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Retentive force of conical crowns combining zirconia and fiber-reinforced composite

Abstract

Purpose: This study investigated the retentive force of conical crowns combining zirconia primary and fiber-reinforced composite (FRC) secondary crowns and their changes due to aging.

Methods: Zirconia primary crowns were produced with a convergence angle of 3°. Thirty-two secondary crowns were milled from FRC and divided into two groups (n = 16/group) based on the polishing method of the secondary crown inner surfaces: diamond paste (Group 1) and silicone points (Group 2). After fitting the secondary crowns with different fitting forces (F), loosening forces (L) were determined. Tests were repeated after an occlusal stop (OS) was added to the secondary crown and artificial aging (10,000 insertion/removal cycles). Data were compared using the Wilcoxon and Mann–Whitney *U* tests.

Results: Crowns without an OS showed L/F ratios of 0.4586 (Group 1) and 0.4104 (Group 2). With an OS, maximum retention was not significantly affected by the polishing method and could be limited to L_{max} = 19.31±7.77 N (Group 1) and L_{max} = 16.12±5.92 N (Group 2).

Conclusions: These findings suggest that the combination of conical zirconia primary and FRC secondary crowns can obtain acceptable retentive forces that are not affected by aging if the inner surfaces are polished with diamond paste. OS generation could limit maximum retention, but should be adjusted if the target value of 10 N is not to be exceeded. With a change of the convergence angle to 4°, L/F values for crowns without an OS would be close to 1/3, which is considered ideal for conical crowns.

Clinical significance: The combination of zirconia primary crowns and FRC secondary crowns was found feasible to ensure the required retention for clinical use over a long time span. Furthermore, it offers an alternative to metal-based restorations while ensuring high levels of biocompatibility and esthetics.

1. Introduction

More than a century has passed since the development of the double crown system as a retainer for removable partial dentures [1]. Many studies have already demonstrated the long-term stability of natural teeth and dentures [2–9]. Double crowns are a kind of retainer that can also be used for implants [10], and in the last two decades, mainly in Europe, treatment for stabilizing dentures by strategically placing implants into partially edentulous jaws and connecting natural teeth and implants with double crowns has been developed [11–13]. Numerous studies have demonstrated high survival rates for both natural teeth and implants as abutment teeth for dentures [14–17].

Double crowns can effectively transmit occlusal forces in the axial direction of the abutment teeth and resist the vertical and horizontal force components caused by denture displacement [18,19]. In addition, compared with clasps, double crown attachments are superior in terms of esthetics, make it easy to maintain good hygiene of the abutment teeth when the dentures are removed, and are easy to repair when abutment teeth are lost [20]. There are three main types of double crowns: telescopic crowns with a parallel side wall, conical crowns with a tapered side wall, and resilient telescopic crowns with clearance between the primary and secondary crowns [7]. In the past, double crowns were fabricated by casting using the lost wax technique [21], but recently, it has become possible to fabricate double crowns using computer-aided design/computer-aided manufacturing (CAD/CAM) technology [22]. The application of CAD/CAM technology offers various advantages, such as improved work efficiency and reduced fabrication costs [23]. Now that many materials can be processed by CAD/CAM technology, attempts are being made to apply nonmetal materials for double crown fabrication [24–27]. In recent years, zirconia has been preferred for primary crowns from the viewpoints of biocompatibility and esthetics [27]. For secondary crowns, materials such as electroformed gold, fiber-reinforced composite

(FRC) and poly (ether ether ketone) (PEEK) have been applied [28–30]. We previously investigated the retentive force of telescopic crowns using zirconia for the primary and FRC for the secondary crown and reported that the method of polishing the inner surface of the secondary crown affected the retentive force; however, the retentive behavior of conical crowns made of this material combination remains unclear [31].

With the aim of establishing the clinical application of conical crowns combining zirconia primary and FRC secondary crowns, this study investigated changes in the retentive force before and after repeated insertion/removal tests and the effects of the polishing method. We formulated the null hypotheses that there would be no difference in retention 1) between the test groups differing in polishing method and 2) within test groups due to aging (repeated crown insertion and removal).

2. Materials and Methods

2.1. Conical crown fabrication

A total of eight Frasaco typodont teeth (bilateral central incisors, canines, second premolars, and second molars) were selected as samples from a maxillary jaw model (ANA-4, Frasaco, Tettnang, Germany). These samples were prepared as abutment teeth (preparation angle 3°, planned substance removal of 1.5 mm on occlusal area and 1.2 mm on circumferential areas), and each tooth was replicated in CoCr alloy. The completed replicated teeth were welded on top of a stainless steel cylinder that could be attached to equipment for repeated insertion/removal tests and retentive force measurements (Fig. 1). The replicated teeth were three-dimensionally (3D) scanned using a dental laboratory scanner (D 2000; 3Shape, Copenhagen, Denmark) and the primary crown was digitally waxed using dental CAD software (Dental Designer; 3Shape) with the insertion axis parallel to the cylinder axis. Eight primary crowns with the convergence angle set at 3° were milled from zirconia blanks (Cercon ht Cercon Brain Xpert; DeguDent, Hanau, Germany) and sintered with Cercon heat plus (DeguDent). The primary crown and replicated teeth were cemented with adhesive resin cement (Panavia F 2.0; Kuraray, Tokyo, Japan) and used as abutment tooth samples. Then, the conical surfaces were ground and polished with a set of customized 3° tapered diamond burs (Komet, Gebr. Brasseler, Lemgo, Germany) using a parallel milling machine (Fraesgeraet-F1; Degussa, Frankfurt, Germany). The minimum wall thickness of the primary crown was set to 0.6 mm. The mirror finish was achieved using a brush and diamond paste (Fegupol; Feguramed, Buchen, Germany). The completed primary crowns were then 3D scanned with the aforementioned dental scanner and the respective conical retention areas determined (Table. 1). To be able to generate later on a occlusal gaps with constant width between the primary and secondary crowns, the primary crown surface was sectioned at the coronal end of the conical region, and the occlusal part of the surface was elevated by 0.5 mm (Geomagic Design X; Rock Hill, SC, USA). Digital wax-up of the secondary crown was carried out using Dental Designer based on the modified primary crown data, with all gap parameters set to zero. The minimum wall thickness of the secondary crown was set to 1.0 mm. In addition, the cusps of the secondary crowns were cut off with a horizontal plane, and a cylindrical pin enabling fixation in the test setup was added above the respective crown center. The secondary crowns were milled from FRC discs (TRINIA; Bicon, Boston, MA, USA) with a milling machine (PrograMill7; Ivoclar Vivadent, Schaan, Liechtenstein). A total of 32 secondary crown specimens, four from each of the eight tooth types, were fabricated and divided into two groups according to the subsequent polishing method used for the inner surfaces of the secondary crowns. In Group 1, polishing was carried out with cotton and abrasive paste (Fegupol HAI Polish, Feguramed) consisting of 30% wax binder and 70% diamond and alumina particles with grain sizes between 1 µm and 20 μm. In contrast, silicone points (CompoMaster; Shofu, Kyoto, Japan) were used for the polishing procedure in Group 2. The silicone points were composed of synthetic rubber and abrasive particles (diamond) and magnesium oxide. The polishing was carefully performed using a dental laboratory microscope while checking the inner surface of milled secondary crown. The completed secondary crowns were stored in distilled water at 37 ± 1 °C for 1 week before the retentive force was measured.

2.2. Retentive force measurements

A universal testing device (Zwick/Roell Z005; Zwick, Ulm, Germany) was used to measure the loosening forces L (Figs. 2 and 3) required to separate the two crowns when fitting them with a series of forces F = 12.5, 25.0, 37.5, 50.0, 75.0, and 100.0 N. Insertion and removal of each secondary crown to the primary crown were performed with a crosshead speed of 1 mm/min. For each fitting force magnitude, the retentive force L was measured three times per sample under dry conditions. For conical crowns with an open occlusal gap, the L/F ratio is constant and given by $L/F = (\mu_0 - \tan\alpha) / (\mu_0 + \tan\alpha)$ [26]. Hence, the coefficient of friction (μ_0) could be calculated with given convergence angle α and the L/F ratio.

Next, for the occlusal gap between the primary and secondary crowns, an occlusal stop (OS) with composite resin (Rebilda DC; VOCO, Cuxhaven, Germany) was added to the inner surface of the secondary crown while fitting the crowns with F = 30 N. This modification intends to prevent relative movement between the primary and secondary crowns for fitting forces F exceeding 30 N, thereby limiting the maximum retentive force L_{max}. Retention force measurements were repeated for the crowns modified with an OS, as described above. Subsequently, crowns were exposed to artificial aging, which consisted of 10,000 insertion/removal cycles (see below for details). After artificial aging, retentive force measurements were conducted once again.

2.3. Artificial aging

A chewing simulator (CS-4; SD Mechatronik, Feldkirchen-Westerham, Germany) was used for the repeated insertion/removal test of the secondary crown. This simulator allows for various weights to be attached to the top of the crosshead, thereby allowing for varying loads. In this study, a 4-kg weight acted at a rate of 30 mm/s through a spring-damper system (spring stiffness 43 N/mm, damping constant 135 Ns/m), simulating a maximum fitting force of 53 N (static force 39 N). When loosening the secondary crown from the primary crown, the crosshead moved upward at a speed of 30 mm/s. Repeated insertion/removal tests were performed up to 10,000 times. Since the simulator has eight test chambers, the tests were conducted in two sessions (16 specimens per group). Primary crown surfaces were kept wet with distilled water and thus not immersed in water, which could block the fitting process.

