Comparison of Fit Between Zirconia and Metal Copings Fabricated Conventionally or Using Different CAD/CAM Techniques

Keywords

Direct Metal Laser Sintering
Additive Technology
Marginal Gap
Cobalt Chromium
Intimacy of Fit

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Received: 18.05.2020
Accepted: 02.12.2020
doi: 10.1922/EJPRD_2108Sambrook07

ABSTRACT

This study was designed to assess the fit of cobalt chromium copings fabricated using direct metal laser sintering and to compare with copings fabricated from nickel chromium (traditional casting) and zirconia (milled from partially sintered blanks). For both cobalt chromium and zirconia groups, impressions were generated using direct or indirect digitization. There were 5 experimental groups of 12 copings fabricated for a prepared maxillary right molar. The intimacy of fit (measured at the margin, axial wall and occlusal) was assessed using a replica method technique. The results showed that zirconia copings produced using direct digitization had significantly smaller marginal, axial and occlusal measurements compared to other groups (p<0.05). Nevertheless, all groups had a mean marginal gap within accepted clinical values. Though there was a decrease in the intimacy of fit from the margin to axial wall to the occlusal surface. It can be concluded that the fit of zirconia copings fabricated using direct digitization was significantly better than the other groups. However, it can be expected that further enhancement and refinement of additive technology such as direct metal laser sintering will offer clinicians a viable alternative to nickel chromium analogue production methods in the future.

INTRODUCTION

Computer-aided design (CAD) and computer-aided manufacturing (CAM) have revolutionised the production of indirect restorations. The use of CAD/CAM via a digital workflow has been shown to improve the efficiency of restoration fabrication,[1] yet the precision of fit, across materials and techniques is still being debated.[2-5] Nevertheless, as manufacturing technology evolves, the material choices also continue to expand, enhancing the restorative options available.

To date, 'subtractive' manufacture utilising milling machines dominates CAM in dentistry.[6] It supports a myriad of materials which have historically been utilised in analogue workflows. This technology has also enabled the introduction of alternative materials, such as resin hybrid ceramics and zirconia, for use in fixed dental prostheses (FDP). Whilst subtractive CAM technology offers an effective alternative to conventional casting for fabrication of dental prostheses, it still has several limitations including material waste, geometry restrictions and cost.[6,7]

More recently, the use of 'additive' manufacture in dentistry has gained momentum. Currently, 'additive' manufacture is predominantly stereolithography apparatus (SLA) 3D printing using photopolymerizing resin. Continued efforts to optimise materials and production techniques has seen the introduction of Direct Metal Laser Sintering (DMLS), a powder bed fusion technology for 3D metal printing.[7] This technology uses metal powder layers which are laser melted to sequentially build 3D components. The 3D component is then post processed as required. Amidst the various metals suitable for use in DMLS, of interest is Cobalt Chromium (CoCr).

Base metal alloys have been successfully used for many different indirect FDP, such as resin bonded bridge frameworks, copings for porcelain fused to metal (PFM) crowns and inlay/overlays. The advantages of using base metal alloys include cost, bonding potential and high modulus of elasticity.[6] Despite this, it is a technically challenging and labour-intensive material for fabricating dental restorations. The base metal most commonly used for FDP is Nickel Chromium (NiCr), yet this material is hindered by the risk of nickel allergies. Subsequently, CoCr is preferred, though to date, its routine use has been limited by the difficulties faced in laboratory production. Subsequently, the capacity of DMLS to effectively produce CoCr restorations overcomes some of the major challenges to its utilisation.

Historically, parameters have been recommended and continue to be used, defining the minimum standards which restorations should meet to be 'clinically acceptable'.[8,9] For any new material or production method, it is essential to establish whether the resultant restoration meets these standards. In addition, it is worth comparing, in a controlled environment, against existing production methods and materials, to gain further insights into the suitability as a restorative solution.

This study was designed to assess the intimacy of fit of copings made from CoCr using DMLS and compare that with both NiCr copings and a yttria-tetragonal polycrystal zirconia (Y-TZP) copings fabricated using traditional casting and milling via a digital workflow, respectively. For the digital workflows, both direct and indirect digitisation techniques were used to generate digital dies for production of the CoCr and Y-TZP copings. The primary null hypothesis is that there would be no difference in the intimacy of fit of the restorations regardless of the material used. The secondary null hypothesis is that the technique used to generate the digital die had no impact on the fit of the restoration.

