechanical Torque Devices Employed in Five Dental Implant Systems. *BioMed Res. Int.* **2017**, *2017*, 8652720. [CrossRef] [PubMed]
54. Pincha, S.; Shetty, S.; Mithra, A.N. Accuracy of Implant Torque Wrenches after Clinical Service. *J. Interdiscip. Dent.* **2018**, *8*, 13. [CrossRef]
55. Shiba, H.; Sato, Y.; Furuya, J.; Osawa, T.; Isobe, A.; Hayashi, M.; Kitagawa, N. Experimental study on the factors affecting torque of beam-type implant torque wrenches. *BMC Oral Health* **2021**, *21*, 344. [CrossRef] [PubMed]
56. Lee, J.H.; Lee, J.B.; Kim, M.Y.; Yoon, J.H.; Choi, S.H.; Kim, Y.T. Mechanical and biological complication rates of the modified lateral-screw-retained implant prosthesis in the posterior region: An alternative to the conventional Implant prosthetic system. *J. Adv. Prosthodont.* **2016**, *8*, 150–157. [CrossRef] [PubMed]

57. Varalakshmi Reddy, S.; Sushender Reddy, M.; Rajaneesh Reddy, C.; Pithani, P.; Santosh Kumar, R.; Kulkarni, G. The Influence of Implant Abutment Surface Roughness and the Type of Cement on Retention of Implant Supported Crowns. *J. Clin. Diagn. Res.* **2015**, *9*, ZC05–ZC07. [CrossRef]
58. Abou Obaid, A.; Al-Khudairy, R. Effect of Abutment Height and Cement Thickness on the Retention of Cement-Retained Implant-Supported Restorations. *Adv. Dent. Oral Health* **2018**, *9*, 555767. [CrossRef]
59. Seong, W.J.; Grami, S.; Jeong, S.C.; Conrad, H.J.; Hodges, J.S. Comparison of Push-In versus Pull-Out Tests on Bone-Implant Interfaces of Rabbit Tibia Dental Implant Healing Model. *Clin. Implant. Dent. Relat. Res.* **2013**, *15*, 460–469. [CrossRef]
60. Oliscovicz, N.F.; Shimano, A.C.; Junior, É.M.; Lepri, C.P.; Dos Reis, A.C. Analysis of Primary Stability of Dental Implants Inserted in Different Substrates Using the Pullout Test and Insertion Torque. *Int. J. Dent.* **2013**, *2013*, 194987. [CrossRef]