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CAD/CAM cobalt-chromium alloy single crowns in posterior regions: 4-year prospective clinical study

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ABSTRACT

Aim To evaluate the 4-year clinical outcomes of ceramic veneered CAD/CAM Co-Cr single crowns supported by natural teeth in posterior regions.

Material and methods Eighty-nine patients were provided with 120 ceramic veneered CAD/CAM Co-Cr single crowns replacing either premolars and molars. Specific inclusion criteria were set and tooth preparations were standardized and performed by undergraduate students under the supervision of 2 expert prosthodontists. CAD/CAM Co-Cr frameworks were fabricated and veneered with ceramics. The restorations were cemented using a self-etching, dual-cure resin luting agent. The patients were recalled at follow-up every 6 months after baseline evaluation, for a total observational period of 4 years. The survival and success rates of the restorations were evaluated. The technical and esthetic outcomes were examined using the United States Public Health Service criteria. The biologic outcomes were analyzed at abutments and contralateral teeth and descriptive statistics were performed.

Results None of the SCs was lost at follow-up, resulting in 100% cumulative survival rate and 99.2% cumulative success rates. No losses of retention were recorded. One hundred and eighteen restorations were rated alpha in all the measured parameters. A minor chipping of the veneering porcelain was detected in 1 restoration. No significant differences between the periodontal parameters of test and control teeth were observed.

Conclusions CAD/CAM Co-Cr single crowns proved to be a valid treatment option and a viable alternative to noble metal-ceramic restorations in posterior regions after 4 years of clinical function.

INTRODUCTION

Due to the increasing cost of noble metals, the use of cobalt-chromium (Co-Cr) alloys for dental restorations has become more and more widespread with various and successful clinical applications (1).

According to the classification proposed by the American Dental Association (ADA) in 1984 (2), the Co-Cr alloys are predominantly base metals (noble metal content < 25%); they are composed of 75 wt% or more of base metal elements and of 25 wt% or less of noble metals (Au, Ir, Os, Pt, Rh, Ru), although in clinical practice they do not contain noble metal elements at all (3, 4, 5).

The binary Co-Cr alloy was proved to be very strong and stain resistant. It is characterized by high strength, heat resistance, limited fatigue damage and excellent biocompatibility; it is non-magnetic (so particularly indicated in patients undergoing magnetic resonance imaging or MRI) and demonstrated favorable resistance to corrosion, wear and tarnish (6, 7, 8). Moreover, the Co-Cr alloy shows a high modulus of elasticity (E: 200-220 GPa), providing reliable rigidity for intraoral use with no need for heavy cross-sections even in case of long span fixed dental prostheses (FDPs), so reducing the weight and room of metal frameworks (1, 9).

However, casting of base metal alloys is more technique sensitive compared to that of noble alloys, mainly because of the high melting range and oxidation of base metal alloys during casting (10).

Base metal alloys tend to form thicker and darker oxide layers that could cause esthetic drawbacks (11). Moreover, increased oxidation could cause poor bond

strength between Co-Cr and the veneering porcelain due to chromium ions diffusion (12). Consequently, other metallic components, such as Ce, Ga and Nb, can be added in Co-Cr alloys to control thermal expansion, provide fluidity and modify the oxidation characteristics, thus improving the metal-ceramic bond. Molybdenum (Mo) and tungsten (W) can be used as strengthening agents (1).

The high solidus temperature of Co-Cr alloys, different from ceramic sintering temperature, reduces the risk of framework distortion after sintering (13). Nonetheless, the high coefficient of thermal expansion and melting temperature could cause technical drawbacks during the dental laboratory procedures (14). The stiffness of Co-Cr alloys makes it more difficult to grind or cut the frameworks, making finishing more time consuming (9, 11).

As to dental applications, the Co-Cr alloys were first used in the 1930s to fabricate the substructures of removable partial dentures (RPDs) (1). Their popularity increased rapidly, since they have almost half the density of gold-based alloys and consequently the weight of dental restorations was significantly lighter (4).

The use of the Co-Cr alloys for the fabrication of porcelain-fused-to-metal (PFM) FDPs began in the 1970s, due to the rapid increase of the price of gold. Nowadays, Co-Cr alloys are mainly used to produce the frameworks of RPDs, single crowns (SCs) and FDPs as alternatives to other metals: they are cheaper than gold and free from the risk of Ni-related allergic responses (15, 16, 17, 18, 19).

