THE EFFECT OF VARIOUS SPRUE DESIGNS ON THE PROPERTIES OF BASE METAL ALLOY CASTINGS

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CERTIFICATE

This is to certify that this dissertation title **"THE EFFECT OF VARIOUS SPRUE DESIGNS ON THE PROPERTIES OF BASE METAL ALLOY CASTINGS."** is a bonafide record of work done under our guidance during the study period between 2003-2006.

This Dissertation is submitted to THE TAMILNADU Dr. M.G.R. MEDICAL UNIVERSITY, in partial fulfillment for the Degree of **MASTER OF DENTAL SURGERY - PROSTHODONTICS, BRANCH VI.** It has not been submitted (partial or full) for the award of any other degree or diploma.

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INTRODUCTION

The casting of dental alloys is one of the procedures to prepare various types of metallic restorations in prosthodontics. William Taggart (1907) first described the lost wax casting process in dentistry. The procedure involves the preparation of the wax patterns, spruing the wax patterns, investing and wax burn out procedures followed by ingress of molten metal into the mold. The ability of the molten alloy to completely occupy the mold created by the elimination of a pattern is defined as castability. Incomplete castability may result in deficient castings.[53]

The structural faults in a dental casting can result from any combination of problems related to spruing, investing, wax elimination, alloy melting, casting, and solidification of the casting. The defects such as shrinkage porosity, porosity due to occluded gases, porosities due to back pressure of gases in the mold, porosities due to inclusion of investment, incomplete filling of the mold prior to solidification, incomplete filling of the margins due to surface tension effects, and suck back porosities can occur resulting in unacceptable casting.[15]

Initially gold alloys were used for dental cast restorations. It was recommended to flare the sprue at the point of attachment along with large diameter sprues of shorter length to facilitate the entry of molten gold into the mold for high density gold alloys. The increased cost of precious alloys led to the use of base metal alloys, for the fabrication of metallic restorations in prosthodontics. The base metal alloys were introduced in dentistry at the early 1930's, which are mostly nickel, and chromium-based alloys.[12] The popularity of base metal alloys have evolved as an alternative to gold alloys due to various reasons such as low cost, increase in hardness, high elastic modulus and high melting range compatible with ceramic application.

The base metal alloys have a reputation for being technique-sensitive and their inherent physical and chemical characteristics make them susceptible to minor changes in the casting environment.[44] Moreover low density of base-metal alloys presents problems of castability because it allows these alloys to absorb gases more easily at the high temperatures and greater centrifugal pressure is therefore needed to cast them.[39]

The porosity and incomplete filling of the mold cavity can be avoided by the evacuation of entrapped gas from the molten metal and the mold cavity before the metal solidifies. The factors such as sprue design, type of investment material, investing procedures, burn out procedures, venting and casting procedures helps in gas elimination.

The effect of various sprue designs and their mode of attachment to the wax pattern on parameters such as, castability, porosity and density of base metal alloy castings has been studied by various researchers.[25, 31, 39, 40, 44, 53.] There are different types of sprue designs recommended by various authors to obtain improved castings with base metal alloys. While some authors[44, 53] have postulated that conical sprue designs were superior, others[3, 31, 40]recommend the use of bottle neck sprue design to create a venturi effect to obtain dense castings. Yet others,[22, 38] have not specified any particular sprue design while casting with base metal alloys. This implies that sprue design is a key and controversial variable that can affect the properties of base metal alloy castings. Castability, mass, surface texture, porosity, microstructure and abrasion resistance of the castings can influence the mechanical properties such as microhardness, abrasion resistance, tensile strength, yield strength, proportional limit, and fatigue life of the restorations during use.

Microhardness can be related to the strength, ductility and percent elongation of the cast restorations. The porosities and the altered grain structure of the cast alloy can affect the microhardness of the castings.[6] There are reports of evaluation of microhardness of base metal alloys with respect to alloy composition,[2,10] heat treatment [6, 27, 34] and casting procedures.[52] However, there is lack of data with regard to effect of different sprue designs on the microhardness of the cast alloy.

Hence this invitro study was ***aimed to*** compare the effect of three different sprue designs on the properties of castability, mass, microhardness and porosity of base metal alloy castings.

The ***objectives*** of this study were:

- To compare the ***castability*** of the castings obtained from conical, cylindrical and bottle neck sprue designs.
- To compare the ***mass*** of the castings obtained from conical, cylindrical and bottle neck sprue designs.
- To compare the ***microhardness*** of the castings obtained from conical, cylindrical and bottle neck sprue designs.
- To compare the ***porosity*** of the castings obtained from conical, cylindrical and bottle neck sprue designs.

REVIEW OF LITERATURE

The lost wax casting procedure even though considered as one of the oldest existing techniques, but the most preferred and most commonly used method for casting restorations. This mode of casting is favored for dental application because asymmetrical castings incorporating extremely fine details can be fabricated conventionally and inexpensively. Regardless of the materials used, it is invincible that the sprue design is essential till the molten alloy flow through the mold space created by the sprue.

It is mentioned by Robert G Craig in the text book of Restorative Dental Materials that the description of theophillus on metal working, that a wax sprue was disabled as being a round like slender candle and a half finger in length was attached to a funnel. The clay was utilized as the mold material and dewaxing was done on warm coal. According to him the molten metal was pored through the funnel when the mold was hot.

Philbrok (1897) introduced the casting process to the dental profession.

William Taggart (1907) first described the lost wax casting process in dentistry and that the restorations of undersized.

Elwood Haynes (1910) succeeded in alloying chromium, cobalt, molybdenum and Tungsten to produce a series of hard corrosion resistant alloys.

Erdle RW, Prange CH (1933) introduced nickel **-** cobalt – chromium base metal alloy for use in dentistry.

Asgar K, Peyton FA. (1959)[4] investigated the factors such as sprue gauge, length and direction, single or double sprues, pressure of casting machine, amount of gold, and flaring of the sprues and there effect on the pits and voids on the inner surface of gold crowns and he concluded that by increasing the casting pressure, amount of gold, and sprue diameter and by employing proper sprue direction and length tend to reduce the number or eliminate completely these pits. Flaring of the sprue may act like a reservoir close the wax pattern and it may facilitate the flow of molten alloy into the mold cavity.

Moffa J *et al* (1973)[32] evaluated the physical properties of non precious alloys for use with porcelain veneers and concluded that the value for hardness, rigidity, resistance to permanent deformation, sag resistance, and bond strength to porcelain of the nonprecious alloys were significantly greater than those of the gold based alloys.

Fusayama T, Yamane M (1973)[22] investigated the surface roughness of castings made by various casting techniques and he concluded that the roughness of the general areas as well as the area of the especially rough parts were smallest with the stream-pressure casting, small with the air-pressure casting, and greatest with the centrifugal castings.

Vincent PF, Stevens L, Basford KF (1977)[54] compared the property of castability for certain precious and non precious ceramic alloys by measuring pattern reproducibility over a selected range of diameter. The patterns were made using nylon fishing line. Completeness of the casting is affected by factors other than the properties of the alloy being cast. Probably the most significant of these is casting force.

And he concluded that the alloys tested varied with respect to their castability. This variability is related to density. Problems caused by low density by increasing the casting force.

Eugene F Huget, Jesus M Vlica, Richard M Wall (1978)[21] investigated the characterization of two ceramic- base- metal alloys, and studied their compositions, microstructures , properties and heat treatment characterization and reported that they had significant compositional and structural differences.

Howard WS, Newman SM Nunez LJ (1980)[26] a test pattern composed of 14 gauge sprue wax and various gauges of nylon lines was constructed, and used to differentiate the castability of several alloys. The castability of seven commercial low gold content alloys for porcelain fused to metal restorations was compared. Five commercial low gold content yellow alloys for full cast restorations were compared to each other and to a Type III certified control.

Mc Lean J (1980)[31] advocated large diameter sprue that tapered to a cone of half the sprue diameter at the attachment to the wax pattern. And he concluded that a constricted sprue attachment increases the velocity of the molten alloy entering the mold space by creating a Venturi effect at the point of entry and there by improving the density of the casting.

Duncan JD (1980)[19] reported that the marginal discrepancy of four Ni-Cr alloys was generally greater than that of an Au-Pt-Pd alloy (Jelenko “O”). Omega and Microbond N/P2 exhibited marginal discrepancies ranging from 0.25mm to about 0.70mm. Ultratek, a Ni-Cr-Be alloy, demonstrated discrepancies ranging from approximately 0.12 mm to 0.33 mm compared to a range of from 0.04mm to 0.19mm for Jelenko “O”. The relatively poor performance could be due to inadequate mold expansion, poor castability or a combination of these factors.

Howard WS, Newman SM, Nunez LJ (1980)[26] evaluated castability of seven commercial low gold content alloys for porcelain fused to metal restorations was compared. A test pattern composed of 14 gauge sprue wax and various gauges of nylon lines was constructed, and used to differentiate the castability of several alloys. Five commercial low gold content yellow alloys for full cast restorations were compared to each other and to a Type III certified control.

Wight TA, Grisius RJ, Gaugler RW (1980)[58] evaluated three variables affecting the casting of base metal alloys. All the vented samples with sprue widths of 2 mm or more were defect free, whereas the corresponding unvented samples had extensive voids and porosity in all but one casting. All castings with a sprue width of 1 mm were defective regardless of whether or not vents were used. The thickness of the investment above the pattern had no effect on casting results.

