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RESEARCH ARTICLE OPEN ACCESS

Engineering a hydration-responsive PMMA denture base using potassium polyacrylate

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Abstract
Objective: This research aimed to identify the characteristics and the impact of potassium polyacrylate (KPA) as a heat-polymerised PMMA additive on the water sorption behaviour, mechanical property, surface characteristics, and cytocompatibility.
Methods: PMMA specimens were fabricated in different KPA concentrations (0, 0.5, 2.5 and 5 wt%). Water sorption and solubility tests were performed according to ISO's guidelines. Mechanical characteristics were determined by three-point bending and Vickers hardness tests. Surface characteristics and chemical stability were investigated using scanning electron microscopy and Fourier transform infrared spectroscopy. MTT assay was performed on fibroblast cell cultures to determine cytocompatibility.
Results: Water sorption, but not solubility, increased with the addition of the KPA in a concentration-dependent manner. Measurement of mechanical properties showed a gradual decrease in both flexure strength and hardness values by increasing KPA content, but all were within clinically acceptable ranges. Uniformly dispersed at lower loading levels and micro-porous controllability at higher concentrations without PTMS degrading the PMMA matrix was observed in the microscopic analysis. The cytotoxicity test revealed high cell viability for all the formulations, suggesting that biocompatibility was maintained.
Conclusion: PMMA modified with potassium polyacrylate exhibits enhanced hydration while maintaining an acceptable mechanical and biological performance. The application of mixed-in additives for a multifunctional denture base material may have some potential merits to xerostomic patients, and such ways in prosthetic biomaterials design will be a great future.

Keywords: PMMA, Potassium Polyacrylate, Denture Base Materials, Water Sorption, Xerostomia.

Plain English Summary

This study investigated whether adding a water-absorbing material (potassium polyacrylate) to denture base plastic (PMMA) could help keep the mouth moist in patients with dry mouth (xerostomia). The results showed that the modified material absorbed more water while maintaining acceptable strength and safety for oral use. This approach may lead to more comfortable dentures for patients suffering from dry mouth

Introduction

The denture base is prepared using polymethyl methacrylate (PMMA) due to its desirable esthetics, ease of processing and low cost. It, however, has a number of limitations, which are a low thermal conductivity, high thermal expansion, colour instability and brittle nature, which amplify the risk of fracture during clinical applications. Moreover, water is a plasticiser of the acrylic matrix, causing the dimensional change, surface

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cracking, and the possible decrease in long-term mechanical stability. Even though PMMA has acceptable water sorption, water hydration can lead to reduced mucosal lubrication, especially in xerostomic patients, which is associated with fatigue failure and reduced denture fit. Such restrictions have promoted the formulation of hygro-mechanical reinforcement measures in order to enhance the hygro-mechanical efficacy of denture base fabrications (1, 2).

It has explored the use of various fillers, fibres, and copolymeric additives to improve the mechanical and functional properties of denture base polymers. Of late, the use of superabsorbent polymers (SAPs) has generated some interest through their capacity to absorb and retain high levels of water. Potassium polyacrylate (KPA) is an ionic, cross-linked acrylic polymer, and has carboxylate groups that are hydrophilic and which give it great swelling power and enable it to be used as an internal water reservoir. The property allows long-term hydration as well as stability of polymer networks. Thus, the addition of SAPs to PMMA could be considered a promising solution to enhance the moisture control and performance of denture base materials in general (3, 4, 5).

Biocompatibility remains an important criterion of denture base materials, because these are in prolonged contact with the mucosa and require chemical stability as well as cellular tolerance. PMMA has an extensive clinical background in dental as well as medical fields; however, residual monomer release and byproducts of polymerisation remain problematic. New composite PMMA systems with reinforcement, also filled with bioactive filler, TiO2 and nanostructured material, have been shown to induce good cellular responses and tissue integration in experimental models. These results suggest that, when designed in a controlled manner, additive addition can preserve or improve biological compatibility while imparting novel functionalities. Indeed, hydration-promoting composites need to be tested for their mechanical strength and biological properties in the oral cavity (6).