Recently, different technologies alternative to conventional casting were proposed to produce Co-Cr frameworks and reduce handling difficulties: Computer Aided Design/Computer Aided Manufacturing (CAD/CAM) and Selective Laser Melting (SLM), commonly known as laser sintering technique or spark erosion (20). Both fabrication methods could limit the weakening due to internal porosities and represent viable alternatives to conventional casting (1). Furthermore, CAD/CAM and laser sintering were proved to reduce production time, improve the precision of fit and limit estethic problems due to oxidation of Co-Cr frameworks (21, 22, 23).

Although Co-Cr alloys have been used as an alternative to conventional noble metals in fixed prosthodontics, to date only a few studies investigated the clinical performances of Co-Cr prostheses (9, 11, 24, 25). No adverse reaction to Co-Cr were reported but some patients experienced both biological and technical problems; a few ceramic fractures were reported after 3 to 7 years of clinical service (11). Conversely, no ceramic chipping was reported after 47 months of function in laser sintered Co-Cr SCs and the clinical results were comparable to those obtained with conventional metal-ceramic restorations (25). Similar results were also achieved on implants with Co-Cr prostheses veneered with ceramics and titanium-acrylic restorations after 5 years of function; veneering chipping were noticed in both groups (24).

The present prospective clinical study aimed at evaluating the 4-year clinical outcomes of ceramic veneered CAD/CAM Co-Cr single crowns supported by natural teeth in posterior regions.

MATERIALS AND METHODS

Recruitment of patients

Eighty-nine consecutive patients requesting single restorations in posterior areas of both maxilla and mandible were enrolled in the present prospective clinical protocol.

Fifty-two male and 37 female patients were recruited from May to July 2012 at the Department of Fixed Prosthodontics of the University "Federico II" of Naples (Italy) and were included in the present prospective study; their ages ranged from 21 to 68 years (mean age 41.2±8.4). All patients were in good general health; none of them showed parafunctional habits and 37 were smokers.

The procedures followed were in accordance with the Helsinki declaration of 1975, as revised in 2000; before being included in the study, all patients underwent an informative interview and had to sign an informed consent form. The present prospective clinical study was approved by the Ethical Committee of the University "Federico II" of Naples.

Inclusion and exclusion criteria

The following inclusion criteria were used to recruit patients:

- good general health;
- ASA I or ASA II according to the American Society of Anesthesiologists;
- periodontal health;
- Angle Class I occlusal relationship;
- minimum of 10 couples of opponent teeth;
- good oral hygiene;
- no evident signs of parafunctions and/or temporomandibular disorders.

Furthermore, the abutment teeth had to fulfill the following inclusion criteria:

- periodontal health (absence of tooth mobility, absence of furcation involvement);
- proper positioning in the dental arch (tooth axis adequate for a SC);
- sufficient occlusal-cervical height of the clinical crown (≥ 4 mm) for the retention of a SC;
- vital or endodontically treated to a clinically sound state;
- opposing natural teeth.

Conversely, were excluded from the study patients with the following conditions:

- high caries activity;

	Maxilla	Mandible	Total
1st premolar	26	7	33
2nd premolar	12	5	17
1st molar	20	23	43
2nd molar	11	16	27
TOTAL	69	51	120

TABLE 1 Distribution of the Co-Cr single crowns.

FIG. 1 Prepared abutment in region 15.

- presence of periodontal disease on the abutment tooth;
- occlusal-cervical height of the abutment tooth < 4 mm;
- reduced interocclusal distance or supererupted opposing teeth;
- unfavorable crown-to-root ratio;
- wear facets, clenching and/or bruxism;
- presence of RPDs;
- pregnancy or lactation;
- alcohol and/or drug addiction.

Prosthodontic procedures

A total of 120 ceramic veneered CAD/CAM Co-Cr SCs replacing either premolars and molars in both maxilla and mandible were fabricated; each patient received only 1 crown. One hundred and two abutments were vital while 18 teeth were endodontically-treated to a sound state. The distribution of the restorations is reported in Table 1.

All the prosthodontics procedures were standardized and performed by students of the last year of the Degree Program in Dentistry under the supervision of 2 experienced and calibrated prosthodontists. Oral hygiene procedures as well as any necessary core build-up, endodontic treatment and/or post-and-core placement were carried out before the prosthodontic steps.