Presswood RG *et al (*1980)[41] demonstrated that nickel chromium alloy can be accurately casted and recovered without undue technical adaptation and /or difficulty. They also showed that they had smooth surface character on recovery and demonstrated to bond to porcelain.

Barreto MT, Jon Goldberg A, Nitkin DA, Mumford G, (1980)[8] evaluated several commercially available phosphate-bonded investments and their influence on the quality and completeness of castings made from a high-fusing precious metal and three base metal alloys.

Hesby DA, Kobes P, Garver DG, Pelleu GB Jr. (1980)[23] compared the physical properties of non-precious alloys after repeated casting without the addition of any new alloy. The tensile strength, percentage of elongation, and hardness properties were determined and compared. There were no significant differences observed in the physical properties tested among any of the four generations of casting. This finding indicates that the metal can be reused for at least four generations.

Ogura H, Raptis CN, Asgar K (1981)[37] evaluated six variables that could affect the surface roughness of a casting were investigated. The variables were (1) type of alloy, (2) mold temperature, (3) metal casting temperature, (4) casting machine, (5) sandblasting, and (6) location of each section. Higher mold and casting temperatures produced rougher castings, and this effect was more pronounced in the case of the base metal alloy. Sandblasting reduced the roughness, but produced scratched surfaces. Sandblasting had a more pronounced effect on the surface roughness of the base metal alloy cast either at a higher mold temperature or metal casting temperature. Other variables such as sprue positioning, number of sprues, thickness of the wax pattern, and other types of casting machines should be investigated.

Vaidyanathan *et al* (1981)[50] evaluated the correlation between macroscopic porosity location and liquid metal pressure in centrifugal casting technique. And he concluded that macroporosity is primarily shrinkage porosity. The portion of a casting that solidifies last is the low pressure side of the liquid metal close to the free surface of the button, and therefore the macroporosity always appears in that portion of the casting, but this porosity can be reduced or eliminated by providing a reservoir contiguous or close to the low pressure end of the liquid metal thereby displaces the shrinkage porosity to the reservoir.

Antti Yli-Urpo, Elina Uusalo (1982)[2] investigated the microhardness of three high-fusing alloys at the metal/porcelain interface and centrally in the fused specimen during different stages of alloy preparation. Low hardness values at the porcelain/metal interface area were a notable characteristic of the Au-Pt-Pd alloy. Only slight differences in hardness were found between the center and the edges in each of the alloys.

Duncan JD (1982)[19] investigated the casting accuracy of four nickel-chromium alloys and a commercial precious alloy widely used for porcelain application. He concluded that nickel-chromium alloys did not cast as consistently as precious alloy. And he also stated that alloy composition and technique parameters may also influence the accuracy of the casting.

Eugene F Huget, Vermilyea SG (1982)[21] studied the properties, heat treatment characteristics, composition and microstructure of three low-gold dental alloys. Laboratory evaluation of the properties of these test materials suggest their potential use in fixed prosthodontics.

Presswood RG (1983)[42] investigated the castability of multiple recast of a nickel chromium beryllium alloy and found that the alloy was sufficiently stable to consummate multiple castings, assuming that the ultimate composition should be considered the same as that of the original alloy.

Baran GR. (1983)[7] reviewed the metallurgy of Ni-Cr alloys for fixed prosthodontics. Relationship among composition and microstructure, mechanical properties, handling, and indications for these alloys were reviewed. He concludes that Ni- Cr alloys continue to be an important part of dental restorative material.

Mc Lean JW (1983)[31] the sprue system is affixed to the sprue base with periphery wax and this connection is shaped into the form of a venture. It is secured with minimum of sticky wax.

Robert Kelly J, Rose TC (1983)[45] reviewed the nonprecious alloys for use in fixed prosthodontics on the constituents, physical properties, biocompatibility, porcelain bonding and corrosion resistant. The physical properties of nonprecious alloys differed significantly from those of alloys containing a high percent of gold. Toxicity of nickel, and beryllium and allergic contact dermatitis appears to be a health risk to certain patients from nickel containing prostheses. On four year studies on corrosion resistant found that the corrosion is very little for the nonprecious alloys obtained from various studies.

Vermilyea SG, Kuffler MJ, Tamura JJ. (1983)[51] evaluated the effect of investment material the casting accuracy of five base metal alloys was evaluated. Overall, the fit of the test castings was poor. Individual alloy-investment interaction appears to be significant. Although marketed for use with base metal alloys, it appears that investment manufacturers' recommended techniques require alteration to enhance the fit of base metal restorations.

Moffa JP *et al* (1984)[33] investigated the clinical evaluation of two base metal alloys and a gold alloy for use in fixed prosthodontics for a period of five years and reported that the clinical performance of certain base metal alloys was found to be quite similar.

Compagni R, Faucher RR, Yuodelis RA (1984)[15] investigated the effects of various sprue designs, casting machine, and heat sources, on casting porosity with five popular spruing techniques four widely used casting machines, and various heat sources.

Sheldon Winkler, Harold F Morris, John M Monterio (1984)[48] studied the changes in mechanical properties and microstructure following heat treatment of nickel – chromium base alloy and found that heat treatment produced changes in percentage of elongation , modulus of elasticity and hardness of the base metal alloy.

Anusavice KJ, Kaminski RA, Okabe T, Morse PK, Casteel PE (1985)[3] investigated the effects of remelting and casting procedures on castability with repeated melting. And he concluded that silver-palladium alloys exhibited lower castability values compared with the type 3 gold alloy and the silver-indium alloy.

Asgar K, Arfaei AH (1985)[5] evaluated the castability of five casting machines and four casting alloys. The casting machines used included one broken arm unit, one induction unit, one resistance unit, and two vacuum air pressure units. The alloys included one base metal alloy, two high-fusing noble metal alloys, and one type III gold alloy. Results of analysis of variance showed that at the 95% confidence level there was a significant difference among casting machines and alloys, the casting machines had a stronger effect on castability.

Hinman RW, Tesk JA, Parry EE, Eden GT (1985)[24] evaluated the effects of technique variables on the fit of FPDs and concluded that the bench-set technique and an all-wax sprue system produced the least distortion and highest consistency in the fit of multiple-unit FPD castings.

Hinman RW *et al* (1985)[25] developed and tested a technique for characterizing casting behavior of dental alloys. The method employs easily reproducible specimen patterns and uses equipment and procedures generally available in dental prosthetic laboratories. A castability value is arrived at by counting complete segments of a cast alloy grid.

Donald R Nelson ***et al*** **(1986)**[17] investigated the expediting the fabrication of a nickel – chromium alloy and reported the conventional burnout is 2 to 3 hours from room temperature to 1350o F, plus a heat soak period of 1 to 2 hours at 1350 ^{o} F. The total burnout time can be as long as 5 hours. The substantially reduced by placing the invested waxed framework directly into an oven preheated to 1350^{0} F for 1 to 11/2 hours.

Peregrina AM, Rieger MR (1986)[39] evaluated six sprue designs used in making high-palladium alloy castings to determine which, if any, could be used to produce more complete castings with a high-palladium alloy. A standardized mesh test pattern was used to ensure objective measurements and accurate evaluations of the spruing techniques. In his study of problems usually encountered when casting high-palladium alloys found that: Differing sprue designs effect significant differences in obtaining complete castings (p less than .05) as indicated in the ANOVA. The connection between the casting and the sprue should be constricted to improve castability of high-palladium alloys.

Nelson DR ***et al*** **(1986)**[35] reported the effect of recasting in the physical properties of nickel chromium alloy with addition of new alloy to the used alloy. The properties of yield strength, tensile strength, modulus of elasticity percentage of elongation and micro hardness were evaluated up to 10 generations and they concluded that the mean value exceeded the minimum ADA specification.

Rieger MR, Tanquist RA, and Vainer S. (1986)[44] examined a conical sprue and its benefits over the traditional sprue and the reservoired, cylindrical sprue, and its effect on casting base-metal alloys. And he concluded that the conical sprue design was superior over the traditional sprue design. No specific pattern to the casting incompleteness for either the control or experimental group was apparent. The surface texture of all castings was smooth.

Verrett RG, Duke ES (1989)[53] investigated four sprue attachment designs-straight, flared, abrupt constriction, and gradual constriction. It has been postulated that constricted sprue attachment increases the velocity of the molten alloy entering the mold space by creating a Venturi effect at the point of entry, thus improving the density of the casting Standardized wax copings simulating complete veneer metal ceramic crowns with knife-edge margins were sculpted on refractory investment dies, sprued, invested, and cast with Olympia alloy. Castability is the ability of the molten alloy to fill the mold space. Incomplete castability may result in incomplete cast crown margins, which lead to secondary caries, periodontal and esthetic problems. It can also affect the structural durability of the restorations. Castability has been evaluated with customized mold forms such as spring like coils, nylon line projections, filaments and fibers, flat rectangular patterns, saucer-shaped patterns, mesh grid patterns, and wedge-shaped patterns; of this castability was more easily accomplished with the mesh grid The specimens were embedded, sectioned, and polished. Castability was analyzed by measuring the width of the cast meniscus of the margins. The margin widths of the flared and the straight sprue attachment groups were significantly less than the abrupt or gradual constriction attachment group (p less than 0.05). Photomicrographs revealed discernible differences in the relative quantity and location of porosity in the sprue-coping junctions. The straight and flared sprue attachment groups were less porous than the abrupt or gradual constriction groups (p less than 0.01). Flared and straight sprue attachments optimized castability and minimized porosity.

