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Original article

Fitness and retentive force of cobalt-chromium alloy clasps fabricated with repeated laser sintering and milling

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ABSTRACT

Purpose: With computer-aided design and computer-aided manufacturing (CAD/CAM), the study was conducted to create a removable partial denture (RPD) framework using repeated laser sintering rather than millingand casting techniques. This study experimentally evaluated the CAM claspand compared it to a conventional cast clasp.
Methods: After the tooth die was scanned, an Akers clasp was designed using CAD with and without 50 μm of digital reliefon the occlusal surface of the tooth die. Cobalt-chromium (Co-Cr) alloy clasps were fabricated using repeated laser sintering (RLS) and milling as one process simultaneously (hybrid manufacturing; HM). The surface roughness of the rest region, gap distances between clasp and tooth die, initial retentive forces, and changes of retentive forces up to 10,000 insertion/removal cycles were measured before and after heat treatment. The HM clasp was compared to the cast clasp and the clasp made by repeated laser sintering only without a milling process.
Results: The HM clasp surface was smoother than those of cast and RLS clasps. With the digital relief, the fitness accuracy of the HM clasp improved. The retentive forces of the HM clasps with relief and after heat treatment were significantly greater than for the cast clasp. HM clasps demonstrated a constant or slight decrease of retention up to 10,000 cycles.
Conclusions: HM clasp exhibited better fitness accuracy and retentive forces. The possibility of clinically using HM clasps as well as conventional cast clasps can be suggested.

1. Introduction

With computer-aided design and computer-aided manufacturing (CAD/CAM), the study was conducted to use repeated laser sintering rather than milling a framework from an alloy disk or milling patterns and then casting to fabricate removable partial denture (RPD) frameworks [1–9]. The advantages of repeated laser sintering as compared to milling and casting techniques are as follows: (1) near net shape forming can be achieved, (2) chips do not occur while cutting, (3) irregular shapes—clasps, connectors, and undercut areas—can be formed, (4) worn cutting tools cannot cause imprecision, (5) many frameworks can be simultaneously fabricated, (6) all processes are completely automatic, and (7) the cost is low [10,11].

In 2008, Tiossi et al. [12] examined the mechanical properties of laser-sintered as compared to conventionally cast cobalt-chromium (Co-Cr) and titanium alloys [12]. The laser-sintered Co-Cr and titanium alloys demonstrated higher tensile strengths and proof stresses than those of cast alloys, although there were no significant differences in the elongation and elastic modulus between them. These phenomena would be caused by laser-sintered alloys composed of fine structures using fine alloy powders. Almufleh et al. [13] reported on patient satisfaction with laser-sintered RPDs versus conventional cast RPDs using a crossover study [13]. Although it was short clinical observation, laser-sintered RPDs might lead to better patient satisfaction than conventional RPDs.

The limits and problems of conventional repeated laser sintering are surfaces that are too rough and, consequently, worsening fitness accuracy [14–16]. To make the surface smooth

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on the RPD framework, we have attempted a hybrid process, namely, repeated laser sintering and milling as one simultaneous process. In our previous study, the surface roughness, fitness accuracy, and retentive force of Co-Cr Akers clasps fabricated by hybrid processing were evaluated and compared to cast Co-Cr and commercial pure (CP) titanium alloys [17]. Remarkably smoother surfaces could be obtained by the hybrid processing than for cast clasps, and similar gap distances were observed at the clasp arm and clasp tip, except in the rest region. The initial retentive forces of the hybrid processed clasp were comparable to those of the cast clasp. In addition, the hybrid processed clasp showed little decrease of retentive forces with up to 10,000 insertion/removal cycles as compared to the cast clasp.

However, it has been unclear why the fitness accuracy on the rest region was worse than that of conventional cast clasps and the effect of heat treatment. There have not yet been reports about influences on the amount of relief during CAD and heat treatment on the fitness accuracy and retentive forces. The purpose of this study was to determine how to obtain better fitness on the rest region of the hybrid manufactured Akers clasps and changes of fitness and retentive forces after heat treatment. The fitness accuracy of the relieved clasp and the durability of the retention of the heat-treated clasps were measured *in vitro*.

