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Original article

Comparison and evaluation of marginal and internal gaps in cobalt–chromium alloy copings fabricated using subtractive and additive manufacturing

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ABSTRACT

Purpose: To evaluate the marginal and internal gaps of cobalt–chromium (Co–Cr) alloy copings fabricated using subtractive and additive manufacturing.
Methods: A study model of an abutment tooth 46 was prepared by a 2-step silicone impression with dental stone. Fifteen stereolithography files for Co–Cr alloy copings were compiled using a model scanner and dental CAD software. Using the lost wax (LW), wax block (WB), soft metal block (SMB), microstereolithography (μ-SLA), and selected laser melting (SLM) techniques, 15 Co–Cr alloy copings were fabricated per group. The marginal and internal gaps of these Co–Cr alloy copings were measured using a digital microscope (160×), and the data obtained were analyzed using the non-parametric Kruskal–Wallis H-test and post-hoc Mann–Whitney *U*-test with Bonferroni correction.
Results: The mean values of the marginal, axial wall, and occlusal gaps were 91.8, 83.4, and 163 μm in the LW group; 94.2, 77.5, and 122 μm in the WB group; 60.0, 79.4, and 90.8 μm in the SMB group; 154, 72.4, and 258 μm in the μ-SLA group; and 239, 73.6, and 384 μm in the SLM group, respectively. The differences in the marginal and occlusal gaps between the 5 groups were statistically significant ($P < .05$).
Conclusions: The marginal gaps of the LW, WB, and SMB groups were within the clinically acceptable limit, but further improvements in the μ-SLA and SLM approaches may be required prior to clinical implementation.

1. Introduction

Fixed partial denture (FPD) restorations in dentistry are routinely manufactured using the lost wax technique, but recently computer-aided design (CAD)/computer aided manufacturing (CAM) methods have been used more often [1–4]. A typical fixed restoration, manufactured using a dental CAD/CAM system, undergoes a process of scanning, design, and CAM. Such dental CAM systems are divided into those using subtractive manufacturing (SM) and those using additive manufacturing (AM) methods [1–3]. Subtractive manufacturing uses an end-mill for milling solidified blocks, while additive manufacturing involves a layer-by-layer free-form fabrication using various materials. SM or AM methods used by CAD/CAM systems are frequently preferred to the lost wax technique for the manufacture of metal copings, which are the lower structures of porcelain-fused-to-metal (PFM) crowns—a type of fixed partial dental restoration [4].

One method for manufacturing metal copings by SM is to cut a wax block into a wax coping, through a process involving investing, burn-out, and casting. As these processes introduce errors, a direct method of cutting a hard metal block has also been developed. However, mechanical cutting of such hard metal leads to undue stress on the cutting equipment and end-mill. Therefore, soft metal blocks have been developed as a solution. Soft metal blocks place less stress on the equipment than hard metal blocks, and obviate the need for investing, burn-out, and casting, thereby minimizing the associated errors in restoration and manufacturing [5,6]. However, during SM from soft metal blocks, external forces and vibrations are applied to the end-mill and equipment, resulting in precision problems during the manufacture of complicated restorations [7].

Recently, AM has emerged as a possible solution for overcoming the problems encountered during SM of metal copings. Microstereolithography (μ-SLA), in particular, is an AM method that uses