Peregrina A, Schorr BL (1990)[40] Compared the effects of three sprue designs on the internal porosity in crowns cast with a silver-free high-palladium alloy. The designs evaluated consisted of: (1) a cylindrical sprue, (2) a cylindrical sprue with a reservoir, and (3) cylindrical sprue with a constriction at the point of attachment with the pattern. The basic principle involved in using a tapered or constricted sprue attachment design is that, the point of entry of molten alloy is narrowed so that metal can flow into the casting with a minimum of turbulence. Minimum turbulence of the alloy leads to reduced porosity and therefore a higher density casting He concluded from his study that a constricted or tapered sprue design casts as well or better than a cylindrical design with a flare at the point of attachment and a cylindrical sprue with a reservoir.

Morris HF (1990)[34] compared the mechanical properties of seven metal ceramic alloys in as-cast and heat-treated conditions resulted in significant differences. The alloys that were tested included seven cobalt-chromium metal ceramic alloys. Mechanical properties include strength, elongation, modulus of elasticity, and micro hardness randomly selected for heat treatment with the Ceramco technique. Results indicated that the tested alloys had similar mechanical property values as a group in both the as-cast and the heat-treated conditions. The heat treatment had little effect on the cobalt-chromium alloys, although several did become significantly harder. The high value of hardness and the low percent of elongation would make these alloys difficult to handle clinically.

Veronesi GS, Consani S, Ruhnke LA. (1992)[52] investigated the influence of air/gas, and electric casting methods on the surface micro hardness and crystalline formation of three aluminium-copper alloy was verified and he concluded that the surface micro hardness of the alloys was modified according to the heat sources used, and the crystalline grain deposition was also adversely influenced by the heat sources, with the exception of goldent alloy.

Bailey JH (1993)[6] evaluated the effect that the two-piece post and core casting had on the microhardness of the completed post and core. Microhardness can also be correlated to the strength, ductility, and percent of elongation of the castings and is representative of the microporosity and grain structure of the alloy. And he concluded that there was no significant difference between the microhardness of post and cores made with the two-piece or one-piece casting techniques.

Alex Wen Cheng King *et al* (1994)[1] compared the surface hardness of machine milled titanium and cast titanium, and the surface hardness profile of a gold-palladium alloy, a nickel chromium alloy. Five specimens of each group underwent one of three treatments: (1) no heat treatment, (2) a standard heat treatment, or (3) an extended heat treatment. Knoop hardness values were determined. Results indicated that the Knoop hardness of cast titanium was less than that of the cast titanium extended treatment group. Knoop hardness of milled titanium was less than that of the milled titanium standard treatment and milled titanium extended treatment groups. For the surface hardness profile, cast titanium showed a decreasing surface hardness as the distance from the surface of the specimen increased. No such tren was identified for the other groups tested.

Chan D, Guillory V, Blackman R, Chung KH (1997)[14] measured the effects of the sprue number and position on the roughness and porosity of cast titanium crowns. The results indicate the roughness value of the occlusal third of the crowns for the single sprue group (Ra = 3.0 +/- 0.9 microns) was significantly higher than other measurements ($p < 0.05$). There were statistically significant differences in values of porosity areas between the single sprue group (1.5 +/- 0.7 mm2) and the double sprue group (0.2 +/-

0.2 mm2) ($p < 0.01$). The double sprue design resulted in a relatively smoother casting surface and less internal porosity than the single sprue design. And he concluded that the reduced degree of roughness and porosity of titanium crown castings were the result of the double sprue design.

Watanabe I *et al*. (1997)[57] investigated the influence of heat treating on the strength properties of soldered joints of two gold alloys (NC Type 4 and Sofard), which can be age hardened at intraoral temperature. The hardness values of Sofard significantly ($p<0.05$) increased during aging at 37^{o}C and produced adequate strengths of the soldered joints, especially with the harder solder. The results of this study indicated the possibility of strengthening soldered joints in the oral environment, thus eliminating the necessity for any additional hardening heat treatment.

Bezzon OL, de Mattos Mda G, Ribeiro RF, Rollo JM. (1998)[9] verified the effect of beryllium on the castability and resistance of ceramometal bonds in nickel-chromium alloys. In their study the amounts of chromium, manganese, and niobium were maintained, the variations in the amounts of beryllium allowed the estimation that Be-containing alloys presented better castability than Be-free alloys. The 0.9% Be-containing alloy demonstrated higher resistance of the ceramometal bond than the Be-free alloy.

Galvin M, Bagby M. (2000)[22] the amount or mass of a material in a given volume is the density of the material. The higher density of most metal objects makes them feel heavy. Density depends on the type of atom present, (as the atomic number increases, so does the density) the packing together of atoms and molecules and the voids present in the material

Bezzon OL, de Barros C, de Almeida Rollo JM, Di Lorenzo (2001)[10] investigated relationship between the hardness and abrasion resistance of two base metal alloys used for metal-ceramic restorations and found no significant correlation between hardness and mass loss for either alloy.

Bezzon OL, Ribeiro RF, Rollo JM, Crosara S (2001)[11] investigated the castability and resistance of ceramometal bonding in Ni-Cr and Ni-Cr-Be alloys. They compared fundamental properties for the clinical use of Ni-Cr alloys, determining the advantage of the addition of beryllium, despite the involved risks and they concluded that the presence of Be in Ni-Cr alloys was not necessary to guarantee the castability and the ceramometal bond resistance of the alloys tested.

O' Brien WJ (2002)[38] the purpose of spruing the wax pattern is four fold: a. To form a mount for the wax pattern and fix the pattern in space so a mold can be made. b. To create a channel for elimination of wax during burnout. c. To form a channel for the ingress of molten alloy during casting. d. To compensate for alloy shrinkage during solidification.

Wataha JC (2002)[55] reviewed the bio compatibility property of a casting alloy. Systemic and local toxicity, allergy, and carcinogenicity all result from elements in the alloy being released into the mouth during corrosion. Little evidence supports concerns of casting alloys causing systemic toxicity. The occurrence of local toxic effects adjacent to the alloy primarily because local tissues are exposed too much higher concentrations of released metal ions. Several elements such as nickel and cobalt have relatively high potential to cause allergy, but the true risk of using alloys containing these elements remains undefined. Several elements in casting alloys are known mutagens, and a few such as beryllium and cadmium are known carcinogens in different chemical forms.

Rambhia SK, Nagy WW, Fournelle RA, Dhuru VB (2002)[43] examined hexed gold prosthetic screws for internal defects and determined the effect of these defects on tensile strength. Metal fatigue is recognized as a common cause of structural failure under repeated loads. Stress raisers are defined as discontinuities in structures/ materials that cause stress concentration. Metallurgical stress raisers, which can occur in the form of porosity or inclusions, may reduce fatigue life or even initiate fatigue. Their presence at or near the surface often initiates fatigue failure. The occurrence of porosity and/or inclusions below the surface may initiate fatigue if the loading conditions are appropriate. Reduction or elimination of these defects may minimize fatigue failure and consequent fracture of the casting. The microstructure, microhardness, and major constituent of the alloys were determined. There were no significant defects in the screws tested, but differences were observed in the microstructure, microhardness, alloy composition, and fracture load values between manufacturers. The results of this suggest that variability in the physical properties of similar hexed gold prosthetic screws made by different manufacturers, as well as different lots from the same manufacturer, may affect the clinical success.

Bezzon OL, Pedrazzi H, Zaniquelli O, da Silva TB (2004)[12] assess the surface roughness of 2 base metal alloys, submitted to different casting techniques, to determine the influence of surface roughness on loss of mass after polishing compared to commercially pure titanium castings. And he concluded that the base metal alloys submitted to vacuum casting showed decreased surface roughness, similar to that of titanium, compared to base metal alloys submitted to acetylene-oxygen flame casting. There were no significant differences in loss of mass after polishing for all tested specimens.

MATERIALS AND METHOD

This study was conducted to compare the efficacy of 3 sprue designs on the castability, mass, microhardness and porosity of base metal alloy castings.

The following materials were used for the study:

- Prefabricated, wax mesh pattern (BEGO, Germany) (Fig. 1).
- Pattern Resin (GC Corporation, TOKYO, JAPAN) (Fig. 5).
- Colloidal Silica. (Investment BS Liquid 1, Heraeus Kulzer GmbH, Germany) (Fig.13a).
- Phosphate bonded investment (MOLDAVEST exact, Heraeus Kulzer, GmbH, Germany). (Fig.13b).
- Base metal nickel chromium alloy (HERAENIUM-S, Heraus Kulzer, GmbH, Germany) (Fig.17).

The testing equipments used in the study included the following:

- Physical balance (Mettler Tolledo Digital Weighing Machine, Co., OHIO, U.S.A.) (Fig.22).
- Microhardness tester (Reichert Microhardness tester, Reichert, AUSTRIA) (Fig.27).
- Quantimet Image Analyzer (Quantimet Corp., LONDON., ENGLAND) (Fig.30).