MATERIALS AND METHODS

A maxillary right molar (16) KaVo typodont was prepared for a crown with 1.5 mm occlusal reduction, an axial taper of 6 degrees and a 360 degree rounded shoulder finish line of 1 mm. An impression of the model with the prepared tooth was taken using polyvinyl siloxane (PVS) impression material (Aquasil) for fabrication of a polyurethane resin cast (Biresin G26). This served as the reference model. The reference model was then used to generate the working casts.

A flowchart of the experiment's process is presented in Figure 1. In total, there were 5 experimental groups with 12 copings in each group. The NiCr copings for Group 1 were fabricated using an analogue impression technique. Twelve (12) impressions using PVS impression material were taken of the reference model. The impressions were poured with type IV die stone (Silky-Rock), according to manufacturer's recommendations. Each cast was removed after one hour and dies were sectioned. The resulting dies were inspected for defects and labelled with a number.

Prior to manually fabricating the wax patterns, die spacer was applied within 1 mm of the margin of each die. A uniform thickness of 60 μm was applied utilising a layering technique with two different varnishes (silver 10 μm and blue 20 μm, Kerr Die spacer). Each wax pattern was assessed with a thickness gauge to ensure a coping of 0.6 mm. The wax pattern was then embedded in a phosphate bonded investment (Whipmix Corp) and subsequently cast with NiCr alloy (Schütz Dental GmbH) Germany) by using an induction casting machine (Easy-Cast-1). Once complete, the casting was left to bench-cool before divesting. Remnants were removed with 50 μm aluminium oxide.

The above laboratory processes were performed by a single, skilled dental technician (MW).

An additional 12 analogue PVS impressions were taken of the reference model and stone dies generated for the indirect digitization for Groups 2 & 3. The indirect digitalization of the 12 stone dies was performed using Renishaw DS30 non-contact optical scanner after calibration with the compatible software. The lab scanner uses non-contact blue light technology and allows the simultaneous scan of eight dies with an accuracy of 7 μm. The 12 stone dies were scanned in 2 groups of 6 dies each.

Following this, 12 Y-TZP copings (Group 2) and 12 CoCr copings (Group 3) were designed using Renishaw Dental Studio CAD software, powered by Exocad DentalCAD. The following design parameters were used, 60 μm of cement space was provisioned and the coping 0.6 mm thick.

The CAD program and design of the zirconia restorations compensated for the expected 20% shrinkage of the partially sintered zirconia post milling. The CAD data were transferred to the milling device. The CAM milling process of the Y-TZP copings was carried out by Renishaw's Incise DM10 Milling System. Partially sintered zirconia billets were used (99.0% ZrO_2 / HfO_2 / Y_2O_3, 0.3% Al_2O_3, 0.20% Fe_2O_3) with a milling speed of 60,000 rpm (Renishaw Zr100). After milling, sintering of the copings was completed in a sintering furnace, for 6 hours and at a temperature of 1470oC as per the manufacturer's instructions.