Preliminary alginate impressions were made to obtain study casts (DIA, Trayart SRL, Castelbaldo, Italy), diagnostic wax-ups, light-cured resin customized impression trays (Elite LC Tray, Zhermack SpA, Badia Polesine, Italy) and acrylic temporary restorations (Unifast III, GC Europe N.V., Leuven, Belgium). Silicone indexes (Vestige putty soft-fast, Trayart SRL) were fabricated from the diagnostic wax-ups to check a proper tooth structure reduction during the procedures of abutment preparation that were standardized as follows (Fig. 1), according to the requirements of the CAD/CAM framework production:

- margin design: 1 mm circumferential rounded chamfer;
- cavo-surface angles: rounded;
- axial reduction: 1.5 mm;
- occlusal reduction: 1.5-2 mm;
- total occlusal convergence angle: 10°-14°.

The margins of the preparations were slightly subgingival, never violating the biologic width. The acrylic resin temporary restorations were relined intraorally with self-polymerizing resin (Jet Kit, Lang Dental Manufacturing Co., Wheeling, IL, USA) and then cemented with a eugenol-free luting agent (Temp Bond NE, Kerr Corporation, Orange, CA, USA); careful occlusal adjustment of the provisional restorations was performed.

Two weeks were waited after tooth preparation before taking final impressions in order to allow the soft tissues to recover from preparation trauma. The final impressions were taken placing 2 non-impregnated retraction cords (Ultrapak, Ultradent, South Jordan, UT, USA) around the abutment teeth to displace the gingival tissues and taking full-arch impressions with customized light-cured acrylic impression trays and polyether materials (Impregum and Permadyne-L, 3M ESPE, Seefeld, Germany). Intermaxillary registrations were taken by means of a self-polymerizing A-silicone (Vestige bite, Trayart SRL). Then, the provisional restorations were relined and cemented again as previously described.

The master casts were fabricated with super hard gypsum (Elite Rock, Zhermack SpA) and mounted in semi-adjustable articulators (Artex, Amann Girrbach AG, Koblach, Austria). A die spacer (thickness: 30 microns) was applied at the occlusal and axial surfaces of the abutment, starting 1 mm above the preparation margin. The master casts were digitized by means of the Echo CAD/CAM system (Sweden & Martina SpA, Due Carrare, Italy). Co-Cr single frameworks were designed according to the manufacturer's instructions and providing room for an even thickness of the veneering ceramic (Fig.

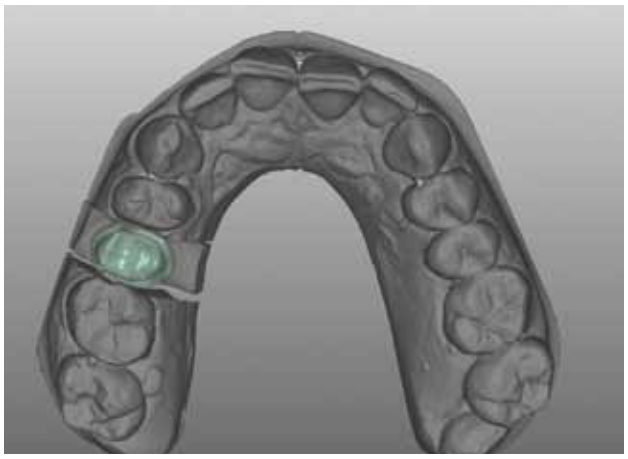

FIG. 2 Occlusal view of the CAD project.

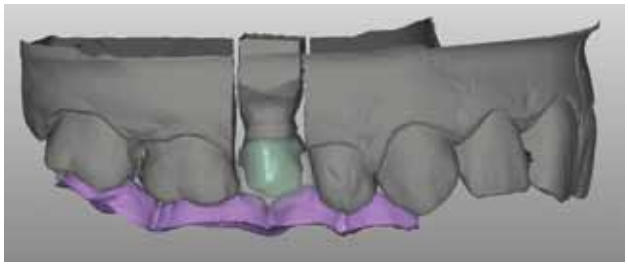

FIG. 3 Buccal view of the CAD project.

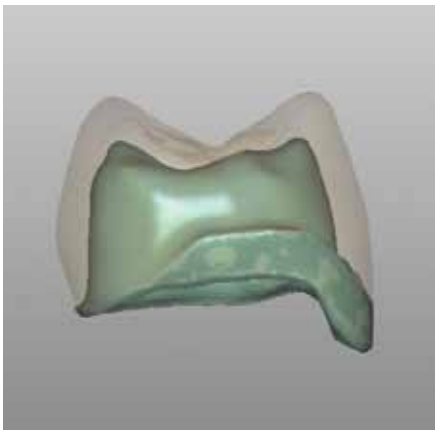

FIG. 4 Cut-back of the CAD project to properly support the veneering ceramic.