Clinically, xerostomia is common among elderly patients and those undergoing medication or radiotherapy, leading to mucosal dryness, discomfort, and reduced denture retention. Reduced salivary lubrication increases friction at the denture–tissue interface, which may cause inflammation and prosthesis instability. Therefore, incorporating potassium (K) was proposed to improve hydration while maintaining the structural integrity of the mandibular prosthesis (2, 7).

Beyond hydration and mechanical considerations, controlling microbial load is essential for the long-term success of prosthetic appliances. The surface characteristics of acrylic denture materials promote biofilm formation and mucosal irritation. Chlorhexidine is considered the gold-standard antimicrobial in prosthodontics due to its broad spectrum and substantivity, effectively reducing microbial colonisation. This is particularly important in xerostomic conditions where reduced salivary clearance favours microbial growth. Combining hydration-enhancing materials with antimicrobial strategies may support the development of multifunctional denture bases that improve lubrication, mechanical stability, and microbial balance, ultimately enhancing clinical longevity (8, 9, 10).

Materials and Methods

A commercially available heat-polymerised polymethyl methacrylate (PMMA) denture base resin (Major Base 20, Major Prodotti Dentari S.p.A., Moncalieri, Italy) was used as the polymeric matrix. The hydrophilic additive potassium polyacrylate (KPA) powder (Sigma-Aldrich, St. Louis, MO, USA) with an average particle size of 50–100 μm was used. Methyl methacrylate (MMA) monomer containing hydroquinone as stabiliser (Merck, Darmstadt, Germany) was used according to the manufacturer's instructions.

Experimental Groups

PMMA was modified by incorporating potassium polyacrylate at four weight concentrations:

Group A (Control): 0 wt% KPA
Group B: 0.5 wt% KPA
Group C: 2.5 wt% KPA
Group D: 5.0 wt% KPA

Each formulation was prepared independently to ensure consistency and reproducibility.

Specimen Preparation

Pre-set amounts of PMMA polymer powder were dry mixed with the required KPA concentration, which was manually blended for 60 seconds to ensure initial homogeneity. The blend was then loaded into a vacuum mixer and placed under a vacuum to remove entrapped air and promote homogeneous dispersion. These products were mixed with MMA monomer and pasted until doughy.

The resin was placed in stainless-steel moulds prepared to standardised dimensions of 65 mm × 10 mm × 3.3 mm for the flexural test and of 10 mm diameter × 2 mm thickness for the sorption/solubility assessment. The polymerised

specimens were prepared with sequential 74 °C in a preheated water bath heat-curing unit for 2h and final boiling at 100 °C for one hour. Thereafter, the moulds were lifted onto a bench for cooling to room temperature to relieve stress in the cured moulded product. Samples were deflasked, polished with standard abrasive paste and placed in distilled water at 37 °C for 48 h to reduce residual monomer levels.
Each test group consisted of n = 10 specimens per evaluation to ensure statistical validity.

Water Sorption and Solubility Testing
Water sorption and solubility were measured according to ISO 20795-1 guidelines. Samples were subsequently dried at 37 °C to constant mass (m_1) and weighed in an analytical balance of 0.001 g precision. Samples were then placed in distilled water at 37 °C for 7 d, reweighed (m_2) and finally conditioned to reach the final mass (m_3) in a desiccator.
Water sorption and solubility were calculated using:

$$\text{Sorption} = \frac{m_2 - m_1}{V}$$

$$\text{Solubility} = \frac{m_1 - m_3}{V}$$

where *V* represents specimen volume.

Mechanical Testing
Flexural strength was evaluated using a three-point bending test on a universal testing machine (Instron 3366, Instron Corp., Norwood, MA, USA). with a gauge length and cross head speed of 50 mm and 5 mm/min, respectively. Load at fracture was recorded and translated into flexural strength.
Surface microhardness was evaluated using a Vickers microhardness tester (HMV-2, Shimadzu Corp., Kyoto, Japan).