2. Materials and methods

2.1. Fabrication of clasp specimens

A tooth die simulating the first molar (diameter: 10.0 mm; height: 8.0 mm; radius of curvature: 7.5 mm) was prepared with 18-8 stainless steel. Akers clasp assemblies consisted of the fully occlusal onlay rests, 5.0mm-wide clasp bodies, and the retentive clasp arms. Clasp arms 12 mm long were designed so that they engaged on the occlusal cone half as the upper arm and on the gingival cone, half as the lower arm, and clasp tips were placed at the 0.25 mm undercut regions (Fig. 1). Using the tooth die, 20 CAD/CAM Akers clasps were fabricated with cobalt-chromium (Co-Cr) alloy for this study.

The working cast was fabricated with hardened plaster (New Zo-Rock, Shimomura Gypsum, Asaka, Japan) after making an impression of the tooth die. The master cast was digitally scanned using a dental laboratory scanner (7Series, Dental Wings, Montreal, Canada). Using a CAD system (DWOS Partial Frameworks, Dental Wings), the Akers clasp was designed with and without 50 μm of digital relief on the occlusal surface of the tooth die. STL clasp data were sent to the one-process molding machine by simultaneous repeated laser sintering and high-speed milling, hereafter "hybrid manufacturing (HM)" (LUMEX Advance-25,

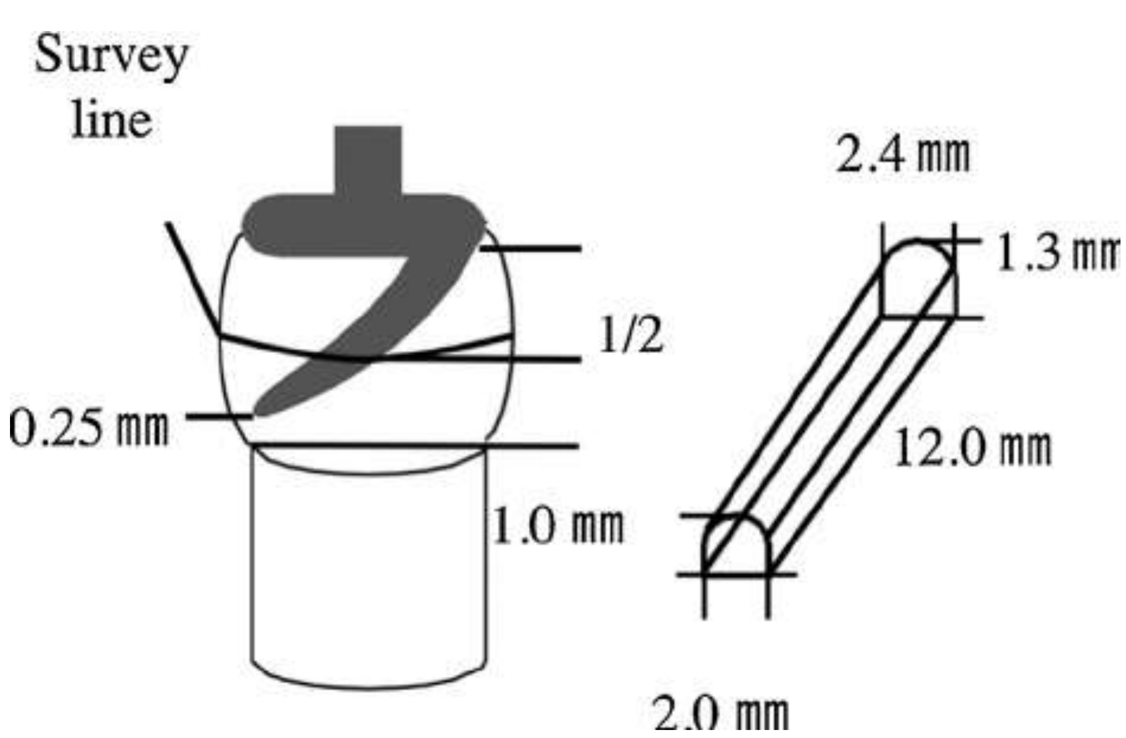

Fig. 1. Akers clasp assemblies on the tooth die and the size of the clasp arm.

Matsuura Machinery Corp., Fukui, Japan). CAM clasps were processed with approximately 50 μm of cobalt-chromium (Co-Cr) alloy powders (Matsuura Cobalt Chromium, Sandvik, Stockholm, Sweden). However, the outside surface of the clasp was not processed by milling because it had no relation to the fitness in this study. To evaluate the milling process in hybrid manufacturing, only repeated laser sintered (RLS) clasps were fabricated without milling. After manufacturing, the support structures were removed, and the clasps were blasting with airborne-particle abrasion under 0.5 MPa atmospheric pressure. The nodules and burs of the HM and RLS clasp specimens were carefully removed and not polished.