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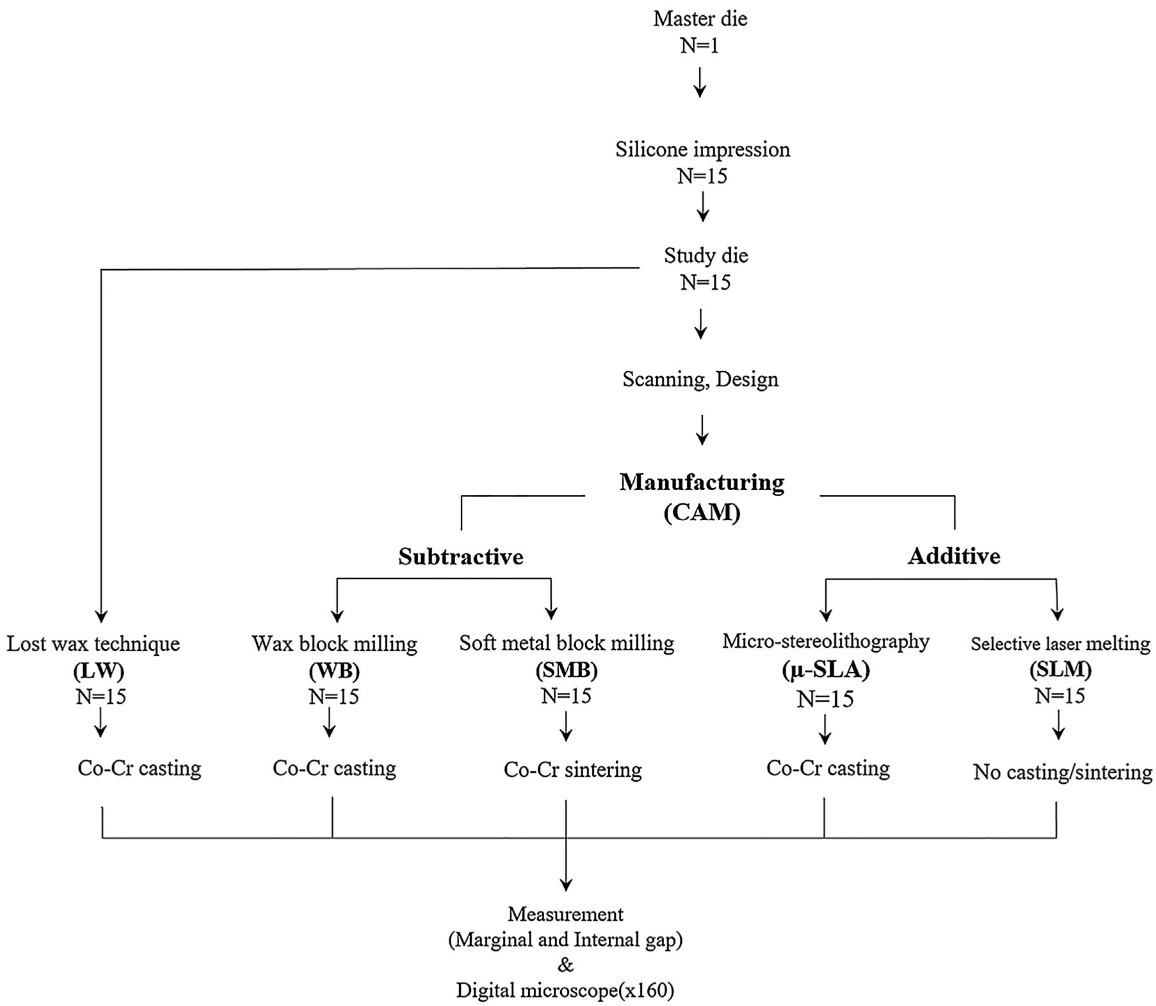

Fig. 1. Schematic of the study.

layered, ultraviolet (UV)-cured resin material to produce a resin coping, which is then cast for manufacturing a metal coping. The equipment used in this process is similar to that used for digital light processing (DLP), but each UV resin layer is only a few microns thick, resulting in a highly precise resin coping [8,9]. However, this method also involves investing, burn-out, and casting processes after fabrication of the resin coping, which can lead to errors. Therefore, selective laser melting (SLM), a method that layers metal powder to manufacture metal copings directly, has recently been introduced. This method has the advantage that it applies fiber lasers directly on the metal powder, thereby reducing errors [10,11]. Additionally, any residual metal powder can be used for future fabrications.

Base metal alloys are preferred over precious metal alloys for the manufacture of metal copings. Among the base metal alloys, cobalt–chromium (Co–Cr) alloys are preferred over nickel–chromium (Ni–Cr) alloys because of their higher biocompatibility, since Ni is known to cause allergies. However, further research is required to establish the utility of Co–Cr alloy restorations comprehensively.

Marginal and internal gaps are important factors in determining the life expectancy and long-term safety of dental restorations. If a microscopic crack or leakage exists near the marginal gap, the cement will dissolve [12], leading to plaque retention, secondary decay, and gingival inflammation [12,13]. The internal gap also affects restoration retention and occlusion. If the internal gap is too wide or narrow, the restoration may be dislodged, or may lead to malocclusion or imperfect mounting of the restoration [14]. Therefore, marginal and internal gaps are critical factors that determine the success of a dental restoration manufacturing process [15–21].

Thus, the purpose of this study was to evaluate marginal and internal gaps in Co–Cr copings manufactured using SM and AM methods and to compare the differences between the two methods.

2. Materials and methods

2.1. Metal master die fabrication

The first molar of the lower right mandible (ANA-4; Frasaco, Tettnang, Germany) was selected as the master die for this experiment (Fig. 1). Using a resin model of the selected tooth, 2 mm was removed from the occlusal surface, and the axis was reduced by 1.5 mm, while maintaining 6° off the axial wall in the buccal–lingual regions and 16° in the mesial–distal regions. It was corrected to maintain the anatomical shape of the tooth; subsequently, a 360° chamfer was applied to the margin, and the edges were rounded to obtain a resin master die for the PFM crown (Fig. 2). The finished resin master die was replicated using replication silicone (Deguform; Degudent GmbH, Hanau-Wolfgang, Germany). The wax master die was prepared by melting wax (Geo Wax; Renfert GmbH, Hilzingen, Germany) in the replicated silicone mold. After the wax had hardened, the master die was

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