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Enhancing the Radiopacity of Complete Denture Acrylic Bases Using Metal Fillers

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Abstract

Objective: Polymethyl-methacrylate (PMMA) is the preferred material for denture manufacture due to its aesthetics and ease of processing; yet, its intrinsic radiolucency offers considerable dangers if fragments are mistakenly consumed or inhaled. This study looks at how different quantities of metal and metal oxide fillers, such as silver (Ag), alumina (Al2O3), and cobalt-chromium (CoCr) alloy, affect the radiopacity and diagnostic detectability of PMMA denture base material.

Materials and Methods: PMMA specimens were fabricated by combining polymer powder with liquid monomer in a 2.5:1 ratio. Metal fillers (Ag, Al2O3, and CoCr) were integrated into the powder at concentrations of 1, 2, and 3 weight percent. Twelve acrylic specimens (50 mm x 20 mm) with differing thicknesses were cured at 78°C. Radiopacity was evaluated in accordance with ISO 4049–2009 standards by comparing the optical density (OD) of X-ray pictures (60 kV, 10 mA) against an aluminum step wedge.

Results: The incorporation of all evaluated fillers markedly improved the radiopacity of PMMA in comparison to unmodified controls. A direct proportional association was noted between filler concentration and radiographic visibility. Specimens with 3 wt% filler loading demonstrated the greatest radiopacity across all groups. Among the fillers, Silver (Ag) exhibited the most significant impact on X-ray attenuation owing to its elevated atomic number and electron density. Although Al2O3 and CoCr enhanced visibility, their impact was relatively inferior compared to that of silver.

Conclusions: Modifying PMMA with minimal metal filler concentrations (up to 3 wt %) is an efficient approach to mitigate its natural radiolucency without necessitating excessive additions that could jeopardize material integrity. This innovation enables the swift radiographic identification of denture pieces, thus enhancing patient safety and diagnostic precision in clinical emergencies.

Keywords: PMMA, Radiopacity, Metal Fillers, Denture Base, Silver, Alumina, Cobalt-Chromium.

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INTRODUCTION

The denture base should be preferably radiopaque and capable of being detected using routine diagnostic radiography procedures and measurement of the ability of electromagnetic to pass through a certain material. Radiopacity is an essential feature for all restorative materials. The patient may ingest (swallow) these shards of denture fracture[1]. Therefore, pure denture base is important to be radiopaque for easy radiological detection. In a recent study, by a review approximately 123 cases of ingested or aspirated dentures or fragments of denture base revealed that requirement for radiopaque for detection these particles, the challenges and time associated in locating these pieces of the denture bases[2]. Incorporation of opaque filler such as metal or ceramic could be the way out. There were attempts to boost radiopacity by adding barium sulfate by ratio 8% to acrylic resin and yet, this did not generate appropriate levels of radiopacity. Increasing the barium sulphate content by ratio 20% produces sufficient radiopacity but regrettably it has a detrimental effect on the mechanical qualities of the resin[3].

Acrylic resin polymethyl methacrylate (PMMA) is the predominant substance used in denture manufacture. It offers numerous advantages, including appealing aesthetics, perfect fitting, and stability in the oral environment, straightforward processing techniques, and cost-effective production[4]. Nonetheless, this material remains inadequate to fulfill the optimal mechanical criteria for dental applications, mostly because of its insufficient fracture resistance and propensity for plaque formation[5, 6]. Various fillers, metal oxides, and carbon graphite fibers are incorporated into the formulation to enhance the mechanical qualities of the resin[7, 8]. The incorporation of nanoparticles into PMMA as a reinforcing agent is one of the most promising novel fillers to address strength deficiencies[9]. Notwithstanding its popularity due to aesthetic appeal, straightforward processing, and ease of repair, the primary issues related to PMMA as a denture base material include inadequate strength, especially under fatigue failure intraorally, impact failure extra-orally, and insufficient radio-opacity[10].

