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Review Article

Plasma Treatment as a Surface Additive for Improved Hydrophilicity on Titanium Dental Implant Surfaces. A Systematic Review.

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Abstract:

Dielectric barrier discharge plasma treatment on implant surfaces allows for increased osseo-integration by way of improved cellular adhesion, proliferation and differentiation. The physicochemical properties including contact angle and hydrophilicity capacitate for additional benefits like immediate cell seeding thereby prolonging the time for native cells to migrate first, rather than bacterial inhabitation. The review is aimed at elaborating the literature on contact angle and hydrophilicity of implant surface with plasma treatment. A total of 32 articles were identified after digital search from databases like PubMed/ Medline, Elsevier, Cochrane Library. Bias analysis was performed using the RoB tool for animal interventional studies (SYRCLE's RoB tool). The Bias analysis evaluating the contact angle and hydrophilicity showed that all the studies showed reduced contact angle and increased hydrophilicity. Thus all the studies show significant increase in contact angle thereby adding to the benefit of plasma treatment to be a major game changes in integration of biological implants.

Keywords: Plasma surface treatment, implant surface, osseointegration, contact angle, hydrophilicity

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INTRODUCTION

Successful implant therapy depends on the primary and secondary stability of implant thus aiding in support for prosthetic therapy. Osseo-integration of titanium implants happens when the bone to implant contact occurs directly without the hindrance of microbial colonization and fibrous attachment. It is noteworthy that any alterations on the surface of the titanium implant leads to an increased response of the bone to the surface.

Despite the long-standing research on modifications on the surface topography of implant, for many years by using various techniques like grit/sand blasting, acid etching by acids, electrochemical anodic oxidation. Sand blasting resulting in surface roughness thus enhancing bioactivity. Plasma treatment has been proposed to have higher edge owing to the increased hydrophilicity thereby empowering cellular seeding facilitating cellular adhesion.

Plasma which is commonly labelled as the fourth state (Fig 1) of matter alters the chemistry of the surface thereby reducing surface contamination. Studies have demonstrated increased biochemical activities like alkaline phosphatase activity, calcium deposition, human stem cells spreading, protein adsorption capacity, osteoblast migration, attachment, spread, and proliferation. Taking advantage of the advances in technology we aim to assess different studies which were done to check the effect of plasma treatment highlighting the osseointegration of dental titanium implants.

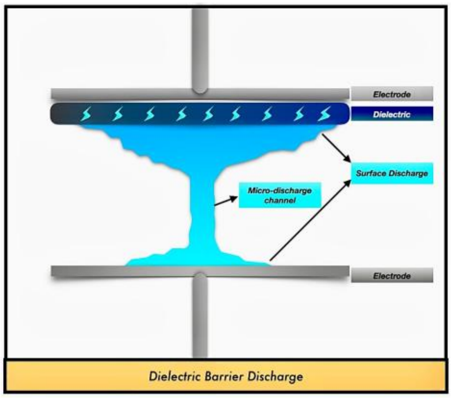

Fig 1: Plasma -fourth state of matter

The observation that different biochemical mechanisms of plasma treatment include increased wettability owing to biologic implications of hydrophilicity (Fig 2) from the initial contact of an implant surface at the host interface with water and ions via conditioning with protein-domained films upto cellular interactions[1]. Furthermore the duration of hydrophilicity is an important aspect which could be improved by using a monomer[2]. The surface roughness an important aspect of the surface modification is very well prevented after plasma treatment as shown in studies[2] thus bestowing super-hydrophilicity sans surface alterations.

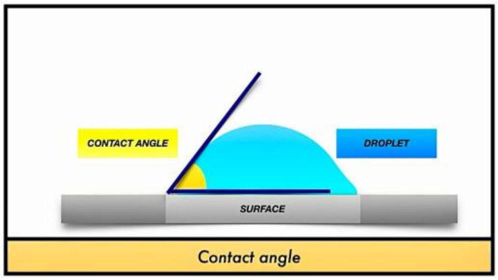

Fig 2: Plasma's role in hydrophilicity

Some of the technical advantages of plasma treatment could be its hydrophilic effects duration, which is due to its chemical structural characteristics. The chemical activities (Fig 3) including activation of osteoclastic-osteoblastic reactions such as macrophage phenotype change through the activation of STAT3, RANTES causes the natural killer cells to produce the inflammatory cytokines IFN gamma, TNF alpha, Dendritic cell activator to stimulate the dendritic cells to produce more osteoblastic genes IL 12, CD 40, MHC2 thus causing osteogenesis, whilst on the other hand there is a suppressive mechanism at stake through production of VEGF, IL 6, IL10, GM CSF, M CSF causing osteoclastic resorption. This balance when disturbed causes the mechanism to either an osteoblastic or osteoclastic pathway.

