ASC
Acta Stomatologica Cappadocia

Volume 1 / Issue 1 / December 2021

Research Article

Retentive Properties of Circumferential Clasps Manufactured by Lost-Wax Method and Additive and Subtractive Manufacturing Techniques

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Kar, M. Salih., Sipahi, Cumhur. & Ezmek, Bahadır. "Retentive Properties of Circumferential Clasps Manufactured by Lost-Wax Method and Additive and Subtractive Manufacturing Techniques". *Acta Stomatologica Cappadocia* 2021;1(1):36-51
DOI: https://doi.org/10.54995/ASC.1.1.4

Received:11.09.2021; Accepted: 23.12.2021

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Retentive Properties of Circumferential Clasps Manufactured by Lost-Wax Method and Additive and Subtractive Manufac-turing Tech-niques

M. Salih Kar, Cumhur Sipahi, Bahadır Ezmek

Abstract

Statement of the problem: The number of studies examining the retention properties of circumferential clasps (CC) produced with different manufacturing techniques and metal alloys is still insufficient.

Objective: The aim of this study was to examine the time-dependent changes of the retention abilities of CCs produced using different production techniques and different metal alloys.

Materials & Methods: 5 abutments were produced by selective laser sintering technique with Cr-Co alloy to use during retention tests. 20 wax CCs were formed on the abutments using standard wax pattern, and 10 Cr-Co (Cr-CoL) and 10 titanium (TiL) CCs were manufacturing using conventional lost wax (LW) method. A virtual CC was designed on digitized abutments using dental CAD software, and STL data of the CC was obtained. 10 CCs were fabricated from Cr-Co (Cr-CoA) by additive manufacturing method (AMM). Using the same virtual CC design and subtractive manufacturing method (SMM), 10 CCs from Cr-Co blocks (Cr-CoS) and 10 CCs from titanium blocks (TiS) were produced. The clasps were subjected to a total of 3000 insertion-removal simulation tests (IRST) using a specially prepared experimental setup.

Results: The initial retention forces of the CCs belonging to 5 different groups are listed as follows; TiS (13.1 N), Cr-CoL (10.8 N), TiL(9 N), Cr-CoS (8.5 N), Co-CrA (8.4 N). At the end of 3000 cycles, the retention values of the CCs belonging to 5 different groups are as follows; TiS (17.3 N), Co-CrS (14 N), Co-CrL (12.6 N), Co-CrA (11.8 N), TiL (10.6 N). Significant differences were found between the retentive force values of the CCs in the TiS and Cr-CoA (P=0.02) and TiS and TiL (P=0.01) groups.**Conclusion.** Vital bleaching agents have the potential to alter the color features of ceramic materials.

Conclusion: CCs manufactured by SMM have a higher retentive force value than clasps manufactured by LW and AMM. The retentive force values of the CCs increase as the number of simulations increases.

Keywords: Additive and Subtractive Manufacturing Method, CAD/CAM, Circumferential Clasp, Lost Wax Technique, Removable Partial Denture, Retention.

Introduction

Removable partial dentures (RPD) are still among the most frequently preferred options in the treatment of partial edentulous patients.[1-3] Although tooth-colored non-metal flexible substructures are preferred in some tooth-supported RPDs cases, especially for aesthetic reasons, metal frameworks are still used in the majority of both tooth-supported and implant-supported RPDs.[4-6]

Undoubtedly, the proper planning and fabrication of the metal framework is crucial for the success of a RPD.[7,8] For almost a century, the metal framework and other components of RPDs have been produced traditionally using only the lost-wax (LW) technique.[9]

Computer aided manufacturing /computer aided design (CAD/CAM) technology, which was first used in the production of fixed restorations, has radically changed the manufacturing methods in dentistry.[10,11] Today, metal frameworks of RPDs can be produced with both substractive manufacturing method (SMM) and additive manufacturing method (AMM) using CAD/CAM techniques.[12]

A PubMed search conducted in April 2021 using the keywords ‘removable partial denture’ and ‘CAD/CAM’ corresponds to 201 results. Majority of these studies are related to the accuracy, retention, patient comfort, digital workflow diagram, production time and cost of RPD frameworks produced with CAD/CAM.[13,14] As of the same date, in a PubMed search using the keywords 'RPD', 'CAD/CAM' and 'AMM' were found 30 studies. However, only 3 studies were available for the keywords ‘RPD’, ‘CAD/CAM’ and ‘SMM’. That is to say, the number of studies investigating the physical or the other properties of removable partial denture frameworks or components produced by subtractive manufacturing technique is extremely insufficient. Moreover, there is a lack of study comparing the physical properties or retentive capabilities of removable partial prosthesis elements obtained by LW method, additive and subtractive CAD/CAM techniques.