2.4. Microscopic observation

The OS on the inner surface of the secondary crown before and after repeated insertion/removal tests was observed with a stereomicroscope (12× magnification, Stemi SR; Zeiss, Oberkochen, Germany). This incident light microscope had a 10x main magnification combined with changeable magnifications between 0,6x and 5x. To enable digital workflow (AxioVision 4.9.1, Zeiss), the microscope had been supplemented by a camera (Axio Cam MRc, Zeiss).

2.5. Statistical analysis

The mean retentive forces of the 3 times in each of teeth was calculated as the representative value. For crowns without an OS, linear regression between L and F was carried out. Furthermore, to show that retention of these crowns did not depend on the conical retention area, linear regression analyses pairing loosening force and conical retention area were conducted for each fitting force magnitude as well. Pairwise statistical analysis was conducted solely for retentive forces recorded with an $F = 100$ N fitting force. After checking for normal data distribution with Shapiro-Wil tests, *t*-tests were used for all pairwise comparisons between the two test groups. The effects of crown modification with an OS and artificial aging within each test group were analyzed using the Wilcoxon signed-rank test. Statistical analysis was performed using SPSS version 27 (IBM, Armonk, NY, USA) with the level of significance set at 0.05.

3. Results

Baseed on Shapiro-Wilk tests, normally distributed retention force data was given in both test groups for all examined states. Figure 4 shows the correlation between the loosening force and the series of fitting forces for each retention test (without OS, with OS before aging, and with OS after aging) in both groups. For conical crowns without an OS, the mean L/F ratio was $L/F = 0.47 \pm 0.10$ in Group 1 and $L/F = 0.42 \pm 0.10$ in Group 2. Linear regression without intercept revealed overall L/F ratios of $L/F = 0.4586$ for Group 1 and 0.4104 for Group 2, corresponding to the respective coefficients of friction $\mu_0 = 0.1412$ and $\mu_0 = 0.1254$. Furthermore, the retention did not depend on the conical retention areas of the primary crowns (Group1: $p > 0.05$ for all fitting forces but $F = 100$ N, Group2 $p > 0.40$ for all fitting forces) (Fig. 5 and 6). For Group 1, the molar crowns had less retention than would have been expected at $F = 100$ N.

Further analysis of data with fitting force $F = 100$ N showed that the mean retentive forces for crowns without an OS were L = 45.17±9.73 N and L = 40.10±11.94 N in Groups 1 and 2, respectively. After the OS was added, these retentive forces were limited to L = 19.31±7.77 N and L = 16.12±5.92 N in Groups 1 and 2, respectively. This reduction in retention was significant for both groups ($P < 0.01$), but no significant difference in the polishing method of the secondary crowns was observed between the two test groups. After repeated insertion/removal tests, a slight increase in retention was seen in Group 1 (L = 19.90±9.21 N, $P = 0.756$) and a moderate increase in Group 2 (L = 21.61±8.82 N, $P = 0.011$) (Fig. 7 and 8). Again, statistical analysis revealed no significant effect of the polishing method on retention. In detail, the differential values of the retentive ΔL force before and after the repeated insertion/removal tests were $\Delta L = 0.59 \pm 4.55$ N and $\Delta L = 6.49 \pm 8.97$ N in Groups 1 and 2, respectively. A tendency toward a higher change in retention was seen in Group 2 (Fig. 9), but no significant difference was found between the two groups ($P = 0.053$).

Figure 10 shows microscopic images of the inner surface of the secondary crown before and after the OS was added and after repeated insertion/removal tests.

4. Discussion

In this study, two polishing methods, polishing paste and silicone points, were set for polishing composite resin. The difference in polishing methods did not affect the retentive force before or after the addition of an OS and after repeated insertion/removal tests. However, the retentive force before and after repeated insertion/removal tests tended to increase after the insertion/removal tests under the condition of polishing with silicone points for composite resin polishing. The first null hypothesis that there would be no difference in retention with regard to polishing method was accepted and the second null hypothesis that retention would not be changed due to aging (repeated crown insertion and removal) had to be rejected in parts. Here, results suggested that, in contrast to polishing with silicon points, polishing of the inner surface with diamond paste caused no significant change in loosening force over the long term and made the change in the retentive force easier to predict.

At the beginning of this investigation, no data was available to perform a sample size calculation. An a posteriori power calculation (80%power, p=0.05) revealed that a very high number of samples/group would have been needed (retention without OS: n= 80, retention with OS before aging: n=64, and retention with OS after aging: n=320) to show significant differences between the two polishing methods. Since significant intra-group changes were found with n = 16 samples/group, the sample size was sufficient to show differences between the different states (Without OS, With OS before aging, With OS after Aging). Since both test groups showed retention behavior sufficient for a recommendation for clinical use and absolute differences in mean retention were small, we did not add a lot of samples to possibly be able to show significant but not relevant group differences in this study.

Since retention behavior did not depend on the conical retention area, the pooling of the eight different tooth types with regard to retention was justified. Only for high fitting forces of secondary crowns without OS of Group 1, a slight decrease in retention with increasing retention area was found. This effect, however, originated from under-proportional increase in the retention of the molar crowns at F = 75 and F = 100. We assume that this behavior was caused by a not planned partial closure of the occlusal gap. Furthermore, it was suggested that the retention mechanism of the conical crown is not related to the size of the conical retention area because it is exerted by the wedging effect of the lower part of the conical retention area contacting the secondary crown.

Previous studies have reported that the combination of a zirconia primary crown and an FRC secondary crown provided the required 3.5–7.0 N for double crowns as the initial retentive force for telescopic crowns [32]. In the present study, the maximum retentive force of each conical crown was controlled by an OS added at a fitting force of $F = 30$ N. With an F/L ratio between 0.41–0.46 on the crowns without an OS, the maximum loosening force should therefore be theoretically limited to 12.3–13.8 N. The crowns with an OS, there still had to be some relative movement between the primary and secondary crowns for fitting forces $F > 30$ N, such that the real loosening force limit was around 20 N, which is larger than the targeted value. The delayed effect of the OS on the retentive force could have been caused by shrinkage of the resin at the time of application of OS, thereby generating a slight occlusal gap at the end of this step. Furthermore, elastic deformation of the secondary crown made of FRC may limit the relative movement between the primary and secondary crowns. The FRC used in this experiment consisted of 55 wt% glass fiber and 45 wt% epoxy resin matrix [34]. The horizontally oriented glass fiber sheets are multidirectionally interlaced and stacked in vertical direction. Therefore, the FRC material is rather flexible compared with CoCr alloy and zirconia [26]. Based on these observations, the OS should be incorporated using lower fitting forces of about $F = 15$ N if a maximum retentive force $L_{max} = 10$ N is targeted. According to Schwindling et al. [26], it is possible to achieve appropriate maximum retentive forces by adding OSs in conical zirconia secondary crowns with a convergence angle of 3° together with zirconia primary crowns. In this study, since the ratio $L/F = 0.308$ was close to $L/F = 1/3$, which is seen as ideal because it still ensures sufficient retention and avoids overly high retentive forces (without the use of an OS), we chose 3° angulation for the new combination zirconia/FRC. With the coefficients of friction μ_0 determined in this study for conical crowns with a zirconia primary crown and an FRC secondary crown, $\alpha_{ideal} = 4.04°$ (Group 1) and $\alpha_{ideal} = 3.59°$ (Group 2) could be computed with $(L/F)_{ideal} = 1/3$. Hence, the convergence angle should be chosen with 4° for this material combination in the future. The ideal convergence angle α_{ideal} depends on the coefficient of friction, which is different for commonly used material combinations. $\alpha_{ideal} = 4°$ is proposed with cobalt–chromium primary and secondary crown combinations, whereas $\alpha_{ideal} = 7–8°$ or $\alpha_{ideal} = 6°$ should be used with a gold alloy or titanium combination, respectively [33].

Microscopic observation revealed wear on the OS after the insertion/removal test, so the occlusal gap was expected to increase with long-term use, resulting in an increase in the maximum retentive force. On the other hand, with the combination of primary crowns made of zirconia and secondary crowns made of FRC, it was expected that the inner surface of the secondary crown would wear and the retentive force would decrease with repeated insertion/removals. Behr et al. [35] reported that ill-fitting of the secondary on the primary crowns led to both decreases and increases in the retentive force. The results of this study revealed that the group polished with silicon points showed an increase in the retentive force after aging. Tasaka et al. [31] reported that silicon point polishing was not sufficiently sensitive, fractured glass fiber tips, and resulted in a rough surface. It was suggested that the rough initial surface morphology changed significantly as a result of aging/wear, leading to ill-fitting between the secondary and primary crowns, which increases the retention. Ten thousand insertion/removal cycles correspond to a clinical service time of 10 years with three insertions per day. Repeated insertion/removal of the primary and secondary crowns may improve the fit by repairing the OS or adding resin to the axial surface on the inner surface of the secondary crown. This will need to be confirmed in further research.

When comparing the retention behavior of conical and parallel crowns, it can be seen that limiting the maximum retentive force is easier with parallel crowns since they possess a predefined end position. However, this also leads to a higher risk of losing retention due to wear [31]. In addition, with a decreasing convergence angle, milling inaccuracies have a greater impact on the end position of the crown, making parallel crowns a bigger challenge for dental technicians.

This study did have some limitations. First, only a 3° convergence angle of conical crowns made of zirconia primary crown and FRC secondary crown were used. Based on the results of this study, a convergence angle of 4° is more appropriate for this combination of materials. The ideal convergence angle of the conical crowns combining zirconia and FRC will need to be confirmed in further studies. In addition, double crown retention is reportedly affected by the phenomenon of hydraulic adhesion during wetting [36]. In the present experiment, only the retentive force in the dry condition was examined; thus, retention might be slightly higher under humid conditions. This study is only an in vitro study, and actual clinical trials with 4-10 years of follow-up are needed to draw more specific conclusions on the use of this double crown.