To investigate the influence of heat treatment, HM clasps were heated from room temperature to 450 °C for 45 min, and to 750 °C for 1 h in the one-chamber stress-relieving furnace under an argon gas atmosphere (NQPC-60/60/100(S6), IHI Corp., Tokyo, Japan). After being kept for 30 min, they were rapidly quenched.

2.2. Measurements of surface roughness

Using the non-contact three-dimensional surface roughness profilometer (NH-3N, Mitaka Kohki Corp., Tokyo, Japan), the surface roughness (Ra) of the internal surface of the onlay rest region of all clasp specimens was measured five times for each specimen. The measurement conditions included a cutoff of 0.8 λc, a measurement pitch of 5 μm, and a measurement distance of 2.0 mm.

2.3. Measurements of fitness accuracy

Before measuring the fitness accuracy, the internal surface of the RLS clasp was carefully adjusted by one dental technician with more than 20 years of experience, since the clasp could not be placed at the exact position on the tooth die because inner surface was too rough. According to previous studies, the fitness accuracy of Akers clasps was evaluated as the gap distance between the clasps and the stainless tooth die using the silicone film [17–21]. White high-viscosity silicone impression material (Fit Checker, GC Corp., Tokyo, Japan) was mixed and inserted between the clasp and the die under a retentive force (N) of 9.80 for three minutes. After the clasp was removed from the die, black silicone material (Bite Checker, GC Corp.) was mixed and injected inside the white silicone material of each clasp to back up white silicone films. After three minutes, the lumped white and black silicone materials were removed from the clasp. The lumps of silicone materials from each clasp were buccolingually sectioned at 0.5 mm from the end of the clasp tip, clasp shoulders, and rest regions using a razor blade. To determine the clasp fitness accuracy, the white silicone layer at each section was measured using a profile projector (V-16E, Nikon, Tokyo, Japan) at a magnification of ×50.

2.4. Measuring retentive forces

After all clasps were placed on the tooth die under a retentive force (N) of 9.8, they were mounted on the tensile test apparatus (EZ-S-2000N, Shimadzu, Kyoto, Japan), and the initial retentive forces were measured at a crosshead speed of 50 mm/min. The retentive force of each clasp was evaluated as the required load for the clasp was removed from the die. The initial retentive force was obtained from the average of the retentive force during the first 10 insertion/removal cycles.

The changes in retentive forces were measured by repeated insertion/removal motion (crosshead speed: 950 mm/min.) up to 10,000 cycles in distilled water at 37 °C, to simulate the placement and removal of RPDs, using an insertion/removal testing apparatus designed by the Tsurumi University School of Dental Medicine

(Fig. 2) [17–21]. The averages of the retentive forces during each cycle, namely, during the 1001–1010, 2001–2010, 3001–3010, 4001–4010, 5001–5010, 6001–6010, 7001–7010, 8001–8010, 9001–9010, and 10001–10010 cycles, were measured and calculated in the same manner as was the initial retentive force.

2.5. Statistical analysis

The fitness accuracy and retentive force data were analyzed with the EZR (Saitama Medical Center, Jichi Medical University, Saitama, Japan), which is a graphical user interface for R (The R Foundation for Statistical Computing, Vienna, Austria) using the Kruskal–Wallis test and Steel-Dwass multiple comparison test at a significance level of $\alpha = 0.05$. More precisely, it is a modified version of R commander designed to add statistical functions frequently used in biostatistics [22]. For changes of all of retentive force up to 10,000 cycles, Friedman test was performed at a significance level of $\alpha = 0.05$. All CAD/CAM clasp data were compared to the cast Co-Cr clasp (Cast) data from our previous study [17].

3. Results

3.1. Surface roughness

Fig. 3 shows the surface roughness (Ra) of all clasps examined in this study. Surfaces of the HM clasps were significantly the smoothest (0.6 μm) ($p < 0.05$), and surfaces of the RLS were significantly the roughest (4.9 μm) ($p < 0.05$). The surface roughnesses of the HM clasp with and without relief (0.6 μm and 0.5 μm) and before and after heat treatment (0.5 μm and 0.5 μm) ($p > 0.05$) were not significantly different.