METHOD

The study included the following procedures:

- Selection of test sample, design and specifications.
- Specifications for the 3 test sprue designs and their fabrication.
- Attachment design of the acrylic sprue patterns to the wax mesh pattern.
- Casting and retrieval of the test samples.
- Evaluation of the properties of the test samples obtained from the 3 different sprue designs.

SELECTION OF TEST SAMPLE, DESIGN AND SPECIFICATIONS:

- A prefabricated, wax mesh pattern (BEGO, Germany), was selected for the fabrication of the alloy test samples in the study. (Fig 1)
- The square wax mesh pattern measured 16mm x 16mm, that provided 6 x 6 square shaped spaces. Each square measured 1.5mm x 1.5mm with 1 mm diameter wax cross filaments between the squares. Thus a wax mesh pattern with a total of 36 squares per mesh pattern was cut out from the ready made wax mesh pattern. (Fig 2).

- Ten wax mesh patterns were randomly assigned to each of the 3 test sprue designs to obtain a total of 30 wax mesh patterns for the fabrication of test samples.

SPECIFICATIONS FOR THE 3 TEST SPRUE DESIGNS:

The 3 test sprue designs selected for this study were:

1. Cylindrical sprue design with a length of l0mm and diameter of 1.5mm. (Fig 3 a)
2. Bottle neck sprue design with a length of 9mm, and a diameter of 1.5mm, and with a 1mm long taper at the attachment end to obtain the bottle neck sprue design. (Fig 3 b)
3. Conical sprue design with a base of 5mm, length of 9mm and with a 1mm long and 1.5 mm diameter cylindrical extension at the attachment end. (Fig 3 c).

To obtain standardized test sprue patterns, a two-part stainless steel mold was fabricated, with three separate mold cavities corresponded to the selected sprue designs. (Fig 4)

PATTERN FABRICATION:

- A thin coat of separating medium was applied on all the sides of the metal die. Pattern Resin (GC Corporation, TOKYO, JAPAN) (Fig 5) was mixed and poured in to all the mold cavities of the metal die.

- The 2 compartments of the metal die were positioned and uniform pressure was applied using the bench press.
- The excess flash outside the metal die was removed and the material was allowed to set. After the resin was polymerized, the 2 compartments of the metal die were separated and thus the acrylic patterns for the 3sprue designs were obtained. (Fig 6)
- In this manner, 10 resin sprue patterns were made for each of the 3sprue designs to be used for the study.

ATTACHMENT OF THE RESIN SPRUE PATTERNS TO THE WAX MESH PATTERN:

The resin sprue patterns were attached to the mesh pattern each by placing a corner of the mesh square against the center of one end of the sprue. Molten, sticky wax was added to the end of the sprue, flowing it into and filling the square – shaped corner space. The attachment area between the wax mesh pattern and the sprue patterns varied for the 3sprue designs.

The different attachment designs to the wax mesh pattern were as follows:

- The cylindrical sprue design was connected to the mesh pattern with a ***straight attachment***. (Fig 7)

- The bottle neck sprue design it was connected to the mesh pattern with a ***constricted attachment***. (Fig 8)
- The conical sprue design it was connected to the mesh pattern with a ***flared attachment***. (Fig 9)
- In this manner, 10 samples for each of the 3 different sprue designs were prepared for the casting procedure.

CASTING AND RETRIEVAL OF THE TEST SAMPLES:

- The sprue pattern along with the wax mesh pattern was attached to the crucible former. (Fig 10)
- An aerosol surface-tension reducer was applied to the pattern. (Fig 11a)
- Casting ring (Fig 11b) was lined with one layer of casting ring liner. (Flex vest liner, Ivoclar Vivadent) (Fig 11c)
- The casting ring was then positioned on the crucible former (Fig 12)
- Phosphate-bonded investment (Moldavest, Heraeus Kulzer) (Fig 13b) was mixed with colloidal silica (INVESTMENT BS 1 LIQUID, Heraeus Kulzer), (Fig 13a) according to the manufacturers specifications for 60 seconds in a vacuum mixer (Whip Mix. Inc. Co. U.S.A) (Fig 14) and carefully poured into the casting ring and allowed to set for 60 minutes.
- The casting ring was placed in muffle furnace (Bego Inc., Co. Germany) (Fig 15) at 23^{o} C and was heated till 270^{o} C at the rate 8^{o} C per minute and was kept on hold for 30 min, and then, heated from 270^{0} C to 950^{o} C

at the rate of 8^{o} C and kept at hold for 30 min for the complete elimination of the resin from the mold space.

- Once the recommended temperature was reached, the casting ring was removed from the muffle furnace and transferred to the induction casting machine.
- An induction coil crucible assembly (Bego Inc. Co., Germany) (Fig 16) was used for the casting procedure, which eliminated the carbon contamination of the metal.
- One ingot of nickel-chromium alloy (HERAENIUM-S Heraeus Kulzer, GmbH, Germany.) (Fig 17) was used for each casting. Once the recommended casting temperature of 1500 ^{o} C was reached, the casting arm was released and rotated for 30 seconds and the molten alloy was forced into the investment mold by centrifugal force.
- Following the casting procedure, the casting ring was allowed to bench cool.
- The cast samples were then divested and sandblasted (Fig 18 a) using 50 microns aluminum oxide, (Fig18 b) at a 45^{o} angle to avoid particles being embedded in the alloy sample.
- In this manner, 10 test samples for each sprue design were obtained for the evaluation of the properties.

EVALUATION OF THE PROPERTIES OF THE TEST SAMPLES OBTAINED FROM THE 3 DIFFERENT SPRUE DESIGNS

The following properties were evaluated:

A. Castability

B. Mass

C. Micro hardness

D. Porosity

A. Castability

- The cast mesh patterns were **first** evaluated for castability.
- The castability values were attributed to the samples by counting the number of complete segments of the cast grid, which indicated the accuracy of the alloy to reproduce the details of the pattern. (Fig 19).
- The test samples were evaluated to record the number of 6 x 6 square shaped spaces with a total of 36 squares per mesh pattern, and the 1 mm diameter cross filaments between the squares. (Fig 20)
- Based on the number of complete segments obtained from each cast mesh pattern, the castability was interpreted as percentage castability.
- All the test specimens; i.e. 10 each obtained from the 3 test sprue designs were evaluated for the property of castability.

B. Mass

- **After** the evaluation of the **castability**, the test samples were evaluated for the **mass** of the cast mesh pattern.

- The mesh portions of the castings were separated from the sprue with a fine carborundum disk (25mm x 0.6mm), by carefully following the contours of the casting. (Fig 21)
- The area of attachment was completely removed to eliminate mass variation, which could affect the weight of the castings.
- The mass of each cast mesh pattern was then measured using a physical balance (Mettler Toledo weighing machine Co. OHIO. U.S.A.) (Fig 22) (Accurate to 0.0001 grams).
- All the test samples; i.e. 10 each obtained from the 3 test sprue designs were evaluated for the property of mass and the results were noted.

C. Micro hardness

- **After** the evaluation of the **mass**, the test samples were evaluated for the **microhardness** of the cast mesh pattern.

I. Preparation of the test samples for determination of micro hardness:

- The cast mesh patterns were specifically prepared to enable the evaluation of micro hardness.
- All the cast mesh patterns obtained from the 3 different sprue designs, were individually embedded in a PVC ring with a diameter of 1 inch with self cure clear acrylic resin) DPI RR cold cure Dental products India Ltd) (Fig 23) (Fig 24).
- After embedding, the mesh samples were polished in 2 stages.

I stage:

- The sharp edges and scratches which were present on the embedded metal samples were removed by polishing.
- Polishing was done using a mechanical polisher (Vibron Polisher, Chennai, METCO) (Fig 25), which consists of a rotating disc fixed with carborundrum papers of different grain sizes.
- These polishing procedures were done sequentially, which consists of rough polishing followed by fine polishing.
- The following finer abrasive papers were used successively for polishing under dry conditions:
    - For rough polishing: 120, 220, 320, 400 & 600.
    - For fine polishing: 1/0, 2/0, 3/0, & 4/0.

II stage:

- The final approximation to a flat scratch free surface was obtained by using another mechanical polisher (Bainpol polishing, Chennai, METCO) (Fig 26)
- It consists of a wet rotating wheel covered with a special linen cloth.
- Alumina powder of 0.3 microns was used as polishing abrasive.
- After the test samples were subjected to polishing, they were washed with running water and air dried.

  - All the samples obtained from the 3 different sprue designs were subjected to micro hardness tests.