Surface Morphology and Chemical Characterisation
Surface microstructure: The surface microstructure was observed using scanning electron microscopy (SEM; JSM-6510LV, JEOL Ltd., Tokyo, Japan). To achieve a better resolution, the specimens were sputter-coated with a thin conductive layer before imaging.
Chemical characterisation was performed using Fourier transform infrared spectroscopy (Nicolet iS10 FTIR spectrometer, Thermo Fisher Scientific, Waltham, MA, USA).

Biocompatibility Testing
Cytocompatibility was assessed with L929 mouse fibroblast cells using the MTT method. Preparations, denominated extracts, were obtained by growing sterile samples in culture medium under controlled conditions. Metabolic activity was measured using a microplate reader (BioTek ELx800, BioTek Instruments Inc., Winooski, VT, USA) after 24 and 72 h of incubation with the extracts. The values were compared with untreated controls and presented as a percentage of cell viability.

Statistical Analysis
Analyses were performed using a statistical package (SPSS). Normality was checked before analysis. Mean group differences were examined using 1-way ANOVA and post hoc testing. Results were considered statistically significant at $p < 0.05$.

Results
Water Sorption and Solubility
The amount of water sorption was determined, and it was found that KPA increased the moisture absorption concentration dependently after being added to PMMA. The control (0% KPA) had
the minimum sorption value, representing the hydrophobic property of conventional heat-cured PMMA. Though the slow application of KPA resulted in a remarkable increase in water uptake, the result is about three times higher compared to the control with 5.0%.
This is in line with KPA's hydrophilic ionic carboxylate moieties, which osmotically swell and retain water within a polymer network. Although the sorption values were relatively high, the samples showed no macroscopically detectable changes in size during immersion, suggesting that swelling was limited to within the composite structure and did not result in macro distortion.
For KPA concentration, values were slightly increased with increasing solubility but are within clinically acceptable limits. Net gains in solubility are indicative of some extent of leaching of weakly bound species or diffusion out of residual monomer, rather than polymer backbone degradation. Importantly, post-desorption, there was no visible etching or deconstruction of the sample surface.
The result of statistical analysis by one-way ANOVA showed that there was a very significant difference in sorption between groups (p 0.05), indicating the stability of the altered material. (Table 1)

Table 1: Comparison of Water Sorption and Solubility between PMMA and that Reinforced with Potassium Polyacrylate

Group	KPA (%)	Sorption (µg/mm³) Mean ± SD	Solubility (µg/mm³) Mean ± SD
A	0	18.4 ± 1.2	1.6 ± 0.3
B	0.5	24.7 ± 1.5	1.9 ± 0.4
C	2.5	36.9 ± 2.1	2.3 ± 0.5
D	5.0	52.5 ± 2.8	2.8 ± 0.6

p-values = <0.05

Mechanical Properties

Moreover, mechanical test results showed that the flexural strength and surface hardness of KPA-containing samples were slowly decreased compared with those of untreated PMMA. Control samples showed the highest bending-stress resistance, reflecting a homogenous and continuous polymer matrix. With an increase in KPA concentration, the local stress concentration zone of the system, probably formed from hydrophilic particle incorporation, would lead to a decrease in load transfer efficiency.

Even so, all modified groups showed flexural strengths that were above the clinically acceptable limit for denture base materials. Statistical significance of the decrease of up to 2% was reached at concentrations > or = 2.5%, and higher loading of SAP changed the internal packing density of the polymer and created micro-voids because of water absorption domains.

Vickers hardness had a similar decreasing tendency as stiffness, and it was suggested that mild softening of the PMMA matrix took place. The presence of polar inclusions may result in enhanced segmental mobility among polymer chains and thus slightly reduce the indentation resistance. Importantly, there was only a limited loss in hardness, and it remained below the level at which brittle or unstable behaviour would be anticipated.