5. Conclusion

Within the limitations of this study in vitro, the combination of zirconia primary crowns and FRC secondary crowns was found feasible to ensure the required retention for clinical use over a long time span. However, the polishing method for the secondary crown inner surfaces appeared to affect the clinical long-term prognosis. If an initial maximum retentive force of 10 N is targeted for conical crowns, the OS should be added with a lower fitting force than applied here, i.e., a fitting force of about 15 N. The inner surfaces of secondary crowns should be polished using diamond paste, and a convergence angle of 4° should be favored over the 3° angle used in this investigation.

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Informed consent

This manuscript concerns an in-vitro study and does not include any study participants, and consequently no informed consent was required.

Declaration of Competing Interest

The authors declare having no financial interest in any of the products, materials or equipment used in the present study.

References

[1] C. Arnold, J. Hey, J. M. Setz, A. F. Boeckler, R. Schweyen. Retention force of removable partial dentures with different double crowns. *Clin Oral Investig*. 22 (2018) 1641-1649. https://doi: 10.1016/j.jdent.2021.103681.

[2] Y. Igarashi, T. Goto. Ten-year follow-up study of conical crown-retained dentures. *Int J Prosthodont*. 10 (1997) 149-155.

[3] T. Widbom, L. Löfquist, C. Widbom, B. Söderfeldt, M. Kronström. Tooth-supported telescopic crown-retained dentures: an up to 9-year retrospective clinical follow-up study. *Int J Prosthodont*. 17 (2004) 29-34.

[4] B. Wöstmann, M. Balkenhol, A. Weber, P. Ferger, P. Rehmann. Long-term analysis of telescopic

crown retained removable partial dentures: survival and need for maintenance. *J Dent*. 35 (2007) 939-945. https://doi: 10.1016/j.jdent.2007.09.010.

[5] A. Piwowarczyk, K. C. Köhler, R. Bender, A. Büchler, H. C. Lauer, P. Ottl. Prognosis for abutment teeth of removable dentures: a retrospective study. *J Prosthodont*. 16 (2007) 377-382. https://doi: 10.1111/j.1532-849X.2007.00211.x.

[6] B. Dittmann, P. Rammelsberg. Survival of abutment teeth used for telescopic abutment retainers in removable partial dentures. *Int J Prosthodont*. 21 (2008) 319-321.

[7] F. S. Schwindling, B. Dittmann, P. Rammelsberg. Double-crown-retained removable dental prostheses: a retrospective study of survival and complications. *J Prosthet Dent*. 112 (2014) 488-493. https://doi: 10.1016/j.prosdent.2014.02.017.

[8] K. Ishida, T. Nogawa, Y. Takayama, M. Saito, A. Yokoyama. Prognosis of double crown-retained removable dental prostheses compared with clasp-retained removable dental prostheses: A retrospective study. *J Prosthodont Res*. 61 (2017) 268-275. https://doi: 10.1016/j.jpor.2016.12.006.

[9] K. Yoshino, K. Ito, M. Kuroda, N. Sugihara. Survival rate of removable partial dentures with complete arch reconstruction using double crowns: a retrospective study. *Clin Oral Investig*. 24 (2020) 1543-1549. https://doi: 10.1007/s00784-019-03030-8.

[10] R. Verma, T. Joda, U. Brägger, J. G. Wittneben. A systematic review of the clinical performance of tooth-retained and implant-retained double crown prostheses with a follow-up of 3 years. *J Prosthodont*. 22 (2013) 2-12. https://doi: 10.1111/j.1532-849X.2012.00905.x.

[11] G. Krennmair, M. Krainhöfner, O. Waldenberger, E. Piehslinger. Dental implants as strategic supplementary abutments for implant-tooth-supported telescopic crown-retained maxillary dentures: a retrospective follow-up study for up to 9 years. *Int J Prosthodont*. 20 (2007) 617-622.

[12] R. Kaufmann, M. Friedli, S. Hug, R. Mericske-Stern. Removable dentures with implant support in strategic positions followed for up to 8 years. *Int J Prosthodont*. 22 (2009) 233-241.

[13] S. Rinke, D. Ziebolz, P. Ratka-Krüger, E. Frisch. Clinical Outcome of Double Crown-Retained Mandibular Removable Dentures Supported by a Combination of Residual Teeth and Strategic Implants. *J Prosthodont*. 24 (2015) 358-365. https://doi: 10.1111/jopr.12214.

[14] G. Bernhart, A. Koob, M. Schmitter, O. Gabbert, T. Stober, P. Rammelsberg. Clinical success of implant-supported and tooth-implant-supported double crown-retained dentures. *Clin Oral Investig*. 16 (2012) 1031-1037. https://doi: 10.1007/s00784-011-0592-1.

[15] P. Rammelsberg, G. Bernhart, J. Lorenzo Bermejo, M. Schmitter, S. Schwarz. Prognosis of implants and abutment teeth under combined tooth-implant-supported and solely implant-supported double-crown-retained removable dental prostheses. *Clin Oral Implants Res*. 25 (2014) 813-818.

https://doi: 10.1111/clr.12197.

[16] S. Schwarz, G. Bernhart, A. J. Hassel, P. Rammelsberg. Survival of double-crown-retained dentures either tooth-implant or solely implant-supported: an 8-year retrospective study. *Clin Implant Dent Relat Res*. 16 (2014) 618-625. https://doi: 10.1111/cid.12023.

[17] H. Fobbe, P. Rammelsberg, J. Lorenzo Bermejo, S. Kappel. The up-to-11-year survival and success of implants and abutment teeth under solely implant-supported and combined tooth-implant-supported double crown-retained removable dentures. *Clin Oral Implants Res*. 30 (2019) 1134-1141. https://doi: 10.1111/clr.13527.

[18] J. B. Breitman, S. Nakamura, A. L. Freedman, I. L. Yalisove. Telescopic retainers: an old or new solution? A second chance to have normal dental function. *J Prosthodont*. 21 (2012) 79-83. https://doi: 10.1111/j.1532-849X.2011.00797.x.

[19] G. O. Isaacson. Telescope crown retainers for removable partial dentures. *J Prosthet Dent*. 22 (1969) 436-448. https://doi: 10.1016/0022-3913(69)90211-x.

[20] H. J. Wenz, K. Hertrampf, K. M. Lehmann. Clinical longevity of removable partial dentures retained by telescopic crowns: outcome of the double crown with clearance fit. *Int J Prosthodont*. 14 (2001) 207-213.

[21] A. G. Gurbulak, K. Kilic, Z. Eroğlu, E. Gercekcioglu, B. Kesim. Evaluation of the retention force of double conical crowns used in combination with a galvanoforming and casting fabrication technique. *J Prosthodont*. 22 (2013) 63-68. https://doi: 10.1111/j.1532-849X.2012.00897.x.

[22] R. A. Danielczak, T. Stober, W. Bömicke. Treatment with a CAD-CAM-fabricated, double-crown-retained, removable partial denture: A clinical report. *J Prosthet Dent*. 121 (2019) 220-224. https://doi: 10.1016/j.prosdent.2018.02.019.

[23] M. Schimmel, M. Walther, N. Al-Haj Husain, K. Igarashi, J. Wittneben, S. Abou-Ayash. Retention forces between primary and secondary CAD/CAM manufactured telescopic crowns: an in vitro comparison of common material combinations. *Clin Oral Investig*. 25 (2021) 6297-6307. https://doi: 10.1007/s00784-021-03928-2.

[24] V. Stock, P. R. Schmidlin, S. Merk, C. Wagner, M. Roos, M. Eichberger et al. PEEK Primary Crowns with Cobalt-Chromium, Zirconia and Galvanic Secondary Crowns with Different Tapers-A Comparison of Retention Forces. *Materials (Basel)*. 9 (2016) 187. https://doi: 10.3390/ma9030187.

[25] C. Wagner, V. Stock, S. Merk, P. R. Schmidlin, M. Roos, M. Eichberger at al. Retention Load of Telescopic Crowns with Different Taper Angles between Cobalt-Chromium and Polyetheretherketone Made with Three Different Manufacturing Processes Examined by Pull-Off Test. *J Prosthodont*. 27 (2018) 162-168. https://doi: 10.1111/jopr.12482.

[26] F. S. Schwindling, T. Stober, R. Rustemeier, M. Schmitter, S. Rues. Retention behavior of double-crown attachments with zirconia primary and secondary crowns. *Dent Mater*. 32 (2016) 695-702. https://doi: 10.1016/j.dental.2016.03.002.

[27] I. Turp, E. Bozdağ, E. Sünbüloğlu, C. Kahruman, I. Yusufoğlu, G. Bayraktar. Retention and surface changes of zirconia primary crowns with secondary crowns of different materials. *Clin Oral Investig*. 18 (2014) 2023-2035. https://doi: 10.1007/s00784-013-1183-0.

[28] F. S. Schwindling, U. K. Deisenhofer, A. C. Séché, F. Lehmann, P. Rammelsberg, T. Stober. Randomized trial investigating zirconia electroplated telescopic retainers: quality of life outcomes. *Clin Oral Investig*. 21 (2017) 1157-1163. https://doi: 10.1007/s00784-016-1869-1.

[29] T. Zahn, B. Zahn, S. Janko, P. Weigl, S. Gerhardt-Szép, H. C. Lauer. Long-term behavior of double crown retained dentures with metal and metal-free secondary crowns and frameworks made of Vectris(©) on all-ceramic primary crowns: a prospective, randomized clinical trial up to 14 years. *Clin Oral Investig*. 20 (2016) 1087-1100. https://doi: 10.1007/s00784-015-1597-y.