II. Evaluation of micro hardness of the castings:

- Vickers microhardness test was employed for the evaluation using a micro hardness tester (Reichert Polyvar 2 Met Microhardness tester, Reichert, AUSTRIA). (Fig 27)
- Micro hardness was determined at nine selected sites on each of the test sample. (Fig 28).
- The micro hardness tester was equipped with a 136^0 diamond indenter with a square pyramidal face, and was forced into the embedded test samples with a force of 150 grams for 5 seconds.
- After the indenter had been withdrawn, the dimensions of the indentations all the nine sites were calculated for each of the test samples, based on which the micro hardness were calculated.(Fig 29)
- The micro hardness values were obtained for the test samples as Vickers Hardness Number (VHN).
- All the test samples; i.e. 10 each obtained from the 3 test sprue designs were evaluated for the property of microhardness and the results were noted

D. Porosity

- The test samples which were subjected to micro hardness tests were then analyzed for porosity.
- They were analyzed for porosity at 400 X magnification using a Quantimet Image Analyzer (Quantimet Corp., LONDON., ENGLAND). (Fig 30)
- The same nine sites which were used for testing the micro hardness were selected for the analysis of porosity of the test samples. Each analyzed site covered an area of approximately 0.39mm^2.
- The mean amount of porosity from all the analyzed sites for each test sample of bottle neck, conical and cylindrical sprue designs was calculated as a percentage of porosity. Porosity at a test site in the pattern obtained with cylindrical, conical and bottle neck sprue design as observed with Quantimet Image Analyzer (Fig 31a, b, c.)
- Thus each of the 10 samples obtained from 3 test sprue designs were analyzed for porosity.

The results obtained by the evaluation of castability, mass, micro hardness, and porosity for all the test samples obtained with the three test sprue designs were tabulated and statistically analyzed and compared.

RESULTS

The basic data obtained by the evaluation of castability, mass, micro hardness, and porosity for all the test samples obtained with the three test sprue designs were tabulated and statistically analyzed and compared. These are described sequentially.

Castability:

Table I shows the results obtained with the three test sprue designs for **percentage castability.** The results of this study indicated **complete castability** for all the three test groups as was confirmed by the counting method.

Graph I shows the bar diagram representing the ***mean percentage castability of the three test groups.***

Mass:

Table II shows the basic data obtained in this study for the **mass (gm)** of the test samples obtained from the 3 test sprue designs.

Table V shows the **statistical analysis** of the **mean mass** with the standard deviation for the test samples obtained by ANOVA method. The samples obtained by the **bottle neck sprue design** had a **mean mass** of **0.90 gram** with a **standard deviation** of **±3.14**, those obtained by the **conical sprue design** had a **mean mass** of **0.89 gram** with a **standard deviation** of **±3.18** and those obtained by the **cylindrical sprue design** had a **mean mass** of **0.88 gram** with a **standard deviation** of **±3.09**. The **test of significance**

indicates that the **p value** is **0.612**, which is ***statistically insignificant*** (p< .05).

Graph II shows the bar diagram representing the ***mean mass values of the three test groups.***

Microhardness:

Tables IIIa shows the **micro hardness values (VHN)** of the test samples obtained from the **conical sprue design**.

Tables IIIb shows the **micro hardness values (VHN)** of the test samples obtained from the **bottle neck sprue design**.

Tables IIIc shows the **micro hardness values (VHN)** of the test samples obtained from the **cylindrical sprue design**.

Table VI shows the **statistical analysis** of the **mean values** with **standard deviation** for the **mean micro hardness (VHN)** of the test samples obtained by ANOVA method. The samples obtained by the **bottle neck sprue design** had a **mean microhardness** of **311.7 VHN** with a **standard deviation** of **±22.1**, those obtained by the **conical sprue design** had a **mean microhardness** of **286 VHN** with a **standard deviation** of **±17.19** and those obtained by the **cylindrical sprue design** had a **mean microhardness** of **284 VHN** with a **standard deviation** of **±20.8**. The **test of significance** indicates that the **p value** is **0.556**, which is ***statistically insignificant*** (p< .05).

Graph III shows the bar diagram representing the ***mean microhardness of the three test groups.***

Porosity:

Table IV shows the basic data obtained for the **percentage of porosity (%)** of the test samples obtained from the 3 test sprue designs.

Table VII shows the **statistical analysis** of the **mean values** with **standard deviation** for the **mean percentage porosity** of the test samples obtained by ANOVA method. The samples obtained by the **bottle neck sprue design** had a **mean porosity** of **1.584 %** with a **standard deviation** of ±**1.096**, those obtained by the **conical sprue design** had a **mean porosity** of **3.022 %** with a **standard deviation** of **±1.356** and those obtained by the **cylindrical sprue design** had a **mean porosity** of **8.311 %** with a **standard deviation** of **±2.935**. The **test of significance** indicates that the **p value** is **0.000**, which is ***statistically significant*** ($p< .05$).

Graph IV shows the bar diagram representing the ***mean percentage porosity of the 3 test groups.***

Table VIII shows the **multiple comparison** of the **mean percentage of porosity** of the test samples obtained by **Post Hoc test**. The **mean difference** between **conical and bottle neck** sprue designs was **1.438** and the **test of significance** indicated that **p value** is **0.405**, which is ***statistically insignificant***.

The **mean difference** between **bottle neck and cylindrical** sprue designs was **6.727** and the **test of significance** indicated that **p value** is **0.000**, which is ***statistically significant*.**

The **mean difference** between **conical and cylindrical** sprue designs was **5.289** and the **test of significance** indicated that **p value** is **0.000**, which is ***statistically significant***.

Graph V shows the bar diagram representing ***comparison of bottleneck and cylindrical sprue design for mean porosity***.

Graph VI shows the bar diagram representing ***comparison of conical and cylindrical sprue design for mean porosity.***

Graph VII shows the bar diagram representing ***comparison of conical and bottle sprue design for mean porosity.***

TABLES

Table I

PERCENTAGE CASTABILITY OF TEST SAMPLES OBTAINED FROM THE 3 SPRUE DESIGNS

Samples	Bottle neck sprue design (%)	Cylindrical sprue design (%)	Conical sprue design (%)
S1	100	100	100
S2	100	100	100
S3	100	100	100
S4	100	100	100
S5	100	100	100
S6	100	100	100
S7	100	100	100
S8	100	100	100
S9	100	100	100
S10	100	100	100

Table II

MASS OF TEST SAMPLES OBTAINED FROM THE 3 SPRUE DESIGNS:

Samples	Bottle neck sprue design (gm)	Cylindrical sprue design (gm)	Conical sprue design (gm)
S1	0.9173	0.9131	0.8745
S2	0.8653	0.8542	0.9403
S3	0.8585	0.8417	0.8871
S4	0.9317	0.8969	0.9285
S5	0.8927	0.8982	0.8733
S6	0.8653	0.8542	0.9403
S7	0.8585	0.8969	0.8871
S8	0.9173	0.9131	0.8745
S9	0.9317	0.8417	0.9285
S10	0.8927	0.8982	0.8733

Table IIIa

MICRO HARDNESS (VHN) OF THE TEST SAMPLES OBTAINED FROM THE CONICAL SPRUE DESIGN:

Position of indentation	**Conical sprue design** (VHN)									
	S1	**S2**	**S3**	**S4**	**S5**	**S6**	**S7**	**S8**	**S9**	**S10**
1	263	307	314	314	306	251	256	243	290	287
2	261	439	336	339	273	263	377	281	309	249
3	252	287	255	245	287	252	255	322	271	267
4	251	276	281	273	249	243	287	279	245	259
5	264	255	279	290	267	279	439	286	251	273
6	286	351	286	271	259	261	351	255	290	306
7	280	377	281	309	286	280	251	336	310	270
8	243	251	243	251	270	264	307	314	339	301
9	279	256	322	310	301	286	276	255	314	286

Table IIIb

MICRO HARDNESS (VHN) OF THE TEST SAMPLES OBTAINED FROM THE BOTTLE NECK SPRUE DESIGN:

Position of indentation	**Bottle neck sprue design** (VHN)									
	S1	**S2**	**S3**	**S4**	**S5**	**S6**	**S7**	**S8**	**S9**	**S10**
1	314	250	464	296	306	276	253	424	286	270
2	336	253	436	264	273	284	251	388	275	249
3	256	368	368	258	287	336	368	417	276	287
4	258	276	457	272	249	276	250	368	281	306
5	284	251	388	286	259	258	276	436	258	267
6	276	307	424	275	267	314	255	445	296	273
7	276	255	445	281	286	256	439	399	276	301
8	276	276	399	276	270	299	307	464	264	259
9	299	439	417	276	301	276	276	457	272	286

Table IIIc

MICRO HARDNESS (VHN) OF THE TEST SAMPLES OBTAINED FROM THE CYLINDRICAL SPRUE DESIGN:

Position of indentation	**Cylindrical sprue design** (VHN)									
	S1	**S2**	**S3**	**S4**	**S5**	**S6**	**S7**	**S8**	**S9**	**S10**
1	367	301	247	242	247	349	291	253	245	279
2	342	314	253	248	253	324	277	259	304	243
3	342	291	255	245	254	342	314	251	221	290
4	324	277	261	253	276	367	299	261	245	245
5	349	299	259	250	275	345	301	247	253	276
6	345	277	245	221	245	347	285	245	248	275
7	347	278	259	284	243	342	338	291	242	254
8	370	285	251	304	279	369	278	259	230	253
9	369	338	291	230	290	370	277	255	284	247

Table IV

PERCENTAGE POROSITY OF THE TEST SAMPLES OBTAINED FROM THE 3 SPRUE DESIGNS:

Bottle Neck	Cylindrical	Conical
2.5	3.8	5.6
1.2	8.2	2.3
.39	8.6	4.1
.59	11.7	1.6
1.9	7.4	3.8
.92	13.6	3.5
.76	7.8	2.4
3.7	5.5	1.3
2.3	8.2	2.6

STATISTICAL ANALYSIS

Table V:

MEAN MASS OF THE TEST SAMPLES OBTAINED FROM THE 3 SPRUE DESIGNS (ANOVA METHOD):

Sprue designs	**n**	**Mean (gm)**	**S.D.**	**p - value**
Bottle Neck	10	0.90	±3.14	0.612 **(NS)**
Conical	10	0.89	±3.18	
Cylindrical	10	0.88	±3.09	

The mean is significant at p < .05 level.

