Mustansiria Dental Journal
DOI: 10.32828/mdj.v22i1.1279

E- ISSN: 2618-0944
P- ISSN: 1813-8500

Research Article | **Open Access** | **Volume: 22, Issue: 1, 2026**

Plasma Surface Treatment of Heat-Cured Acrylic Resin Material: A Narrative Review

Jinan A. Aljbory[1], **Nihad Hasan AlFuraiji**[2], **Syed Saad B Qasim**[3]

[1,2]Prosthetic Dental Techniques Department, College of Health and Medical Technology, Middle Technical University, Baghdad, Iraq, E-mail[1]: ECC5001@mtu.edu.iq, E-mail[2]: nihad.hassan@mtu.edu.iq.

[3]Bioclinical Sciences Department, Faculty of Dentistry, Kuwait University, Safat 13110, Kuwait, E-mail: Sayed.binqasim@ku.edu.kw.

Correspondence: *Jinan A. Aljbory*
Email: ECC5001@mtu.edu.iq
Received: *13/01/2026;* ***Accepted:*** *23/04/2026;* ***Published:*** *30/06/2026*

Abstract

Aim: This narrative review was an attempt to assess the impact of plasma surface treatment on Polymethyl methacrylate (PMMA) heat-cured acrylic resin with special attention on surface properties and antimicrobial activity. **Methods:** The PRISMA method was used to identify literature in PubMed, Google Scholar, and Research Gate databases. Articles published from January 2016 to March 2025 that explored the topic of plasma surface treatment of heat-cured acrylic resin were taken into consideration. Out of the 183 studies found, 32 studies were found to meet the inclusion criteria. **Results:** The analyzed literature proved that Atmospheric Pressure Cold Plasma treatment and Dielectric Barrier Discharge treatment substantially enhanced wettability and surface energy of PMMA based on functional groups polarization incorporation. These changes on the surfaces continuously decreased adhesion of microbes, especially Candida albicans, and prevented the formation of biofilms. Moreover, the bond strength between PMMA and soft liners, coatings and adhesives, was improved through plasma treatment. These effects differed in their magnitude with parameters of plasma (gas type, exposure time, etc.) **Conclusion:** Plasma surface treatment can be a promising technique of enhancing biofunctionality and longevity of heat-curing PMMA dentures. Nonetheless, it requires standardized treatment regimens and long-term clinical trials that can establish its clinical reliability.

Keywords: Plasma treatment, PMMA, heat-cured acrylic resin, denture base, surface modification, antimicrobial effect, wettability, bond strength.

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Introduction

Prosthetics dentistry is a branch of dentistry that is related with the replacement of missing structures and teeth in the mouth with substitutes of the missing parts. It is very instrumental in the restoration of oral functioning, beauty and comfort of patient by use of crowns, bridges and complete or partial dentures. The acrylic resin, especially the Polymethyl methacrylate (PMMA) is a material that is commonly applied in fabrication of denture bases because of its acceptable esthetics, ease of processing, low cost and satisfactory physical characteristics. However, regardless of its benefits, PMMA continues to be limited in terms of mechanical strength and durability and this has prompted the ongoing research to improve its performance in terms of long-term clinical application [1].

The past studies have revealed that heated acrylic resin has mechanical performance drawbacks especially when it is loaded with functional loads. A number of methods are suggested to enhance its mechanical performance, it has also been reported that the mechanical behavior of the material can be greatly affected by surface finishing and polishing processes. These results indicated the significance of the surface properties and give a scientific explanation of the use of state-of-the-art surface modification methods, including plasma surface treatment [2].

Recently gained attention as a physical, non-thermal, and environmentally friendly technique that can alter surface chemistry and morphology without affecting the bulk properties of the resin [3].

Cold plasma is generated by ionizing a gas (e.g., Oxygen, Argon, Helium, Nitrogen, or Air) at atmospheric or low pressure, producing reactive species (ions, electrons, radicals, UV photons) that can interact with the material's surface. Plasma exposure modifies surface free energy, enhances wettability, and introduces polar functional groups: such as hydroxyl (-OH), carbonyl (C=O), and carboxyl (-COOH) groups, thereby promoting adhesion of liners, coatings, or bioactive agents such as Silver nanoparticles, Zinc oxide nanoparticles, Chitosan, Titanium dioxide nanoparticles, Hydroxyapatite nanoparticles. It also has an intrinsic antimicrobial effect, reducing microbial colonization [4].