FIG. 5 Buccal view of the Co-Cr framework.

FIG. 6 Palatal view of the Co-Cr framework.

FIG. 7 Buccal view of the Co-Cr single crown.

FIG. 8 Palatal view of the Co-Cr single crown.

FIG. 9 Occlusal view of the Co-Cr single crown.

FIG. 10 Inner view of the Co-Cr single crown.

2-4). The frameworks were milled from Co-Cr blanks at the Echo Scan Center (Sweden & Martina SpA) (Fig. 5-6). The framework thickness was checked at occlusal, axial and marginal surfaces with a digital caliper with an accuracy of 0.01 mm (BES-11445, BES SRL, Napoli, Italy).

The Co-Cr structures were tried-in intraorally and evaluated for accuracy of fit with a silicone disclosing agent (Fit Checker, GC, Tokyo, Japan); if necessary, any pressure spot was transferred to the tooth surface and the adjustment made on the abutment tooth. The marginal precision was checked by means of standardized periodical radiographs.

All the frameworks were veneered by the same experienced dental technician. A conventional powder build-up veneering technique was performed using a feldspathic ceramic specifically dedicated to Co-Cr structures (Noritake Super Porcelain EX-3, Kuraray Noritake, Tokyo, Japan) (Fig. 7-10).

The restorations were cemented using a self-etching, dual-cure, fluoride-releasing resin luting agent (Panavia F 2.0, Kuraray Noritake) strictly following the manufacturer's instructions. If necessary, occlusal adjustments was performed using fine-grit diamond

FIG. 11 Post-operative buccal view of the Co-Cr single crown in region 15.

FIG. 12 Post-operative palatal view of the Co-Cr single crown in region 15.

FIG. 13 Post-operative occlusal view of the Co-Cr single crown in region 15.

FIG. 14 Post-operative view of the Co-Cr single crown in region 15 in occlusion.

burs and reshaped surfaces was meticulously polished with a ceramic polishing system (Jazz P3S, Item #89004, #89008, #89012, SSWhite, Lakewood, NJ, USA).

Baseline and follow-up examinations

The baseline evaluation was performed by 2 experienced clinicians who did not participate in the prosthodontic procedures; the baseline evaluation was recorded 7 days after final cementation of the SCs (Figures 11-14). A periodontal evaluation was performed assessing tooth mobility, probing pocket depth, probing attachment level, gingival index (GI), plaque index (PI) and bleeding on probing (BOP) at the abutment sites (test) and at the contralateral, not restored teeth (control) (26). An electric pulpal vitality test was made at test and control teeth as well. The static and dynamic occlusal contacts were checked and the photographic documentation recorded.
The patients were recalled at follow-up every 6 months after the baseline evaluation, for a whole observational period of 4 years. The same evaluations assessed at the baseline were repeated and the resultant data were recorded.
The survival and success of the restorations were evaluated. The examination for technical and biologic failures or complications was made in compliance with the United States Public Health Service (USPHS) criteria, rated according to the clinical serviceability of the restorations; the SCs were evaluated entirely and the worst finding was used for rating.
The structural integrity of the crowns was evaluated by means of surface probing with a sharp dental explorer under 10x surgical microscope (OPMI PROergo, Zeiss, Oberkochen, Germany). Chipping of the veneering porcelain was defined as minor cohesive fracture of the veneering ceramic not impairing function (27).
The patients' satisfaction score was assessed by means of Visual Analog Scales (VAS) ranging from 0 (worst) to 10 (best).

Statistical analysis

Descriptive statistics were applied to data using a dedicated software (SPSS 17, SPSS Inc., Chicago, IL, USA). The Kaplan-Meier analysis was used to evaluate the 4-year survival rate of the SCs. The Wilcoxon test was performed to compare the periodontal parameters of test and control teeth between baseline and the 4-year follow-up examination, as well as the periodontal differences between test and control teeth after 4 years of clinical service.
The level of significance was set at $p < 0.05$.

RESULTS

During the 4-year observational period, none of the CAD/CAM Co-Cr SCs was lost at follow-up. Neither mechanical

USPHS criteria	Alpha (A)	Bravo (B)	Charlie (C)	Delta (D)	Total
Framework fracture	120 (100%)	0	0	0	33
Veneering fracture	119 (99.2%)	0	0	1 (0.8%)	17
Occlusal wear	118 (98.3%)	2 (1.6%)	0	0	43
Marginal adaptation	119 (99.2%)	1 (0.8%)	0	0	27
Anatomical form	120 (100%)	0	0	0	120

TABLE 2 USPHS scores.

failures nor losses of retention were detected and only 1 crown on a mandibular molar showed a minor chipping of the veneering porcelain on the mesial-buccal cusp. Consequently, 100% cumulative survival rate according to Kaplan-Meier analysis and 99.2% cumulative success rates were recorded respectively.

