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The effect of the material type of dental prostheses on oral microbiome: A systematic review

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Abstract

Dental prostheses are commonly used to replace missing teeth and improve both the appearance and function of the oral cavity. On the other hand, the materials used in these prostheses, which include zirconia, titanium, lithium disilicate ceramics, etc., have a direct effect on the oral microbiome.

When these materials are used in the oral cavity, they help maintain a balance of microbes and prevent oral diseases. Several studies in this regard show that zirconia can create less biofilm compared to titanium and lithium disilicate ceramics.

However, although titanium is highly biocompatible when exposed to oral bacteria such as streptococcus mutans, can be corroded and cause changes in the composition of the oral microbiome.

In addition, lithium disilicate ceramic prostheses, which have microbial permeability, can not only cause secondary caries but can also cause gingivitis. This can lead to loss of oral microbiome balance.

The mentioned microbial changes can also have systemic consequences, including an increased risk of heart disease, diabetes, etc. As a result, it is very important to choose dental prosthesis materials based on the characteristics of biofilm ability and their role in the oral microbiome.

In this regard, there is a need for more research for a long-term investigation, i.e. the of these substances on the oral microbiome and systemic health of people, so that more complete information can be obtained in this field.

Keywords: oral, microbiome, material, dental, titanium

Introduction

Dental prostheses are structures that are designed and made to replace missing teeth and restore the appearance and function of patients' mouths. These prostheses are designed in such a way that they act as well as they are in harmony with natural teeth in terms of shape and position. Also, they play an important role in improving the quality of life of patients [1,2].

The number of people who use dentures due to tooth loss is estimated to be very high, and in fact, it includes something as high as 41 million users in the United States alone in 2020. These mentioned prostheses are made up of various materials such as monolithic zirconia, ceramic-veneered zirconia, ceramic-veneered titanium, lithium disilicate, hybrid ceramics, milled PMMA (poly (methyl methacrylate)), PEEK (polyether ether ketone), or 3D-printed resins, but the effect that each of these species can have on the oral microbiome has been increasingly noticed [3,4,5,6].

The oral microbiome is a collection of microorganisms that live naturally in the oral cavity. It is also influenced by several factors which include diet, oral and dental hygiene, etc.[2,7].

Concerning zirconium, the result of a study was clearly as follows: In vitro biofilm formation with optical density values on Zp (0.14 ± 0.01), Zpt (0.14 ± 0.02), Zm (0.13 ± 0.01) and Zmt (0.13 ± 0.01) was significantly lower than on Tp (0.21 ± 0.05) and Z14 (0.20 ± 0.04) ($p < .05$). In situ biofilm formation was significantly higher on Z14 (0.56 ± 0.45) ($p < .05$), while no significant differences in optical density were observed among Zp (0.25 ± 0.20), Zm (0.36 ± 0.34) and Tp (0.28 ± 0.22). SEM analysis supported quantitative findings[8]. During a study by Daubert D et al, it was noticed that titanium can imbalance the microbiome of the oral cavity. The microbiome in the oral cavity can disrupt the biocompatible titanium dioxide surface layer. For example, Streptococcus mutans can increase the corrosion current and induce titanium corrosion[9].

On the other hand, during a study, it was revealed and mentioned that Lithium disilicate glass-ceramic (LDC) restorations exhibit microorganism infiltration, recurrent caries, pulpal lesions, and periodontal inflammation. Each of these cases, in turn, causes the

balance of the microbiome in the oral cavity to be disturbed. Therefore, it is obvious that choosing the suitable type of dental prosthesis can have a significant action on the health of the mouth and teeth of such patients [2,10,11,12].

On the other side, creating conditions in which the balance of the oral microbiome is disrupted can harm the immune system. Thus, bacteria can have an action on oral health by producing metabolites that affect immune responses[13,14].

As per the above-mentioned reasons, there is a need for more research to investigate how the type of dental prostheses can affect the production of metabolites and thus the health of the oral cavity and teeth remain safe[15,16].