The aim of the present study is to compare the retentive properties of circumferential clasps (CC) produced by LW, additive and substractive CAD/CAM methods. The null hypothesis of this study was that the fabrication method or the type of metal alloy used in manufacturing would not affect the retention properties of CCs.

Materials & Methods

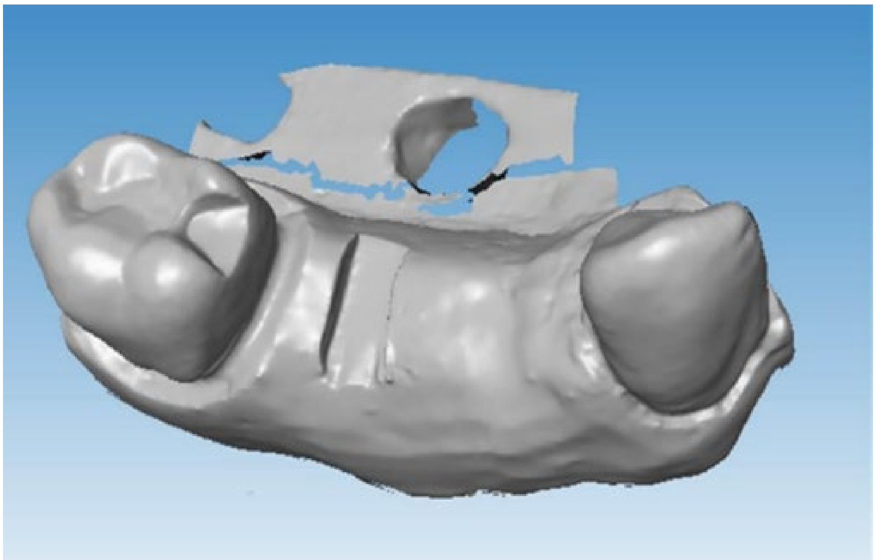
The present study was carried out in 6 stages.

1. Fabrication of 5 physical metal models (PMM) simulating partial edentulism
2. Fabrication of 20 CC samples using traditional LW manufacturing method,
3. Fabrication of 10 CC samples using additive CAD/CAM method,
4. Fabrication of 20 CC samples using subtractive CAD/CAM method,
5. Execution of the retention tests of the CC samples,
6. Statiscal analyses of obtained data.

1. Fabrication of 5 PMMs simulating mandibular partial edentulism

A mandibular jaw simulator (MJS) without 1^{st} and 2^{nd} premolar teeth was used to 5 similar PMMs. Impression of the MJS was made with additional silicone impression material (Variotime, Kulzer Mitsui Chemical Group) using monophase impression technique and impression cavity was filled with casting wax (Occlusal Wax, Bego, Germany). After the wax pattern had completely cooled, it was removed from the impression and moved to the surveyor (Degussa VG-3, DeguDent GmbH, Germany). The following processes were performed on this wax pattern, respectively; an undercut area with a depth of 0.5 mm was prepared at the cervical third of the distobuccal facies of the first molar tooth, where the retaining part of the circumferential clasp arm would be inserted. An occlusal rest preparation 2,5mm in length, 2,5mm in width, and 2mm in depth was applied on the mesioocclusal part of the 1^{st} molar. To provide a standardized insertion and removal of the clasps during retention tests, a rectangular seating space was prepared on the edentulous crest, parallel to the path of insertion. The wax pattern was removed from the surveyor, invested with phosphate bonded refractory material and casted with chromium-cobalt (Wironit, Bego, Germany) dental alloy. After polishing, the metal model was digitalized with a desktop 3D scanner (7 series, Dental Wings, Canada) and the obtained data was saved as an standard tesellation language (STL) file (Figure 1).

Figure 1. Digitized image of PMM.



Using this STL data, the metal alloy having 30 µm diameter chrome-cobalt (Cr-Co) particles (EOS CobaltChrome SP2 GmbH, Germany) was transformed into 5 identical PMMs in a selective laser sintering (SLS) device (EOS 270, EOS GmbH, Germany). Finally, annealling and polishing procedures of the PMMs were executed (Figure 2).

