Preliminary Evaluation of Mechanical Properties of Co-Cr Alloys Fabricated by Three New Manufacturing Processes

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A preliminary tensile test was performed to evaluate the mechanical properties of cobalt-chromium (Co-Cr) alloys fabricated by three new manufacturing processes: metal milling, milling for soft metal, and rapid prototyping (n = 6). For comparison, the three alloy materials were also used to fabricate specimens by a casting procedure. In all groups tested, the proof strength and elongation were over 500 MPa and 2%, respectively. The milled soft alloy in particular showed a substantially greater elongation, whereas the alloy fabricated by rapid prototyping exhibited a higher proof strength. *Int J Prosthodont 2015;28:396–398. doi: 10.11607/ijp.4298*

In dentistry, cobalt-chromium (Co-Cr) alloys have been widely used for the fabrication of fixed and removable restorations and appliances. However, fabrication using conventional casting is often difficult, mainly due to the high melting point, hardness, and limited ductility of the alloys.[1] In the last decade, computer-aided design/computer-assisted manufacturing (CAD/CAM) and three-dimensional (3D) printing technologies have revolutionized dental manufacturing processes.[2] However, there seems to be only limited data on the mechanical properties of Co-Cr alloys manufactured by such techniques.

The purpose of this preliminary study was to compare the basic mechanical properties of Co-Cr alloys prepared by three new manufacturing techniques with the conventional casting method.

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Materials and Methods

The mechanical properties of the Co-Cr alloys were evaluated using a tensile test. Six dumbbell-shaped specimens were prepared according to ISO 22674[3] by one of the three new manufacturing processes (metal milling [MM], milling for soft metal [MS], and rapid prototyping [RP]) (Table 1). For each technique, the corresponding Co-Cr alloy material was used. For the soft Co-Cr alloy (Soft Metal, LHK), the specimens were prepared using a machine for milling green state zirconia and then sintered. The three alloy materials were also used to fabricate specimens by a casting procedure (MM-C, MS-C, and RP-C). All of the above fabrication procedures were performed according to the manufacturers' instructions.

The specimens were then tested for 0.2% proof strength, percentage elongation after fracture, and Young's modulus on a universal material testing machine (3366, Instron) at a crosshead speed of 1.5 mm/minute.[3] Within a Co-Cr alloy material (Table 1), values were analyzed using the Student t test (α = .05). The fractured surfaces were observed using a scanning electron microscope (SEM) (JSM-6700F, Jeol).

Results

The tensile test results are shown in Fig 1 and Table 2. MM showed a significantly lower 0.2% proof strength and elongation at fracture than MM-C (P = .010/.019). MS exhibited a significantly higher elongation than MS-C (P < .001). On the other hand, RP showed significantly higher proof strength and elongation than RP-C (P < .001/= .016). The manufacturing procedures did not significantly affect the Young's modulus

Table 1 Six Test Groups

Group	Co-Cr alloy material	Manufacturing machine
MM (metal milling)	Magnum Lucens* (MESA di Sala Giacomo)	High-speed milling machine (RXD5, Röders)
MM-C	Magnum Lucens*	Centrifugal casting machine (Centrifico, Kerr)
MS (milling for soft metal)	Soft Metal† (LHK)	Zirconia milling machine (T1, Wieland Dental + Technik) and sintering furnace (Well Burn, Denstar)
MS-C	Soft Metal†	Centrifugal casting machine (Centrifico)
RP (rapid prototyping)	Remanium star CL‡ (Dentaurum)	Metal 3D printer (M1, Concept Laser)
RP-C	Remanium star CL‡	Centrifugal casting machine (Centrifico)

Composition: *Co 60%, Cr 29%, W 5%, Nb 4%; †Co 63%, Cr 29%, Mo 5.8%, Si 0.8%; ‡Co 60.5%, Cr 28%, W 9%, Si 1.5%, other elements < 1%.

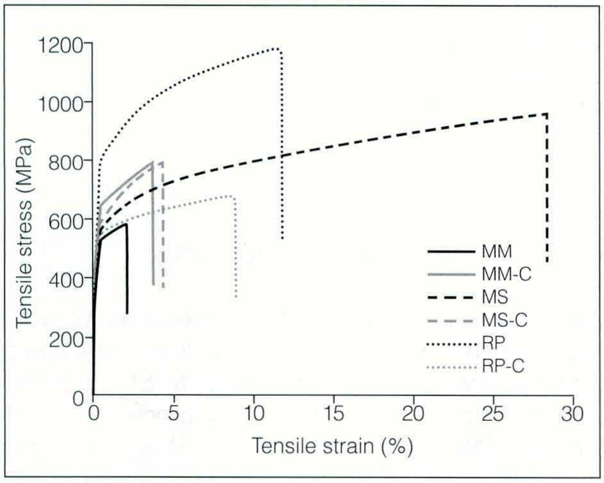

Fig 1 The stress-extension curves for the Co-Cr alloys tested.