Since the need to use dental prostheses remains strong even in modern dentistry, their impact on the general health of the body can be considered as a new and important research field in dental science. Therefore, this article, in addition to addressing the results of previous studies and analyzing new data in this field, also offers suggestions for future research[17,18].

Background

As already mentioned earlier, the microbiome of the oral cavity is a complex ecosystem that is very useful for maintaining oral health. These microbiomes exist naturally in the oral cavity of all humans in addition to being influenced by various factors such as diet, oral and dental hygiene, systemic conditions of the body, etc. If the balance of these microorganisms is disturbed, there will be a possibility of causing various types of oral diseases, including tooth decay, gingival diseases, etc[19,13,20].

Over the years, various materials have been used to make dental prostheses, including zirconia, titanium, and advanced polymers. Prosthetic materials are chosen not only because of their strength and beauty but also because of their biocompatibility and interaction with the oral environment. For example, zirconia and titanium are popular materials for making prostheses due to their high resistance and favorable

biocompatibility. However, the influence of these materials on the oral microbiome is more complex than originally thought[8,21].

Each of the materials used in the prosthesis can have different effects on the amount of biofilm accumulation. A clear example is zirconia because this material has a good resistance against the creation and formation of biofilm, such that this percentage is lower even compared to titanium. Although titanium has biocompatibility and even high mechanical resistance, it can cause a series of disturbances in the balance of the oral microbiome. An example of this is streptococcus mutans, which by damaging and destroying the surface of titanium can cause its corrosion and subsequently cause a change in the microbial composition of the mouth, as a result of which a series of negative effects may occur on oral health and the stability of prostheses[22,23,24].

Among other materials are lithium disilicate ceramics. In addition to having a beautiful appearance, these materials also have high strength and durability. However, their disadvantage is that they can cause the penetration of microorganisms and lead to the occurrence of secondary caries and even inflammation of the gingival tissue. This in itself can cause the balance of the oral microbiome to be disturbed[25,13].

The effects that each type of oral prosthesis has on the oral microbiome can also cause systemic pathogenic effects due to metabolic substances produced by oral bacteria. An obvious example is the disturbance in the balance of the oral microbiome, as a result of which the immune reactions are activated and bring diseases or disorders for people including cardiovascular, diabetic diseases, etc[4,26,27].

1.1. Purpose of Review

The purpose of this review is to evaluate the impact of different dental prostheses on the oral microbiome. Specifically, this review explores how various prosthetic materials affect the microbial balance in the oral cavity and how these changes can influence both oral and systemic health.

1.2 Primary Objectives of Review

a. To investigate the effects of different types of dental prostheses (e.g., zirconia, titanium, lithium disilicate) on the composition of the oral microbiome.

b. To assess the potential consequences of changes in the oral microbiome on overall oral health, including dental and periodontal health.

1.3 Secondary Objectives of Review

a. To identify future research challenges related to the long-term effects of dental Prostheses on the oral microbiome.

b. To discuss the systemic effects of microbiome disturbances caused by prosthetic materials, including implications for immune responses and the development of systemic diseases.

METHODOLOGY

Identifying the Research Questions:

a. How do different dental prostheses affect the oral microbiome, including bacterial colonization and biofilm formation?

b. What are the long-term effects of oral microbiome alterations due to different prosthetic materials?

c. what are the systemic health implications of microbiome changes induced by dental prostheses?

2.1 Search Strategy

A comprehensive search was conducted using databases such as PubMed and Scopus,

with the following keywords: “dental prostheses,” “oral microbiome,” “biofilm formation,” “zirconia,” “titanium,” and “lithium disilicate.”

2.2 Inclusion Criteria

a. About 1200 studies from PubMed and ResearchGate, which their focus on the interaction between prosthetic materials and the oral microbiome were selected and among them 50 studies were included in the present systematic review based on the inclusion criteria which is mentioned below.

b. Clinical and in vitro studies assessing microbiome changes due to the use of dental prostheses were taken care of to be focused as much as possible due to the reason which is mentioned in the limitations of the current research part of this study.

2.3 Exclusion Criteria

a. Studies lacking clear focus on prosthetic materials or oral microbiome alterations.

b. Research that did not present new insights relevant to the aims of this review.

c. Studies thay are not published in English language.