The PMMA used frequently today is radiolucent and cannot be visualized using conventional radiography methods, rendering the identification of unintentional ingestion, aspiration, and traumatic impaction of dental appliances exceedingly challenging and necessitating invasive procedures or advanced imaging techniques. Procrastination in localizing or extracting the foreign body may provide a life-threatening risk[11]. Recently, much focus has been placed on the integration of inorganic nanoparticles with PMMA to enhance its characteristics. The characteristics of polymer nanocomposites are contingent upon the nature of the included nanoparticles, their dimensions and morphology, as well as their concentration and interaction with the polymer matrix[12]. Nanoparticles underwent surface treatment with a saline coupling agent and were implanted in PMMA[13]. Numerous efforts have been made to integrate inorganic nanoparticles into PMMA. Alumina nanoparticles were coated with acryloxypropyldimethyl methoxysilane to produce a PMMA/alumina nanocomposite exhibiting enhanced mechanical characteristics compared to pure PMMA[14]. Calcium carbonate nanoparticles treated with stearic acid were integrated into PMMA to enhance its abrasion resistance[15]. Barium sulfate nanoparticles were incorporated into PMMA to augment radiopacity[16].

The radiopacity of dental materials is important in order to distinguishing dental restorative materials from adjacent tooth and surrounding structures[17-19]. It is also a great tool for evaluating the absorption of materials in non-structural applications[20]. Cement degradation and marginal adaption can be identified through the varying radiopacity levels of restorative materials[21]. Optimal radiopacity in dental cements is crucial for clinical diagnostics, facilitating accurate viewing of the contact between the restoration and the tooth structure[22]. Insufficient radiopacity in luting agents prevents physicians from accurately detecting voids, interfacial gaps, or poor marginal adaptation, thereby resulting in complications like as secondary caries and periodontal problems[22]. Moreover, due to their exposure to the oral environment, these materials must possess sufficient radiopacity to identify cement dissolution or washout over time, so assuring that any marginal seal loss is discernible as a radiolucent area on a radiograph[22]. Consequently, radiological identification of dental materials can be crucial in instances of unintentional airway blockages or embedment in adjacent anatomical structures[23, 24].

The radiopacity of dental materials is characterized by an optical density value[25]. The measurement of radiopacity in dental materials is generally represented as an equivalent thickness of aluminum (mm Al), a figure obtained by contrasting the radiographic density of a material specimen with a reference aluminum step-wedge through a calibration curve[26]. This standardized measurement is essential for clinical diagnosis, as International Organization for Standardization (ISO) protocols, including ISO 4049, mandate that a restorative material exhibit radiopacity equal to or exceeding that of the same thickness of aluminum to guarantee clear differentiation from dental structures such as dentin and enamel[26]. The logarithmic optical dentistry calibration curves for the aluminum step wedge utilized in each investigation are employed to convert the measurements into an equivalent aluminum (eq Al) thickness value (in mm). It is essential to articulate a material's radiopacity in equivalent aluminum thickness (mm) for comparative analysis with another research.

Various studies have demonstrated that the radiopacity of dental materials is essential and should be contingent upon the intended application of the tooth restorative material[27-29]. Conversely, highly radiopaque materials may induce a Mach effect, leading to erroneous positive or negative discrimination[30]. In dental restorations, the radiopacity must align with that of the dental structure being rebuilt. Consequently, if the restored section comprises dentin or an enamel layer, the radiopacity of the restorative material must mimic the characteristics of the layer it is substituting[29].