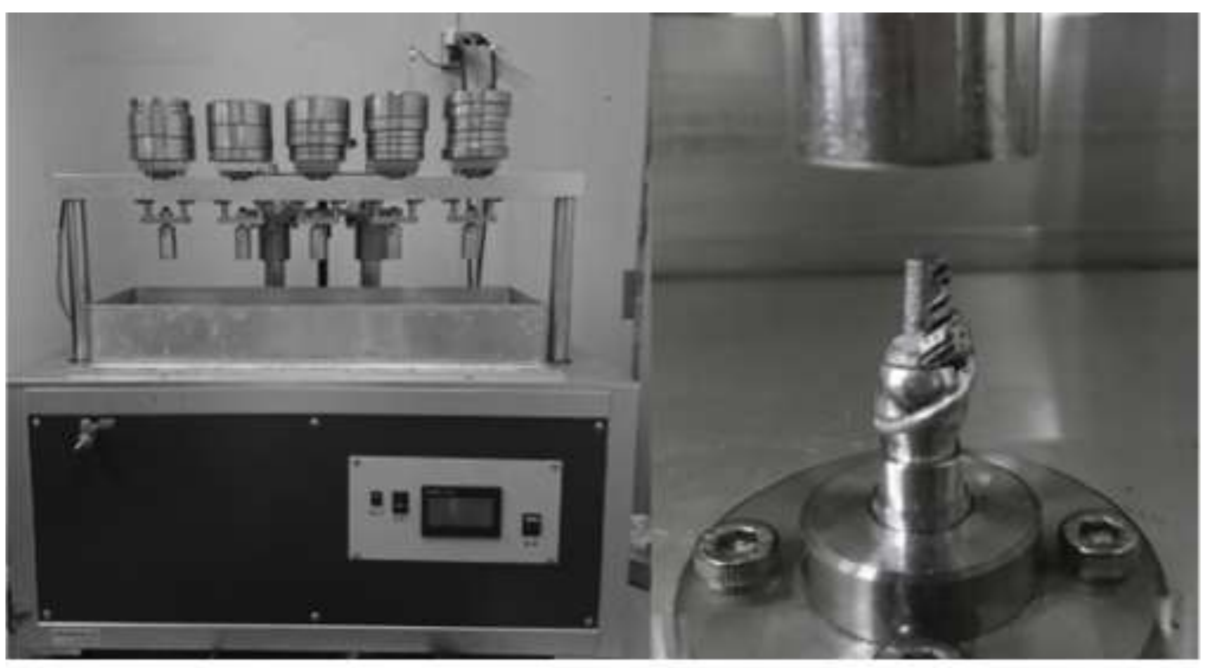

Fig. 2. Testing apparatus provided a repeated insertion/removal motion (crosshead speed: 950 mm/min) up to 10,000 cycles in distilled water at 37 °C, to simulate the placement and removal of RPDs.