1.4 Qualitative Evaluation of Selected Articles

The selected studies were evaluated based on their methodology, sample size, relevance to the research questions, and the type of prosthetic material examined.

1.5 Search Results

From an initial pool of several studies, the studies which are mentioned in the **r**eferences met the inclusion criteria. These studies were categorized based on the type of prosthetic

material (zirconia, titanium, lithium disilicate) and their specific effects on the **o**ral microbiome, including biofilm formation and systemic health consequences.

Results

According to the investigations, the most reliable result is that the type of materials used in dental prostheses can have significant effects on the oral microbiome. As a clear example, it can be said that although some studies state that prostheses made of zirconia have less biofilm accumulation than other materials such as titanium and lithium disilicate, but still can not confidently prove it, hence more researches are required in this regard. on the other hand, a study showed that the optical density of the biofilm formed on zirconia (0.01± 0.14 for Zp, 0.14 ± 0.02 for Zpt) was significantly lower than titanium (0.05 ± 0.21 for Tp) and older zirconias (0.04 ± 0.20 for Z14. Although these results were obtained in vitro, they were also confirmed by in situ studies where, in addition, zirconia also showed a better performance in preventing biofilm accumulation[28,8,29].

In addition to the above-mentioned cases, the results showed that although titanium has high biocompatibility, but still can't be stated that the only cause of disturbances in the balance of the oral microbiome is this material, so more and more studies are required to confirm it. In other words, it can be said that oral bacteria can decompose the protective layer of titanium dioxide, and this subsequently causes titanium corrosion. Streptococcus mutans, as mentioned in previous frosts, is an important bacteria in the oral cavity. In previous frosts, is an important bacteria in the oral cavity. In addition to increasing the chance of corrosion in the titanium material, this bacteria can subsequently cause adverse changes in the composition of the oral microbiome[30,31,32,33].

Another material that can be concluded is lithium disilicate ceramics, which, although it has a beautiful appearance and mechanical resistance, research has shown that it has weaknesses against microbial penetration. Prostheses that use this type of material can cause microbial penetration and subsequently cause secondary decay and gingivitis. This ultimately not only disturbs the balance of the oral microbiome, but also increases the risk of oral diseases[34,35,22].

Discussion

Since in the results section, several cases have confirmed the aforementioned claims, it can be concluded that zirconia can be a more suitable option to choose because of its high resistance to biofilm formation, especially compared to titanium. This is especially important for patients who need to pay more attention to the health of their mouth and teeth as well as the microbial balance of their oral cavity. It should be noted that as the findings of this review are consistent with other studies hence accordingly can confidently mention that zirconia is definitely a better choice in order to prevent the accumulation of bacteria causing oral infections[28,15,36,37,29].

But it should be stated that although titanium has high mechanical and biocompatibility characteristics, it is vulnerable to microbial corrosion, which is especially evident in contact with oral bacteria. This phenomenon can subsequently decompose the titanium surface and disrupt the balance of the oral microbiome. For this reason, it can be claimed that the use of titanium in dental prostheses needs to be investigated and evaluated due to the existence of such risks[38,39,40].

Other materials which are been already discussed earlier are lithium disilicate ceramics and stated that they have a beautiful appearance and good resistance, it has also been mentioned that these materials may not be a suitable choice in some cases due to the risk of increasing the risk of microbial penetration and also causing gingival inflammation, but along with those materials, other materials as well as various applicatory techniques have been used during the studies, so then more studies are required to ensure that the only cause of harm is these materials alone or not. But still, it can be suggested that with the present knowledge, the appropriate solution in this regard can be the use of protective coatings to reduce microbial permeability or preferably replace other materials[25,34,41].

In a general situation, it can be stated that it is very important to choose the type of dental prosthesis by carefully evaluating its effects on the oral microbiome and especially the the ability of the material to prevent the formation of biofilm and related damages, because these materials are used in such treatments, as well as they can have a direct action on the oral and even systemic health of patients[42,30].