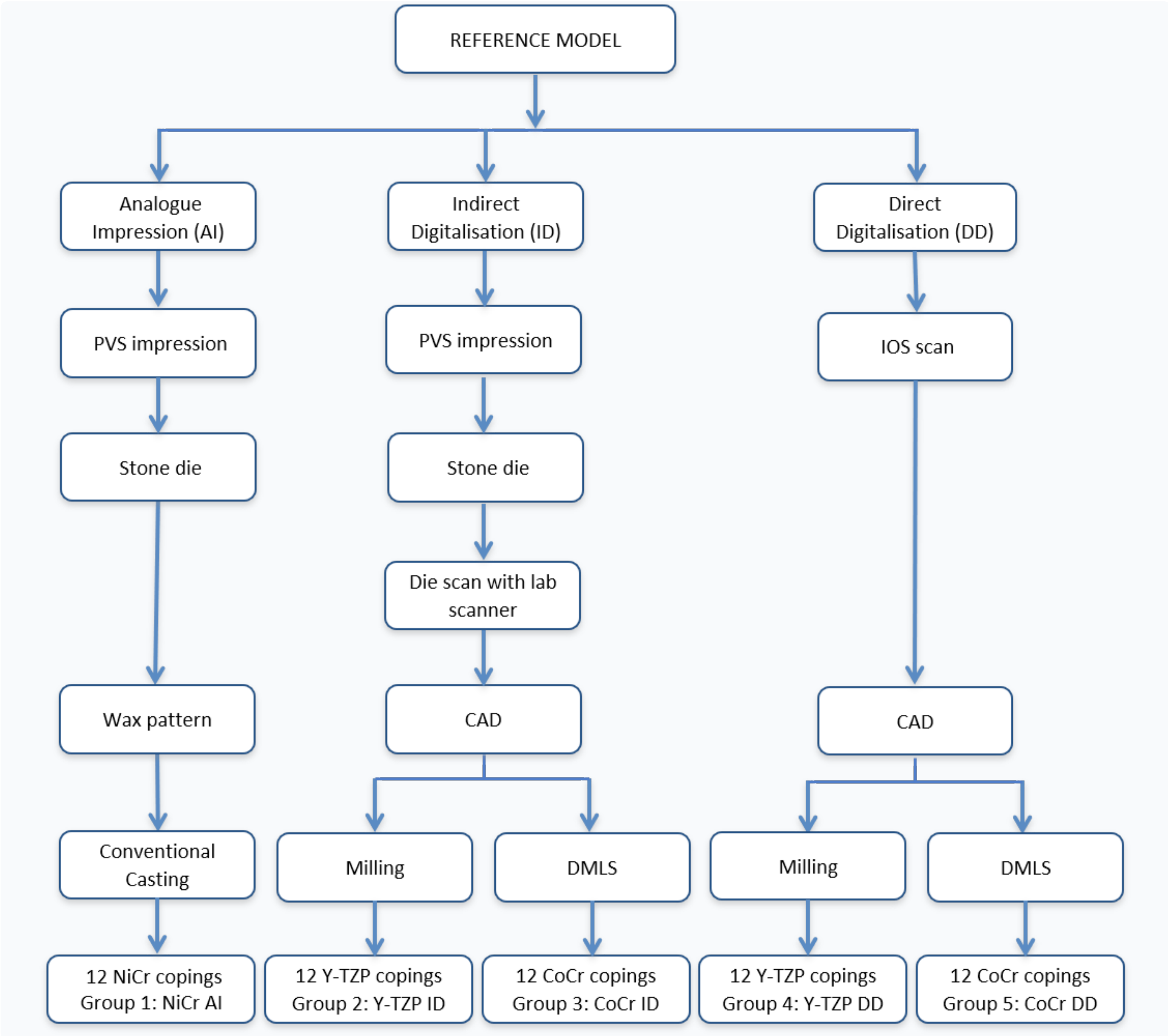

Figure 1: Experimental Flowchart

The CAD data for the 12 CoCr copings was transferred to the corresponding DMLS manufacturing machine. The CAM production of the CoCr copings took place in Renishaw AM250 additive manufacturing machine. The metal powder (Renishaw Cobalt Chrome DG1) and the build plate were loaded to the machine, argon inert gas filled the chamber. The metal powder particles were 15-45 microns and the metal powder layers were melted and fused by the 400W ytterbium fibre laser (80 μm laser beam). The process was completed after 9 hours.

For Groups 4 & 5, the direct digitalisation of the reference model was carried out with a Trios intraoral scanner (Trios 3 Basic) (3 Shape) without any powder application. Prior to scanning, the manufacturer's instructions were followed for calibration of the scanner, utilising the calibration tip attachment. After preheating the scanner tip, the reference model was scanned using the manufacturer's recommended scanning procedure. This technique involved scanning the preparation before scanning the occlusal, buccal and palatal surfaces of the arch posterior then anterior to the preparation. The scans were observed on the screen and areas with missing data on the preparation were automatically highlighted by the programme and scanning of these areas was repeated. Once scanning was completed, unnecessary parts were digitally trimmed. The direct digitalization of the reference model was completed 12 times by the same operator (NK).