[30] O. Schubert, J. Reitmaier, J. Schweiger, K. Erdelt, J. F. Güth. Retentive force of PEEK secondary crowns on zirconia primary crowns over time. *Clin Oral Investig*. 23 (2019) 2331-2338. https://doi: 10.1007/s00784-018-2657-x.

[31] A. Tasaka, F. S. Schwindling, S. Rues, P. Rammelsberg, S. Yamashita, Retentive force of telescopic

crowns combining fiber-reinforced composite and zirconia. *J Prosthodont Res*. 66 (2021) 265-271. https://doi: 10.2186/jpr.JPR_D_20_00163.

[32] S. Bayer, H. Stark, L. Gölz, L. Keilig, D. Kraus, A. Hansen et al. Clinical retention force development of double crowns. *Clin Oral Investig*. 16 (2012) 407-411. https://doi: 10.1007/s00784-011-0530-2.

[33] C. Fingerhut, H. J. Schindler, K. Schweizerhof, B. Kordass, J. Lenz. Finite element analysis of the principles and loosening force of the conical telescopic crown: a computer-based study. *IntJ Comput Dent* 17 (2014) 199–218.

[34] N. Suzaki, S. Yamaguchi, N. Hirose, R. Tanaka, Y. Takahashi, S. Imazato et al. Evaluation of physical properties of fiber-reinforced composite resin. *Dent Mater*. 36 (2020) 987-996. https://doi: 10.1016/j.dental.2020.04.012.

[35] M. Behr, E. Hofmann, M. Rosentritt, R. Lang, G. Handel. Technical failure rates of double crown-retained removable partial dentures. *Clin Oral Investig*. 4 (2000) 87-90. https://doi: 10.1007/s007840050121.

[36] F. Beuer, D. Edelhoff, W. Gernet, M. Naumann. Parameters affecting retentive force of electroformed double-crown systems. *Clin Oral Investig*. 14 (2010) 129-135. https://doi: 10.1007/s00784-009-0271-7.

Tables

Primary crown on tooth	Conical retention area [mm^2]
17	134.2
15	111.9
13	89.4
11	95.9
21	88.8
23	83.1
25	102.5
27	124.2

Table. 1: Conical retention areas determined for the different primary crowns.

Figure

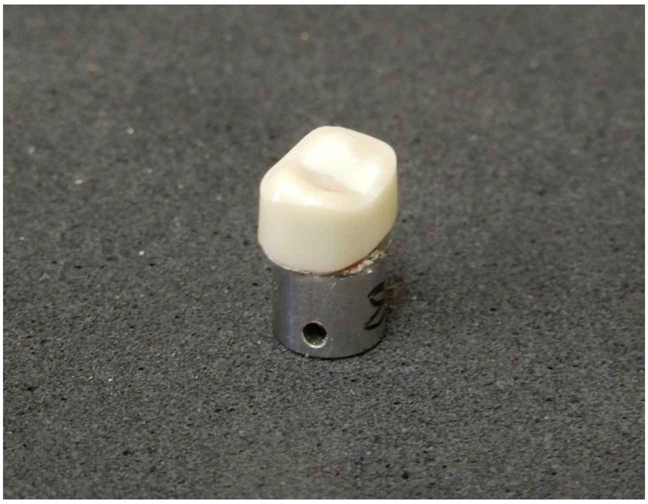


Fig. 1: Primary crowns were embedded in steel molds in a vertically oriented insertion direction.

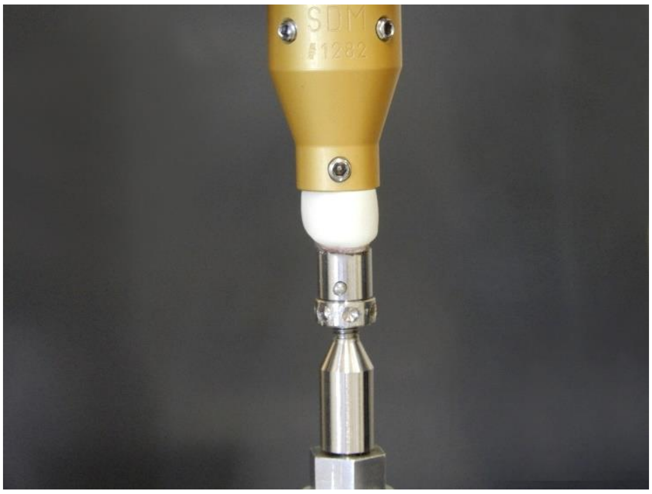


Fig. 2: All samples were tested using a universal testing device with a fitting force of 100 N.

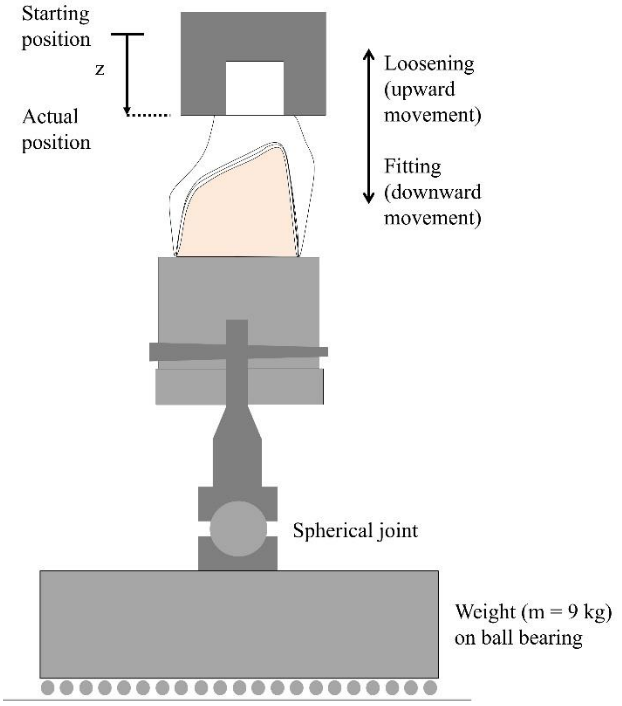


Fig. 3: Schematic of the test setup with the secondary telescopic crown attached to the cross-bar and the primary telescopic crown fixed on a weight such that horizontal forces were excluded.

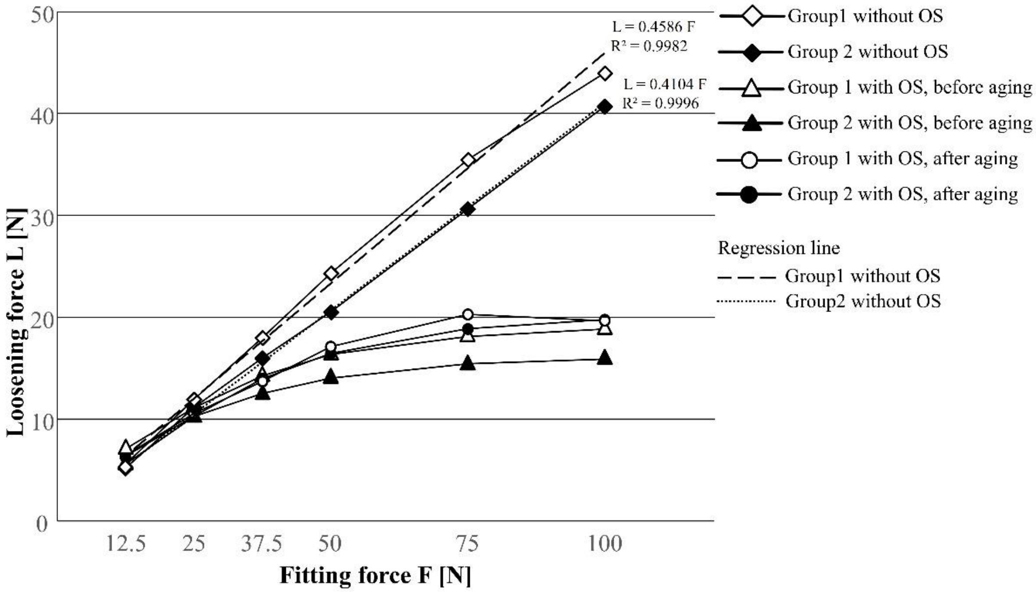


Fig. 4: Correlation between the fitting and loosening forces. OS: occlusal stop; Aging: insertion/removal test.

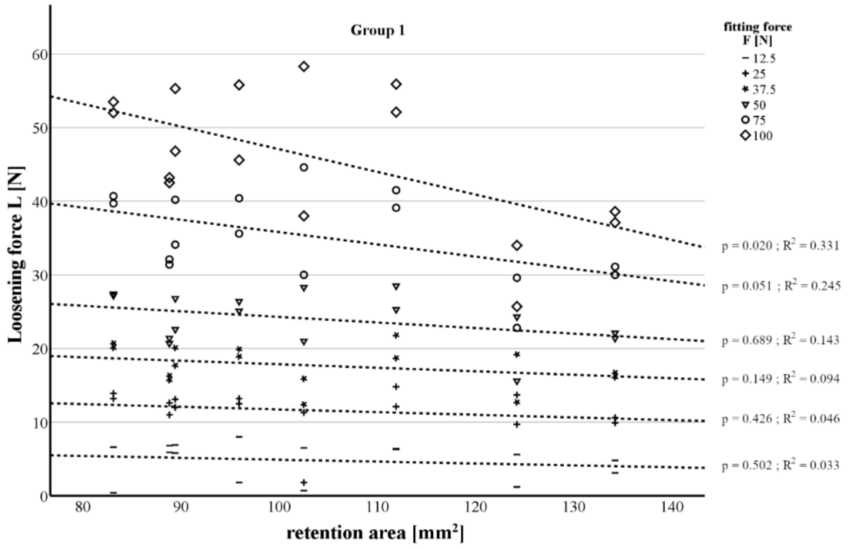


Fig. 5: Correlation between conical retention area of the primary crowns and loosening force of secondary crowns without OS at the different fitting force levels. Linear regression results (p and R2) are given separately for each fitting force magnitude.