Statistical analysis showed that intergroup differences were significant for both flexural strength ($p < 0.05$) and hardness ($p < 0.05$). A post-hoc analysis showed that the 0.5% concentration group maintained mechanical performance like the control, whereas higher concentrations resulted in measurable but clinically acceptable changes. (Table 2)

Table 2: Mechanical Performance of Potassium Polyacrylate–Modified PMMA Denture Base Materials

Group	Flexural Strength (MPa) Mean ± SD	Vickers Hardness (HV) Mean ± SD
A	92.5 ± 3.4	20.8 ± 0.7
B	88.1 ± 3.0	19.9 ± 0.6
C	81.6 ± 2.7	18.5 ± 0.5
D	74.3 ± 2.5	17.2 ± 0.5

p-values = <0.05

Surface Morphology and Chemical Characterisation

Progressive microstructural changes with increasing KPA, as observed by scanning electron microscopy. Control specimens had a smooth, consistent surface compatible with well-polymerised PMMA. Uniform particle distribution, though without conspicuous aggregation, is observed in the low concentration KPA samples, which indicates a good integration of KPA with the polymer matrix.

At higher concentrations, isolated micro-agglomerates were observed, together with fine porosity related to hydration zones. These are potentially the features formed by KPA when swollen and in immersion, creating pockets of local micro-reservoirs without destruction of matrix continuity.

Fourier transform infrared spectra verified that maintaining the PMMA backbone and ester carbonyl, methyl methacrylate successions remained unchanged among all groups. The relatively small element of spectral broadening in the hydroxyl region indicated that physical hydrogen bonding took place, in contrast to chemical grafting or polymer degradation.

Taken together, SEM and FTIR results suggest a physical composite model with KPA as a dispersed hygroscopic phase having no effect on the basic PMMA chemistry. (Table 3)

Table 3: Surface Morphology and Chemical Characterisation of Potassium Polyacrylate–Modified PMMA.

Group	Particle Distribution	Surface Porosity	FTIR Observation
A	Homogeneous	None	Standard PMMA peaks
B	Uniform dispersion	Minimal	Weak hydrogen interaction
C	Moderate clustering	Mild porosity	Physical bonding features
D	Agglomeration zones	Noticeable micro-pores	No chemical alteration

Biocompatibility (MTT Cytotoxicity Assay)

Cell viability studies showed good cytocompatibility for all formulations. Metabolic activity (ATP levels) of the fibroblast cultures after exposure to PMMA-KPA extracts was above 85% compared to untreated controls, fulfilling currently agreed upon cut-offs for non-cytotoxic biomaterials.

Even though a slight reduction of viability was observed by increasing the concentration of the KPA, it could be due to a transient effect, osmotic or residual leachables. However, under microscopic examination, morphological findings suggestive of cell stress, detachment or membrane damage by LPS were not observed.

72h viability remained constant from 24 to 72 h, indicating no late toxicity of cisplatin. Statistical analysis showed no significant difference between groups ($t > 0.05$), indicating that the biological safety of KPA loading specimens was not hampered by the addition of KPA. (Table 4)

Table 4: Cytotoxicity and Cell Viability of Potassium Polyacrylate–Modified PMMA

Group	24 h Viability (%)	72 h Viability (%)
A	97 ± 2	95 ± 3
B	95 ± 3	93 ± 3
C	91 ± 4	89 ± 4
D	88 ± 5	86 ± 5

p-values = <0.05

Integrated Results Overview

The combined results demonstrated that potassium polyacrylate incorporation effectively enhanced the water storage capacity of PMMA while maintaining material consistency and biological safety. Mechanical properties showed gradual, concentration-dependent reductions that remained within clinically acceptable ranges. Surface analysis confirmed composite stability without chemical decomposition, and cytotoxicity testing verified the biocompatibility of all modified formulations.

Discussion

The investigation indicated that incorporating K-PA on heat-polymerised PMMA (HPMMA) would significantly change the hydration properties of the original material network, which had long been a standard denture base material (1). Polymethyl methacrylate (PMMA) is the most widely used denture base material because of its aesthetics and processability, yet its low water sorption limits its potential to retain water while being in contact with mucosa, especially in a xerostomic oral environment (1). The increased water uptake with increasing potassium polyacrylate concentration is typical for the osmosis swelling behaviour of superabsorbent polymers, in which ionic carboxylate groups tend to trap water internally (3). This is because the modified composite only partially absorbs surface water as an enhanced internal moisture sink, ensuring better hydration stability without any macroscopic deformation (4).

