CLINICAL RELEVANCE OF LASER-SINTERED CO-CR ALLOYS FOR PROSTHODONTIC TREATMENTS: A REVIEW

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ABSTRACT
The acceptance of metal additive manufacturing (AM) technique in dentistry depends on the clinical evidence and performance. There is an increased interest in laser-sintered cobalt-chromium (Co-Cr) alloys as it is reported to have advantages over conventional cast Co-Cr alloys. Laser sintering is a complex thermo-physical process that can vary the final product, which is dependent on alloying constituents, laser beam, accuracy of scanners and building machines and the parameters of the controlled environment**.** This review looks at all relevant publications over the last 10 years on *in-vitro* mechanical and biocompatibility properties used to verify the suitability of intraoral laser-sintered Co-Cr alloys. For the purpose of this review the term laser sintering also refers to laser melting technologies. The review notes that although there has been considerable progress with laser-sintered Co-Cr alloys, there is still a gap in knowledge and hence, further studies need to be undertaken to ascertain their suitability and provide recommendations.
Keywords: additive manufacturing**,** laser sintering, cobalt-chromium alloy

INTRODUCTION

The increased importance of providing affordable prosthodontic treatments is underpinning developments of new, potentially more efficient methods of manufacturing. Since digital manufacturing (Computer aided design and manufacturing) was introduced in dentistry, the industry has been inundated with a variety of additive manufacturing (AM) technologies. EOS CC SP2® (Electro Optical Systems, GmbH, Germany) is one of the most widely used Co-Cr alloy powders suitable for fixed and removable prostheses (Figure 1 and Figure 2). No alloy is 100% biologically safe and hence it is necessary that the clinical performance of the alloys used be fully understood (Wataha, 2012).

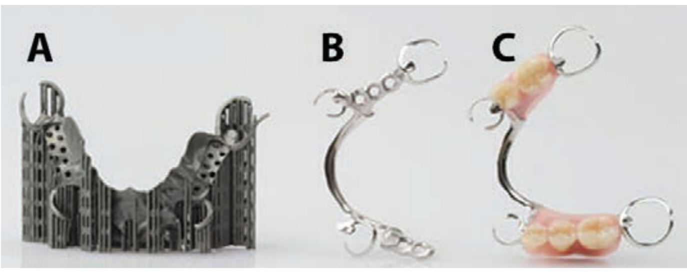

Figure 1. Stages of production for a laser sintered removable partial denture. A) Dental prosthesis directly after manufacturing, B) with support structures removed and surface polished, C) after completion (left to right). *Source: EOS GmbH*

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Figure 2. Dental prostheses (steps in production from left to right: with support structures, surface ready for veneer, after ceramic veneer) on a dental model. *Source: EOS GmbH*

IN VITRO CLINICAL EVALUATION TESTS

For clinical performance and patients' safety, dental alloys must exhibit sufficient physical, mechanical and biocompatibility properties (Anusavice and Cascone, 2003). These properties are usually verified with *in vitro* tests, as they are faster, less expensive, more reproducible and more scalable than other types of tests (Wataha, 2012). However no test is sufficiently robust to predict how a material would function in the mouth due to the complex nature of the oral cavity. The International Organization for Standardization (ISO) and American Society for Testing and Materials (ASTM) have provided the basis for comparison of products. They have established standards that allow the use of consistent terminologies through standard definitions and provided guidelines for test procedures to identify sub-standard products (Stanford, 1987). For instance, the ISO 12836:2012 specifies test methods for the assessment of the accuracy of digitizing devices for computer aided design and computer-aided manufacturing systems for indirect dental restorations.

Mechanical properties

Cobalt-chromium alloys are characterized by high strength and good performance at high temperatures without deformation. Dental metallic devices built by laser-sintering are reported to show adequate strength (yield strength, tensile strength and elongation) for intraoral use (Alifui-Segbaya, 2011; Jevremović *et al,* 2012). Laser-sintering also prevents casting-induced flaws and porosities in the alloy frameworks. However, mechanical properties are dependent on factors that include constituent elements of the alloy, manufacturing process, porosity and heat-treatment making comparison somewhat difficult (Vandenbroucke and Kruth 2007; Alifui-Segbaya *et al.,* 2014). Table 1 (Alifui-Segbaya, 2011) shows superior tensile test properties (ISO 22674:2006) of a Type 5 alloy, Wirocast® (major components: Co-Cr-Fe-Mo, Bego, D-28359 Bremen, Germany) cast alloy compared to a Type 4 laser-sintered EOS CC SP2® alloy (major components: Co-Cr-Mo-W, Electro Optical Systems, GmbH, Germany).