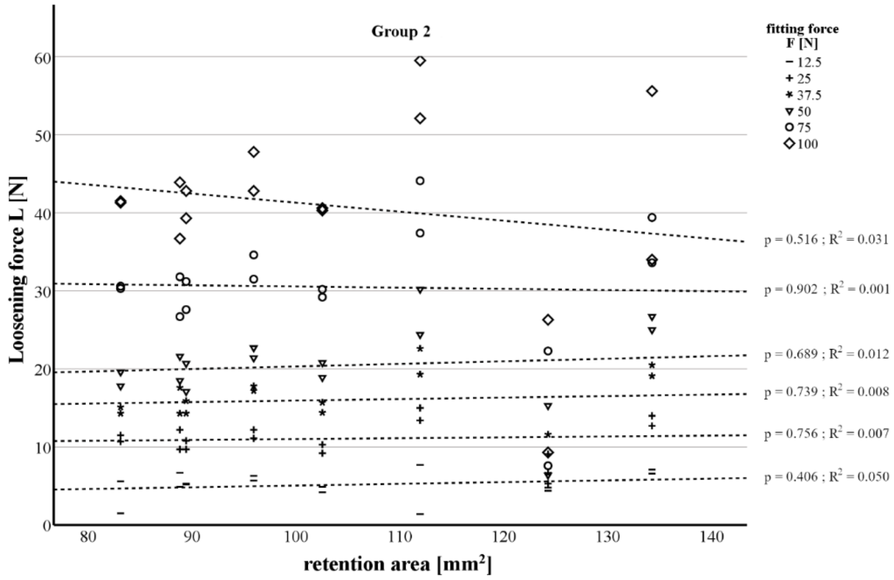


Fig. 6: Correlation between conical retention area of the primary crowns and loosening force of secondary crowns without OS at the different fitting force levels. Linear regression results (p and R^2) are given separately for each fitting force magnitude.

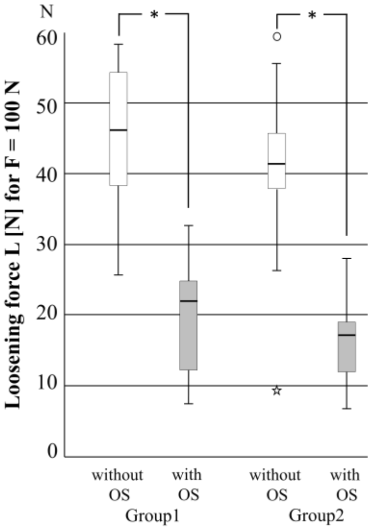


Fig. 7: Retentive force without and with an occlusal stop (OS). Asterisks show significant differences identified by the Wilcoxon test.

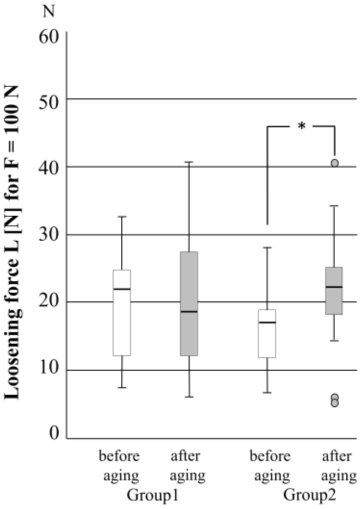


Fig. 8: Retentive force before and after aging (insertion/removal tests). Asterisks show significant differences identified by the Wilcoxon test.

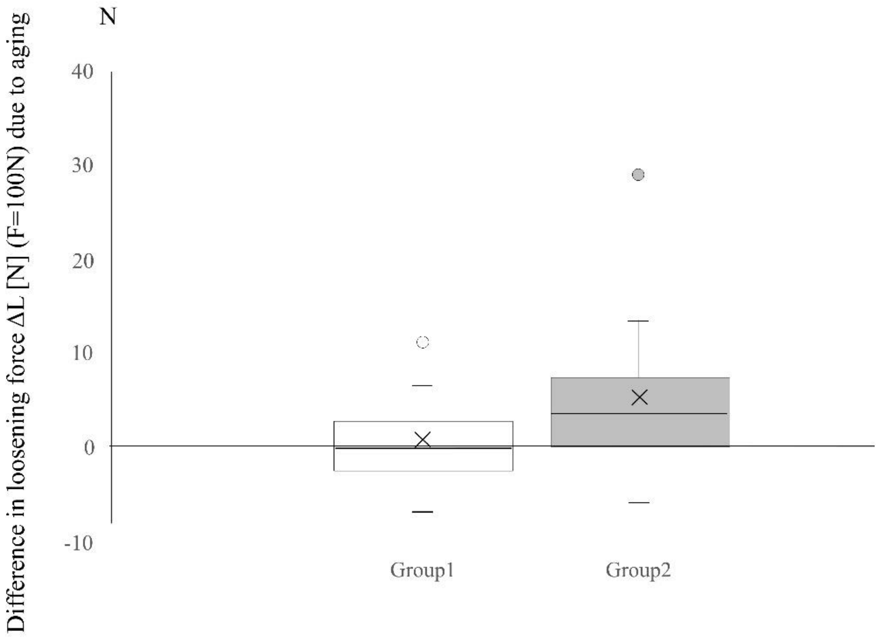


Fig. 9: Differential value of retentive forces after insertion/removal tests.

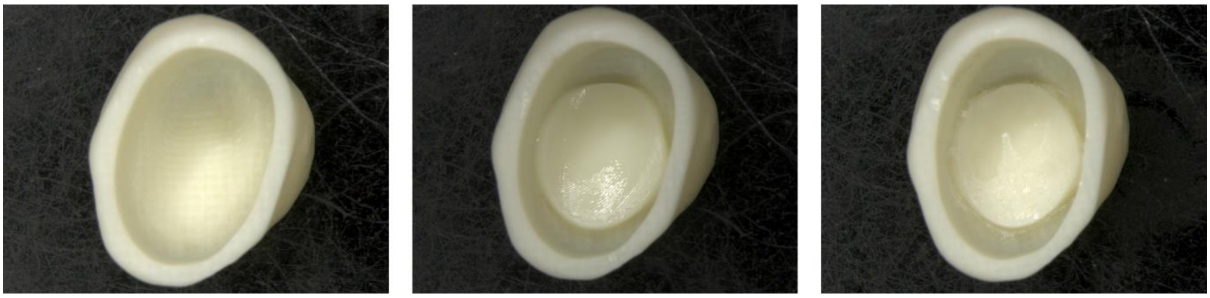
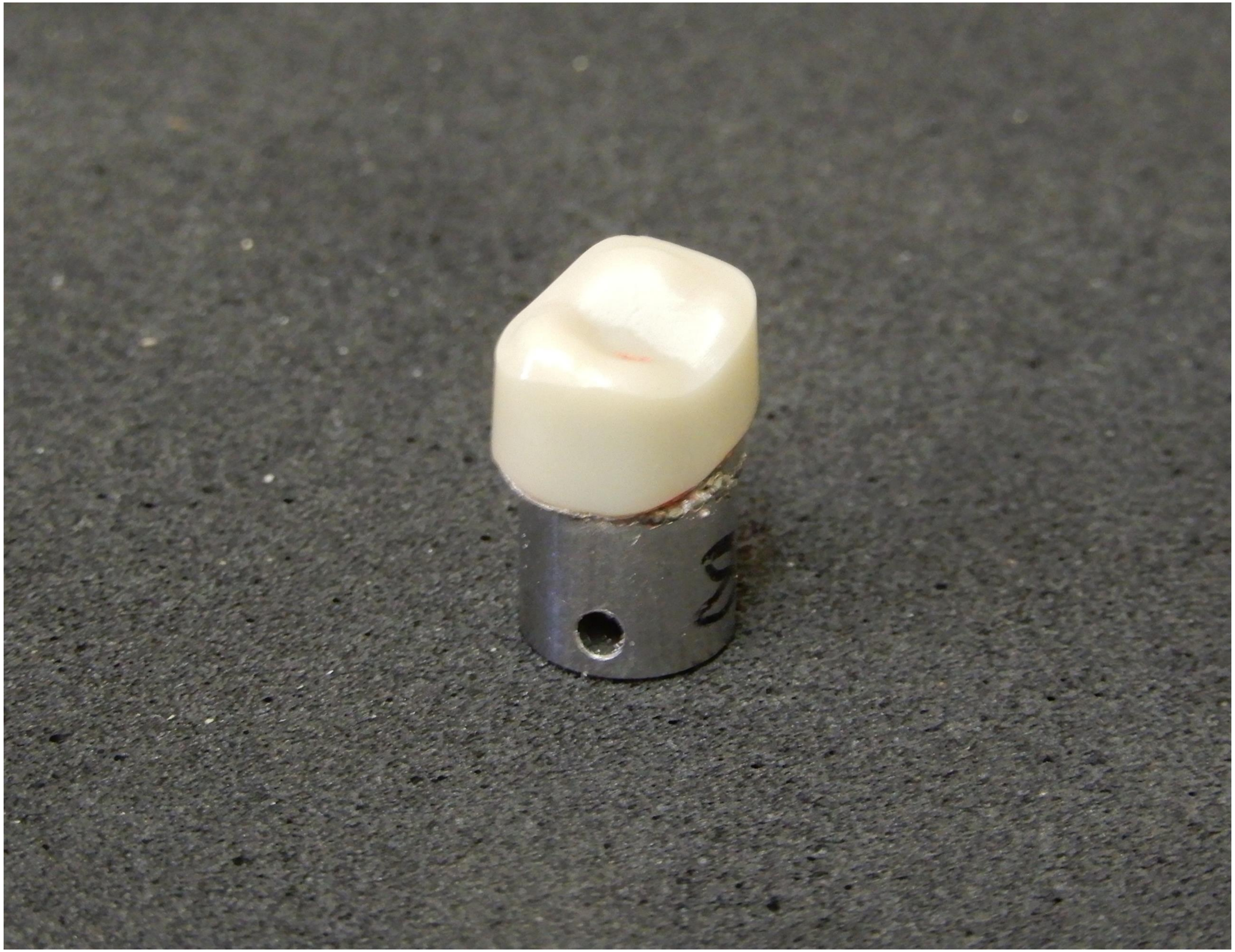


Fig. 10: Microscopic images of the secondary crown surface (12×). Left image: without an OS before the insertion/removal tests. Center image: with an OS before the insertion/removal tests. Right image: with an OS after the insertion/removal tests.