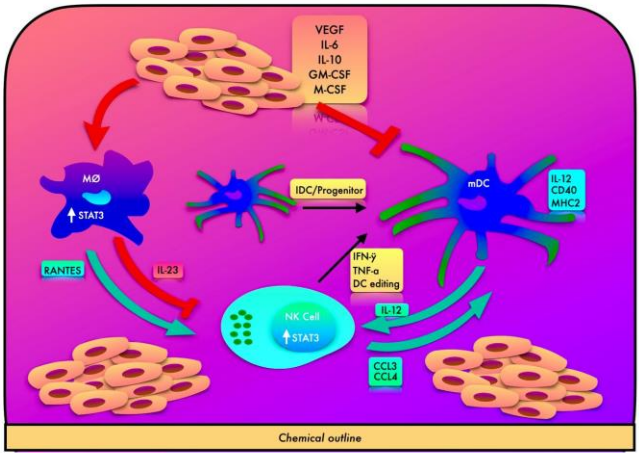

Fig 3: Chemical properties of Plasma treated surface.

The aim of this systematic review is to evaluate the effects of plasma treatment on the implant surface with relation to hydrophilic characteristics.

MATERIALS AND METHODS

STUDY DESIGN:

This systematic review registered under Prospero (Registration number pending) reviews the different experimental studies done on the effectiveness of plasma treatment on dental implant surfaces.

SEARCH STRATEGY:

The following electronic databases were used to find published articles on the effectiveness of plasma treatment on implant surfaces. PubMed, Elsevier science direct, Wiley online library, Prospero, Scopus. Each database was searched to obtain the articles using Mesh representations. The MeSh term used was “implant surface” AND “plasma treatment.” After the search, a total of 32 articles were obtained among which 17 articles were finalized for further studies.

ELIGIBILITY CRITERIA

Inclusion criteria:

1) Studies published in English
2) Articles on the effectiveness of plasma treatment on implant
3) Invitro studies
4) Animal studies

Exclusion criteria:
1) Articles published in other languages
2) Unrelated articles

SEARCH ENGINES

- PubMed
- Cochrane library
- Elsevier science direct
- Wiley online library

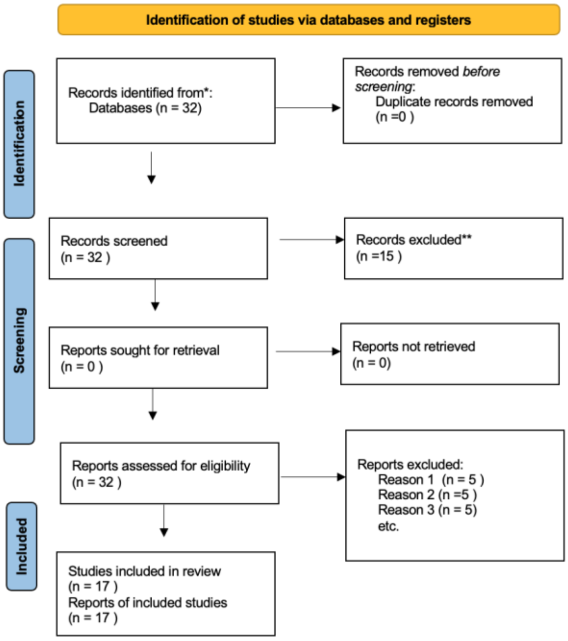

Figure 4. Flow diagram showed the number of studies identified, screened, assessed for eligibility, excluded and includedin the systematic review

Results

The review comprising of 17 articles curated from PubMed, Elsevier, Cochrane databases (Fig 4) were tabulated into three different ways as characteristics of the different intervention types (Different plasma systems) in the included studies, the characteristics of the outcomes and results obtained in the different studies and finally the Bias analysis done amongst all the 17 articles.

The different interventions as mentioned in the table 1 are Plasma source Ion Implantation, Helium plasma treatment, Non thermal Atmospheric pressure plasma (NTAPPJ) , Air atmospheric pressure plasma (AAPPJ), Low pressure plasma, Plasma Oxidation, Dielectric Barrier Discharge. The different gasses used are Oxygen, Helium, Hydrogen, Argon, Nitrogen. All done as invitro/ non clinical/ Preclinical studies on different types of implants/ discs, organosilanes, Zirconia.

The characteristics of the studies included were based on the types of animals used, duration of plasma treatment and analysis, preparation/ sample used, The type of plasma treatment system/ process. The different techniques used were a broad classification of plasma technologies used in different biomaterials with different settings like time duration, pressure parameter, Volume of gas used, power supply, Temperature, Frequency, distance between sample and plasma source.