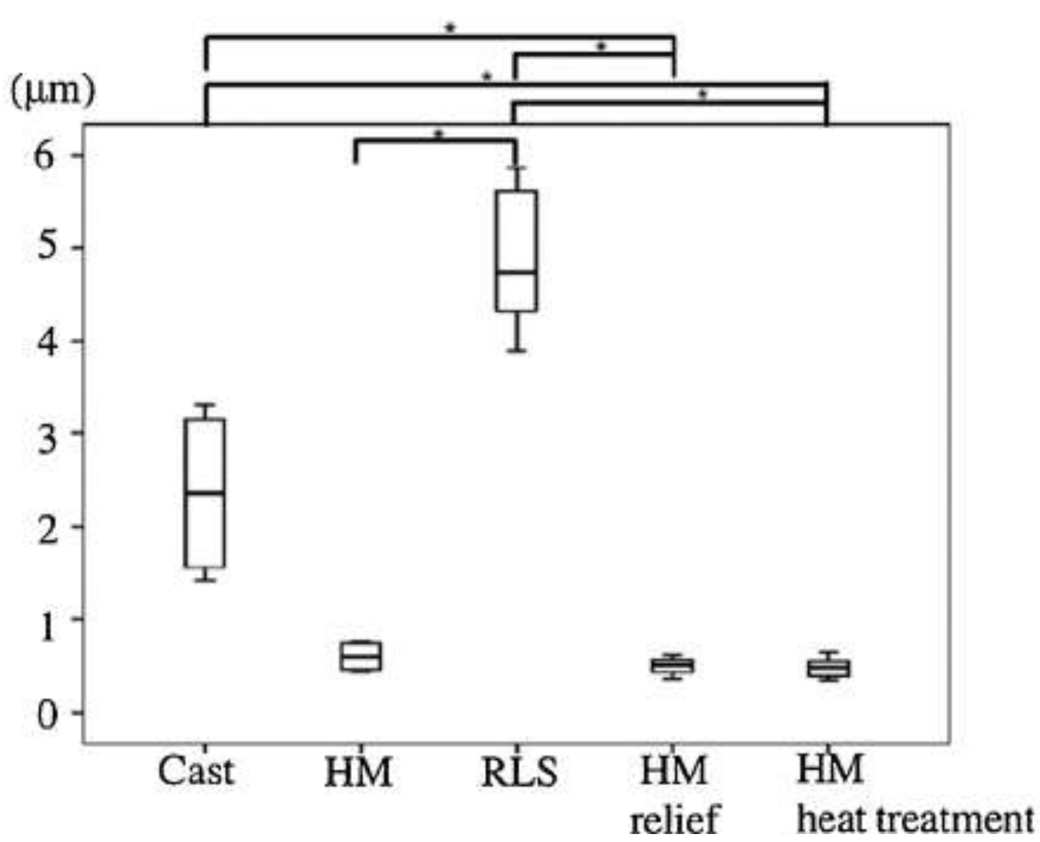

Fig. 3. Surface roughness (Ra) of the internal surface of the only rest region of all clasp specimen ($n = 5$, $p < 0.05$).

3.2. Fitness accuracy

The fitness accuracy at three regions of all clasp assemblies, namely, the rest, the clasp arm, and the clasp tip, are shown in Fig. 4a–c, respectively. Comparing the three regions, the rest tended to have a greater gap distance, as compared to the clasp arm and tip. Of the rest region, the HM clasp without relief exhibited a greater gap distance (162.0 ± 5.0 μm) than it did with relief (75.5 ± 1.6 μm) ($p > 0.05$), although the difference was not significant ($p > 0.05$). Similarly, no significant differences were observed in the gap distances of the HM clasp before and after heat treatment (75.5 ± 1.6 μm, 73.9 ± 1.6 μm) ($p > 0.05$). There were no significant differences in the clasp arm and tip regions among all clasps tested in this study ($p > 0.05$).

3.3. Initial retentive force

Fig. 5 shows the initial retentive forces of all clasps. The initial retentive forces of the HM clasp with relief (16.1 ± 0.8 N) were significantly higher than those of the cast clasp (12.9 ± 3.5 N) and HM clasps without relief (12.3 ± 2.6 N) ($p < 0.05$). The HM clasp after heat treatment (21.5 ± 5.3 N) also demonstrated similar initial retentive forces as compared to before heat treatment (16.1 ± 0.8 N) ($p > 0.05$).

3.4. Changes of retentive forces

The changes of retentive forces up to 10,000 cycles in all clasps are exhibited in Fig. 6. Although the cast and RLS clasps showed a remarkable decrease of retentive forces from initial to 2000 insertion/removal cycles ($p < 0.05$), the HM clasp showed a constant or slight decrease up to 2000 cycles ($p > 0.05$). The final retentive forces and decrease ratios in all clasps after 10,000 insertion/removal cycles are, respectively, as follows: cast clasp, 7.6 N and 41.1 %; HM clasp without relief, 8.9 N and 27.6 %; RLS, 11.2 N and 30.5 %; HM clasp with relief, 13.76 N and 14.3 %; and HM clasp after heat treatment, 14.9 N and 30.8 %. The HM clasp with relief showed a significantly lower decrease ratio than did other clasps ($p < 0.05$).

4. Discussion

In advanced dental laboratories worldwide, RPD frameworks have been digitally manufactured by repeated laser sintering rather than by conventional lost-wax and casting techniques [23–25]. One limitation of laser-sintered frameworks was the rough surface [14–16]. While Nakata et al. [17] could obtain a clasp with a smooth surface using hybrid manufacturing, there have been few reports regarding hybrid manufactured clasps. In this study, the influence of relief designs and heat treatment for hybrid manufactured clasps on the fitness accuracy and clasp retention has been clarified.