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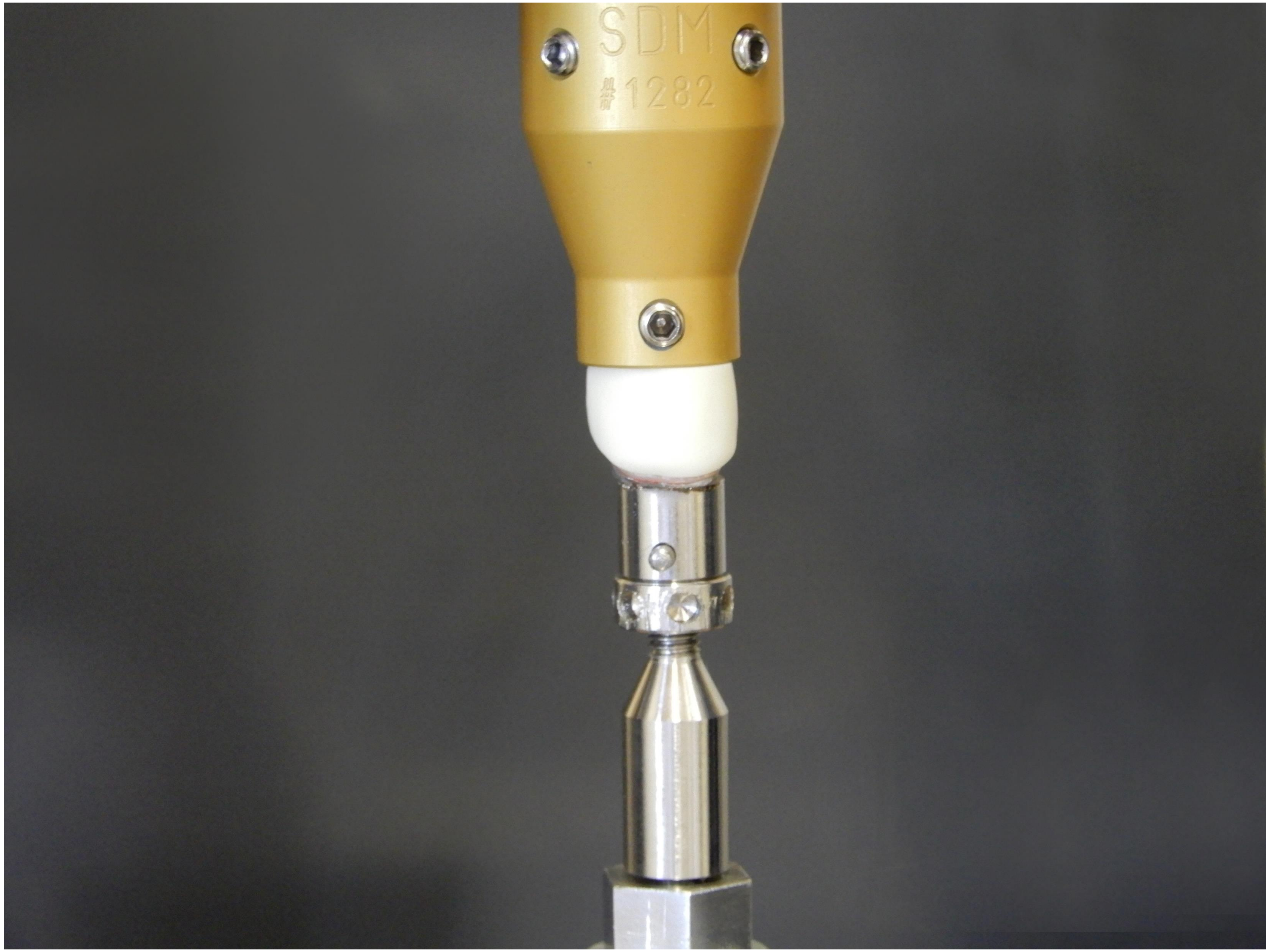

Fig. 2: All the samples were tested in a universal testing device with fitting forces of 100 N.

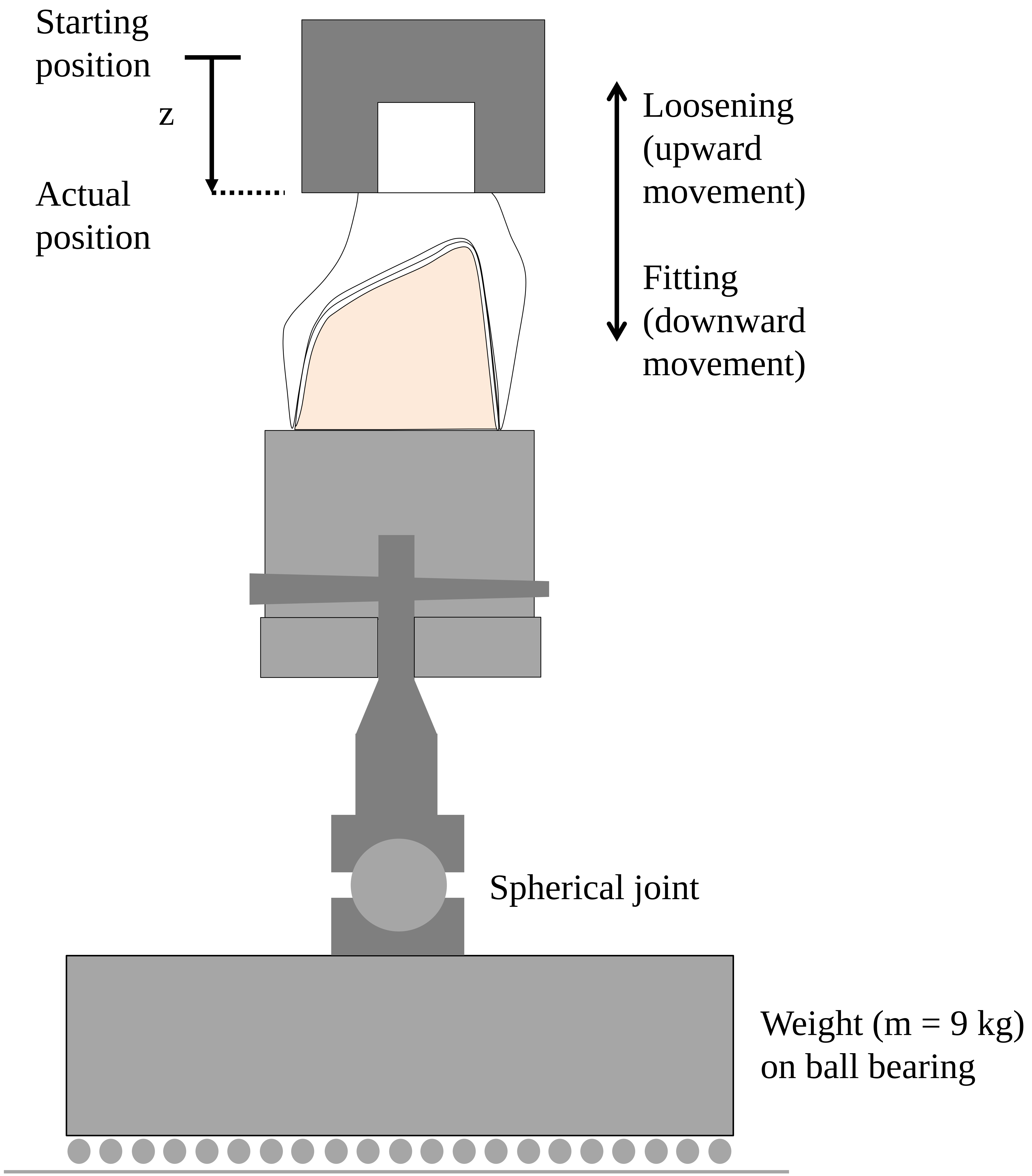

Fig. 3: Scheme of the test setup with the secondary crown attached to the cross-bar and the primary crown fixed on a weight such that horizontal forces were excluded.