One hundred and two abutments were vital at the beginning of the study and they all remained vital during the entire observational period.

The technical evaluation by means of the USPHS criteria showed very good clinical performances of the Co-Cr SCs (Table 2). In terms of fracture resistance, all of the frameworks rated alpha; regarding occlusal wear, 2 restorations rated bravo, and occlusal wear was detected mainly at the level of the opposing natural teeth.

Neither radiographic evidence nor signs or symptoms of proximal decay or periapical pathologies were noticed during the entire follow-up period.

No significant differences in the average periodontal parameters between test and control teeth were detected at any follow-up examination; 116 restorations scored 0 for both GI and PI, while 4 crowns scored 1 for both variables; none of the sites around the crowns was positive to BOP.

According to the Wilcoxon test, the periodontal parameters of the test and the control teeth were not significantly different ($p>0.05$); furthermore, the SCs had no effect on the periodontal parameters after 4 years of clinical function ($p>0.05$).

According to the patients' VAS judgments, the overall function of the SCs showed a mean value of 9.1 ($\pm$1.2) while the overall esthetics scored a mean value of 9.4 ($\pm$0.4).

DISCUSSION

In the present study, the use of CAD/CAM Co-Cr restorations confirmed either the mechanical and biological advantages reported in the literature for this type of restorations (1, 8, 9).

The CAD/CAM technology allowed the dental technician to reduce the laboratory working time in comparison with the conventional procedures needed to fabricate metal frameworks. Moreover, the mechanical needs required by function in posterior load bearing areas were proved by the optimal clinical performances of the investigated restorations.

The overall survival and success rates of the Co-Cr SCs noticed in the present study were consistent with data published in scientific literature (9, 11, 24, 25). The reliable mechanical performances of thin Co-Cr frameworks in withstanding static and dynamic loads were confirmed in posterior regions.

Doubtless, a correct management of the prosthetic procedures is to be addressed as one of the main success factors in order to avoid possible biological complications such as recurrent caries and periodontal problems; particularly, accurate abutment preparations, precise provisional prostheses for optimal soft tissue conditioning, flawless impressions (delayed from 10 to 14 days after tooth preparation for achieving stable and sound soft tissues) and careful cementation procedures have all to be considered paramount for successful clinical outcomes.

During the 4-year observational period, only 1 crown on a mandibular molar showed a minor chipping of the veneering porcelain on the mesial-buccal cusp; the patient reported to be aware of this occurrence after an impact during mastication. As after careful intraoral polishing such cohesive fracture did impair neither function nor esthetics, the restoration remained in situ and was not considered as failed.

None of the restorations showed loss of retention, proving that dual-cured resin cements could be safely used in the presence of Co-Cr frameworks. Although glass-ionomer luting agents are easier to clean up, the application of a resin cement together with an alloy primer could improve the retention of metal restorations, particularly in posterior regions, where the anatomical height of the abutment teeth and the circumstantial procedural interferences (i.e. limited mouth opening) could result in non ideal total occlusal convergence and preparation geometry (28).

As to the periodontal parameters evaluated in the present study, slight soft tissues inflammation (i.e. Gi and PI score 1) was observed in 4 restorations, particularly during the first month after cementation; such an

occurrence was observed on the lingual surfaces of 2 mandibular second molars and on the distal aspects of 2 maxillary second molars and was probably due both to the difficulty in removing cement remnants and the difficult home hygienic maintenance. The problem was easily overcome increasing the patients' motivation toward oral hygiene.

Within the limitations of the present prospective clinical study, the mechanical and biological effectiveness of Co-Cr restorations was confirmed, resulting in survival and success rates of 100% and 99.2% respectively.

The fracture resistance and marginal integrity of the crowns was excellent and the overall function and esthetics were considered very satisfactory by patients.

CAD/CAM Co-Cr single crowns proved to be a valid treatment option and a viable alternative to noble metal-ceramic restorations in posterior regions after 4 years of clinical function.

Further multicentric clinical studies with wider patient populations and longer follow-up observational periods would be advisable to validate the encouraging results of the present prospective clinical investigation.

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