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Relevance of Common Casting Defects in Restorative Clinical Practice

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ABSTRACT: Indirect or cast restorations are fabricated in the dental laboratory by technical staff while the restorations are placed by clinicians. Clinicians generally do hold theoretical knowledge of the casting process and casting defects but lack experience of fabrication. This hampers them from having an understanding of a particular casting defect. This article reviews the recent evidence in casting defects and implies their application in clinical practice. The aims and objectives of such a review are to allow clinicians to be in a better position to identify these defects of casting and accordingly take action. The article also presents a brief appraisal of the materials involved and their potential behaviour in causing such defects. The casting technique and the properties of the material that interact during the fabrication of indirect restorations have also been discussed.

KEYWORDS: Casting technique, investment materials, base metal alloys, noble alloys, fixed partial denture.

1 INTRODUCTION

Restorative and prosthetic dentistry, in particular, makes extensive use of cast or indirect restorations. They are created in the dental laboratory using a time-honoured casting process that follows the same principles as the ‘lost wax’ technique, which is commonly used in casting a wide variety of household and industrial objects.[1] Properly fitting dental casting is a primary goal of the casting and investment process. The likelihood of marginal leakages and secondary caries caused by the dissolution of commonly used cements increases in proportion to the breadth of the exposed cement line and the degree to which the restoration does not fit precisely.[2] Obtaining accurate casting is predicted to compensate for the thermal shrinkage of the noble and/or base metal alloys, which occurs as it cools in the investment mould. A shrinkage value of 1.4% (±0.2%) is considered a logical value for modern dental casting gold alloys, while it is more for base metal (2.25%) or non-precious dental alloys.[3] During the buildup of the wax pattern, the size of the pattern is made as such so that after it is converted into metal, which will undergo shrinkage upon cooling, it should be the exact replica of the desired prosthesis. This shrinkage of dental alloys during casting is achieved by different technical procedures that require accurate settings and control. These methods include expanding the wax pattern by thermal means, expanding the investing material during setting, investing underwater to hygroscopically expand the investment, and finally expanding the investment by using thermal means.[1,4] Another important objective is the production of dense casting with a smooth surface, as these enhance the strength of the casting and do not affect the overlying colour and translucency of bonded ceramics.[5] Internal porosity results in voids, which weaken the casting. Higher failure rates of more than 69% are as a result of mechanical failures, which in turn are dependent upon the features of the tooth preparation and degree of luting.[6] External porosity allows tarnish and corrosion to occur, posing serious difficulties for plaque removal. Biofilm deposition on restorative materials can deteriorate the material and roughen its surface, leading to bacterial infiltration at the interface between tooth structure and restorative material, resulting in secondary caries and impacting pulp pathology.[7] To obtain a high-quality casting requires a thorough knowledge of the composition elements of casting alloys and their handling characteristics and meticulous attention to the technical details of the investing and casting process, irrespective of machine being operated digitally or using artificial intelligence.[8] The importance of solidification of the metal in the molten alloy in the mould also cannot be neglected. As the casting solidifies, it first occurs in the thinner areas; it contracts, but at the same time, molten metal is continuously being fed through the sprue opening from the still molten button.[9] This ensures dense casting while eliminating the chances of inadequate casting or incorporation of porosity. The sprue solidifies, followed by the button. In this manner, any porosity will be located in the sprue and button and not in the casting.[1,3,9] Although it is true that perfect casting has never been made, dental casting procedures have progressed to an extent at which failure has become a rare exception, usually not traced following the basic principles associated with sound techniques.

Most clinicians do not hold expertise in the casting process since all castings are performed by dental technicians in the production laboratories. However, the clinicians have to decide whether the defect in the casting should be accepted or rejected, for which it is mandatory for him to reason out what will be the effects on the treatment if the defective casting is placed in the patient's mouth. Finance and time factors often influence such decisions. Chairside adjustment can be difficult and exhausting for both the patient and clinician, and it has been identified as a prevalent source of clinician irritation, resulting in the consumption of important clinical time and jeopardising patient trust.[10] In recent times, there have been some significant advancements in industrial casting processes due to digitisation of investing and casting machines.[11] A lot of focus has been on the factors that are often subjectively controlled, like expansion of the mould, with promising results.