Table 1. Tensile test data for Type 5 cast and Type 4 laser-sintered Co-Cr alloy from Lloyd Material Testing Machine LS 100 (Lloyd Instruments Ltd, U.K.)

Wirocast/Type 5	Max.	Min.	Mean	Median	CV (%)	SD
Max Load (N)	6663.8	6093.2	6438.7	6421.1	3.1	200.5
Deflection at Max. Load (mm)	2.9	1.2	1.8	1.9	31.1	0.6
Work to Max. Load (J)	13.6	3.9	7.4	6.3	45.6	3.4
Stiffness (N/m)	12348000	11771000	12011000	12040000	1.7	209520
Load at Break (N)	666.4	609.3	643.8	642.1	3.1	20.1
Deflection at Break (mm)	2.9	1.3	1.9	2.1	29.6	0.6
Work to Break (J)	13.9	4.3	7.8	7.1	43.1	3.4

EOS CC SP2/ Type 4	Max.	Min.	Mean	Median	CV (%)	SD
Max Load (N)	9677.6	95550.3	9585.9	9570.9	0.4	42.4
Deflection at Max. Load (mm)	3.3	2.6	2.9	2.8	8.9	0.3
Work to Max. Load (J)	22.6	18.5	19.7	19.3	7.2	1.4
Stiffness (N/m)	14498000	11962000	13353000	13635000	7.4	983290
Load at Break (N)	967.7	955.1	958.6	957.09	0.4	4.3
Deflection at Break (mm)	3.4	2.7	3.1	2.9	8.7	0.3
Work to Break (J)	23.3	19.3	20.3	19.9	6.9	1.4

Key - CV: coefficient of variance **SD:** standard deviation

Heat treatment, Corrosion and Biocompatibility

Heat treatment is an essential stress-relieving procedure employed to remove internal stresses from long-span Co-Cr denture frameworks. This post-treatment technique is also used to improve the mechanical properties of alloys but has been linked to increased corrosion in laser-sintered Co-Cr alloys (Alifui-Segbaya *et al.,* 2014). Corrosion of dental alloys could be continuous in the mouth and can lead to poor aesthetics, compromise of physical properties and may have adverse biological effects such as toxicity, allergy or mutagenicity in sufficient quantities. It is hence important to understand the nature and quantity of metal ions released into the oral environment to evaluate the potential biological risks of all metallic dental restorations (Wataha, 2000; Ardlin *et al.,* 2005). Scanning electron micrograph (SEM) images of non-heat and heat-treated laser-sintered EOS SP2 CC alloy before they were tested for *in vitro* elemental release (Alifui-Segbaya *et al.,* 2014) show crevices in the heat-treated samples at high magnifications (Figure 3. A-D). Crevices shown in Figure 3D possibly contributed to the increased elemental release ($p<0.01$) in the heat-treated Co-Cr alloy (Upadhyay *et al.,* 2006). A previous study showed the alloy displayed higher resistance to corrosion for surfaces prepared as highly polished and electrobrightened to simulate clinical conditions of removable partial denture (RPD) frameworks. In the same study, the laser-sintered Co-Cr alloy performed better in a corrosive environment than cast Co-Cr alloy primarily due to the superior homogeneity of the laser-sintered alloys and perhaps the inclusion of tungsten in the laser-sintered Co-Cr alloy (Alifui-Segbaya *et al.,* 2013). A previous study also confirmed the superiority of a laser-sintered Co-Cr alloy over a cast Co-Cr alloy under similar test conditions (Vandenbroucke and Kruth, 2007).

Galvanic corrosion constitutes a frequent form of corrosive assault in dentistry. Corrosion analyses of Co-Cr implant abutments joined to titanium (Ti) implants were deemed safe in accordance with ISO standards while the long-term clinical performance of Co-Cr implant superstructures outperformed Titanium superstructures in a 5-year clinical study (Renishaw PLC). A laser-sintered Co-Cr alloy (Sandvik Osprey F-75) used for removable partial denture frameworks was confirmed non-cytotoxic under experimental conditions specified in ISO 7407:2008 (Jevremović *et al.,* 2011).

