A comparative study on investment casting of dental crowns for veterinary dentistry by using ABS patterns with and without wax coating

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Abstract. The fused deposition modelling (FDM) assisted investment casting (IC) is one of the commercially established routes for fabrication of biomedical parts requiring high precision. In past two decades number of studies has been reported on use of thermoplastic and wax based FDM patterns for IC of dental crown (DC) in human dentistry. But hitherto little has been reported on comparison of Ni-Co-Cr based DC prepared by using FDM printed virgin acrylonitrile butadiene styrene (ABS) pattern and wax coated ABS pattern for veterinary patients (VP). In this work, first molar and canine teeth in left side of lower mandible of a 3-year German Shepherd male dog has been prepared by using virgin ABS and wax coated ABS patterns followed by IC of Ni-Co-Cr alloy. The result of study suggests that wax coated ABS samples-based DC has better surface hardness, grain structure, surface roughness (Ra) and controlled surface porosity thus may be used as commercial manufacturing strategy. The results have been supported with scanning electron microscopy (SEM) and energy dispersive X-ray (EDX) analysis.

1 Introduction

The fabrication of orthoses and prostheses as per the customized requirements includes selection of bio material, patient specific design and blended manufacturing processes for meeting the biomedical industry standards. Different orthoses are used for spine, knee, arm, hand/ wrist, hips, ankle, dental, cervical thoracic, diabetic shoe etc. for assisting externally and prostheses such as artificial teeth, limb, joint, artery, bone, heart valve and many other as per patient's requirement for their better life [1]. Commercially different conventional and non-conventional manufacturing techniques combined with digital modelling-based 3D printing (3DP) are being used for solving patient specific issues related to orthoses and prostheses. In case of VP, teeth are used for chewing foods, sensing and to defend themselves from any external attacks. During the life span of VP, teeth may be damaged due to any disease, traumatic condition, improper ingesting of food, fighting among them and natural wear and tear. So, these VP may require proper dental hygiene [2]. Non-conventional crown designing for VP is one of the troublesome techniques as the VP can't communicate directly. So, the combined decision of veterinarian, dentistry, VP owner play a significant role to address this issue. The dog is having eight strategic teeth. These are two canine teeth and two first

molar (M1) teeth in mandible and two canine teeth and two fourth premolar teeth in maxilla [3].

Different manufacturing processes such as computer aided design (CAD) based milling, electroforming, swaging, IC, 3DP etc. are used in fabrication of DC by using bulk of solid, liquid, wire and powder as material for humans as well as VP [4]. FDM is one of the thermoplastic filament wire fusion techniques used to fabricate simple to complex parts as per customised design requirements. In this process, a spool of wire fed to the extruder melted and passed precisely through the nozzle tip over the built platform to prepare the functional parts. The parameters like: nozzle tip diameter, wire thickness, wire melting temperature, layer height, infill geometry, air gap, density, staircase effect affects the final part properties [5]. So, the selection of parameters according to customized requirements plays an important role while designing and fabricating. The ABS is one of the biocompatible materials widely used as feed stock filament in FDM printers [6]. Lost wax IC is one of the oldest methods used for making high precision complex parts. But now a days this concept is adopted for making customized parts by using thermosetting resins and thermoplastic polymers in addition to paraffin wax, hard wax, microcrystalline wax and filler with hybridisation of CAD techniques [7]. Different types of wax are mainly aliphatic compounds having straight chain carbon atoms, whereas the resins and fillers are aromatic

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compounds having ring structured carbon atoms. The structure and composition of these compound determine key qualities such as hardness, viscosity, melting point, rheological features, congealing point, rate of expansion, contraction and setting [8,9]. Based on application, wax can be termed as runner wax, pattern wax, reconstituted reclaim wax, water soluble wax and special wax (for minute repair and finishing). Industry standard wax has been tested through drop (melting) point, ash content, congealing point, viscosity and penetration. The wax while melting in furnace undergoes subsequent phases as solid-plastic-semiplastic-semisolid-semiliquid-liquid to create cavity for casting. But the thermoplastic pattern evaporates directly at elevated temperature. After selecting specific pattern, ingate and runner material for IC, the preparation of investment is a significant phase. In this phase the parameters like powder to water concentration, mixing time, pouring height, angle of pouring, air entrapment, viscosity etc. are predominant for making of strong investment. In next phase, time of baking is important. After this, the pouring of molten metal into the baked investment in a controlled way also results the success of IC [10,11]. The literature review reveals that in past two decades number of studies has been reported on use of thermoplastic and wax based FDM patterns for IC of DC in human dentistry. But hitherto little has been reported on comparison of Ni-Co-Cr based DC prepared by using FDM printed virgin ABS pattern and wax coated ABS pattern for VP. In this work, first molar and canine teeth in left side of lower mandible of a 3-year German Shepherd male dog has been prepared by using virgin ABS and wax coated ABS patterns followed by IC of Ni-Co-Cr alloy.