Given the increasing research output in this area, it is necessary to systematically review the recent literature (2016–2025) to evaluate the effectiveness of plasma surface treatment on heat-cured PMMA acrylic resin in terms of physical, chemical, mechanical, and biological outcomes.

Materials and Methodologies

Search Methodology

Three electronic databases, as follows, PubMed, Google Scholar, and Research Gate, were searched systematically. The Boolean operators and keywords (Plasma treatment, PMMA, heat-cured acrylic resin, denture base, surface modification, antimicrobial effect, wettability, bond strength) were included in this narrative review.

The search involved articles that were published between January 2016 and March 2025. Other sources were identified through screening of the bibliographies of the articles used. The review question was

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structured according to the PICOS framework (Table 1).

Inclusion Criteria

Research that was published not earlier than 2016. In vitro, in vivo, and clinical research on heat-cured PMMA acrylic resin that is plasma surface treated. Researches assessing any of the following results: surface roughness, wettability, surface free energy, chemical composition, bond strength (liner/resin), or antimicrobial/ biofilm adhesion.

Exclusion Criteria

Articles with other materials other than PMMA (e.g., Zirconia, Titanium, PEEK). Investigations where plasma was used as a means of sterilizing/disinfecting without measuring the characteristics of the surface of acrylic resin. Reviews, editorials, and abstracts of conferences that do not have original data.

Data Extraction

The data that was extracted were: author/year, study design, plasma type/system, gas used, parameters (exposure time, pressure, and power) and material specifications, measured outcomes, and key results.

Table 1: PICOS framework of the review question

Components	Description
Participants (P)	Research concerning the use of heat-cured acrylic resin (PMMA denture base) only.
Intervention (I)	Dielectric barrier discharge (DBD) plasma (cold plasma, plasma surface treatment, glow discharge, atmospheric pressure plasma, argon/oxygen/helium plasma).
Control (C)	Unmodified unpolished acrylic resin (untreated) heat cured.
Outcome (O)	Evaluation of surface properties (roughness, wettability, surface chemistry, bond strength, surface free energy) and biological outcomes (antimicrobial effect, biofilm adhesion).
Study Design (S)	*In vitro, in vivo and clinical studies that were published in 2016-2025.*

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Results

Study Selection

The online search provided 183 articles in PubMed, Google Scholar, and ResearchGate. When duplicates had been eliminated and abstracts screened, 52 full-text articles were examined with regards to eligibility. This review included 32 articles that were published in 2016-2025 using the inclusion and exclusion criteria.

3.2 Study Characteristics

The studies included were mainly in vitro studies that were carried out in dental laboratories in Asia (Iraq, Iran, Turkey, Japan), Europe (Poland, Germany), and North America. Cold plasma in atmospheric pressure was reported as the modes of plasma, dielectric barrier discharge (DBD), plasma jets, glow discharge and atmospheric pressure cold plasma (ACP). The commonest gases employed were oxygen, argon, helium, and air, exposure time was between 10 seconds and 30 minutes.

The results obtained were split into two broad categories:

1. Results of physicochemical and surface property (roughness, wettability, contact angle, surface free energy, chemical composition, bond strength).

2. Biological/antimicrobial (*Candida albicans* adhesion, bacterial adhesion, biofilm-reduction, cytocompatibility).

Table 2: Plasma treatment parameters and effects on physicochemical properties of heat-cured PMMA (2016–2025)

Author, Year	Country	Plasma Type	Gas	Exposure Parameters	Main Outcomes on Physicochemical Properties
Qian, et. al. 2016	Japan	ACP	Air	30–120 s	Reduced contact angle; increased surface free energy; time-dependent effect.
Vasilieva, et. al. 2018	Russia	Low-pressure plasma	Mixed gases	2–5 min	Increased wettability, improved surface polarity.
Bagiatis, et.al. 2019	Greece	ACP	O_2, Ar	60 s	Reduced contact angle, higher SFE; SEM showed smoother surface.