Figure 2. Fabricated PPMs.

2.Fabrication of 20 CCs by LW technique.

A total of 20 CC wax patterns were shaped on the PMMs using standard casting waxes (Rewax, Renfert GmbH, Germany). On the PMM, distobuccal corner of 1st molar was chosen as the end point of the retentive arm and this point was marked with a round burr. The retentive arm of the clasp was prepared with 1.4 mm thickand 1.4 mm in width in the undercut area, and

2.5 mm in width and 2.1 mm in thickness on the equator line. The reciprocal arm of the clasp was formed with a width and thickness of 2.5 mm and extended on the lingual surface to the distal corner on the middle third of the crown. The occlusal rest was prepared with a length of 2.5 mm, a width of 2.5 mm and a thickness of 2 mm. In order to properly attach the vertical pin that will connect the clasp to the chewing simulator, an extension was formed starting from the mesial surface of the clasp and extending to the middle of the edentulous crest and sitting on the crest surface. Pin slots were created on this extension for easy soldering of the pin onto the plate extension. Finally, wax patterns of 20 CCs were completed, and 10 of them were cast using Cr-Co dental alloy (Wironit, Bego, Germany) and phosphate bonded investment (Wirovest, Bego, Bremen, Germany). The remaining 10 wax patterns were invested with phosphate-bonded investment (Rematitan Plus, Dentaurum, Germany). After the setting of investment, dental titanium alloy was melted with an electric-arc melting device (Rematitan Autocast, Dentaurum, Almanya) in inert gas atmosphere and molten metal was sent to the cavities left by the wax pattern in the investment by applying vacuum pressure. After the casting was completed, sprues were cut, CCs were sandblasted with 250 micron aluminum oxide sands and polished. 10 cast CC samples obtained from Cr-Co alloy were registered as Cr-CoL (Figure 3), and the other 10 samples obtained from titanium alloy were recorded as TiL group (Figure 4).

Figure 3. CC samples obtained from Cr-Co alloy using LW.

Figure 4. CC samples obtained from titanium alloy using LW.

3.Fabrication of 10 CCs by CAD/CAM method using additive manufacturing technique.

Each PMM was digitalized with the same desktop 3D scanner and the obtained data was saved as STL. The STL data of the digitized PMMs was transferred to the CAD software (DWOS PFW) and the virtual path insertion was established. Retentive arm, reciprocal arm and the occlusal rest of the virtual CCs were designed using CAD software by taking the dimensions and shape of the cast CCs as a guide. After the virtual CC was formed and the design was completed, the STL data were transferred to CAM unity (EOSINT M270, EOS GmbH, Germany). In the CAM unity, a total of 10 CCs were produced by the additive manufacturing method using the SLS technique from Cr-Co dental alloy (Wirobond® C+, Bego, Germany) having 30 µm-thick particles. After the annealing and polishing processes were completed, 10 CC samples produced by additive manufacturing method were registered as Cr-CoA group (Figure 5).

Figure 5. CC samples obtained from Cr-Co alloy using additive manufacturing method.

4.Fabrication of 20 CCs by CAD/CAM method using subtractive manufacturing technique.

To obtain CCs by subtractive manufacturing method, STL data of the virtual CC designed to be used in additive manufacturing method was utilized. The data was transferred to 5-axis milling machine (Yenamak D-30, Yena Makine, Turkey) of the CAM unit. During subtractive manufacturing, Cr-Co blocks (Magnum Ceramic Co, MESA, Italy) were subjected to wet-milling and the obtained 10 CC samples were registered as Cr-CoS group (Figure 6).

Figure 6. CC samples obtained from Cr-Co alloy using subtractive manufacturing method.

The blocks containning dental titanium alloy (Copra ti-5, White Peaks Dental Systems GmbH, Germany) were also subjected to the same milling procedure and the obtained 10 CC samples were recorded as TiS group (Figure 7).

Figure 7. CC samples obtained from dental titanium alloy using subtractive manufacturing method.

5. Execution of the retention tests of the CC samples

The retention test of a total of 50 CC samples collected in 5 different groups was carried out using an insertion-removal testing simulator (IRTS) and data acquisation device (Birant Makina, Ankara, Türkiye). Standard stainless steel screws having 50 mm lenght and 3 mm diameter were provided so that each sample could be attached to the insertion-removal testing simulator. These screws were welded to the plates extended from the mesial surface of the CCs onto the edentulous crest, parallel to path of insertion using a surveyor (VG-3, Degussa, Germany). The welding process was done with the metal inert gas welding (MIG, Oz-San Makine, Turkey) which enables the joining of different metals.