The HM clasp exhibited a smoother surface as compared to the cast clasp and the RLS clasp. Since the hybrid manufacturing in this study was performed by laminated sintering with 50 μm of Co-Cr particles and layered surfaces were milled after the lamination layer has reached 500 μm, a surface similar to a conventional milling surface could be obtained. Thus, the selection of the diameter of the bar used in hybrid manufacturing is very important

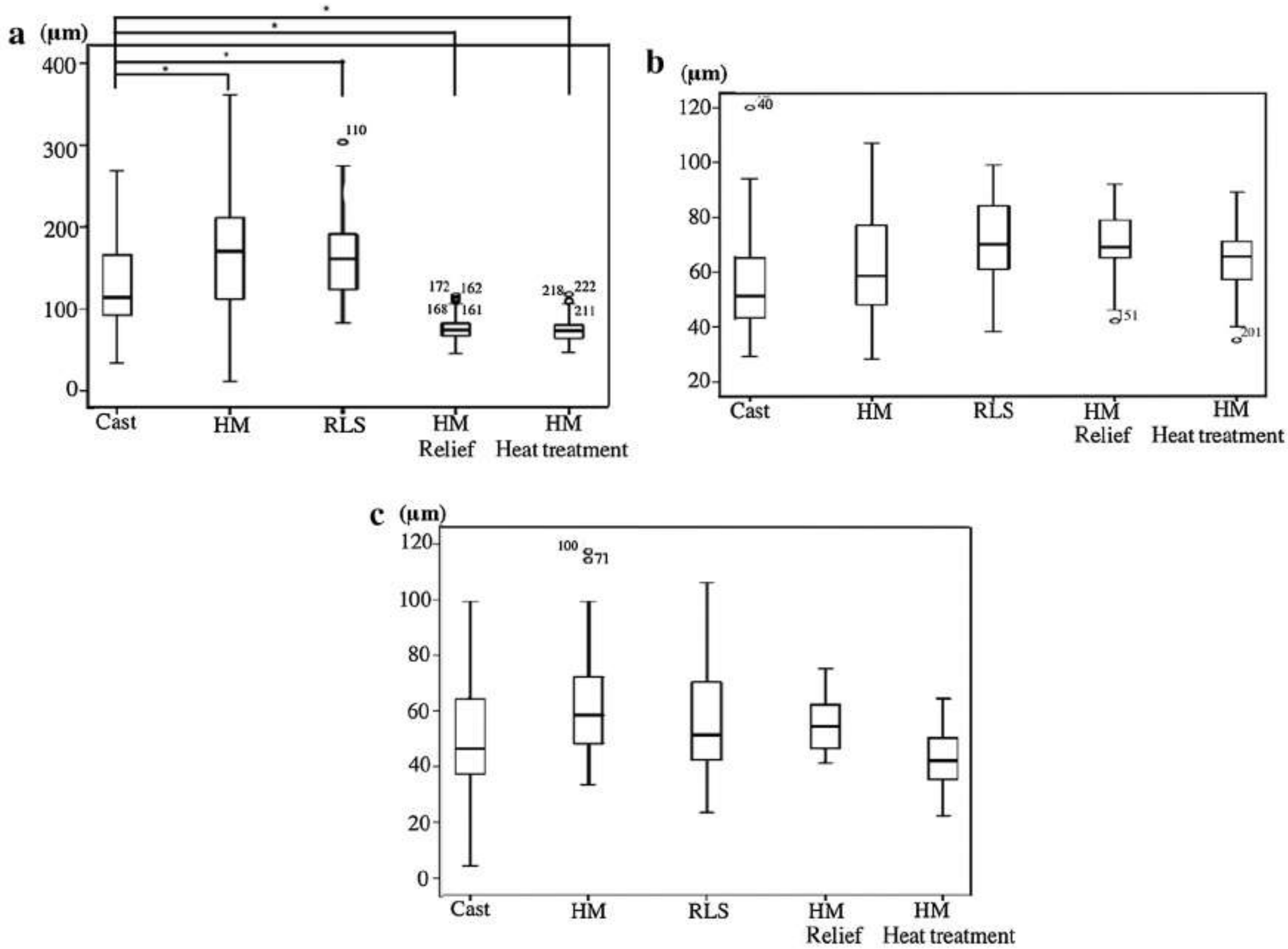

Fig. 4. (a) Fitness accuracy of each clasp, rest region ($n = 5$, $p < 0.05$). (b) Fitness accuracy of each clasp, clasp arm ($n = 5$, $p < 0.05$). (c) Fitness accuracy of each clasp, clasp tip ($n = 5$, $p < 0.05$).

for its surface roughness. In this study, heat treatment did not affect the surface roughness.