This literature analysis aimed to thoroughly assess the trends in casting of dental restorations in recent years. The primary aim being to enhance knowledge based on new research findings, enabling clinicians to apply in practice. Different medical electronic databases [Medline, Proquest, Pubmed, Scopus, Google Scholar] were searched for material spanning from 2010 to 2024. Search terms of significance comprised: clinical study, cross-sectional, randomised, placebo-controlled, qualitative or quantitative, empirical, survey, fixed partial denture, dental casting procedures, casting investments, casting alloys, and failures related to FPD. To identify pertinent studies, two independent reviewers used a piloted review form to examine the titles, abstracts, keywords, references, and full texts.

2 Spruing of patterns

Sprue may be made of plastic, wax, or metal. A sprue is attached to the wax pattern at the other end of the crucible, into which a casting ring can be inserted. Sprue former should be at least 14 gauge (1.7mm) in diameter unless the pattern is extremely small, and sprue former up to 10 gauge (2.5mm) may be used for very large patterns such as bulky crowns.[3,5,12] Long, thin sprue formers are likely to cause internal porosity, commonly shrinkage porosity; the metal will freeze in the sprue before it freezes in the inlay or crown. Should a reservoir be used, it must have a greater bulk than the corresponding section of the design into which the sprue former is placed. The sprue former's length should be changed to let the pattern run roughly 3–6 mm from the ring's open end. If a greater thickness of investment is present, backpressure porosity may result. When investment is bulky, air cannot escape through the investment and the metal is prevented from completely filling the mould. A digitally designed casting sprue system was investigated and found to be more effective in distributing molten alloy to the casting while undergoing the solidification process.[5,13] Greater thickness of investment can lead to changes in back pressure porosity. Bulky air cannot escape through the investment; hence, the metal cannot fully occupy the mould. Ideally, the influence of poor sprue designs leads to major defects in the castings, which face rejection by the dental technicians. Therefore, these castings may not reach the dental practitioner, where he has to face the consequences or make a clinical decision. However, it has a significant impact on the accuracy of castings for major implant restorations involving multiple implants (fully bone-anchored or multiple implant overdentures).[14] Porosity when observed in the pontic can be accommodated clinically by application of a resin; however, such defects have an influence on the accuracy of the margins of adjacent retainers.[15] By adding chill vents that speed the cooling of the pontic relative to the components of the cast external to the dental unit itself, porosity can be reduced when a dental casting comprises both thick and thin pieces.[15,16] Later on, these cast extensions are taken off. Throughout the investing process, cleanliness is really important. Before making an investment, the wax design should be clean of any oil film or trash. One can lower the wax pattern's surface tension by running a debubblizer. This helps the pattern surface to moisten better. Some wax patterns are so tickled that it becomes extremely difficult to obtain a dense, non-porous casting. In such cases, a chill set may be used. It is generally a sprue former wax (18 gauge), which is attached to the wax pattern directly opposite to the larger sprue former and which terminates within the investment but close to its periphery.

It is said that molten metal going to mould goes directly to chill set, which begins to solidify first because it is small and towards the external surface of the mould.[17] This then induces solidification in the main body of the casting and causes it to freeze before the sprue. A very short sprue can produce porosity in the area of casting to which the sprue is attached since the button, which should solidify lost and therefore not be dense, is too close to the casting.[5,18] The sprue length should be adjusted so that the top of the wax pattern is within 6.5mm (1/4") of the open end of the ring for gypsum-bonded investments.[2,8,12] With phosphate-bonded investments, it may be possible to position within 3.25 (1/8") of the top of the investment.[5,13,17] For reproducibility of casting accuracy, the pattern should be placed as close to the centre of the ring as possible.[8,12] A short sprue former can also place the mould sprue in the investment so far from the end of the casting ring that gases that remain from the wax burnout cannot escape easily through the investment.[19] This may result in back pressure porosity. For this reason, the sprue former must be located about 6 mm from the open end of the ring.[8,17] With a very long sprue, it is more likely that the first pattern to solidify will be the sprue with resulting shrinkage porosity in the casting. A reservoir can be used when the length of the sprue former is such that it places the button too far from the casting.[8,12] The sprue former should be as straight as possible in order to lessen the change of excessive turbulence as the alloy enters the mold.[9] Such turbulence increases porosity. The use of two sprue formers may be advantageous for wax patterns that possess two bulky areas separated by a thinner area.[8,12] A single sprue former attached to only one of the bulky areas increases the potential for shrinkage porosity.[12,20] Since early solidification of the thin areas prevent further supply of molten alloy to the other bulky area. The attachment of the sprue former to wax pattern should be such that the transition in form from sprue former to pattern is smooth and does not possess pits or irregularities into which investment can flow investment that can be broken off and carried into the mould by the molten alloy, thus producing defects in the casting.[8,17,20] Irregularities in the sprue may also cause turbulence in the flow of the molten alloy entering the mold. When multiple units are being cast, the use of a transverse or runner bar is advocated.[8,17] The alloy enters the mould through the larger sprue former of the (8 gauge) in the horizontally positioned transverse bar (10 gauge) and finally into the sprue formers to individual units after (12 gauge).[17]