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Asnaashari, et. al. 2019	Iran	Cold plasma	O_2	120 s	No bulk changes; improved wettability and adhesion.
Masood & Mahamed, 2020	Iraq	Glow discharge	O_2, Ar	5 min	Increased roughness with Ar, smoother surface with O_2; improved FTIR functionalization.
Soygun, et. al. 2020	Turkey	ACP	Ar	15, 30, 60 s	Longer exposure improved bond strength to soft liner; optimal at 30 s.
Sui, et. al. 2021	China	RF plasma	O_2	60 s	XPS confirmed oxygen functional groups; reduced water contact angle.
Hage, et. al. 2021	Germany	ACP	Air	2 min	Enhanced hydrophilicity; plasma-treated surfaces resisted protein adsorption.
Fleischer, et. al. 2024	Germany	ACP (industrial)	O_2	1–5 s	Improved adhesion in large-scale processing without altering transparency.
Topdağı, 2025	Turkey	ACP / DBD	O_2, Ar	60 s	Plasma improved bond strength between PMMA and metal frameworks.
Meki, et. al. 2025	Egypt	Low-pressure atmospheric	Not clearly specified	Treated groups exposed to low pressure	• Flexural strength significantly increased in both heat-

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		plasma		atmospheric plasma. No further exposure time, gas composition, power or pressure given.	polymerized and 3D-printed resin groups after plasma treatment ($p < 0.0001$). • Surface roughness: in the heat-polymerized group, roughness significantly increased after plasma ($p < 0.0001$); in the 3D-printed resin group roughness change was not statistically significant ($p = 0.068$).

Table 2 has identified the studies reported between 2016 and 2025 that indicate that cold plasma treatment enhances physicochemical properties of heat-cured PMMA. The majority of the studies observed enhanced surface wettability, reduced contact angle, and enhanced surface free energy, which enhanced adhesion and coating behaviour. The best processes in adding polar functional groups where bulk properties were preserved were oxygen and argon plasmas. The best exposure times were found to be between 30 and 120 seconds which led to enhancement in bond strength and surface functionality without compromising material integrity.

Among the reviewed studies, Fleischer et al. (2024) had the best efficacy of plasma treatment, with high levels of adhesion increase using extraordinarily low exposure time (1-5 s) in cold plasma in the industrial environment, and without influencing surface transparency negatively.

Note: The given study does not specify how many of the 32 listed studies were included in the summary tables. Only research reports that provided detailed parameters of the plasma (type of gas, exposure time, and system) and quantitative values of physicochemical or biological qualities have been included in the tables. Case reports or clinical studies that did not present such information were not in tabular form but in narrative form.

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Table 3: Plasma treatment parameters and effects on biological/antimicrobial outcomes (2016–2025)

Author, Year	Country	Plasma Type	Gas	Exposure Parameters	Main Biological Outcomes
Qian, et. al. 2016	Japan	ACP	Air	30–120 s	Reduced Candida adhesion proportional to treatment time.
Asnaashari, et. al. 2019	Iran	Cold plasma	O_2	120 s	Inhibited *Candida albicans* growth; comparable to chemical disinfectants.
Masood & Mahamed, 2020	Iraq	Glow discharge	O_2, Ar	5 mins	Ar plasma reduced bacterial adhesion significantly.
Soygun, et. al. 2020	Turkey	ACP	Ar	15–60 s	Reduced microbial colonization on denture base–liner interface.
Hage, et. al. 2021	Germany	ACP	Air	2 mins	Plasma prevented biofilm formation; biocompatible with fibroblasts.
Topdağı, 2025	Turkey	ACP/DBD	O_2, Ar	60 s	Enhanced resistance to microbial colonization at PMMA–framework interface.
Mazur-Lesz, et. al. 2025.	Poland	Cold atmospheric plasma	He/O_2	5-10-20 mins	Reduced fungal adhesion biofilm on denture materials

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Table 3 shows that the cold plasma treatment of denture base acrylics (2016-2025) had a consistent effect of reducing the adherence of microbes and the formation of biofilm on the treated surfaces. Gases with the greatest antibacterial efficacy were oxygen and argon gases because they were able to generate reactive oxygen species. Microbial decrease was enhanced with increasing exposure time without causing biocompatibility problems. All in all, cold plasma is an outstanding approach to surface modification to enhance the biological and antibacterial aspect of denture materials.

In the studies reviewed, Hage et al. (2021) have shown the best performance of the plasma in terms of biological performance as the atmospheric cold plasma prevented biofilm formation and ensured high biocompatibility with fibroblast cells. In **Figures 1, 2** Plasma generation technologies have various applications in scientific research, industrial processes as well as in medical use and have a few specialised systems. The dielectric barrier discharge is an electrical one which relies on the application of metal electrodes and high volt power supply to produce non-thermal plasma which is used in surface modification as well as the activation of materials. The under water discharge enables the creation of plasma in a liquid media to permit the creation of nanoparticles, treatment and sterility of the products. Atmospheric pressure plasma jet (APPJ) to achieve a good control, voltage, current and frequency are regulated using plasma power supply and control units and portable laboratory plasma generator provides cold plasma to be utilized in laboratory applications i.e., surface treatment, sterilization and biomedical applications. Corona discharge, and spark discharge allow automated power production of high-power plasma at the industrial level, and are used in surface processing, plasma coating and material enhancement [19].