The twelve scans were converted into stereolithography (STL) files and Dental System Design software (3 Shape) was used to design the copings for both Y-TZP (Group 4) and CoCr (Group 5). The same design parameters as Groups 2 & 3 were employed (60 μm of cement space and the coping 0.6 mm thick). The CAD data was transferred to the milling device and the DMLS manufacture machine. The CAM milling process of the Y-TZP copings followed the description provided for Group 2, whilst the DMLS process for fabrication of the CoCr copings followed the description provided for Group 3.

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No adjustments of the internal surface of any of the copings was performed postproduction.

The intimacy of fit of the resulting copings was evaluated using a replica-technique. The prepared 16 on the reference model was sectioned to generate a single die (PU die). Low viscosity PVS impression material was syringed into the intaglio of the coping until completely full and it was immediately seated on the single PU die. The first 30 seconds excess material from the margin was removed under firm finger pressure and thereafter a 5 kg load was applied for 10 minutes, using a loading device. After complete setting of the impression material, the coping was carefully removed, ensuring maintenance of the impression material on the PU die. If tearing of the material was observed or it remained in the coping, the process was repeated. The silicone film produced represented the gap between the coping and the PU die. A special tray was filled with heavy-body PVS impression material and the PU die with attached silicone film was embedded. Once the material set, the PU die was removed and the space representing the prepared tooth was filled with PVS impression material. After setting was complete, the replicated silicone was cut using a No. 11 scalpel mesiodistally and buccolingually resulting in four cross-sections. This was repeated for all the copings.

Each cross section was examined using a reflected light stereomicroscope (Wild M5-Wild) at × 15 magnification. Digital images were taken of every section using a digital single lens camera (CoolSnapPro Color) through the microscope. The images were directly transferred to a computer and observed under a further 100% on-screen magnification. A total of 480 images were taken (8 sides × 12 copings × 5 groups).

To quantify the intimacy of fit, the marginal, axial and occlusal gaps on each image were analysed using ImagePro Plus v4.5 software.

Each image was divided into 3 measurement areas, Marginal, Axial and Occlusal. Two continuous lines representing a series of points were marked on the outer and inner border of the light body silicone on each area. The software automatically calculated the average distance between these points by constructing perpendiculars joining the opposing lines (*see Figure 2*). A total of 1440 measurement values were generated (8 sides × 3 measurement values × 12 copings × 5 groups).

All measured values were exported to a spreadsheet (Microsoft Excel). For the data analysis the Statistical Package for the Social Science Version 24 (SPSS) was used. Homogeneity of data was tested using Levene's test. Results were analysed using One Way Analysis of Variance followed by multiple comparisons using Dunnett T3 test due to lack of homogeneity of variances. The level of significance was set at 5% ($p < 0.05$).

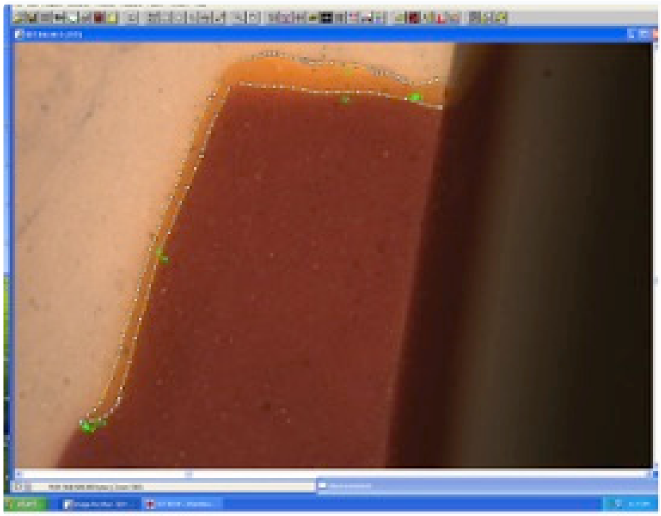

Figure 2: Example of an image analysed in ImagePro Plus v4.5 software with a series of points marking the outer and inner border of the light body silicone.