3 INVESTING MOLD

The crucible former forms the conical depression in the end of the investment mould that guides the molten alloy into the chance (left by the sprue former and on its void in which the wax pattern is located).[4,13] It may be made of rubber, metal, or plastic.[12,19] This should be free of any investment or foreign material prior to attachment of the sprue.[13] It is advantageous to coat the surface with a thin layer of petroleum jelly to prevent adherence of the investment.[17] This allows the molten alloy to pick up small particles of investment, thereby producing inclusions or voids in the casting.[8,21] The casting ring must be lined with a sheet of asbestos or ceramic paper to permit greater freedom of expansion.[8,9,12,15] If ring liner is not used, there is restriction of the expansion of the mould space, resulting in smaller casting.[15] There should be no overlap of liners. Liners always must be stabilised with sticky wax.[8,15] A liner that is 3 mm short of the open end of the ring promotes more equal expansion of the casting in the axial and horizontal directions. In the wet liner technique, the water absorbed may also assist in semihygroscopic expansion in addition to normal setting expansion. Two thicknesses encourage more setting expansion than obtained from one liner.[12,15] Ceramic liners have now replaced asbestos considering the health hazard.[13] These liners absorb less water and may result in significant incidence of fins in the castings.[22] The manufacturer's direction for any given investment should be followed carefully. A variation of 1 ml of water can significantly alter the setting expansion and also the manipulation of the investment and character of the casting surface, especially in gypsum-bonded investments.[13,15] Although increasing the water powder ratio makes investing easier, the investment will lose strength. The reduced strength may cause cracks to occur during heating, and the surface of the casting will be inferior. Therefore, water should be accurately measured in a graduated measuring cylinder and the powder weighed. The powder and water must be mixed properly to wet all particles. Mixing under vacuum is performed. The investment material must be initially painted over the wax pattern to avoid entrapping of the air.[8,22] After the casting has been filled with investment material, any excess should be removed before the material sets. The filled ring is set aside for investment material to complete its setting reaction and expansion, then placed in a burnout oven or water bath at 100 degree fahrenheit (F).[12,23] For phosphate-bonded investments, the mould cavity is increased by increasing the number of asbestos layers, using fibrous ceramic lining, increasing the special liquid ratio, decreasing the total liquid water content, hygroscopic expansion, and burning out at higher temperatures. No residual gypsum must be present, which may accelerate the set and will break down at 1300 degrees F, liberating sulphur gases that can be deterrent to casting.[13,22] Because the mixing process releases ammonia gas, it's crucial to place the combined investment in a hoover immediately afterward to release part of the gas and lessen the likelihood of bubbles sticking to the wax design.[24] Thus, bubbles may cause little spheres on the coping surface, which have to be ground. The invested pattern should rest for at least 45 minutes before burnout procedures commence. If the invested pattern cannot be burnt out within 1 hour or two, the ring should be stored in a humidor at 100% humidity.[25] To prevent excessive drying during burnout, invest the pattern in a humidor after several hours, as molten wax from the burnout process may be absorbed into the dry investment. To clean cast a ring, place it on a raised object and heat it without allowing it to cool. Place the mould in a preheated furnace at 480 degree centigrade (C) for 20 minutes, then raise to 700 degrees C for 30 minutes.[9,12,13] Avoid heating gypsum or silica investments to avoid breaking them. Gypsum-bonded investments should be heated to 468 degrees C for hygroscopic or 650 degrees C for thermal expansion, and 700 degrees C to 870 degrees C for phosphate-bonded investments.[8,12,15,22] Burnout should be done wet to prevent wax adhesion and flush wax out. High-heat technique converts carbon into gases.[8,9]