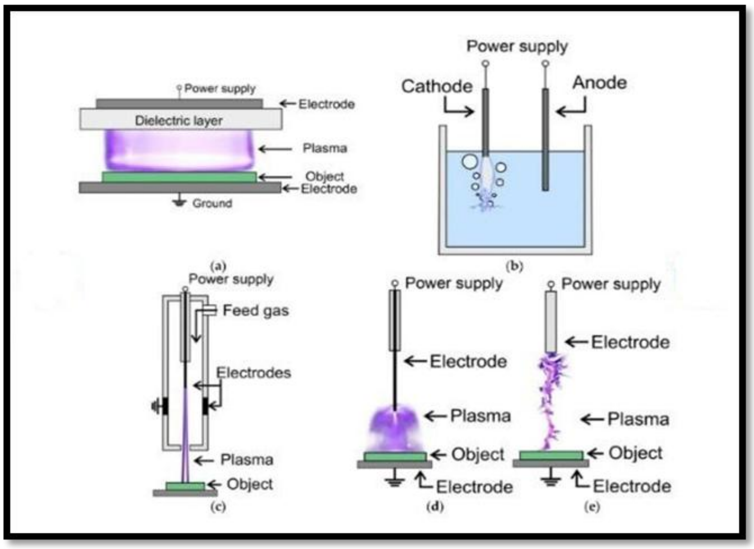

Figure 1: the schematic of plasma devices, (a) dielectric barrier discharge (DBD), (b) under water discharge, (c) Atmospheric pressure plasma jet (APPJ), (d) corona discharge, and (e) spark discharge [26].

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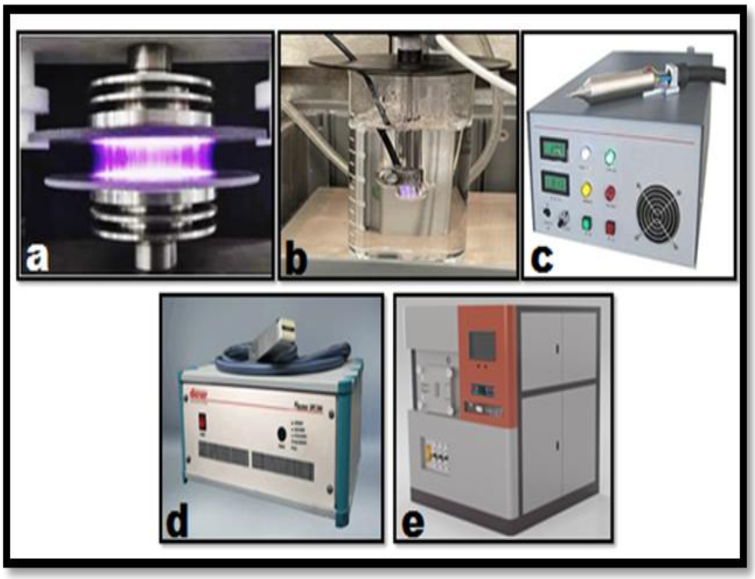

Figure 2: plasma machines, (a) dielectric barrier discharge (DBD), (b) under water discharge, (c) Atmospheric pressure plasma jet (APPJ), (d) corona discharge, and (e) spark discharge [26].

Summary of Results

Surface properties: Nearly all of the studies provided results of surface wettability and surface free energy, with oxygen plasma exhibiting the most significant ones. Surface roughness as caused by argon plasma was more likely to build on the surface and this is known to promote mechanical interlocking although they must be balanced to prevent over roughness (Table 2).

Bond Strength: PMMA bond strength was enhanced with the exposure of the materials to the plasma treatment, notably in the instances of the optimization of exposure time (30-60 s) (Table 2).

Biological outcomes: *Candida albicans* and bacterial adhesion were also greatly reduced by plasma in various studies and the effect lasted several days. Synergies were achieved with a combination of plasma and antimicrobial coating (Table 3).