The radiopacity of a denture base should ideally be radiopaque and detectable using standard diagnostic radiography procedures, as well as by the measurement of electromagnetic permeability of the material. Radiopacity is a crucial characteristic for all restorative materials[31]. The patient may ingest these bits of the fractured denture. Consequently, a pure denture base must possess radiopacity for efficient radiological identification. A prior study reviewing 123 cases of ingested or aspirated dentures or denture base pieces indicated the necessity of radiopaque materials for their detection, highlighting the challenges and time required to locate these denture base fragments[19]. The integration of an opaque filler, such as metal, may provide a solution. Attempts to enhance radiopacity by incorporating 8% barium sulfate into acrylic resin were unsuccessful in achieving adequate radiopacity levels. Augmenting the barium sulfate concentration by 20% provides adequate radiopacity; however, it adversely impacts the mechanical qualities of the resin[3]. The fundamental issues of dentures are easily identifiable radiologically and exhibit radiolucency due to the low X-ray absorption characteristics of carbon, oxygen, and hydrogen atoms. The patient may intermittently ingest dentures and could potentially aspirate a denture fragment during a severe incident, such as a vehicle accident. Consequently, the radiological detection of denture fragments is employed to assist in the patient's treatment[32, 33]. Early method for detection was through the incorporation of heavy-metal salts as physical mixtures with the polymers[34]. An alternative method involves the integration of glass materials, including barium, aluminum, strontium, zinc, and zirconia, to create composites that are radiopaque (impervious to X-rays), hence improving their visibility on radiographic film[35]. This is crucial for diagnostic purposes and radiographs that may distinguish between different specimens depending on their radiopacities. The radiopacity of dental resin composites typically arises from the inclusion of elements with relatively high atomic numbers, such as Ba, Zr, Sr, V, and La, within the resin matrix[34]. Numerous efforts were made to get elevated radiopacity values for PMMA as a denture base material and bone cement. Dental materials were formulated utilizing heat-curing PMMA, created by combining liquid and powder constituents. The liquid component comprises MMA as the monomer, an inhibitor to avert premature polymerization of the monomer, and a promoter for the breakdown of the initiator. The powder component comprises PMMA as the polymer, a mineral powder such as barium sulfate ($BaSO_4$) or zirconium dioxide (ZrO_2) serving as a radiopaque agent, and a free radical initiator, commonly benzoyl peroxide (BPO) [36, 37]. A study on reinforcing with γ-MPS-treated Al_2O_3 particles indicated that the addition of 4% Al_2O_3 to cement is sufficient for achieving optimal radiopacity[31]. Certain denture base materials improve radiopacity by integrating heavy metal compounds, such as barium or radiopaque glass fillers. Nevertheless, incorporating up to 20 wt% of these materials is frequently essential to provide sufficient radiopacity, which may compromise mechanical strength and adversely impact the denture's aesthetics[31]. The weight fraction of the filler and matrix in resin composites affected the scattering and diffraction of X-ray interactions[38]. The majority of the examined prostheses are radiopaque, whereas the removable prostheses are likely to be radiolucent. Consequently, the detachable prostheses, specifically the complete acrylic denture, were not discernible, although the upper partial acrylic denture was fairly perceptible[39]. The PMMA denture base is prone to fracture during accidents or when subjected to excessive masticatory force, and patients may inadvertently eat these particles. Additionally, it is radiolucent and indistinguishable from soft tissues.

The objective of this study is to investigate the effect of incorporating different metal fillers into polymethyl methacrylate (PMMA) denture base material on its radiopacity. The study aims to evaluate how varying types and concentrations of metal fillers can enhance the radiographic detectability of the acrylic denture base using conventional imaging techniques, while maintaining acceptable mechanical and physical properties. Furthermore, it seeks to determine the optimal composition that achieves radiopacity levels comparable to natural dental tissues, thereby improving diagnostic accuracy and ensuring patient safety in cases of accidental ingestion or aspiration of denture fragments.

MATERIALS AND METHODS

The materials that used in this research are PMMA powder (Mw, 996.000 g/mol; (Merck chemical, Darmstadt, Germany), and Silver (Ag), Alumina (Al_2O_3) and Chrome cobalt alloy (CoCr) fillers particles.