Table VI:

MEAN MICRO HARDNESS (VHN) OF THE TEST SAMPLES OBTAINED FROM THE 3 SPRUE DESIGNS (ANOVA METHOD):

Sprue designs	**n**	**Mean (VHN)**	**S.D.**	**p - value**
Conical	10	286	±17.19	0.556 **(NS)**
Cylindrical	10	284	±20.8	
Bottle neck	10	311.7	±22.1	

The mean is significant at p < .05 level.

Table VII:

MEAN PERCENTAGE POROSITY OF THE OF THE TEST SAMPLES OBTAINED FROM THE 3 SPRUE DESIGNS (ANOVA METHOD):

Sprue designs	n	Mean	S.D.	p value
Conical	10	3.022	±1.356	0 .000 **(sig)**
Bottle Neck	10	1.584	±1.096	
Cylindrical	10	8.311	±2.935	

The mean is significant at p < .05 level.

Table VIII:

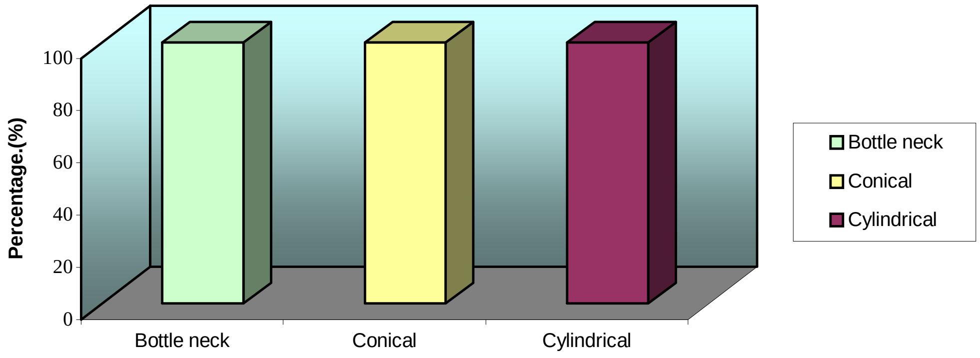
MULTIPLE COMPARISON OF MEAN PERCENTAGE POROSITY OF THE TEST SAMPLES OBTAINED FROM THE 3 SPRUE DESIGNS (Post Hoc test):

Sprue designs	Mean Difference (%)	p - value
Bottle Neck and Conical	1.438	0.405 **(NS)**
Bottle Neck and Cylindrical	6.727	0.000 **(sig)**
Conical and Cylindrical	5.289	0.000 **(sig)**

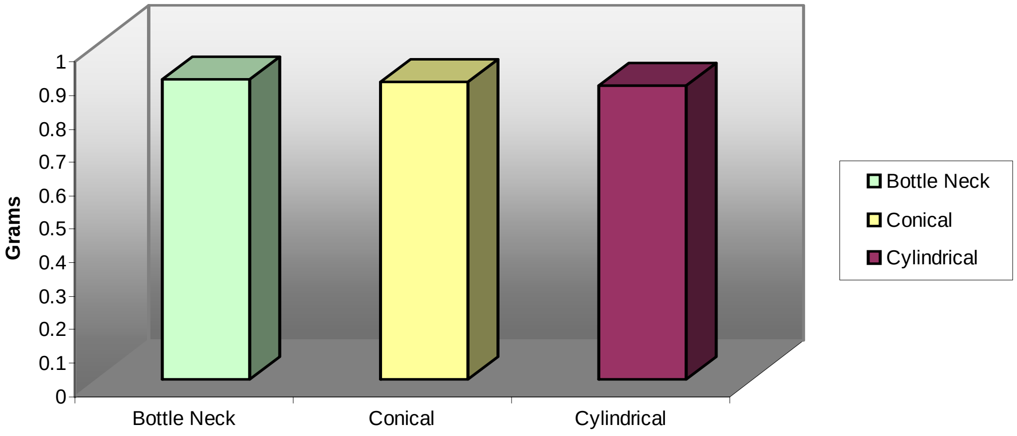
The mean difference is significant at p < .05 level

GRAPHS

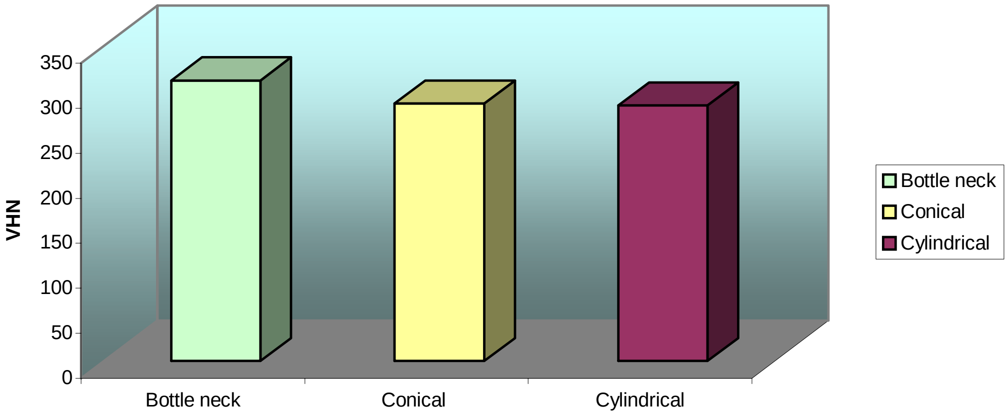
Graph I : Mean percentage castability of the test patterns obtained from the 3 sprue designs



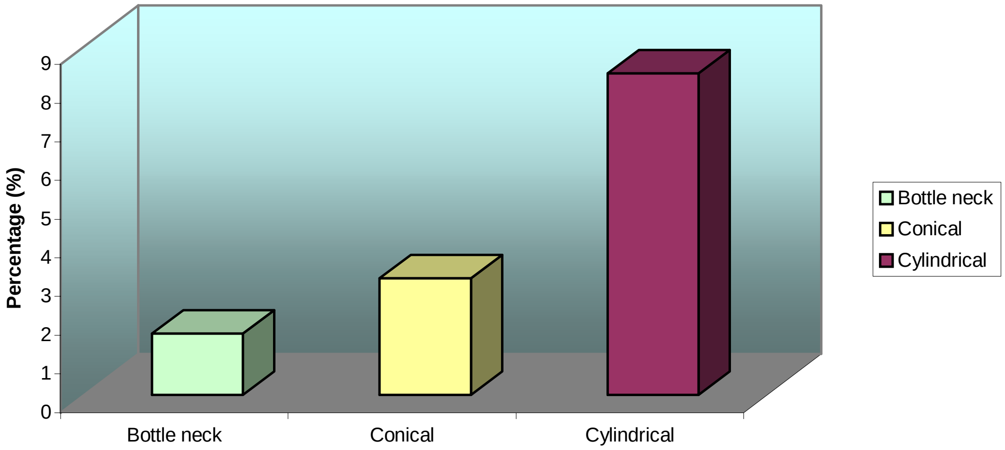
Graph II Mean Mass of the test pattern obtained from the 3 sprue designs



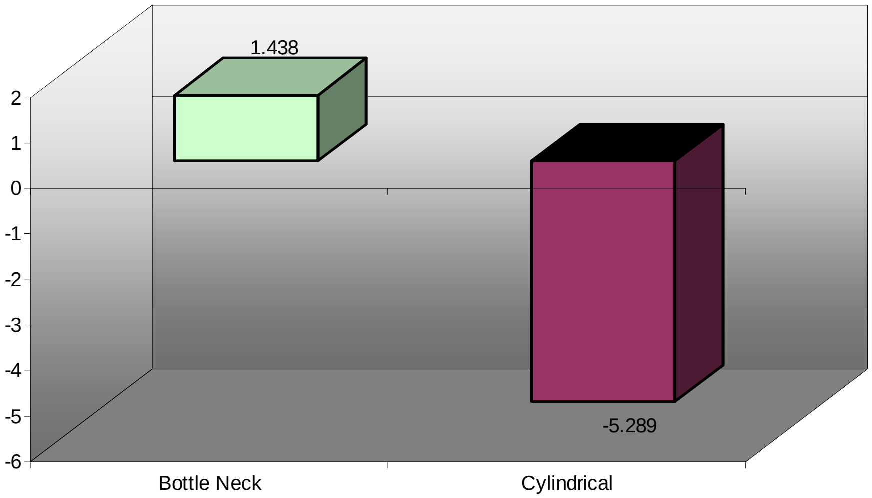
Graph III: Mean Microhardness of the test patterns obtained from the 3 sprue designs