The hygroscopic low heat technique compensates for expansion through water bath expansion, warm water entering the investment mould, and causing thermal expansion. The mould can be placed in a preheated furnace for 7 hours without disintegration. To increase expansion, increase the water bath temperature to 40 degrees C, use two layers of liner, and increase the burnout temperature range.[22] The high heat technique for gypsum investments involves heating the mould to 650–700 degrees C in 60 minutes and holding it for 15–30 minutes to prevent cracking and separation.[12,17] Casting must be made immediately to prevent contamination and brittleness.[26] High heat technique for phosphate investments involves expanding the wax pattern, setting it higher than gypsum investments due to special liquids, and achieving greater thermal expansion at higher temperatures. Burnout temperatures range from 750 degrees C to 900 degrees C, with heating rates slow to 315 degrees C and rapid to complete after 30 minutes.[12,15]

Casting should be done immediately, with a time allowable of 1 minute without noticeable change in dimension. Alloy can be melted using torch flame, electrical resistance, or air pressure and then cast into the mold. The centrifugal casting machine uses a broken arm to melt metal in a crucible, increasing its rotational speed.[12,24] The heated casting ring is released, and the metal fills the mould, causing a hydrostatic pressure gradient of 30-40 pound per square inch (psi) at the tip, promoting heat transfer and solidification. The electrical resistance heated casting machine uses an automatic melting process in a graphite crucible, preventing oxidation and ensuring complete solidification from the casting ring's tip to the bottom surface.[15] The induction casting machine melts metal using an induction field in a crucible, then forces it into a mould using air pressure or vacuum.[17]

4 CASTING DEFECTS

One of the most major issues one has while developing and eliminating the design from the mouth or die is distortion. It follows from stress release and temperature changes. The tensions come from contraction on cooling, moulding, carving, removal, time, and temperature during storage.[13] Like other thermoplastics, waxes prefer to revert to their natural form following manipulation. Elastic memory is what we call it here. Thus, the pattern has to be invested right after being taken out of the preparation. As the metal cools around the wax pattern, some distortion of it results. The setting and hydroscopic expansions of the investment could cause the pattern's walls to move unevenly. The smaller the distortion, the smaller the setting expansion is. Also change the pattern's thickness to lower distortion. Although it's not a major issue, distortion explains some of the inexplicable errors in small castings.[22] While on the inside surface may preclude correct seating of an otherwise accurate casting, excessive roughness or imperfections on the outside surface call for extra finishing and polishing. Still, the technique's roughness on the casting is rather more than that of wax pattern. This variation corresponds with the investment's particle size and its capacity to replicate the wax pattern with microscopic accuracy. On the casting, air bubbles show up as tiny nodules that adhere either during or after the investing operation. Vacuum investing is the greatest way to prevent air bubbles. Care should be taken even using a manual approach to prevent including air bubbles into the investment. Regular use of a mechanical mixer and vibration before and after mixing should be followed. Preventing the gathering of air bubbles on the surface of the pattern could be achieved with the use of a wetting agent. The wetting agent should also be air dried since any extra may dilute the investment and maybe cause surface flaws on the casting. This type of surface irregularity can show up over the surface as minute ridges. Wax has no binding power over investments. A water layer may develop irregularly over the surface whenever investment material is not in close proximity to wax. A wetting agent could help to prevent such an irregularity; too high a water-to-powder ratio may also have this impact.[24]

A flaking of the investment as the water or steam flows into the mould clearly results in fins or spines on the casting or a particular surface roughness. Too rapid heating causes this. Moreover, such a surge of steam or water could contain some of the salts utilised as modifiers into the mould, left as deposits on the walls following the water evaporation. The investment-filled ring from room temperature to 700 degrees C must be heated very slowly; at least sixty minutes should elapse during this process. One should heat it more slowly the larger the bulk is.[12,22]

If the heating duration is too short or if the furnace lacks enough air, incomplete removal of wax residues results. The casting from the gases generated when the heated alloy comes into contact with carbonaceous residue may show voids or porosity. Sometimes the casting is carried with a tenacious carbon covering that pickling almost cannot remove.[8] The W: P ratio affects the roughness of casting, with higher ratios resulting in rougher investment. Accurate water measurement is crucial. Prolonged mould heating can cause disintegration and roughening, potentially contaminating the alloy. Thermal expansion techniques should be heated to 700 degrees C and cast immediately.[14,17] Molten gold should be elliptic, yellow-orange, and spin. Use a 15-20-pound or 7-9-kg pressure or 4-turn centrifuged machine.[12] The surface texture of a casting is influenced by the binder-to-quartz ratio and coarse silica. Surface roughness is not a factor if the investment meets ADA specification no. 2.[15] Sharp deficiencies indicate foreign particles, bright concavities, and sulphur contamination. A rough crucible with investment may cause roughness upon removal. Proper sprue casting involves avoiding surface roughness and glancing impacts on the investment surface. Pattern placement should be in different planes to prevent wax expansion and potential cracking. Improper torch adjustment can lead to carbon absorption, carbides, or visible carbon inclusions. Improper melting and reuse of metals can alter physical properties and reduce corrosion resistance. Contamination with copper during improper picking can cause future surface changes. Mercury contamination can cause discolouration and increased corrosion susceptibility in gold alloy restoration.