RESULTS

The differences between mean values of the gap measurements of the groups by the area measured is illustrated in Table 1.

For the marginal gap, Y-TZP DD presented the smallest mean value of 51.43 ±12.34 μm, reaching a statistically significant difference from the marginal gap of the other four groups ($p \leq 0.001$). This was also the smallest mean value across all measurements. The smallest axial and occlusal gaps were also recorded for Y-TZP DD being 71.16 ±11.68 μm and 88.26 ±16.45 μm respectively.

When comparing the method used to generate the digital die, for Y-TZP, direct digitization (Group 4) was statistically significant from indirect digitization (Group 2) across all measurement areas with direct digitization producing smaller discrepancies. In contrast, for CoCr, statistical significance was only achieved between digitization method when comparing the occlusal gap (290.39 ±57.40 μm and 257.99 ±48.18 μm). Though, the indirect digitization method consistently produced smaller gap measurements when compared with the direct digitization method.

For each group, the mean values progressively increased from marginal to axial to occlusal (*see Figure 3*).

DISCUSSION

Traditional manufacturing techniques for indirect restorations are being challenged by the speed, reliability and accuracy of newer digital technologies.[10] In addition, materials for dental restorations, either too difficult to process using conventional techniques or limited to CAD/CAM production are now being validated as alternative options for use as indirect restorations.

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Table 1. Comparison of the mean measurement values and standard deviation (SD) for Groups 1-5. Different superscript letters in columns indicates significant difference between groups (p<0.05) using Dunnett T3 test.

	Marginal Gap		Axial Gap		Occlusal Gap	
	MEAN (μm)	SD	MEAN (μm)	SD	MEAN (μm)	SD
Group 1: NiCr AI	61.89[a]	22.34	91.30[a]	34.87	133.39[a]	42.87
Group 2: Y-TZP ID	63.24[a]	20.66	76.76[b]	12.48	100.36[b]	19.24
Group 3: CoCr ID	63.85[a]	21.30	146.90[c]	37.15	257.99[c]	48.18
Group 4: Y-TZP DD	51.43[b]	12.34	71.16[d]	11.68	88.26[d]	16.45
Group 5: CoCr DD	64.26[a]	21.59	152.50[c]	31.24	290.39[e]	57.40