Controlled internal hydration has clinical significance since recurring dehydration-rehydration cycles are predetermined conditions in favouring dimensional fatigue and microcrack growth in acrylic UE bases (2). Moisture gradient stabilisation through the polymer network using potassium polyacrylate aids in reducing stress concentrations by cyclic shrinkage (1). This minor rise in solubility with the additive level is likely because of diffusion of some loosely bound structure and not polymer degradation, which also substantiates the fact that crosslinked polyacrylate systems are not susceptible to chemical degradation (4). Long-term clinical stability and decreased surface material change depend on retention of low solubility (1).

The flexural strength was observed to decrease with the concentration, which is a natural behaviour with composite polymers in which the redistribution of local stress occurs due to the presence of hydrophilic particulates (5). Such a behaviour as that of glassy reinforced polymers, though not occurring under catastrophic failure conditions, has

been observed in most other problems in polymer-based systems when secondary phases alter the internal stress transfer efficiency (5). Despite the quantifiable decreases that were found, the modified forms still showed flexural readings within the clinically acceptable limits, and no harm was caused to the functional integrity by the increase in hydration levels (7). This trend of softening can be attributed to the moderate plasticization of the PMMA matrix by the moist areas, which can result in an increased absorption of energy during impact (11).

Such plasticization has the potential to enhance resistance to crack propagation, which is one of the predominant causes leading to denture fracture (7). Fracture strength is of special interest since mechanical fatigue and repeated functional loading are known causes for fractures in a prosthesis (12). The trade-off between hydration functionality and structure protection is consistent with the state-of-the-art design of composite biomaterials (5).

The surface analysis supports the mechanical results, as demonstrated by SEM images showing homogeneous particle dispersion at a lower potassium polyacrylate level with efficient stress transmission (13). At the higher concentrations, see their micro-pores, which we interpret as hydration pockets and indicate swelling behaviour reported for superabsorbent polymer composites (3). Significantly, the FT-IR spectra demonstrated that the chemical backbone structure of PMMA was unmodified during the incorporation of potassium polyacrylate and appeared as a physical composite interaction rather than gelation (1). Retaining the polymer identity leads to predictable curing and a permanent, stable structure (1).

Biocompatibility of a denture base material remains important, and there was no loss of cell viability amongst the formulations, demonstrating that the addition of potassium polyacrylate does not result in a cytotoxic degradation product. Modified PMMA formulations have had a good tissue response in implant and reconstruction applications in the past, indicating that the composite formulations are likely to be compatible (6). The small decrease in viability with increasing concentration implies reversible osmotic interactions rather than intrinsic toxicity (4). Patient, end-clinical xerostomia is a constantly threatening aspect for the denture wearer, leading to chronic irritation of the mucosa with associated discomfort and non-retentive in nature (14). A denture base that can store local wetness may therefore reduce such problems and prevent the mucosal lubrication as well as tissue compatibility to be continued (2). The incorporation of hydration-based mechanisms into PMMA is part of the broader trend towards prosthetic biomaterials that, in addition to their mechanical functions, also serve biological ones (8). Similar developments have occurred in denture liner systems, which consider the need for a balance of resiliency, hydration and tissue compatibility (10). Thermocycling findings also support the necessity of retaining a stable interfacial bond and mechanical properties with modified denture materials (11).

Such alteration of the composite reflects that a small amount of potassium polyacrylate, when added to the BCJA, is good for the enhancement of hydration and maintenance mechanics (6). For biomaterials, a balance is also needed where multipurpose could not be traded for strength (1). Analogous reinforcement methods across polymer systems have also shown that controlled dispersing of additives is equally important for realising the potential performance improvement (13). Larger materials studies in general have shown the compomer that controls how long the bottle functions (12).

Overall, the present findings suggest that (potassium) polyacrylate–modified PMMA should be a prospective candidate material for denture base restoration, due to its better hydration properties, while preserving mechanical and biological stability (1). Study the long-term fatigue resistance, intraoral ageing, and clinical efficacy under xerostomic conditions to confirm translational potential (6).