The PMMA denture base material was prepared using powder components mixed with liquid component. The powder components were comprised of PMMA powder, metal fillers as impact modifier particles. (Ag), (Al2O3) and (CoCr) powder ware added to PMMA powder and mixed with 1, 2 and 3 wt %, respectively.

Each of the powder mixture components were mixed with liquid component by hand mixing, respectively. The mixing of powder mixture to liquid medium (P/L) ratio was set at 2.5:1, according to standard dental laboratory usage. The composite reached the dough stage (working stage) for easy forming of the paste around 15 min, the mixture was packed into the specific mold.

The curing process is carried out by placing the mold in a water bath. The temperature of water bath was kept at 78 °C for 90 min to complete the heat polymerization. The mold was removed from the water bath and then left to cool slowly to room temperature. The samples were removed from the mold, then, trimmed and polished by using emery paper 240. This procedure is in accordance to ISO 1567:2001 dentistry-denture base polymer standard method for preparing a conventional denture base in a dental laboratory[32].

Twelve acrylic specimens in three groups with dimensions of the length 50 mm × 20 mm width, having a thickness range from 0.5 mm to 5.0 mm were prepared using conventional flasking and packing in gypsum moulds, (4 specimens for each group) as shown in fig.1. The film density of each formulation's image was measured by optical density (OD) using a densitometer machine (RMI, USA).

Figure 1: Show PMMA specimens used in this study.

Radiopacity was assessed according to ISO 4049–2009 standard specifications. The experimental procedure was carried out according to the following produces; the specimens and the aluminum plate were irradiated with X-ray at 60 kV, 10 mA and the exposure time of 0.4 s using an X-ray machine (Philips RO 1750 ROT 380, Germany).

The aluminum plate had compositions of, at least 98% of aluminum, 0.1% of copper and 0.1% of iron present in plate. While, dimensions of aluminum plate, the length 60 mm × 20 mm width, having a thickness range from 0.4 mm to 5.0 mm. The film density of each formulation's image was compared to the aluminum plate .

RESULTS

Fig. 2 shows the radiopacity test for the PMMA denture base the specimens compared to aluminum specimen represent the standard radiopaque properties (according to ISO 4049 – 2009 standard specifications) in which it is white in the image.

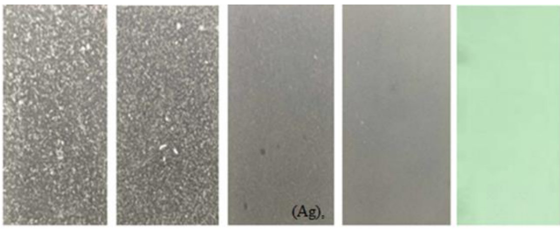

Figure 2: X-ray examination of specimens mixed with 0%, 1%, 2% and 3% Al2O3 as Filler and compared with aluminum plate.

The formulations of different additions of Silver (Ag) filler of 1, 2, and 3 wt % show slightly visible in ratios 2 and 3 wt % than 1 wt % the formulations compared to PMMA matrix, and commercial PMMA as shown in Fig. 2. The result showed higher filler loading give higher radiopacity property.

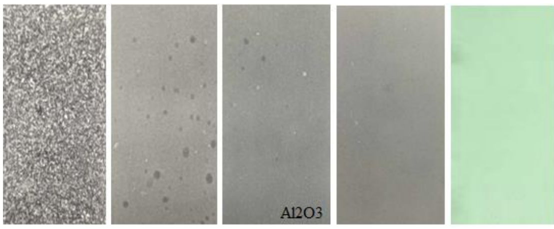

Figure 3: X-ray examination of specimens mixed with 0%,1%, 2% and 3% Al2O3 as Filler and compared with aluminum plate.