Fig. 4 : Correlation between fitting force and loosening force.
OS: occlusal stop aging: insertion/removal test

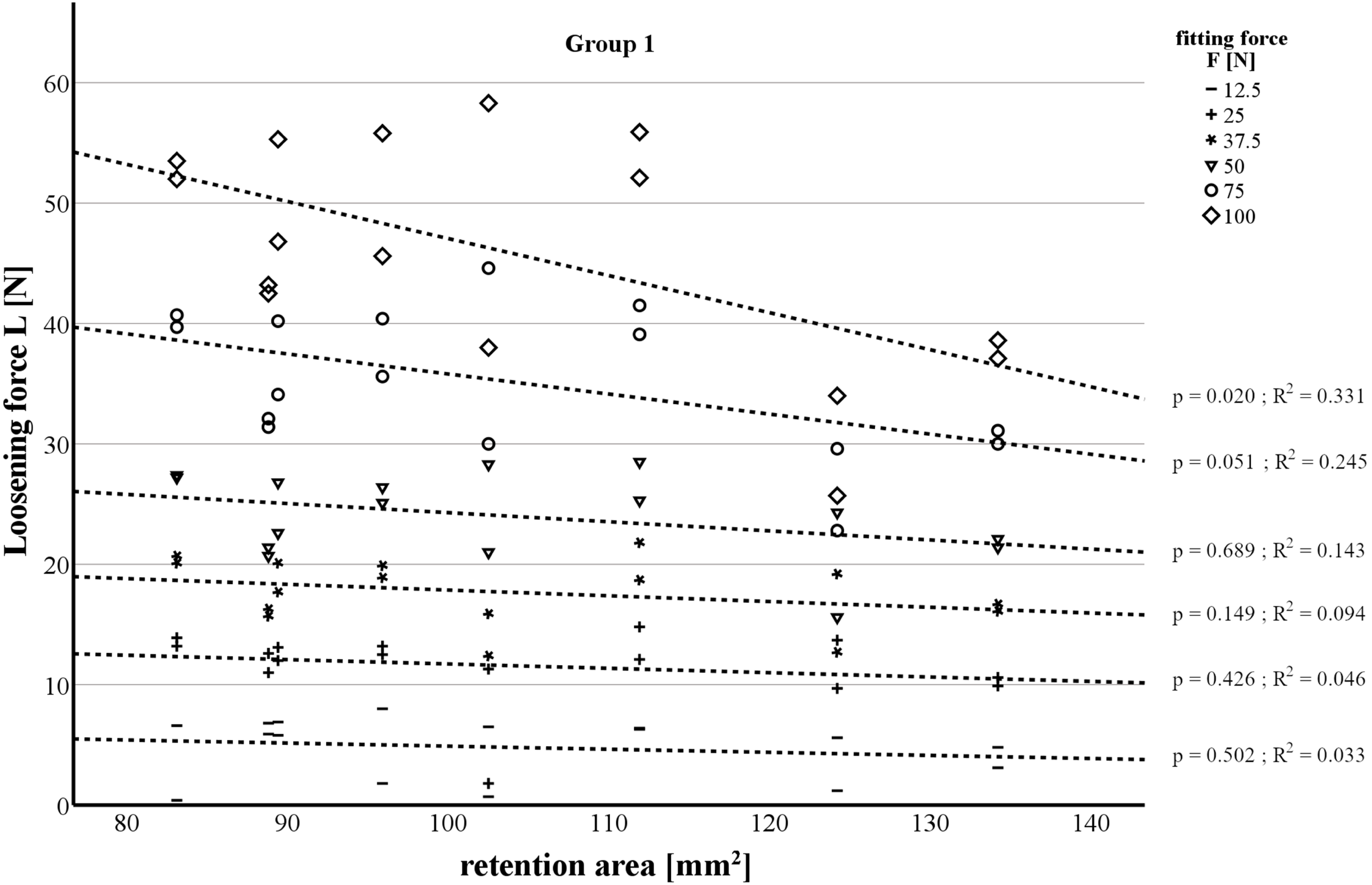

Fig. 5: Correlation between conical retention area of the primary crowns and loosening force of secondary crowns without OS at the different fitting force levels. Linear regression results (p and R2) are given separately for each fitting force magnitude.

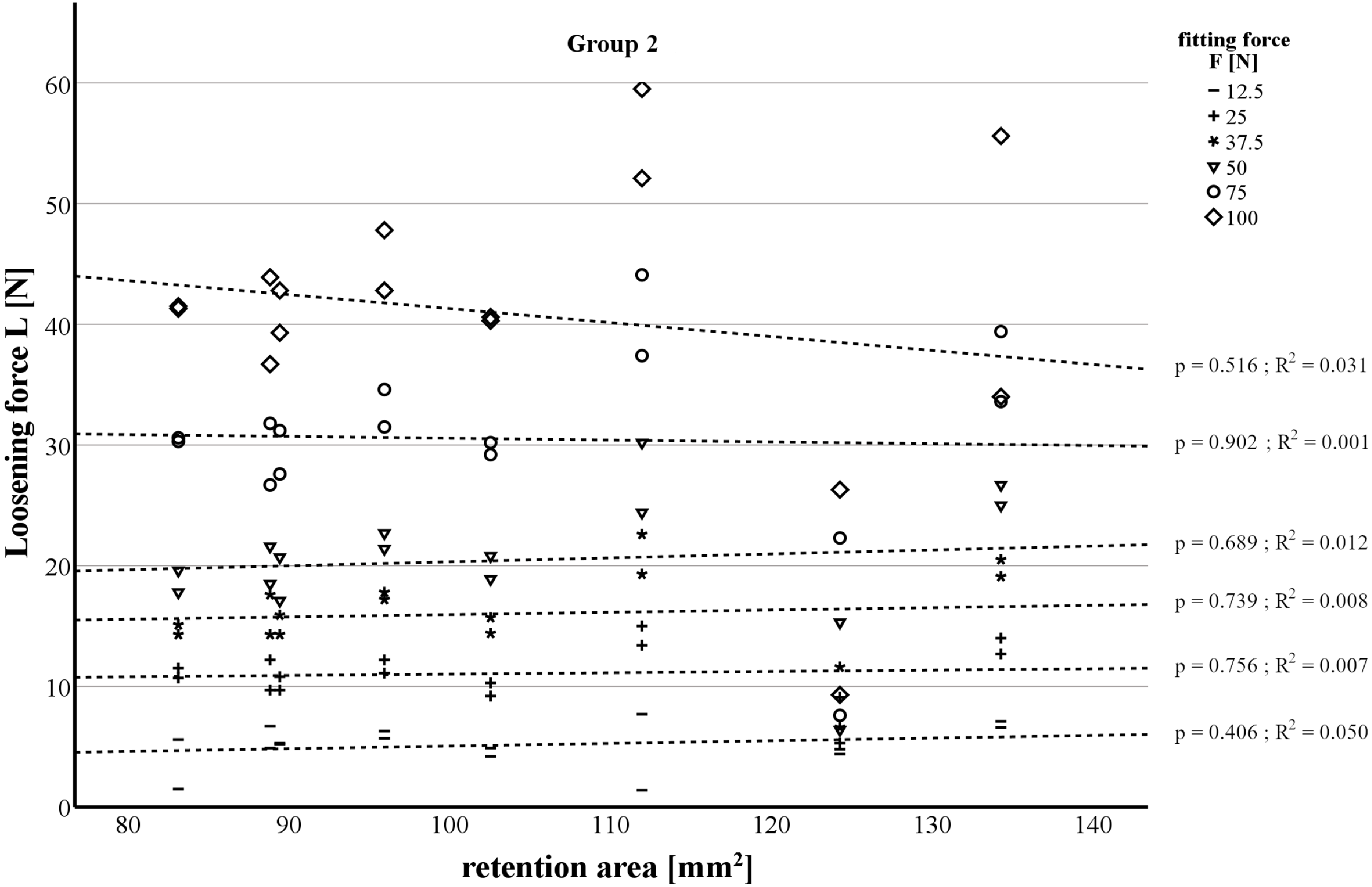

Fig. 6: Correlation between conical retention area of the primary crowns and loosening force of secondary crowns without OS at the different fitting force levels. Linear regression results (p and R2) are given separately for each fitting force magnitude.