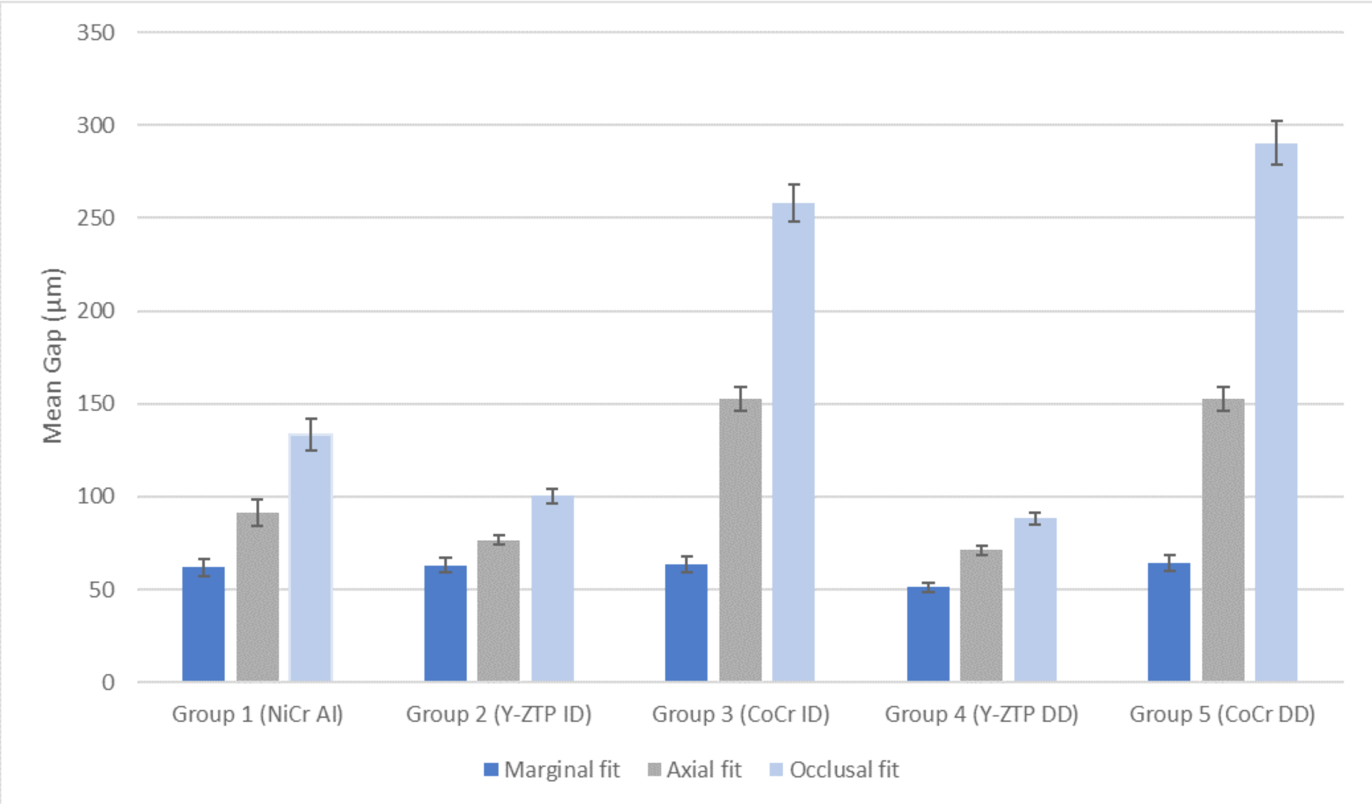

Figure 3: Comparison of the mean differences in fit (measured in μm) across groups 1-5 for marginal, axial and occlusal areas. The error bars are at 95% CI.

This study sought to determine if copings fabricated from CoCr using additive DMLS technology were comparable in intimacy of fit compared to both a material fabricated using a conventional casting technique (NiCr) and a material fabricated with a subtractive CAM technique (Y-TZP), irrespective of the impression technique.

The Y-TZP restorations fabricated from a direct optical impression presented the smallest mean marginal gap, axial gap and occlusal gap and was significantly different to all other groups. Consequently, the primary null hypothesis that there would be no difference in the intimacy of fit of the restorations regardless of the material used was rejected. Nevertheless, regardless of material or impression technique the mean marginal gap for all groups was within accepted clinical limits of <120 μm as proposed by McLean and von Fraunhofer.[9] Whilst the NiCr copings fabricated using a conventional casting technique by an experienced technician had a clinically acceptable mean, this group also had the highest standard deviation for the marginal gap. This illustrates one of the challenges for achieving consistency with conventional fabrication techniques utilising this material.

A second element of this study was to assess for differences between digital impression techniques. The null hypothesis that there would be no differences in the fit of the restoration between the technique used to generate the digital die was also rejected. For Y-TZP there were statistical differences in the intimacy of fit across all measured values with direct digitization having enhanced intimacy of fit. Similar to this study, Kocaagaoglu *et al*., (2017) compared the production of zirconia copings using both a direct and indirect technique to generate a digital scan and demonstrated improved marginal adaptation for the direct digital group.[11] The authors suggested that these differences may be related to the accuracy of the cast.[11] Though, a number of systematic reviews have assessed the accuracy of fit of restorations fabricated from digital and conventional analogue impressions and have not been able to demonstrate any significant differences in accuracy of fit. [4,12-14] In this study, for CoCr, the indirect method of digitization proved to have a statistically enhanced fit for the occlusal gap measurements. This illustrates that intimacy of fit may be affected by many factors including impression type, die material, type of restoration, fabrication technique and restorative material.[12]

For both axial and occlusal gaps, regardless of impression technique, Y-TZP had an improved intimacy of fit compared to the other materials, whilst CoCr had the poorest. Despite the advances which have been made with additive technology, this illustrates that when compared to either a conventional technique or subtractive digital technique, CoCr copings fabricated using DMLS is still not equitable.[15] Nevertheless, further studies are required to better understand how tooth preparation, material used or coping thickness may influence the accuracy or intimacy of fit with restorations produced using additive manufacturing.[16]