On the other hand, the different additions of Alumina (Al2O3) of 1, 2, and 3 wt % show slightly visible in ratios 3 wt % than 2 and 1 wt % the formulations compared to PMMA matrix, and commercial PMMA as illustrated in Fig. 3. The result showed higher filler loading give higher radiopacity property.
A different perspective would be adding of Chrome cobalt alloy (CoCr) of 1, 2, and 3 wt % show slightly visible in ratios 2 and 3 wt % than 1 wt % the formulations compared to PMMA matrix, and commercial PMMA as depicted in Fig. 4. The result showed higher filler loading give higher radiopacity property.
(Silver (Ag) ,Alumina (Al_2O_3) and Chrome cobalt alloy (CoCr)

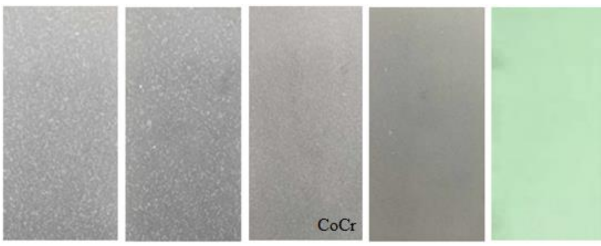

Figure 4: X-ray examination of specimens mixed with 0%,1%, 2% and 3% CoCr as Filler and compared with aluminum plate.

The radiographic evaluation demonstrated that the incorporation of metal fillers into the PMMA matrix significantly improved its radiopacity compared to unmodified and commercial PMMA. For silver (Ag) fillers, specimens containing 1 wt% showed only slight improvement in visibility, whereas those with 2 wt% and 3 wt% exhibited noticeably higher radiopacity, appearing more distinct under X-ray examination. This indicates a direct relationship between filler concentration and radiopacity, where increasing the weight percentage of silver enhances X-ray absorption due to its high atomic number.

Similarly, the addition of alumina (Al_2O_3) particles resulted in a gradual increase in radiopacity with increasing filler content. The 3 wt% Al_2O_3 formulation demonstrated the highest visibility among the tested groups, while 1 wt% and 2 wt% showed comparatively lower but still improved radiopacity relative to the control PMMA. These findings confirm that alumina, as an inorganic filler, contributes effectively to radiopacity enhancement, although its effect is less pronounced than that of metallic fillers due to differences in atomic density.

In the case of cobalt-chromium (CoCr) alloy fillers, a comparable trend was observed. The specimens containing 2 wt% and 3 wt% CoCr displayed greater radiographic contrast than those with 1 wt%, indicating improved detectability. The presence of high atomic number elements such as cobalt and chromium enhances X-ray attenuation, thereby increasing the radiopacity of the denture base material.

Overall, the results from all tested fillers (Ag, Al_2O_3, and CoCr) consistently showed that increasing filler loading leads to a proportional increase in radiopacity. Among the tested concentrations, 3 wt% provided the highest radiographic visibility without excessive filler addition. These findings suggest that the incorporation of metal and metal oxide fillers into PMMA is an effective strategy to overcome its inherent radiolucency, making denture bases more easily detectable in clinical radiographic examinations and improving patient safety in cases of accidental ingestion or aspiration.

DISCUSSION

This study investigated the impact of various metal and metal oxide fillers—silver (Ag), alumina (Al_2O_3), and cobalt–chromium (CoCr)—on the radiopacity of polymethyl methacrylate (PMMA) denture base material. The results indicated that the incorporation of these fillers improved the radiopacity of PMMA relative to the unmodified and commercial materials. This enhancement is due to the presence of elements with elevated atomic numbers, which augment X-ray absorption and hence enhance radiography visibility[34, 35].

A progressive enhancement in radiopacity was noted with higher concentrations of silver (Ag) fillers. The specimens with 2 wt% and 3 wt% Ag exhibited significantly enhanced visibility during X-ray analysis in comparison to the 1 wt% specimen and the control PMMA. This trend aligns with other research demonstrating that materials with high atomic number elements, like silver, show increased radiopacity owing to their superior X-ray attenuation properties[34, 36].