The outcome and results as tabulated in table 2 are the different parameter characteristics obtained using the different plasma systems and as depicted in the table showed enhanced Cellular attachment especially fibroblasts, osteoblasts, stronger bone to implant contact, higher osteogenic gene expression, Increased vinculin formation, reduced pathogenicity of biofilm, more pronounced fibrillogenesis, increased polar interactions thus increasing hydrophilicity, increased shelf life of implants, Improved crystallinity, microhardness besides maintaining an unchanged surface thereby maintain the integrity of the dental implant surface.

The surface properties have been changed sans topographical modifications which serve as a superior method compared to other surface altering technologies like subtractive process which produce a rough surface thereby causing more biofilm. A surface with a polished surface, no doubt attracts less biofilm formation compared to rough surfaces.

The Table 3 which gives the analysis results done through the RoB tool for Animal intervention studies (SYRCLE's RoB tool) which is based on the COCHRANE analysis and has been adjusted for aspects of bias that play a specific role in invitro/ animal studies. Majority of the studies show less risk. The parameters to be noted for unclear risk include blinding and Incomplete data in some studies, however if overall bias results are considered, studies show un clear risk as shown in Fig 5.

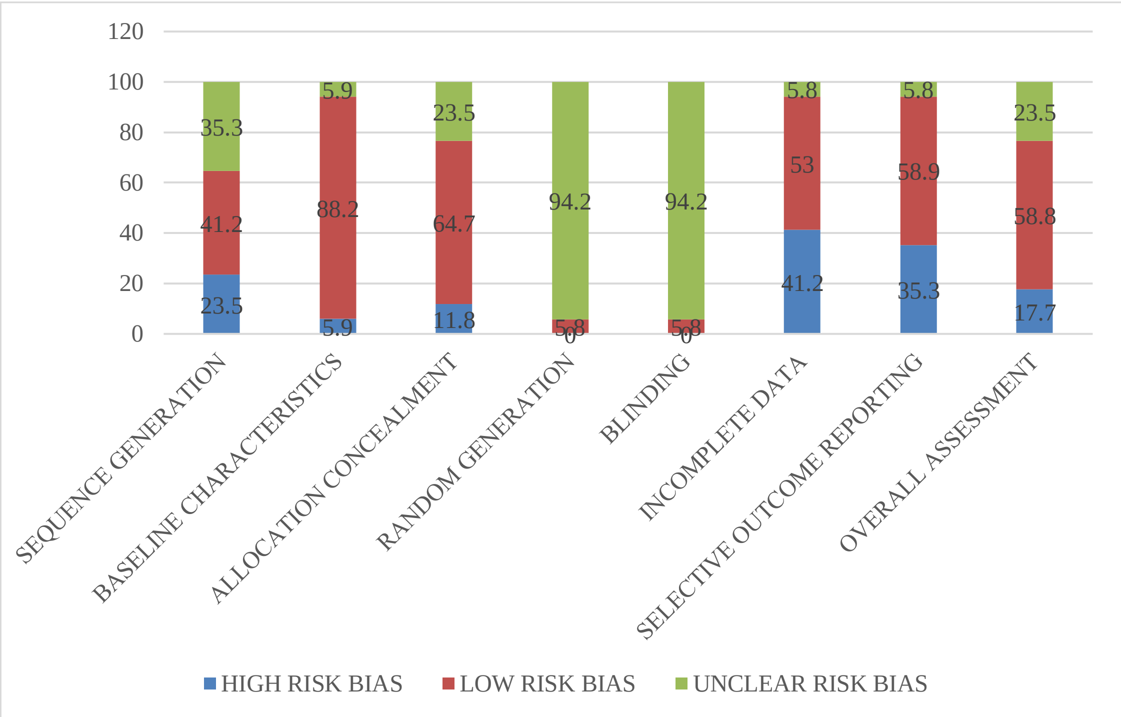

Fig 5: Overall Percentage Distribution Of Bias Analysis Included In Our Systematic Review

DISCUSSION

Expeditious osseointegration is important to achieved initial stability after the implant placement. Many researchers have shown that plasma treatment confers surface super-hydrophilicity to titanium implant and thus plays a major role in osseointegration.[19] Over the time it was observed that the material involved in osseointegration showed high adhesive strength on the surface of the plasma-treated titanium surface.[20] Various study have examined how plasma treatment of titanium surface affects the tissue surrounding the implant. The effect of plasma treatment is to make hydrophobic materials hydrophilic by the effects of ablation and surface activity on the material surface.[22] In our study, a total of 33 articles were obtained. After careful assessment of the 32 studies, and further evaluation, 17 articles backed the study.

Yuko Hirakawa et al. in 2011 did a randomized study in 6 female dogs, he used plasma source ion implantation (PSII) method for titanium disks and implant. PSII implant are used in experimental group while non-deposited titanium disks are used in control group[3]. There is no significant difference in the roughness parameters between TiO2-deposited disks and the control disks. Both D-PSII and I-PSII indicate super-hydrophilic surfaces which enhanced the bone formation. Result show the combined applications of pFN and PSII produced hydrophilic titanium surfaces which accelerate early osseointegration.