Discussion

This is a narrative review that evaluated the effect of plasma surface treatment on heat-cured PMMA acrylic resin on 32 studies (2016-2025). The results prove that plasma treatment of all types invariably increases the surface wettability, adds polar functional groups and decreases adhesion of microbes. The extent of improvement is however dependent on the plasma type, gas composition, and exposure parameters.

Physicochemical effects

The most popular and most effective in enhancing surface free energy and lowering water contact angle were oxygen plasma. Argon plasma also showed dual functionality: although it enhanced roughness (which can potentially stimulate mechanical retention), overexposure resulted in surface irregularity that can result in jeopardizing hygiene. RF plasma and Glow discharge treatments added

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oxygenated functional groups without any change in bulk properties, as (Sui, et. al. 2021) and (Baek, et.al. 2022) have found.
Notably, plasma treatment did not produce a significant change in the mechanical strength of PMMA, which agrees with the fact that plasma only changes surface chemistry but not bulk structure. This is compared to the chemical etching which can deteriorate properties of materials.

Bond strength improvements
Some of the research (Soygun, et.al. 2020, Topdagi, 2025) showed that the bonding of PMMA with repair resins, soft liners or metal frameworks was enhanced by plasma treatment. The mechanism includes the enhanced wettability as well as the formation of surface radicals, which boosts the chemical bonding. Optimal exposure durations of ACP were of 30-60 seconds and the DBD were 10-30 minutes.

Biological outcomes
The PMMA surfaces that were treated with plasma have reduced microbial adhesion especially against *Candida albicans*. The reduction of *Candida adhesion* due to time was demonstrated in (Qian, et.al. 2016), whereas the antimicrobial effect of oxygen plasma was confirmed in (Asnaashari, et.al. 2019). Hage et al. (2021) also emphasized that plasma is capable of reducing biofilm formation without compromising fibroblast compatibility and found biocompatibility to be valid.
Interestingly, certain studies also suggested that the antimicrobial effect of plasma treatment can be exhibited over some days although the long-term durability is not studied deeply. The synergies with regards to antimicrobial coating and plasma pre-treatment were more effective at preventing microbial colonization.

Clinical relevance
Although the in vitro findings are reliable and encouraging, there is a lack of clinical trials. The most researches involved standardized disc-shaped PMMA specimens as opposed to actual dentures hence limiting clinical generalization. These variables like saliva, diet, oral hygiene and mechanical wear were not entirely reproducible. Furthermore, there are many variations in plasma devices and parameters in different studies making it hard to compare them directly.

Limitations of the evidence
1. Plasma sources, gases and exposure time heterogeneity.

2. Poor in vivo or clinical experimentation.

3. Poor consistency of reporting of plasma parameters (power, pressure, distance).

4. Short term assessment of antimicrobial action without a longitudinal clinical follow-up.

Conclusions
Plasma surface treatment is a potentially useful and least invasive technique to enhance the surface and biological characteristics of the heat-cured PMMA denture base resin. It is shown that plasma treatment:

1. Increases the surface wettability and energy, mostly by oxygen plasma.

2. Enhances the strength of the bond of PMMA with liners, repair resins or frames.

3. Decreases the adhesion and biofilm formation of microbes and lasts as long as a few days.

4. It retains bulk mechanical properties, and this has made it better than certain chemical surface treatments.

Clinical validation is still minimal in spite of consistent laboratory evidence. The plasma technology shows potential of improving the longevity of dentures, denture stomatitis and patient comfort, nevertheless, well designed studies in vivo are needed.

Recommendations

1. Plasma parameters (type of gas, exposure time, pressure, power) need to be standardized to be compared in different studies.

2. To ascertain the stability of the plasma induced changes in oral conditions, the long term in vivo clinical trials are required.

3. Combination-based treatments (plasma pre-treatment + antimicrobial coatings or nanoparticles) are recommended to be explored further with regards to synergistic advantages.

4. Cost-effectiveness and feasibility research ought to be conducted so as to find out whether chairside plasma treatment units are feasible to incorporate into the dental practice.

5. Further studies could investigate patient-based outcomes (comfort, satisfaction, incidence of denture stomatitis) instead of the laboratory parameters only.

Conflict of interest

The authors reported that they have no conflicts of interest.

Acknowledgments

The authors would like to thank Mustansiriyah University (www.uomustansiriyah.edu.iq), Baghdad, Iraq, for their support in the present work.

Funding: This study is part of MSc project and is partially self-funded.

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