2 Methodology

The methodology adopted for this work is shown in Fig.1.

Fig. 1. Adopted path for 3D printing assisted metallic DC fabrication

3 Experimentation

3.1 Development of die stone model

In this step, initially a 3-year German Shepherd male dog was selected. The left mandibular canine and M1 tooth was fixed as bench mark. The dog was given anaesthesia for impression making. A stainless-steel dental tray with calcium alginate colloidal was placed inside the mouth of dog. The veterinary doctor force the lower left jaw against the dental tray to create tooth impression [12,13]. After this the tray was removed from the mouth of dog. The dental gypsum solution was poured into the selected tooth cavities of canine and M1. After hardening, the alginate portion was cut and die stone model was restored. The marking was done on the die stone model (tooth region selected for DC making) after cross verifying with the help of micro-meter and vernier calliper. The casted die stone model is shown in Fig. 2.

Fig. 2. Die stone models of left mandibular canine (a) and M1 (b)

3.2 Virtual modelling for DC

The die stone model of left mandibular canine and M1 teeth were scanned and surface data has been generated with the help of comet LED 5M 3D scanner [14]. The surface data was further processed for 3D modelling in 3-Shape dedicated dental software. In this dental software virtual DC in the form of .STL file was stored by providing 0.6 mm crown thickness. The virtual model of left mandibular canine and M1 are shown in Fig.3.

Fig. 3. Virtual model of left mandibular canine (a) and M1 (b)

3.3 3DP of selected DC

The DC .STL files of left mandibular canine and M1 were imported into Catalyst EX dedicated software of uPrint FDM thermoplastic 3D printer. In this software, smart infill, sparse high density, ten number of copies, full scale with auto orientation were selected for printing. All the files were added into pack followed

with printing command in software, where the number of layers, printing time, consumption of model material and support material were noted [15]. The start model command was pressed on the machine. The chamber was heated up to 78°C and material temperature was elevated to 300 °C which took around 12-15 min. Here ABS was used as model material whereas polycarbonate (PC) used as soluble support material. After completion of printing, the parts were removed from the plastic platform and were put into the detergent solution for one day. The PC got dissolved in the detergent and the ABS-based actual thermoplastic DC was restored. The 3D printed thermoplastic DC were used as pattern material for IC. The thermoplastic DC fabricated by FDM printer is shown in Fig. 4.

Fig. 4. Thermoplastic DC printing in FDM printer (a) and printed DC after cleaning (b)

3.4 Metallic IC of DC

The printed thermoplastic DC as pattern was divided into two groups for IC. Four patterns (two of each canine and M1) were kept as it was and six patterns (two of each canine and M1) were coated with wax externally for final investigation of surface characteristics [16]. Then sprue pattern was attached to each of pattern and put in a water bowl. The investment solution (IS) was prepared by mixing investment powder and required amount of water with the help of a spatula. Two investment trees (with and without wax coated) were made and placed inside the respective casting rings (CR). The prepared IS was poured into the two CR separately with a proper care to avoid bubble formation. The two CR were hardened within 10-12 min. Then these CR were kept vertically downward inside the baking furnace for about 100 min. The wax and ABS present inside CR were evaporated and cavity was created inside it. Then, two CR were removed from baking furnace. The Ni-Co-Cr base dental grade bullet were melted and poured into the first CR (without wax coated) which was attached to a centrifugal casing machine. After releasing spring load, the molten metal flew into the cavities of CR centrifugally. The solidification of molten metal took around 20 min. The same molten metal pouring procedure was followed for the second CR (wax coated). Then the runner and sprue were machined and final metallic investment casted DC were restored. The IC process flow is shown in Fig. 5.