Won-Jun Shon et al. used different type of zirconia hex implants (PIM and plasma-treated with or without roughened). Plasma treatment did not show any changes in roughness of the surface while the implant which is treated with the combination of PIM and He plasma had the contact angle less that 1, which indicate the super hydrophilicity of implant which enhanced the osseointegration without changing the microtopography.[4]

In the study done by Hye Yeon Seo et al., Eun Mi Yoo at al. Jung Hwan Lee et al. used NTAPPJ and AAPPJ in different groups.[5,6,7] The result indicated that both nitrogen air based and AAPPJ treatment in TiO2 surface enhance the hydrophilicity and osseointergration of implant as compare to untreated surfaces. AAPPJ treatment enhances the early attachment while NTAPPJ treatment resulted in higher osteogenic gene expression level, the longer the exposure with NTAPPJ greater the hydrophilicity.

Nathalia Marin-Pareja et al. done a in vitro study in 2015 used two different organosilanes on titanium surfaces that is CPTES and GPTES for 5 minutes. The sample which exhibiting PL-GP treatment show a better fibroblast adhesion formation and fibronectin fibrillogenesis.[8]

Yingdi Yan et al. and Dr.Rutger Matthes et al. used air plasma and low pressure plasma treatment in their study. Both study suggest that increased in the plasma treatment causes increase in the surface hydrophilic character. AP treatment has potential to remove biofilm from rough implant surfaces.[9,10]

Won-Seok Jeong et al. in 2017 investigated the antibacterial effects of chemical changes induced by nonthermal atmospheric pressure plasma (NTAPP) on smooth and rough Ti. The Ti specimens were treated for 10 min by NTAPP with nitrogen gas. There were no differences in morphology between samples before and after NTAPP treatment. NTAPP treatment resulted in changes from hydrophobic to hydrophilic properties on rough and smooth Ti; Before NTAPP treatment, bacterial colony showed greater attachment on rough Ti, and after NTAPP treatment, there was a significant reduction in bacterial attachment. NTAPP treatment inhibited bacterial attachment surrounding titanium implants.[11]

An in vitro study done by Luigi Canullo et al. divided titanium disks into two groups- test group which received argon plasma treatment while control group with no treatment. Argon Atm pressure dielectric barrier discharge enhances the osteoblast attachment within the 12 minutes of experiment.[12]

Study conducted by Sung-Hwan Choi et al. , Anders Henningsen et al. and Henningsen A et al. used UV light and non-thermal plasma treatment in their experiment. Titanium surface which is exposed to UV treatment show no difference in surface characteristic while the combination of NTP and UV treatment showed increased hydrophilicity of the titanium surfaces. Non thermal plasma treatment improves wettability of the surface characteristic.[13,14,15]

Huanhuan Jiang et al. in 2018 done in vitro study with 20 rats as sandblasted and acid-etched (SLA) titanium implant layered with TiOx film layer modified with plasma oxidation used in experimental group (PO-SLA) while SLA implant without any treatment in control group[16]. The result showed that super hydrophilic surface was created out in the PO-SLA surfaces. A high rate of bone to implant contact was also detected in same group.[16]

Zheng Zheng et al. used non-thermal atmospheric plasma (NTAP) treatment with mixed gas for Ti surface activation.[17] NTAP treatment accelerated the proliferation of osteogenic diferentiation and mineralization of MC3T3-E1 mouse preosteoblasts in vitro. The percentage of bone-to-implant contact increased by 25–40%, and the osteoclasts and bone resorption were suppressed by 50% in NTAP-Ti in vivo. As result NTAP-Ti enhanced the physical and biological efects and integration with bone.

While Merlind Becker et al.[18] and Qian Fu et al.[19] in their study in 2020 evaluated the effect of APP and plasma treatment, LPP with hydrogen and oxygen gas in titanium surfaces. The APP and LPP show no significant difference in the initial osteoblast adhesion, but with the combination of oxygen and hydrogen plasma show the properties like hydrophilicity and cell adhesion.

CONCLUSION

The systematic review aimed to assess the different studies that improved the contact angle and hydrophilicity. Bias analysis of seventeen articles were performed and the results have shown that Many studies have utilised non thermal atmospheric plasma with gasses like argon oxygen and helium which seem to increase the surface characteristic properties like contact angle and hydrphilicity alongside increased cellular properties like fibronectin expression, osteogenesis, osteoblast adhesion, fibroblast adhesion formation. However further analysis including meta-analysis could make the present systematic review a better one. Within the limitations of the present study we strongly recommend usage of non-thermal atmospheric plasma application for improving the hydrophilic properties of implant surfaces with increased time and reduced cost.

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Conflicts of interest
There are no conflicts of interest

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