In our previous study [17], the gap distance of the rest regions in the HM clasp without relief was slightly worse than that of the cast clasp. This is because the corner could not be precisely cut by using the conventional milling bar due to the acute angle in the shifting corner of the rest and clasp body. For these cases, the area of the acute angle should be relieved in advance by CAD. In this study, 50 μm relief on the corner brought higher fitness accuracy as compared to that of the cast clasp and the HM clasp without relief. For clasp designs with digital relief, considering the diameter of the bar is necessary at the area of such an acute angle. In clinical practice, average gap distances between abutment teeth and Akers clasps with precious metals were reported to be from 37 to 250 μm [8,26,27]. In the present study, non-precious metals were used; HM clasps with relief and heat treatment showed rest, clasp arm, and tip gap distances of 73.9 μm, 74.3 μm, and 42.3 μm, respectively. Therefore, the HM clasp could be acceptable for clinical use.

The HM clasp after heat treatment showed the greatest retentive forces among all clasps tested, so heat treatment affected the retentive forces. The slight deformation and increase of the

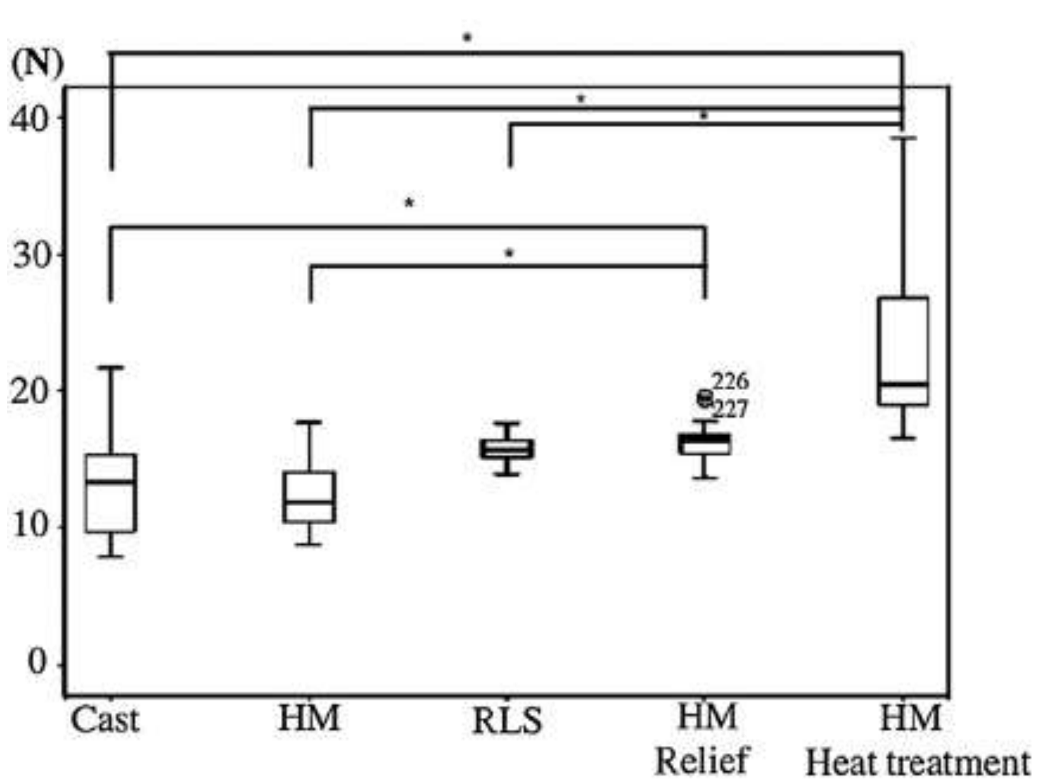

Fig. 5. Initial retentive force obtained from the average of the retentive forces during the first 10 insertion/removal ($n = 5$, $p < 0.05$).