Table 2 Mechanical Properties of the Co-Cr Alloys Tested (Mean ± SD)*

Group	Proof strength of 0.2% non-proportional extension (MPa)	Elongation after fracture (%)	Young's modulus (GPa)
MM	509.2 ± 29.5[a]	2.1 ± 0.5[a]	267.3 ± 27.1[a]
MM-C	594.2 ± 59.1[b]	3.5 ± 1.1[b]	291.4 ± 28.6[a]
MS	525.3 ± 49.7[a]	28.7 ± 3.6[a]	247.0 ± 43.0[a]
MS-C	544.8 ± 35.6[a]	4.2 ± 0.8[b]	237.3 ± 22.9[a]
RP	768.5 ± 36.2[a]	12.1 ± 1.3[a]	281.4 ± 21.2[a]
RP-C	533.7 ± 48.8[b]	8.9 ± 2.4[b]	256.1 ± 18.5[a]

*For each parameter and within a Co-Cr alloy material, values followed by different superscripted lowercase letters are statistically different (Student *t* test, $P < .05$).

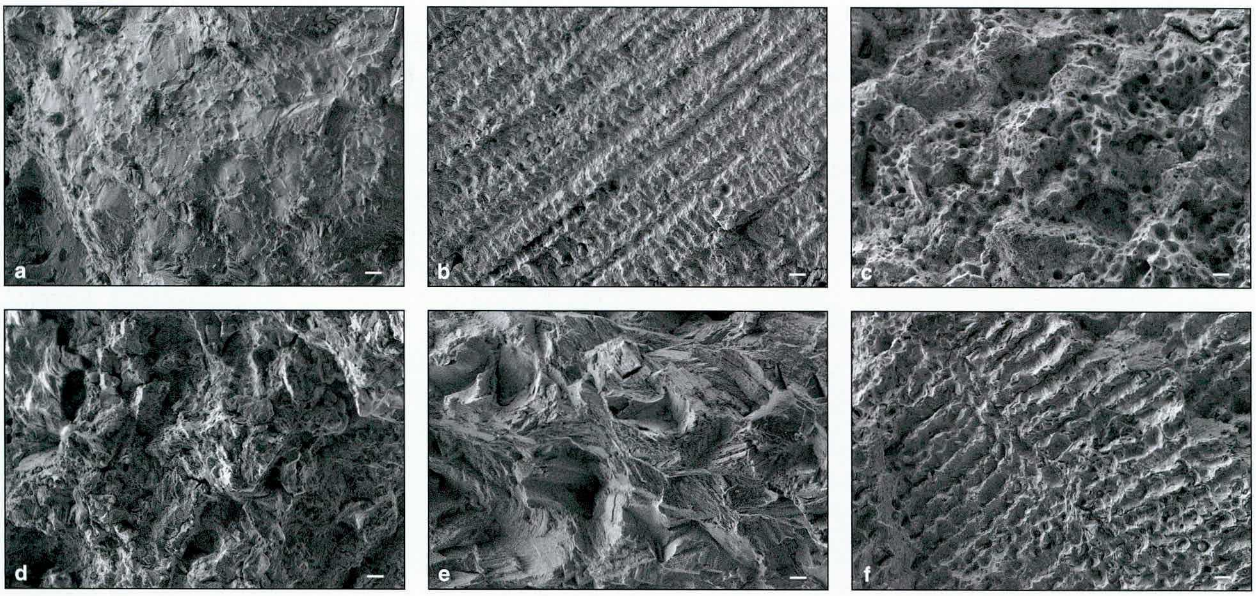

Fig 2 SEM images (500×) of fractured surfaces of the Co-Cr alloy specimens: **(a)** MM; **(b)** MM-C; **(c)** MS; **(d)** MS-C; **(e)** RP; **(f)** RP-C (bar = 10 µm).

($P > .05$) for any of the materials. The SEM images of the fractured surfaces (Fig 2) indicated that each Co-Cr alloy material had a different microstructure depending on the manufacturing process.

Discussion

In all groups tested, the proof strengths and elongations were over 500 MPa and 2%, respectively. This indicates that the alloys can be used for the fabrication of any type of dental restoration and appliance according to ISO 22674.[3] Except for MM and MM-C, the Co-Cr alloys prepared by the new manufacturing procedures (MS and RP) showed superior or at least similar mechanical properties to their casted counterparts (MS-C and RP-C).

The lower mechanical properties of MM as compared to MM-C suggest that the milling technique using a Co-Cr alloy needs further improvement. The results for MS and MS-C indicate that milling soft metal has potential advantages over conventional casting owing to the substantially increased elongation (~30%) and sufficient proof strength, which make the material very tough.[4] Thus, a soft Co-Cr alloy can be conveniently manufactured using a zirconia milling machine, although a subsequent sintering step is required. However, the pores on the fractured surface (Fig 2c) suggest that more optimal milling/sintering conditions should be further studied to enhance the microstructure. The Co-Cr alloy fabricated using rapid prototyping was characterized by high proof strength and large elongation (Table 2), as well as by homogenous and dense microstructure (Fig 2e). This 3D printing technique thus seems to be a promising alternative to conventional casting in terms of mechanical properties.

The three mechanical property parameters obtained indicate the potential usefulness of the three new manufacturing technologies in fabricating dental restorations and appliances. However, properties such as hardness, melting temperature, thermal expansion, density, corrosion/tarnish resistance, and biocompatibility of Co-Cr alloys fabricated using the techniques should also be tested to ensure optimal outcomes for clinical service.[3,5]

Acknowledgments

This work was supported by the National Research Foundation of Korea (NRF) grant funded by the Korea government (MSIP) (2008-0062282). The authors reported no conflicts of interest related to this study.

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