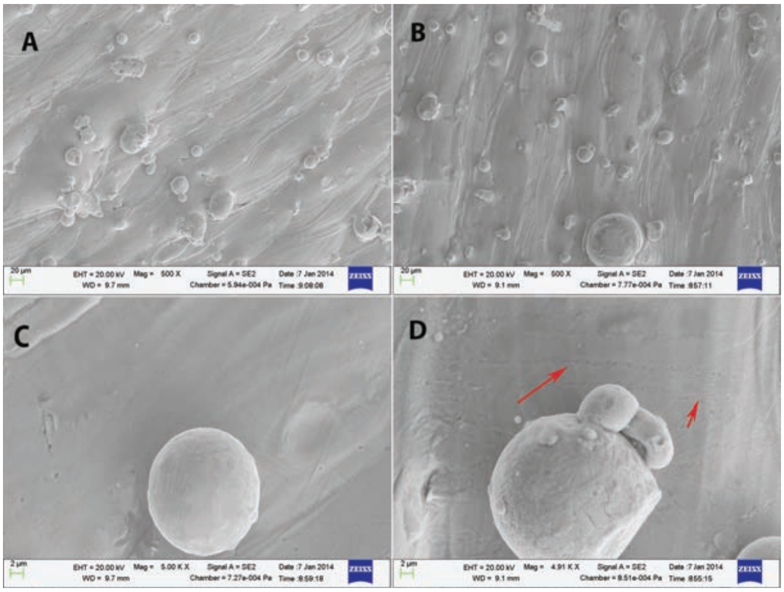

Figure 3. (A) 500x SEM of laser-sintered Co-Cr alloy (non heat-treated) (B) 500x SEM of laser-sintered (non-heat treated) (C) 5000x SEM of non heat-treated Co-Cr alloy without crevices (D) 5000x SEM of heat-treated Co-Cr alloy with crevices (arrows).

Fitting accuracy and Bond strength

Clinical fit of dental prostheses is essential for their longevity and overall oral health of patients. There is however inconclusive evidence concerning fitting accuracy of laser-sintered Co-Cr frameworks since the actual achievable accuracy is highly dependent on various processing parameters and the geometry of the component and, perhaps the varying measuring techniques available. Although, EOS GmbH claims it is possible to achieve an accuracy of ± 20µm with the EOS CC SP2 alloy, Kim et al., 2013 recorded a substandard marginal gap (≥128 µm) in laser-sintered bridges compared to conventionally-produced ones. Reclaru *et al*. (2012) on the other hand reported a 25 µm precision for substructures with a different Co-Cr alloy. While Örtorp *et al*. (2011) recorded the best clinical fit for laser-sintered Co-Cr substructures in a group that comprised substructures manufactured by 'lost-wax' techniques and metal block milling. Ucar *et al*. (2009) however did not find any significant difference between the internal fit of laser-sintered and cast Co-Cr crowns. It is documented that clinical and laboratory steps such as cementation and ceramic firing respectively could alter the marginal fit of metal-ceramic restorations (Quante *et al.,* 2008). Williams *et al.* (2006) on the other hand were the first and only group to report no difference between laser-sintered and cast Co-Cr removable partial dentures.

Another important property of these alloys is their bond strength to materials such as ceramics and resin composites; better bonding prevents unnecessary remakes and cost. Akova *et al.* (2008) and Suleiman and Steyern (2013) did not find any significant difference in bond strength between laser-sintered Co-Cr and cast Co-Cr alloys that were fused to porcelain. In another study by Muratomi *et al.* (2013), no significant difference was found in bond strength between one type of resin composite and Co-Cr alloys from both groups.

CONCLUSION

Current clinical evidence indicates that laser-sintered Co-Cr alloy is safe and comparable to cast Co-Cr alloys for intraoral use. However data from current studies are limited and hence it may be too early to make conclusive claims. AM is a complex thermo-physical process that can vary the final product, which is dependent on alloying constituents, laser beam, accuracy of scanners and building machines and the parameters of the controlled environment. Besides these factors, it is prudent that the following measures are observed:

- Newly developed materials should be tested for accuracy with the various 'open access systems' software available for computer-aided design and manufacturing.
- Clinical and laboratory steps should be carried out in a precise manner to minimise any subsequent errors in the final product.
- Suitable veneering materials should be chosen alongside clinical and laboratory expertise.
- Further studies on fitting accuracy of AM Co-Cr prostheses are highly recommended to ascertain the ability of the process to produce consistent parts under controlled manufacturing parameters.

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