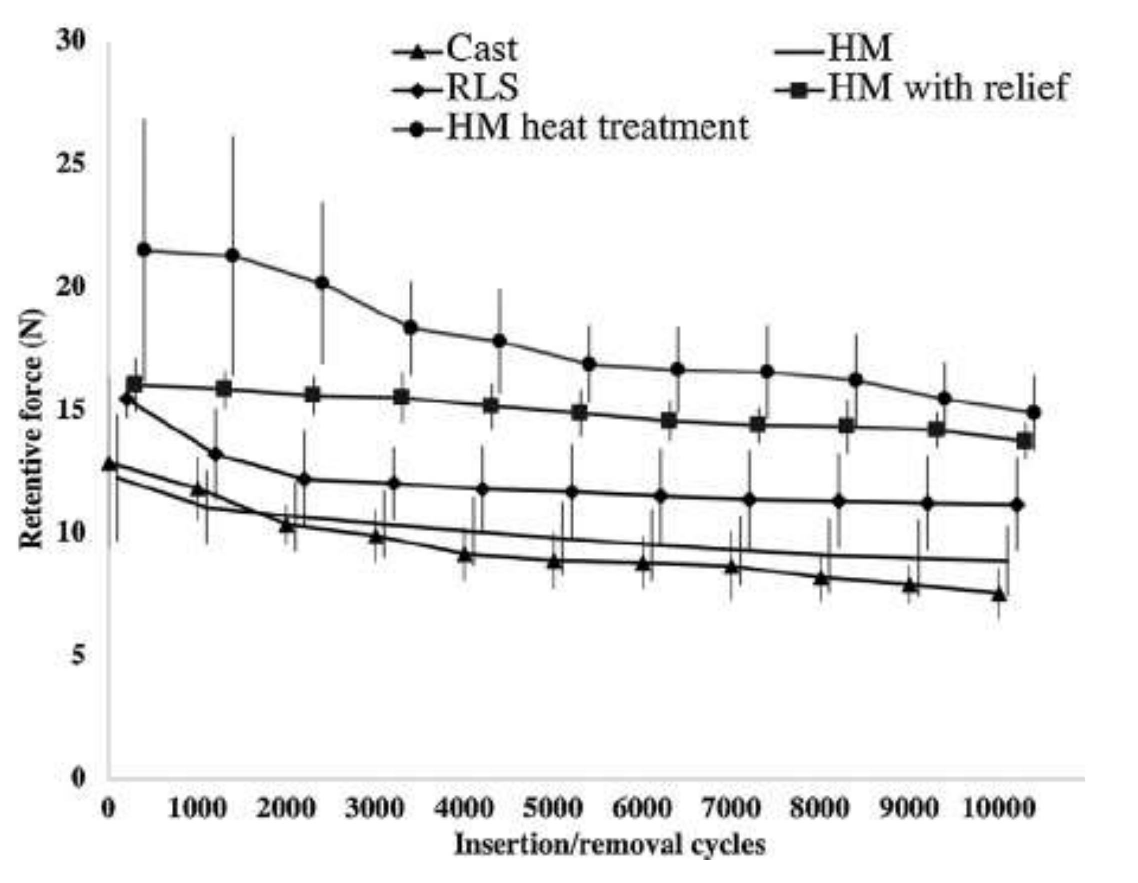

Fig. 6. Changes in retentive force up to 10,000 cycles to simulate the placement and removal of RPDs.

elastic modulus after heat treatment would affect the increase of retentive forces [28–31]. Except after heat treatment, the HM clasp demonstrated a smaller standard deviation of retentive force than did the cast clasp. Constant dimensional accuracy can be provided by CAM, something that cannot be accomplished by casting procedures. Approximately 2000 g may be necessary for RPD retention to protect against removal while chewing sticky foods; thus, retentive forces from 5 N to 10 N would be necessary in one clasp [20,32–34]. In this study, all clasps had sufficient retentive force—ranging from 5 N to 20 N.

No clasps failed with up to 10,000 insertion/removal cycles; however, the retentive forces of all clasps decreased slightly as the number of repeated insertion/removal cycles increased. However, the decrease ratios of digitally manufactured clasps were smaller than for cast clasps. Thus, they must be clinically acceptable from the viewpoint of clasp retention. Especially, the HM clasp before heat treatment indicated the lowest decrease ratio among all clasps; the permanent deformation and wear on the inside surface of the clasp arm would also be the smallest. These findings about the HM clasp suggest its possible suitability for clinical use. However, further studies regarding aeolotropic laminates and fatigue strengths of the HM clasp are necessary before clinical use.

5. Conclusion

CAM clasps with and without relief on the occlusal surface of the tooth die fabricated using repeated laser sintering and high-speed milling in one simultaneous process were experimentally evaluated and compared to conventional cast clasps. The surface roughness, fitness accuracy, and retentive forces were measured before and after heat treatment. Within the limitations of this study, the following conclusions were reached:

1. The surface of the HM clasp was smoother than those of cast and RLS clasps.
2. Digital relief on the acute corner sifting rest and clasp body lowered the gap distances on the rest regions of the HM clasp. Similar gap distances were observed at the clasp arm and tip in all clasps.
3. The retentive forces of the HM clasps with relief and after heat treatment were significantly greater than that of the cast clasp.
4. Whereas the retentive forces of cast clasps were remarkably decreased, HM clasps demonstrated a constant or slight decrease with up to 10,000 cycles.

These results suggest that the hybrid manufactured clasp can be used as well as the cast clasp.

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