Insertion-removal simulations were made for each CC group using the PMM belonging to that group. Thus, it was tried to ensure that the amount of wear that may arise from the friction of the metals is equal for each group. The PMM belonging one of the five experimental groups was fixed to IRTS parallel to path of insertion. The PMM was not removed from IRTS until the insert-removal test of 10 samples in each group is completed. The sensors on the IRTS were adjusted to determine not only the exact seperation of the sample from the PMM but also detect exact seating of the sample on the PMM. The IRTS was set so that each cycle lasted 6 seconds. Data acquisition device of the IRTS was set for 25 measurements in a second. Thus, the highest value at the time of exact separation of CC sample from the PMM was recorded without data loss. All values obtained during the insertion-removal tests were recorded in Newtons (N).

The first retention measurement of 50 samples belonging to 5 groups was performed without any simulation of insertion and removal, and the obtained values were recorded as the results of the first measurement.

A total of 3000 insertion-removal simulations were carried out corresponding to 2-year usage of RPD for each CC sample (Figure 8). Retention measurements were made once at the end of 375 cycles representing each three-month usage simulation and 8 times during the two-year usage simulation. Thus, a total of 9 measurements were performed for each sample. The resistance of each CC to removal from the PMM was converted to numerical values in Newtons by the data acquisition device (Testbox 2010, Teknik Destek Grubu, Turkey) .

6.Statistical analyses

Analysis of the obtained data was performed with the SPSS 18.0 (SPSS Inc, USA) software. The data were subjected to descriptive analysis initially, and mean, median and standard deviation values were calculated. The one-way analysis of variance (ANOVA) was used to determine whether there were any statistically significant differences between 5 groups (α=.05).

Results

The mean, median, standard deviation, maximum and minimum permanent values of 10 Cr-CoL samples obtained from the first measurement made before the insertion-removal simulations and 8 periodic measurements made at 3-month intervals during the insertion-removal process were given in Table 1.

Table 1. The descriptive analysis of retention values obtained from of Cr-CoL samples

	Mean	Median	Standard Deviation	Minimum	Maximum
1st	10,8	8,9	4,6	6,4	19,6
2nd	11,6	10,9	3,6	7,6	18,6
3rd	12,0	12,2	4,0	6,3	19,2
4th	10.9	12,2	3,4	4,9	14,3
5th	10,1	8,9	3,0	6,2	14,5
6h	10,6	9,1	3,0	7,3	14,9
7th	11,1	10,0	3,3	7,0	15,7
8th	11.6	10,5	2,7	8,7	16,0
9th	12,6	13,0	2,9	8,4	16,7

The mean, median, standard deviation, maximum and minimum permanent values of 10 TiL samples obtained from the first measurement made before the insertion-removal simulations and 8 periodic measurements made at 3-month intervals during the insertion-removal process were given in Table 2.

Table 2. The descriptive analysis of retention values obtained from of TiL samples

	Mean	Median	Standard Deviation	Minimum	Maximum
1st	9,0	9,6	2,3	5,2	12,4
2nd	9,3	8,5	2,6	6,2	15,0
3rd	10,0	9,3	2,3	7,1	15,4
4th	10,0	9,6	2,1	7,5	15,2
5th	10,5	10,2	2,1	7,9	15,4
6h	10,4	10,0	1,8	7,2	14,1
7th	10,3	9,9	2,0	7,1	14,5
8th	10,3	9,8	2,1	7,3	14,1
9th	10,6	10,1	1,9	7,6	14,1

The mean, median, standard deviation, maximum and minimum permanent values of 10 Cr-CoA samples obtained from the first measurement performed before the insertion-removal simulations and 8 periodic measurements executed at 3-month intervals during the insertion-removal process were given at the Table 3.