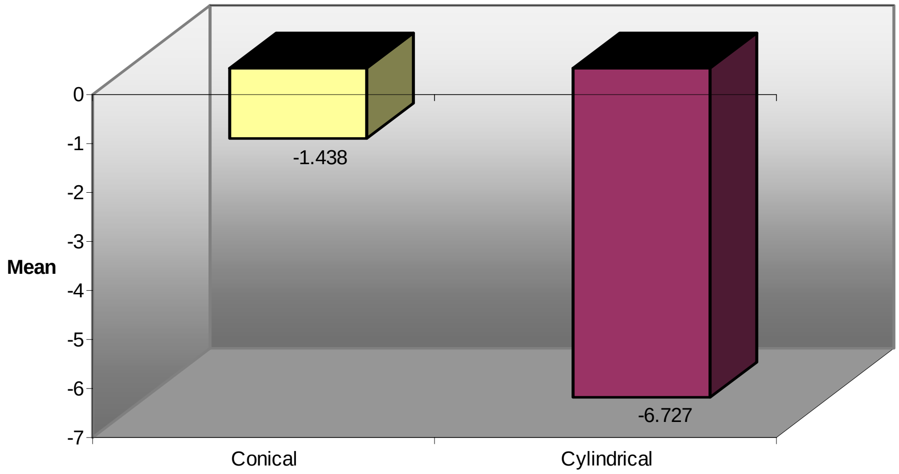
Graph IV Mean Porosity of the test patterns obtained from the 3 sprue designs



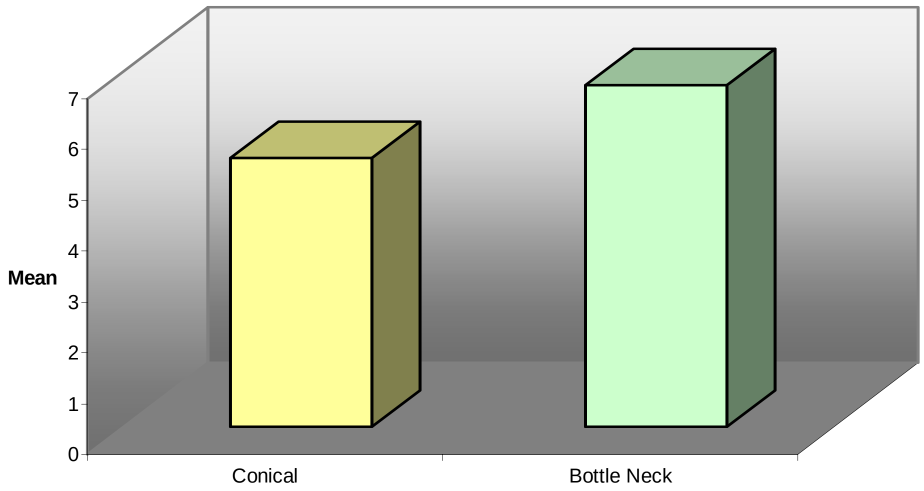
Graph V Comparison of Bottle Neck & Cylindrical Sprue Designs for mean porosity



Graph VI Comparison of Conical & Cylindrical Sprue Designs for mean porosity



Graph VII Comparison of Conical & Bottle Neck Sprue Designs for mean porosity



DISCUSSION

The dental cast restorations can be produced accurately by the lost wax process. The wax pattern is used to produce a precise refractory mold into which the molten alloy is cast. The attachment of the sprue former to the wax pattern plays an important role for fabrication of dental casting.

The efficacy of a sprue system depends on how easily the metal can flow through it and fill the mold cavity. The sprue must supply molten metal continuously so that the gases are forced out of the mold cavity first and compensate for the shrinkage of the alloy in the casting as it solidifies. The ***proper selection of size and configuration of the sprue is critical for the production of a dense, complete and accurate casting.***[40] Ever since these techniques have been followed; various views were suggested regarding the selection and application of various sprue designs and their attachment to the wax pattern.[3, 4, 15, 39, 40]

Initially gold alloys were used for dental cast restorations. For the high density gold alloys, if a long thin sprue is used, the metal will solidify in the sprue before it solidifies in the mold space, thus preventing more metal from entering the mold. This was overcome by using a reservoir or larger sprue[4]. While casting with these alloys, it was recommended to flare the sprue at the point of attachment along with large diameter sprues of shorter length because the flaring acts as a small reservoir placed very close to the wax pattern and also facilitates the entry of molten gold into the mold.[4] The increased cost of precious alloys led to the use of base metal alloys, for the fabrication of metallic restorations in prosthodontics. The base metal alloys were introduced in dentistry at the early 1930's, which are mostly nickel, and chromium-based alloys. The base metal alloys have evolved as an alternative to gold alloys due to various reasons such as low cost, increase in hardness, high elastic modulus and high melting range compatible with ceramic application.

Base metal alloys require casting techniques specifically designed for their physical properties because of their low density and high melting range. This low density of the base-metal alloys presents problems of castability because it allows these alloys to absorb gases more easily at the high temperatures and greater centrifugal pressure is therefore needed to cast them.[39] Hence the sprue designs for base metal alloy castings vary according to the physical properties of the alloys.[45] To achieve complete and dense castings, Mc Lean advocated sprue designs that tapered at the point of attachment of the sprue to the wax pattern.[31] Peregrina and Rieger[39] also recommended using a constricted sprue attachment for casting base metal alloys. This view was also supported by Peregrina A, Schorr B.L[40] who found a constricted or tapered sprue design to be better than a cylindrical sprue with flaring or reservoir. Anusavice KJ[3] and Naylor PK[36] also recommended constricted sprue design for low density alloys. However Verrett RG, Duke ES[53] concluded from their investigations using sprue attachments that were straight, flared, abrupt constriction, and gradual constriction and found that flared and straight sprue attachments optimized castability and minimized porosity for base metal alloys. Rieger[44] studied different sprue designs and recommended a conical sprue design. Thus there are differences of opinion among various authors, regarding the optimal sprue design and its mode of attachment to the pattern for casting base metal alloys.

This study was done to evaluate the efficacy of cylindrical, conical, and bottle neck sprue designs on the properties of castability, mass, microhardness and porosity of base metal alloy castings. Any alteration in these properties has a direct bearing on the long term clinical performance of the restorations under in vivo conditions.[43] Further, any deterioration in these properties will also affect the bonding between the alloy and the applied ceramic. Thus sprue design and mode of attachment are factors which play an important role in controlling the long term performance and success of metal ceramic restorations.[10] In this study, a metal ceramic base metal alloy, having lower density, fluidity and high melting temperature was employed in view of the above considerations.

A prefabricated wax mesh pattern was chosen in this study to standardize the test specimen. The mesh pattern design was chosen because it produced a reduction in the forces while directing the alloy into the mold since the forces were absorbed by the investment when the alloy flow was redirected at an angle of 90 degrees. This procedure provides a measurement of the capability of an alloy to fill a mold.[40]

The two-part stainless steel mold facilitated in standardizing the acrylic patterns for the 3 test sprue designs. The attachment design to the wax mesh pattern, for the cylindrical sprue design was straight, that for bottle neck sprue design was constricted and that for the conical sprue design was flared. The castings obtained from these three different sprue designs were evaluated for the properties of castability, mass, porosity and microhardness and their results are discussed sequentially.

Castability

Castability is the ***ability of the molten alloy to fill the mold space***. Incomplete castability may result in incomplete cast crown margins, which lead to secondary caries, periodontal and esthetic problems. It can also affect the structural durability of the restorations. Hence castability was considered as one of the test parameters.

The manner of evaluating the completeness of casting should be accomplished without the need for sophisticated measuring instruments. Castability has been evaluated with customized mold forms such as spring like coils, nylon line projections, filaments and fibers, flat rectangular patterns, saucer-shaped patterns, mesh grid patterns, and wedge-shaped patterns; of these, castability was more easily accomplished with the mesh grid.[53] The mesh grid pattern fulfills the above requirement and helps in easy visualization and evaluation of the casting.[24, 25, 39, 44] It also provides a simple and rapid means of measuring alloy castability. Hence this counting method was employed for was used for evaluating percentage castability in this study.

The mesh grid method employed to evaluate castability was that proposed by Whitlock et al[31] and later followed by other workers.[24, 44] The castability values were attributed to the samples by counting the number of complete segments of the cast grid, which indicates the accuracy of the alloy to reproduce the details. A distinct advantage of having a counting method is that no precise measuring equipment is required.[24] Rieger P et al, found better castability by using conical sprue design for base metal alloys.[44] Verret et al[53] in their study found that straight and flared sprue attachments produced better castability. However the results of this study indicated complete castability for all the three test groups as was confirmed by the counting method. Hence there appeared to be ***no apparent effect*** of the ***test sprue design and their attachment designs*** to the wax pattern on the factor of ***castability*** in this study.