The findings indicated that radiopacity of alumina (Al_2O_3) increased with higher filler content. The 3 wt% Al_2O_3 specimens exhibited greater visibility than lower concentrations and the control group. Nonetheless, the radiopacity attained with alumina was comparatively inferior to that reported with metallic fillers. This conclusion corroborates previous research, including that of Abboud et al. [31], which indicated that alumina enhances both mechanical characteristics and radiopacity, however its efficacy is moderated by its lower atomic number relative to metals.

The integration of cobalt–chromium (CoCr) alloy fillers enhanced the radiopacity of the PMMA matrix. The formulations with 2 wt% and 3 wt% CoCr exhibited superior radiographic contrast compared to those with 1 wt% and unmodified PMMA. The superior performance of CoCr fillers is due to the synergistic action of cobalt and chromium, which are dense elements that promote X-ray attenuation[34, 35].

The findings demonstrate a clear correlation between filler concentration and radiopacity, whereby an increase in filler quantity enhances radiographic detectability. This discovery aligns with prior research indicating that the integration of radiopaque filler elements into the resin matrix improves their capacity to absorb X-rays[3,38].

Excessive filler content may negatively impact other attributes, including mechanical strength and aesthetics, which must be addressed when determining the suitable filler concentration[3]. The observed increase in radiopacity in this study can be attributed to the effect of metal fillers on the physical properties of PMMA, as similarly documented for other characteristics including thermal conductivity. The integration of fillers such as silver (Ag), alumina (Al_2O_3), and cobalt–chromium (CoCr) into the PMMA matrix enhances material performance owing to their elevated density and atomic configuration, which augment interaction with electromagnetic radiation[40].

Elevating filler concentration results in a corresponding enhancement of characteristics, since increased filler loading improves both thermal conductivity and radiographic clarity, suggesting a common mechanism associated with enhanced energy absorption and transmission within the composite. Of the evaluated fillers, silver demonstrated the most significant effect, owing to its elevated electron density and exceptional physical features, which enhance both thermal energy transfer and X-ray attenuation. While alumina and CoCr enhanced radiopacity, their contributions were somewhat diminished owing to variations in atomic number and conductivity. The findings indicate that altering PMMA with suitable types and concentrations of metal fillers enhances radiopacity and other functional properties, providing a dual advantage for diagnostic detectability and clinical performance, particularly in addressing PMMA's inherent limitations, such as radiolucency and inadequate thermal response[40].

Enhancing the radiopacity of denture base materials is crucial for the identification of cracked, swallowed, or aspirated prosthetic elements from a clinical standpoint. Standard PMMA is radiolucent and challenging to differentiate from adjacent soft tissues in radiographic images, potentially postponing diagnosis and treatment in emergencies[41-43]. The current findings indicate that integrating metal and metal oxide fillers into PMMA effectively addresses this constraint and improves patient safety.

CONCLUSION

The study highlights the ongoing necessity for innovations in dental materials, especially with dental composites. This necessity propels continuous investments in research and development to improve the qualities and performance of denture materials, seeking a more durable and dependable solution for patients. The significant function of metal fillers is emphasized, especially in meeting the demand for enhanced radiodensity. Silver/tin alloy and gold powder demonstrate potential in fulfilling radiodensity criteria for dental cements, providing prospective alternatives for improving diagnostic efficacy in clinical environments. Nevertheless, the study acknowledges the necessity of additional research to thoroughly comprehend the characteristics of dental cements with various radiopacifiers. The study examines the effect of metal fillers on thermal conductivity, indicating an enhancement linked to their integration. The proportion of nanoparticles significantly influences the extent of this rise. Notwithstanding these modifications, the research underscores that the findings conform to established criteria, hence reaffirming the necessity of upholding quality benchmarks in dental material investigations.

In conclusion, enhancing denture base materials necessitates a comprehensive strategy, encompassing the investigation of alternative polymers, the optimization of metal fillers for radiodensity, and the examination of the effects of metal fillers on thermal conductivity. Continued research is crucial to overcome existing constraints and propel progress in dental prosthesis.

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