Table 3. The descriptive analysis of retention values obtained from of 10 Cr-CoA samples

	Mean	Median	Standard Deviation	Minimum	Maximum
1st	8,4	7,9	2,3	4,6	12,0
2nd	9,1	9,1	2,0	5,9	12,4
3rd	9,4	9,0	1.8	6,8	12,8
4th	9,7	9,6	2,1	6,9	14,3
5th	9,7	9,5	7.0	7,0	13,8
6h	10,8	10,5	2,6	7,6	16,3
7th	11,3	10,8	3,3	7,0	17,4
8th	11,5	11,2	3,6	6,3	17,7
9th	11,8	10,8	3,4	7,9	19,4

The mean, median, standard deviation, maximum and minimum permanent values of 10 Cr-CoS samples obtained from the first measurement performed before the insertion-removal simulations and 8 periodic measurements executed at 3-month intervals during the insertion-removal process were given at the Table 4.

Table 4. The descriptive analysis of retention values obtained from of 10 Cr-CoS samples

	Mean	Median	Standard Deviation	Minimum	Maximum
1st	8,5	7,9	2,7	5,0	12,9
2nd	9,4	9,7	4,4	4,0	17,1
3rd	10,8	11,6	4,9	4,5	19,5
4th	11,7	14,1	5,1	5,1	17,6
5th	12,2	12,7	6,0	4,9	23,1
6h	12,6	13,4	6,1	5,3	23,9
7th	13,0	13,3	5,9	6,1	25,1
8th	13,5	12,4	7,1	6,2	28,0
9th	14,0	12,5	7,6	6,6	30,7

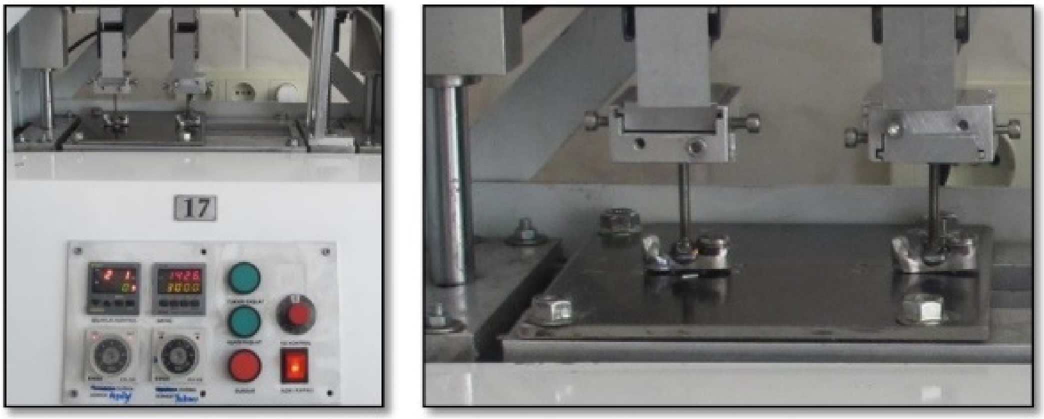
The mean, median, standard deviation, maximum and minimum permanent values of 10 TiS samples obtained from the first measurement performed before the insertion-removal simulations and 8 periodic measurements executed at 3-month intervals during the insertion-removal process were given at the Table 5.

Table 5. The descriptive analysis of retention values obtained from of 10 TiS samples.

	Mean	Median	Standard Deviation	Minimum	Maximum
1st	13,1	14,0	5,8	5,2	21,7
2nd	13,8	15,5	6,0	5,6	24,3
3rd	15,2	15,1	5,0	8,8	24,4
4th	16,0	16,5	5,4	8,8	26,9
5th	16,5	16,8	5,6	7,8	26,0
6h	16,6	17,2	5,4	9,2	26,8
7th	17,0	17,6	6,2	9,4	28,5
8th	17,5	19,0	5,9	9,8	25,6
9th	17,3	18,7	5,9	8,8	27,2

The average values of the initial retention forces (obtained from 1st tests) of the CCs belonging to 5 different groups are listed as follows; TiS (13.1 N), Cr-CoL (10.8 N), TiL(9 N), Cr-CoS (8.5 N), Co-CrA (8.4 N). At the end of 3000 cycles, the average of the retention values of the CCs belonging to 5 different groups, from the largest to the smallest, are as follows; TiS (17.3 N), Co-CrS (14 N), Co-CrL (12.6 N), Co-CrA (11.8), TiL (10.6).The changes in the retention values of the 5 groups over time is given in the Figure 8.

Figure 8. Insertion and removal simulator.



All of the P values obtained from pairwise comparisons between 5 groups are shown in Table 6. According to the pairwise comparison, statistically significant differences were found between the retentive force values of the CCs in the TiS and Cr-CoA (P=0.02) and TiS and TiL (P=0.01) groups.