Mass:

The test samples were then evaluated for the mass of the cast mesh pattern after separation of the sprue. **The amount or mass of a material in a given volume is the density of the material.** The higher density of most metal objects makes them feel heavy. As the test sample dimensions were standardized in the study, the higher values of mass, indicate higher density values of the castings. Density depends on the type of atom present, (as the atomic number increases, so does the density) the packing together of atoms and molecules and the ***voids present*** in the material.[22] In the study, the mass of the cast mesh patterns was measured as it is directly proportional to its density and in turn a direct indicator of dense castings. Also, dense castings imply, less porosity. In a previous study conducted by Rieger et al, conical test sprue designs yielded castings that had superior values for mass.[44] It has been postulated that constricted sprue attachment increases the velocity of the molten alloy entering the mold space by creating a ***Venturi effect*** at the point of entry, thus improving the density of the casting[53]. The basic principle involved in using a tapered or constricted sprue attachment design is that, the point of entry of molten alloy is narrowed so that metal can flow into the casting with a minimum of turbulence. Minimum turbulence of the alloy leads to reduced porosity and therefore a higher density casting[40]

In the present study, the castings obtained from the bottle neck sprue design, conical sprue design and cylindrical sprue design, did not exhibit any statistically significant difference in their mean mass values. Hence there appeared to be ***no apparent effect*** of the ***test sprue design and their attachment designs*** to the wax pattern on the factor of ***mass (density)*** in this study.

Micro hardness:

Microhardness of a material has a bearing on properties such as burnishability, surface wear, and shock absorbancy, which are difficult to quantify.[1] A restoration made of an alloy with a higher surface hardness is more resistant to occlusal wear but may be more likely to wear the opposing dentition if it has a lower surface hardness. The restoration with a higher surface hardness tends to maintain a polished surface longer because of the higher scratch resistance but is more difficult to polish. The burnishability and the ease of adjustment are also related to hardness. A material with a low hardness number is easy to burnish and can conveniently be adjusted, but materials with a high hardness number are difficult to adjust and burnish. Microhardness can also be correlated to the strength, ductility, and percent of elongation of the castings and ***is representative of*** the microporosity and grain structure of the alloy.[6] Microhardness of base metal alloys has been evaluated with respect to the effect of parameters such as alloy composition,[10] various heat sources used for casting[50] and heat treated alloys,[6, 26, 33] but data on the effect of various sprue designs on microhardness is lacking. In the present study, microhardness was selected as a test parameter in view of the above considerations.

Common methods used for hardness evaluation include, Vickers, Knoop, Brinell and Rockwell hardness tests. The Knoop and Vickers tests are classified as microhardness tests in comparison with the Brinell and Rockwell, which are macrohardness tests. Both Knoop and Vickers employ loads less than 9.8N. The resulting indentations are small and are limited to a depth of less than 19µm. Measurements are normally made using a microscope since the indentations are often too small to be seen with the naked eye. Hence, they are capable of measuring the hardness in small regions of thin objects.[3 ,30]

In the present study, the cast mesh patterns were prepared for the evaluation of microhardness using a microhardness tester. The micro hardness values were obtained for the test samples as Vickers Hardness Number (VHN).

In the present study, the castings obtained from the bottle neck sprue design, conical sprue design and cylindrical sprue design, did not exhibit any statistically significant difference in their mean microhardness values. Hence there appeared to be ***no apparent effect*** of the ***test sprue design and their attachment designs*** to the wax pattern on the factor of ***microhardness*** in this study. Since microhardness of an alloy is important in determining the performance of dental restorations under in vivo conditions, the effect of sprue design on this parameter merits further investigations.

Porosity:

The test samples were then analyzed for porosity. Metal fatigue is recognized as a common cause of structural failure under repeated loads. Stress raisers are defined as discontinuities in structures/ materials that cause stress concentration. Metallurgical stress raisers, which can occur in the form of porosity or inclusions, may reduce fatigue life or even initiate fatigue. Their presence at or near the surface often initiates fatigue failure. The occurrence of porosity and/or inclusions below the surface may initiate fatigue if the loading conditions are appropriate. Reduction or elimination of these defects may minimize fatigue failure and consequent fracture of the casting.[42] The effect of sprue design and mode of attachment on the percentage porosity of base metal alloy castings deserves attention.

Researches have employed different methods for analyzing porosity in test samples. Photomicrographs have been used by some to determine the quantity and location of porosity.[15,53] Alternatively, embedded and prepared samples are analyzed for percent of porosity in a Quantimet Image Analyzing computer.[40] This method is considered more accurate for evaluation of porosity. In the present study, mean amount of porosity was obtained by analyzing each of the embedded test samples at 9 selected sites using the Quantimet Image Analyzing computer.

In this, mean percentage porosity and standard deviation were estimated for the test groups. Statistically, there was a ***significant decrease*** in **porosity** for the castings obtained by the **bottle neck** and the **conical** sprue designs when **compared to** the **cylindrical** sprue designs. Though the **castings** obtained by the **bottle neck** sprue design had less **mean percentage porosity** compared to those obtained by the **conical** sprue design, this **difference** was **not statistically significant**.

The International Atlas of Casting Defects states that turbulence is one of the causes of porosity in the casting. The American Society of Metals Handbook relates the entrapment of gas as one of the causes of porosity. The turbulent flow of liquid metal entering the mold is influenced by the shape of the sprue and the pattern. Sharp angular turns of the metal into the mold and different thickness of various parts of the pattern promote changes in direction as the molten metal enters the mold. The casting pressure and the specific gravity of the particular metal are also factors that may contribute to turbulent flow of the metal when it is cast.[40] According to Mc Lean and other workers, using a tapered or constricted sprue design for the base metal alloys at the point of attachment is recommended, provided the length of the tapered section is not too long and the minimum diameter at the junction point with the pattern is not less than half the diameter of the original sprue. Then the entry point for the molten alloy is selected, so that metal can flow into the mold with a minimum of turbulence. The restricted entry point prevents suck back of metal, controls the velocity of the metal and ensures an even distribution of metal.[3, 36, 39, 40] These factors could have attributed to the reduced mean percentage porosity values obtained for the bottle neck sprue design test samples.

The conical sprue design had a uniform taper along its length. this reduction in diameter of the sprue could have aided in reducing metal turbulence at the point of entry leading to reduced mean percentage porosity.

There was no statistically significant difference between the mean percentage porosity obtained with the bottle neck and the conical sprue designs and both these designs exhibited significantly less values for porosity compared to the cylindrical design, suggesting their use in casting low density alloys.

One of the problems associated with any method for evaluating castability, particularly with ceramo-metal alloys is that small variations in materials, equipment, or procedure may have significant effects on the results obtained. Therefore, this method should be used only as a comparative, rather than an absolute measurement procedure. Hence evaluation of castability as affected by alloy constituents, investment, temperature, or other variables should also be accomplished. The clinical and laboratory relevance of sprue geometry and attachment design to castability patterns that are not analogs of ceramometal castings has not been verified. In many textbooks and reference manuals no differentiation is made for sprue attachment design between high gold alloys and non noble alloys.

Sprue attachment geometry may produce different porosity effects for lower density non-noble alloys as indicated from the results of this study. A constricted sprue attachment design has been suggested to obtain improved castability and density and decreased porosity.[39,40] The results of the present study indicate reduced values of mean percentage porosity with the constricted and conical sprue designs compared to the cylindrical sprue design. Further research is required to evaluate the validity of this Venturi hypothesis with other alloy systems to come to more predictable conclusions. Also the effect of sprue design on the microhardness needs further evaluation.

Studies on the effect of various sprue designs on the grain structure and properties such as tensile strength, yield strength, coefficient of thermal expansion, porcelain bond strength are also needed, to enhance the results of the study and to recommend specific sprue and attachment design for a particular alloy system.

CONCLUSION

The results of this study yielded the following conclusions:

1. The bottle neck, conical and cylindrical sprue designs employed in this study exhibited **complete castability**.
2. The differences in the mean mass values between the bottle neck, conical, and cylindrical sprue designs were not statistically significant. The three test sprue designs **did not** exert any **apparent influence** on the **mass (density)** of the castings.
3. The differences in the mean microhardness values between the bottle neck, conical, and cylindrical sprue designs were not statistically significant. The three test sprue designs **did not** exert any **apparent influence** on the **microhardness** of the castings.
4. There was a **significant reduction** in the **percentage porosity** of castings obtained with the **bottle neck** and **conical** sprue designs **as compared to** the **cylindrical** sprue design.
5. There was **no difference** in the **percentage porosity** of castings obtained with the **bottle neck** and **conical** sprue designs.
6. Order of ranking of the three sprue designs that yielded castings with reduced porosity is as follows:
    a. Bottle neck sprue design
    b. Conical sprue design
    c. Cylindrical sprue design

SUMMARY

This study was done to evaluate and compare the properties of castings obtained from three sprue designs, namely, bottleneck, conical, and cylindrical. A wax mesh pattern with a dimension of 16mm x 16mm that provided 6 x 6 square shaped spaces was used as a test pattern. A two-part stainless steel mold was used to prepare the reproducible test sprue designs. The acrylic pattern resin samples, 10 each, for the 3 sprue designs were obtained and attached to each of the wax mesh pattern. The cylindrical sprue design was connected to the mesh pattern with a straight attachment, the bottleneck sprue design with a constricted attachment and the conical sprue design with a flared attachment. The samples were cast with nickel-chromium alloy. The castings were retrieved and evaluated for castability, mass, microhardness and porosity. The results obtained were statistically analyzed. The sprue design did not have any apparent influence on castability, mass and microhardness values of the base metal castings in this study. The bottle neck and conical sprue designs were superior when compared to the cylindrical sprue design in reducing the porosity of the base metal alloy castings.

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