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JPOR 452 No. of Pages 6

ARTICLE IN PRESS

journal of prosthodontic research xxx (2018) xxx–xxx

Contents lists available at ScienceDirect

Journal of Prosthodontic Research

journal homepage: www.elsevier.com/locate/jpor

Original article

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

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ARTICLE INFO

Article history:
Received 18 December 2017
Received in revised form 28 December 2017
Accepted 3 January 2018
Available online xxx

Keywords:
CAD/CAM
Clasp
Relief
Retentive force
Heat treatment

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 milling and casting techniques. This study experimentally evaluated the CAM clasp and 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 relief on 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.
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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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https://doi.org/10.1016/j.jpor.2018.01.001
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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, 5.0 mm-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, 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.

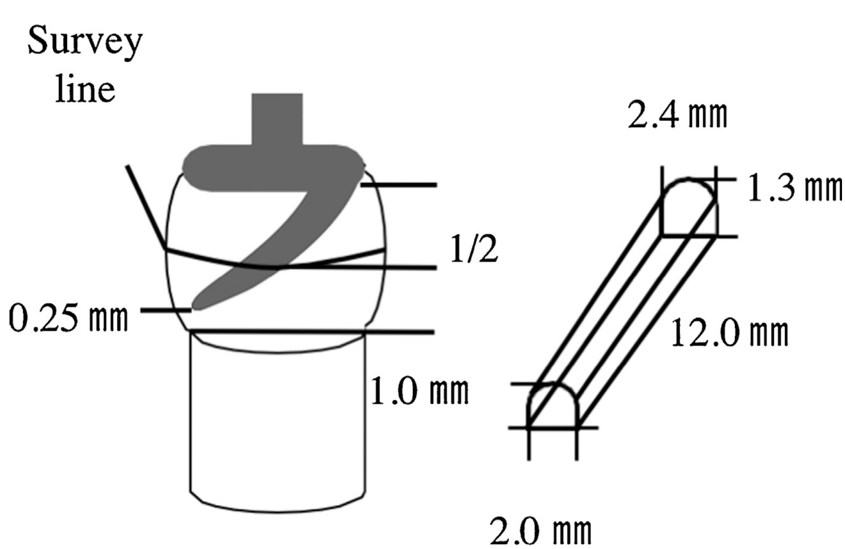

Fig. 1. Akers clasp assemblies on the tooth die and the size of the clasp arm.

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