Table 6. P values obtained from pairwise comparisions.

	Cr-CoL	Cr-CoA	Cr-CoS	TiL	TiS
Cr-CoL		1	1	1	0.11
Cr-CoA	1		1	1	**0.02**
Cr-CoS	1	1		1	0.22
TiL	1	1	1		**0.01**
TiS	0.11	**0.02**	0.22	**0.01**	

Discussion

For a long time, LW was the only method used in the framework fabrication of RPDs.[15] Undoubtedly, the most important reason for this is that the first applications of the CAD/CAM method covered only fabrication procedures of fixed restorations and a standard digital workflow scheme for RPD production could not be established for a long time.[13,16,17]

Today, CAD software developed for the production of metal framewroks of RPDs provides great opportunities for dental professionals. For example, it is possible to create much more precise guide-planes with CAD software compared to the traditional method.[18] Since dental plaster, wax and other intermediate materials are not used during the metal framework production with CAD/CAM technology, it might be thought that the accuracy of the prosthesis obtained would increase. However, the results of studies comparing the accuracy of frameworks produced by LW and CAD/CAM methods might differ from each other.[19-21]

Not only the accuracy, but also the mechanical properties and retention capabilities of RPD elements produced by both conventional and CAD/CAM methods have been an important topic of discussion of the dental literature.[2,3,6,13] Nakata et al[22] reported that Cr-Co clasps produced by additive manufacturing method have less surface roughness than Cr-Co and Grade 3 titanium alloy obtained by casting method. Besides, the authors[22] reported that Cr-Co clasps obtained with AMM were more retentive than Grade 3 titanium clasps produced with LW. They also observed that Cr-Co clasps produced with AMM maintained their retentive abilities longer than Cr-Co and Grade 3 titanium clasps produced with LW. Finally, Nakata et al.[22] reported that Cr-Co clasps produced with AMM slightly lost their retentive ability after 1000-10,000 cycles. The results of this study differ significantly from those of Nakata et al.[22] In the present study, the smallest retentive force values during the 1st measurement were obtained from Cr-Co clasps produced with AMM. In the 1st measurements, the highest rententive force values were found in the TiS group, which had clasps produced from titanium alloy using SMM. Another difference is that in the current study, retention forces increased in all groups after 3000 simulations, regardless of the production method and metal alloy.

There may be more than one reason for the discrepancy between the Nakata et al's[22] observations and the findings of the current study. One of the reasons for this contraversion may be found in the studies of Sato et al[23] and Jiang et al.[24] Sato et al[23] observed that the retentive force values of the CCs increased when the friction coefficient between clasp and the abutment increased. An in vitro study conducted by Jiang et al[24] showed that the type of metal alloy used in abutment fabrication could also affect the retention of the CCs. The authors observed that the retention force values of the CCs sharply increased as the number of simulations increased when the tests was carried out on the abutments which was manufactured by casting of Au-Ag-Pd alloy.[24] They determined that the retention force values of the CCs decreased as the number of simulations increased when the tests was carried out on the abutments which was manufactured by casting of Cr-Co alloy.[24] Contrarily, the retentive force values of the clasps increased in the present study, despite the tests were executed on the abutments which was manufactured by the same metal alloy. Even though the metal alloy used in both studies is the same, the manufacturing method of the abutments is completely different. The effect of differences in manufacturing method on the mechanical properties of the product is a well-known phenomenon in material science.[13,22]

Undoubtedly the present work has several limitations. The most important one is that the abutments used in the evaluation of retention of the CCs are manufactured from a single alloy and using a single production method. Another important limitation of the study is that the simulations were carried out only in dry environment. However, saliva can affect the coefficient of friction between the abutment and the clasp.[23]

Another important limitation is the difficulties in standardizing the classical LW technique. In future studies, the clasps can be designed with CAD software and the resulting design can be printed on 3D printers using castable resin material in order to reach a complete standard in shape and dimension of the clasp to be produced with LW technique. By taking these samples to the casting process, exactly standard clasps can be obtained that pass through the same points of the abutment in both CAD/CAM and LW techniques.

Conclusion

According to the results of the present study;

- CCs manufactured by SMM have a higher retentive force value than clasps manufactured by LW and AMM.

- The retentive force values of the CCs increase as the number of simulations increases.

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