For all groups, the intimacy of fit values progressively decreased from marginal to axial and finally to the occlusal area. This is consistent with other studies comparing these values. It is interesting that for conventional cast restorations, laboratory processes such as waxing, investing and casting have been used to explain these discrepancies.[17] Yet, with digital workflows and computer-aided manufacture, these same discrepancies exist. These differences have been ascribed to scanning imperfections and accuracy of milling devices.[11]

Amongst the methods that have been used to measure internal and marginal fit, a replica technique was chosen for this study. Limitations of this technique include accurate seating, mimicking cement with impression material, risk of rupture or tearing of the impression material and accuracy of assessing the cement space. Despite these limitations, a recent study validated the impression replica technique as a tool for evaluating fit.[18] In addition, the authors identified a higher discrepancy of fit in the 'occlusal' area. This was attributed to the silicone impression material flow. Nevertheless, under ideal conditions, an 11% positive error was detected.[18] Consequently, the discrepancies in this study between the marginal and occlusal gap may also be attributed to the same procedural limitations.

Based on the results obtained from this study, it appears that conventional materials and techniques are being superseded by digital workflows and CAD/CAM technology. The results of this study reflect the software and hardware used, as newer or different versions may result in variations. The results may not be representative of the fit values of larger, multi-unit restorations as the study investigated single copings. Whilst all new technology and materials need to undergo a development period, this study illustrates that the opportunity for utilisation of CoCr using DMLS exists. Subsequently, it can be expected that further enhancement and refinement of additive technology will offer clinicians a viable alternative to NiCr analogue production methods.

CONCLUSIONS

Within the limitations of this *in vitro* study, the following can be concluded:

1. The intimacy of fit of Y-TZP copings fabricated using a direct digital impression technique was statistically significant compared to copings fabricated from CoCr or NiCr. For all restorations produced, the marginal gap was within clinically acceptable limits.
2. When comparing the metal copings, NiCr copings fabricated using a conventional technique had a better intimacy of fit for the axial gap and occlusal gap compared to the CoCr copings fabricated using DMLS.
3. The technique used to generate the digital die (direct or indirect digitization) had an impact on the intimacy of fit. For copings made from Y-TZP, direct digitization was more effective, whilst for CoCr, the indirect method was most effective.

MANUFACTURER DETAILS

- KaVo Dental: Amersham, Bucks, UK
- Aquasil Impression material: Dentsply, Caulk, USA
- Biresin G26: Sika, Germany
- Silky-Rock: WhipMix, Louisville, USA
- Kerr Die spacer: Kerr, CA, USA
- Phosphate bonded investment: Whipmix Corp., Louisville, USA
- Schütz Dental GmbH: Rosbach, Germany
- Easy-Cast-1: Ultraflex power technologies, NY, USA

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- Renishaw DS30 non-contact optical scanner: Renishaw, Gloucestershire, UK
- Exocad DentalCAD: exocad GmbH, Darmstadt, Germany
- Renishaw's Incise DM10 Milling System: Renishaw, Gloucestershire, UK
- Renishaw AM250 additive manufacturing machine: Renishaw, Gloucestershire, UK
- Renishaw Cobalt Chrome DG1: Renishaw, Gloucestershire, UK
- Renishaw Zr100: Renishaw, Gloucestershire, UK
- Trios intraoral scanner: 3 Shape, Copenhagen, Denmark
- 3 Shape: Copenhagen, Denmark
- Wild M5-Wild: Heerbrugg AG, Switzerland
- CoolSnapPro Color: Media Cybernetics, Meyer Instruments, Houston, USA
- ImagePro Plus v4.5 software: Media Cybernetics, Cambridge, UK
- Statistical Package for the Social Science Version 24: SPSS Inc., Chicago, USA
- Microsoft Excel, Microsoft Corp., Redmond, Washington, USA

ACKNOWLEDGEMENTS

Mr Gerry Bower from Renishaw for generously supplying the zirconia copings.

Mr David Boniface for his assistance with the statistical analysis.

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