Study Limitations

Regardless of the positive findings, this research has a number of limitations. The tests were carried out in vitro and in controlled conditions and might not be wholly representative of the complexity of the biological and mechanical environment of the oral cavity. Exposure to long-term saliva, changes in temperature, masticatory forces, and microbial activity may cause changes in the hydration behaviour and mechanical properties compared to those in the case of laboratory conditions. Moreover, cytotoxicity analysis was only carried out in the short-term viability of fibroblasts and not on a wider range of biological reactions, like inflammatory reactions or tissue acclimatisation. Only a limited range of additive concentrations was studied, and intermediate formulations can provide additional optimisation. Thus, further in vivo research is required to determine the fatigue resistance in the long term, dimensional stability, patient comfort, denture retention, and mucosal response.

Conclusion

The addition of potassium polyacrylate to heat-polymerised PMMA presents a significant development in the design of denture base materials, increasing internal hydration potential, whilst not compromising mechanical and biocompatibility properties. Concentration-dependent uptake of water demonstrates that the superabsorbent polymer successfully acts as an internal water reservoir, potentially overcoming the hydration limit in conventional PMMA. Crucially, even though the mechanical properties gradually decreased with increasing concentration of additive, all preparations tested were capable of maintaining structural stability within clinically acceptable performance levels, thus also demonstrating that hydration promotion did not compromise structural integrity.

Surface analyses confirmed that potassium polyacrylate is physically incorporated in the PMMA matrix without any chemical degradation of the polymer, making the behaviour predictable. In addition, the results of cytotoxicity revealed that the modified material still exhibits good cellular compatibility, which implies its potential for intraoral application. Overall, these results indicate that the introduction of potassium polyacrylate can provide a balanced and multifunctional denture base resin to not only improve mucosal hydration but also maintain mechanical strength and biocompatibility. This combination approach is promising for the future design of prosthetic biomaterials to be applied in clinical practice against xerostomia.

Future Directions

Long-term ageing simulations that recreate intraoral conditions like thermocycling, mechanical fatigue and saliva exposure should be considered in further studies. There is also a need to undertake an evaluation of long-term dimensional stability and hydration release kinetics to get a better insight into the clinical prospects of the material. Moreover, in vivo research is necessary to determine mucosal interaction, patient comfort and retention of the prostheses in xerostomic patients. Future studies can also consider better dispersion methods or combination methods of reinforcement to improve mechanical performance and retain hydration properties. The addition of potassium polyacrylate to nano-composite PMMA systems and testing them with the help of clinical trials will be necessary to prove that they are safe, durable, and help the patient.

List of Abbreviations

PMMA: Polymethyl methacrylate
KPA: Potassium polyacrylate
SAP: Superabsorbent polymer
SEM: Scanning electron microscopy
ANOVA: Analysis of variance
SD: Standard deviation
FTIR: Fourier transform infrared spectroscopy
MTT: 3-(4,5-dimethylthiazol-2-yl)-2,5-diphenyltetrazolium bromide
ISO: International Organisation for Standardisation
MMA: Methyl methacrylate
HV: Vickers hardness

Declarations:

Ethics Approval and Consent to Participate

All work was carried out in accordance with the applicable institutional and national ethical standards for laboratory-based (non-human subjects) research because this study was conducted entirely in the laboratory and did not involve any individuals or personal data of any kind.

Consent for Publication

All authors gave their consent for the publication of this work under the Creative Commons Attribution Non-Commercial 4.0 license.

Data Availability

Data for this work are available from the authors and may be provided upon reasonable request.

Competing Interests

None

Funding

None.

Author Contributions

KRA helped with the design, conceptualisation, development of the methodology, supervision, and revision of the manuscript.

GAA was responsible for data collection, experimental procedures, formal analysis, and drafting of the original manuscript.

KIF performed data interpretation, visualisation, and contributed to the results section.

ASS conducted the statistical analysis, validated the findings, critically revised the manuscript, and approved the final version for publication.

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