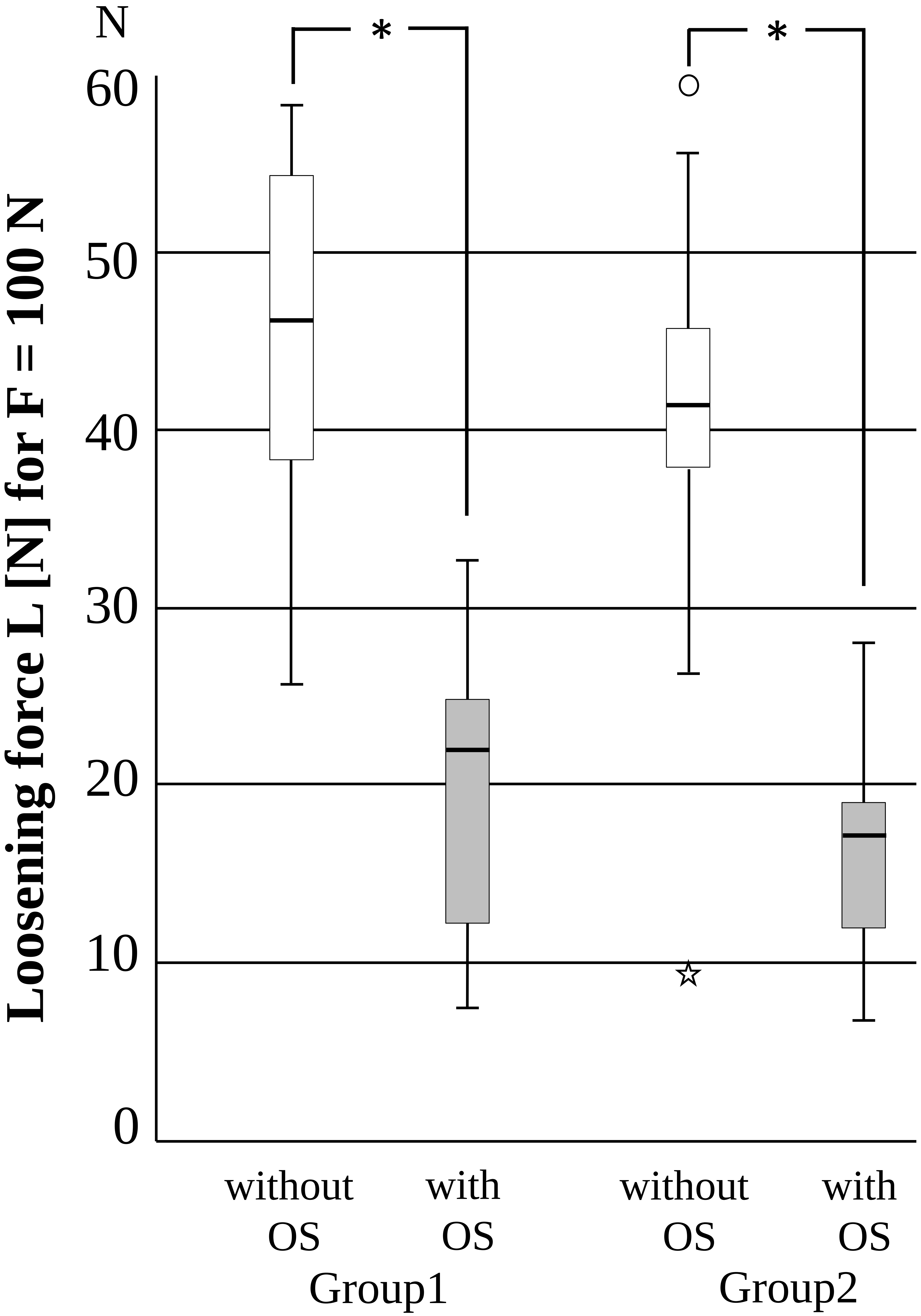

Fig. 7 : Retentive force without and with an occlusal stop (OS).
Asterixes show significant differences identified with Wilcoxon tests.

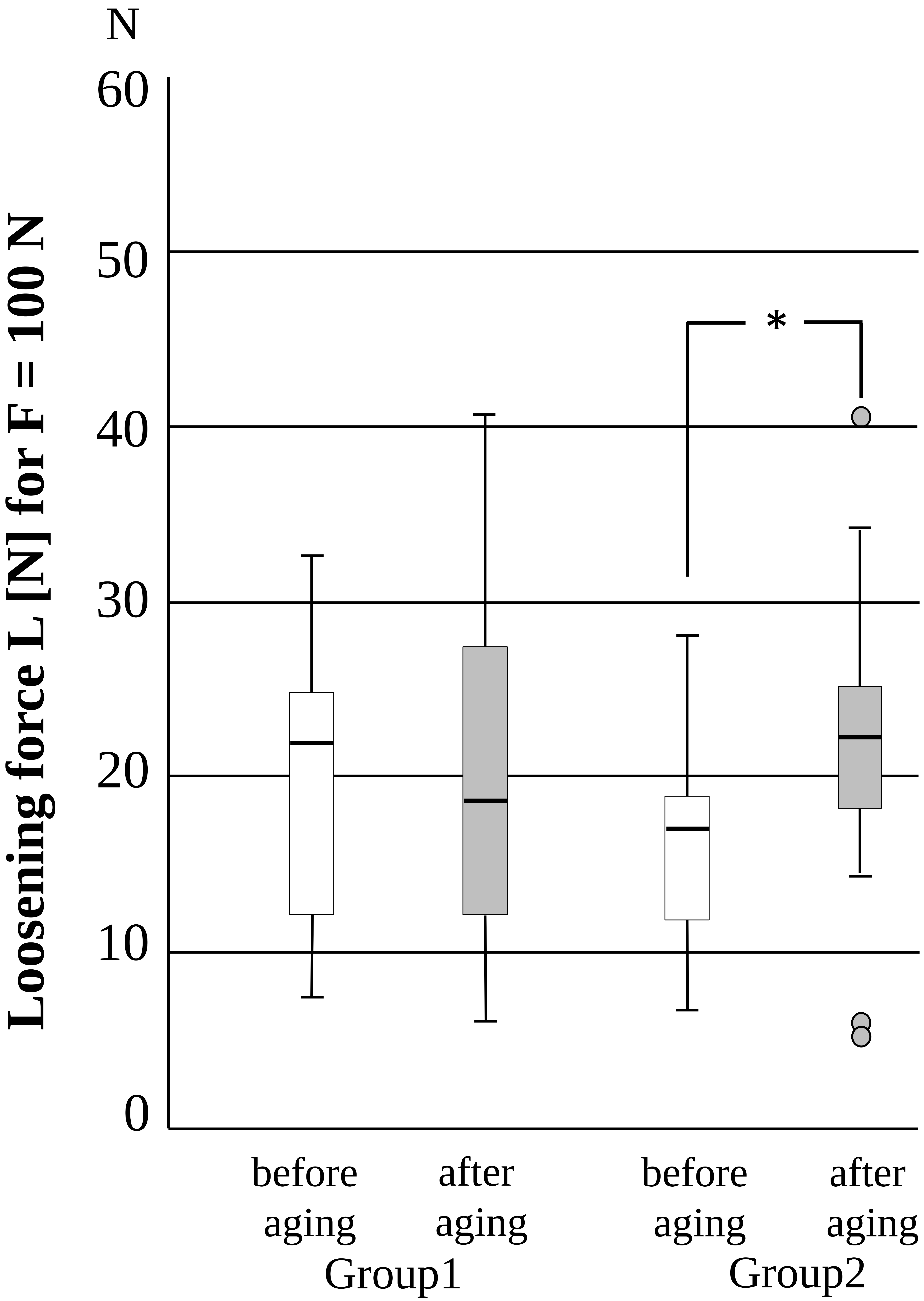

Fig. 8 : Retentive force before and after aging (insertion/removal test). Asterixes show significant differences identified with Wilcoxon tests.

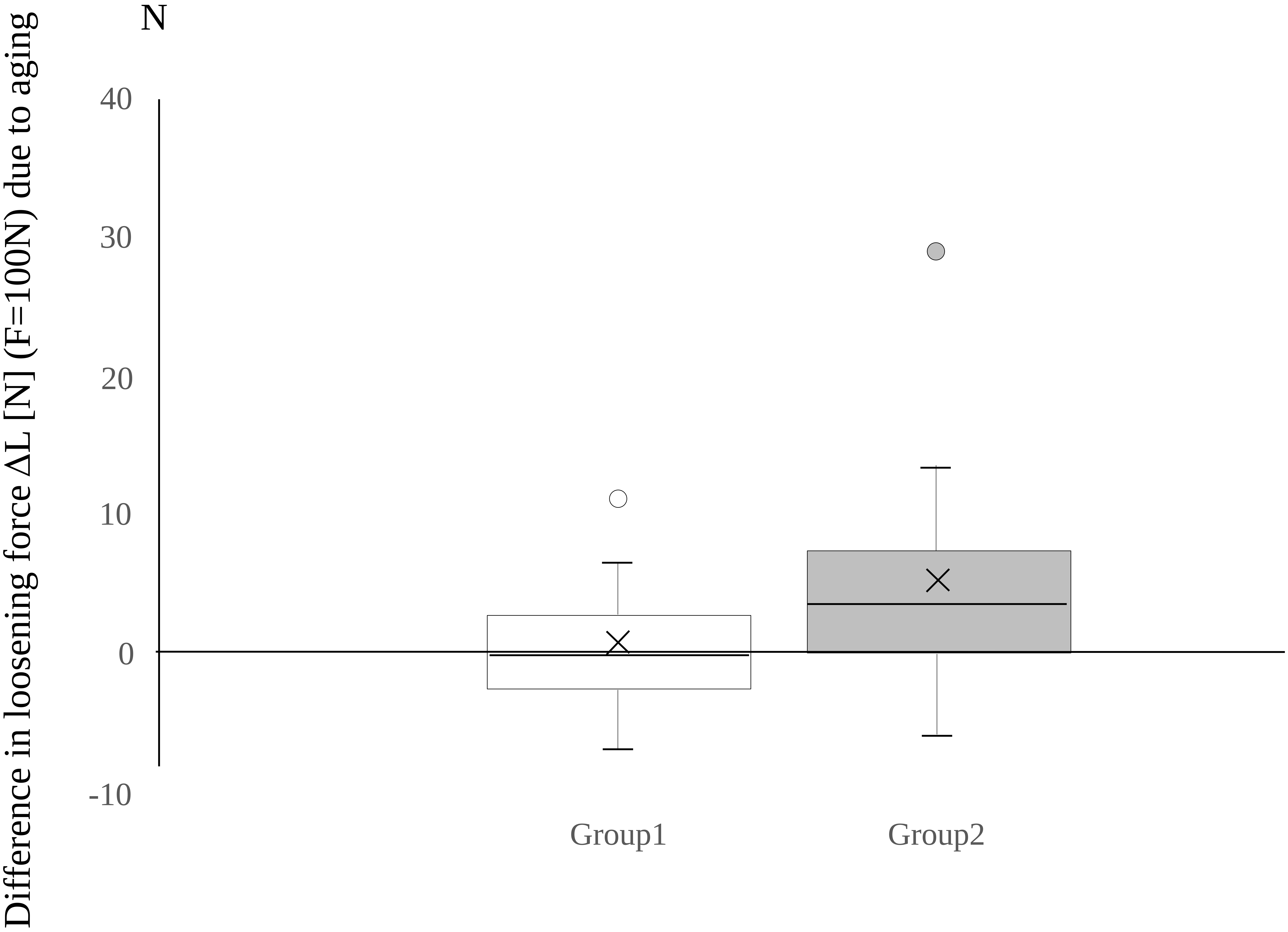

Fig. 9: Differential values of retentive force after insertion/removal test.

Fig. 10: Microscopic images of the inner secondary crown surface (12×）.

Left image: without OS before insertion/removal test
Center image: with OS before insertion/removal test
Right image: with OS after insertion/removal test

Primary crown on tooth	Conical retention area [mm^2]
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