Location Shrinkage Porosity occurs when molten metal is not fully fed during solidification, causing a void in the last portion of the casting.[20] This void can occur at the sprue casting junction, between dendrites, or externally in the crown.[24] To eliminate this, flaring the sprue attachment point and reducing the mould melt differential can be done.[12] Microporosity is a defect in fine-grain alloy castings due to rapid solidification shrinkage, often seen in sectioned castings. Pin holes and gas inclusions are related to gas entrapment during solidification, with gas inclusions being larger than pin holes.[13] Larger voids may be caused by gas trapped by the molten metal or carried in during the casting process. Castings contaminated with gases are black and difficult to clean. Larger spherical porosities can be minimised by premelting gold alloy on a charcoal block and correctly adjusting the blowpipe flame. Sub-surface porosity occurs when solid grains and gas bubbles nucleate at the moment of metal freezing at mould walls. It can be reduced by controlling the metal's entry rate.[25] Back pressure porosity occurs when air in the mould cannot escape through the investment's pores. Proper burnout, mould and casting temperature, and high casting pressure can help eliminate these issues. Incomplete casting can occur due to insufficient venting of the mould and the high viscosity of the fused metal. Adequate casting pressure, applied for at least 4 seconds, is necessary to overcome back pressure and fill the mould, as it takes only 1 second.[12,22] Incomplete mould elimination can occur due to excess combustion products or wax or moisture particles. These castings are shiny and may be due to a strong reducing atmosphere. The alloy's viscosity and surface tension decrease with temperature, so raising it above its liquidus temperature prevents premature solidification.

5 Clinical applications

The implications of dental castings and their relative defects apply to all forms and designs of fixed partial denture treatments, which include customised posts and cores, single crowns, fixed partial denture designs, all implant prostheses, and removable partial dentures. In fixed partial denture treatments, the choice of restoration type and material is primarily determined by the existing natural tooth structure.[27] Alloy restorations in any form offer advantages such as excellent strength-to-volume ratios, high thermal conductivity, allowing for thin-sectioned restorations while maintaining rigidity and fracture resistance.[28] For post-core restorations using base metal alloys, the modulus of elasticity varies significantly between posts, with fibre posts having a higher value of 45.7–54.8 GPa, cast posts ranging from 178.34–198.76 GPa, and dentin posts having an average of 18.6 GPa.[29,30] Cast posts with cores should not bind within the root canal, and fitting cast post-and-core restorations is crucial for good adaptation and passivity.[31] Since cast posts are smaller in size for casting and aren't affected much by the changes in casting shrinkage, they mostly present a casting defect in the form of surface roughness, which usually binds to the prepared walls. Clinically, they are less visible with the naked eye; therefore, a clinician should use a magnifying glass to ensure that the surface is smooth. At times they also could be due to rough pattern, which is more common when using pattern resins for direct technique.[32]

Another aspect of casting defects may not be reflected if they are due to treatment plans or prosthesis designs. Such cases are long-span fixed partial dentures or implant-supported prostheses, where due to the bulk of metal used for restorations, the casting shrinkage results in marginal discrepancies.[33-35] Occlusal discrepancies are mostly due to incorrect occlusal records rather than defects in casting for either a crown or a partial denture.[36] Among other influential factors, the size and shape of the natural tooth or the abutment whose crown is fabricated should also be taken into account. Abnormal fusion of teeth results in multiple different surface anatomical features that may not be able to be replicated under ideal conditions.[37]

6 Conclusion

Casting procedures involves thorough knowledge of each individual material that participates in the process, with each material contributing sufficiently either physically of chemically to have a confounding influence on the final outcome. One cannot conclude that one variable is more important or one is important than the other. All variables influence sufficiently to effect the casting process. A dental practitioner must be in a position to point out the reasons for a poor casting by the laboratory technician.

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Conflict of interest

None

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