Fig. 5. ABS with and without wax coated thermoplastic DC (a), Patterns attached to sprue base well inside CR (b), CR placed inside baking furnace (c), Metallic DC after IC and gate grinding (d)

4 Result Analysis

The results were analysed for surface porosity based on ASTM B 276 standard; grain size analysis based on ASTM E 112 standard. The microhardness and electron dispersive X-ray (EDX) analysis was also carried out. The porosity, grain size, Ra and 3D rendered image-based analysis is shown in Table 1-4. Based upon Table 1-4, it has been ascertained that ABS+ wax based master pattern has less porosity (16.31%) as compared to virgin ABS (23.41%), small grain size number, less Ra value and better signature of amplitude distribution function. Hence ABS+ wax based master pattern may be considered as better option in comparison to virgin ABS.

Table 1. Porosity analysis of IC parts by using thermoplastic patterns with and without wax coating.

IC part	Porosity analysis as per ASTM B 276
Virgin ABS	
ABS + wax	

Table 2. Grain size analysis of IC parts using thermoplastic pattern with and without wax coating

IC parts	Grain size analysis as per ASTM E 112															
Virgin ABS	<table><tr><th>Field</th><th>Mean Intercept</th><th>Diameter in Micron</th><th>Grain Size</th><th>Avg. Grain area(mm.)</th></tr><tr><td>Field1</td><td>211.272</td><td>254</td><td>1</td><td>0.0645</td></tr></table>	Field	Mean Intercept	Diameter in Micron	Grain Size	Avg. Grain area(mm.)	Field1	211.272	254	1	0.0645					
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ABS + wax	<table><tr><th>Field</th><th>Mean Intercept</th><th>Diameter in Micron</th><th>Grain Size</th><th>Avg. Grain area(mm.)</th></tr><tr><td>Field1</td><td>263.3593</td><td>359.2</td><td>0</td><td>0.1280</td></tr><tr><td>Field2</td><td>265.8053</td><td>302.1</td><td>0.5</td><td>0.0912</td></tr></table>	Field	Mean Intercept	Diameter in Micron	Grain Size	Avg. Grain area(mm.)	Field1	263.3593	359.2	0	0.1280	Field2	265.8053	302.1	0.5	0.0912
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Field2	265.8053	302.1	0.5	0.0912												

Table 3. Calculated relative Ra

Table 4. 3D rendered SEM images and amplitude distribution function of metal casted DC

4.1 Mechanical (Microhardness) Test and EDX analysis

The microhardness test was conducted at 0.2 kg load on each metallic DC produced by IC. The detail of test results is given in Table 5.

Fig. 6-8 respectively shows EDX, area mapping, EDX spectrum and line mapping of Ni-Co-Cr alloy. The

elemental analysis of Ni based dental alloy is shown in Table 6.

Table 5. Microhardness test results of different DC fabricated by IC.

Microhardness tester	IC parts	Values in HV at 0.2 kg
ABS for M1	406.8
	ABS + Wax for M1	511.5
	ABS for canine	400.3
	ABS + Wax for canine	503.1

Fig. 6. EDX image at 400× of M1 metallic DC

Fig.7. Area mapped EDX analysis between Ni and Cr

Fig.8. EDX spectrum shows different components of Ni base DC

Table 6. Elements with their percentage from EDX study

Map Sum Spectrum				
Element	Line Type	Weight %	Weight % Sigma	Atomic %
Ni	K series	56.61	4.47	57.44
Cr	K series	29.06	3.36	33.29
Mo	L series	13.38	4.49	8.31
Co	K series	0.95	1.64	0.96
Total		100.00		100.00

Fig. 9. Elemental line analysis on EDX image

5 Conclusions

Following are the conclusions from this work: -

- As regards to surface hardness is concerned the microhardness values has shown greater impact on metallic DC prepared by IC with wax coating on ABS pattern.
- The Ra of DC prepared by IC with wax coated pattern is better than that of virgin ABS pattern. Similar trend was observed for amplitude distribution function.
- The grain structure of DC prepared with ABS+ wax pattern is better than that of virgin ABS pattern.
- Due to wax coating over the ABS pattern, the porosity was also improved.

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