Limitations of the current research

In the studies that have been done on the impact of dental prosthesis materials on the oral microbiome, many advances have been found, but still, there are limitations in this research area. It can be stated that great diversity in study methods and design of experiments in research is of great value when they have diversity, study methods, and in addition, different designs of experiments, otherwise the opposite is true. In this research field, some studies have used in vitro conditions, that is, laboratory conditions, which may not fully simulate the real oral environment. So the results obtained from such tests cannot be definitely and directly generalized to clinical conditions. In vivo studies, i.e. the same as clinical studies, since individual differences in patients vary in various aspects, including oral condition, diet, and level of oral and dental hygiene, there is a high possibility that it will have contradictory results. As per this, it can be stated that these disturbances in the process and study designs make it difficult to compare the results of different research[20,8,29,43].

Another limitation in this research field is the short duration of the studies and most of the researches that exist so far has focused on the short-term effects of dental prosthesis materials and not on the long-term. Therefore, there is no valuable information about the long-term effects of these substances on the oral microbiome and systemic health. It is also worth mentioning that most of the studies focus on a series of specific materials including zirconia or titanium and there is not much focus on emerging materials such as 3D printing resins or advanced polymers[29,30,20,44].

Future directions of research

Regarding future research, it can be stated that if we focus on the development of in vivo and in vitro models that can better simulate the natural conditions of the mouth, the current limitations will be solved. The recommendation of this systematic review is that if the design of these models is such that they evaluate the long-term effects of dental prostheses on the oral microbiome and systemic health, many research questions in this regard will be answered. It should be noted that more research is needed on emerging materials, including advanced polymers, 3D printing resins, as well as their affection for

the oral microbiome, to obtain more comprehensive information about dental prosthetic materials[45,37,46,44].

Also, creating development in multicenter studies in such a way that there are more samples in it and besides that geographical diversity is also taken into account, it greatly improves the accuracy of the results. It is worth noting that individual differences that include genetic factors, diet, level of oral hygiene, etc. are also very necessary to be considered in future research so that more detailed information can be obtained about the effect of dental prostheses on the oral microbiome and the overall health of the body[47,4,48].

Per two distinct studies, one is conducted by Kakka A. et al, and the other is by Li Y et al, it can be stated that in order to evaluate the relationship between changes in the oral microbiome and the occurrence of systemic diseases, which include cardiovascular diseases, diabetes, etc., it can be considered as an emerging research field, so it is important to pay more attention to the effects of prosthetic materials and even to find out how new technologies can be effective in this field (49,50].

Conclusion

The type of materials used in dental prostheses can not only have a significant effect on the balance of the oral microbiome but also affect its health as well as the health of the rest of the body. According to the research, it is clear that although zirconia is not fully free of risk in order to be used in dental prostheses, it is a material that has a high resistance against biofilm formation and can be considered a more appropriate choice. But titanium even though may possess good biocompatibility, can disrupt the microbiome balance by destroying its surface bacteria.

The other materials which are lithium disilicate ceramics have strength and even a beautiful appearance, but they can lead to microbial penetration as well as inflammatory complications in the oral cavity. For this reason, the accurate selection of dental prosthesis materials plays a significant role in maintaining oral and even systemic health.

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Conflict of Interest

The authors declare no conflict of interest.

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Ethics Statement

No human or animal subjects were involved in this study, and no ethical approval was required.

References

1. Chau RCW, Chong M, Thu KM, Chu NSP, Koohi-Moghadam M, Hsung RT, McGrath C, Lam WYH. Artificial intelligence-designed single molar dental prostheses: A protocol of prospective experimental study. PLoS One. 2022 Jun 2;17(6):e0268535. Doi: 10.1371/journal.pone.0268535. PMID: 35653388; PMCID: PMC9162350.
2. Sadeghi, A., Sarrafan, A., Ebrahimi, A., Moghadamnia, N., Semnani, P. M., Tekieh, S. A. R., & Modarresi, A. (2023). The Effect of Dental Prosthesis on Oral Normal Microbes and Life Span. Clinical Cancer Investigation Journal, 12(1-2023), 1-6.
3. Redfern J, Tosheva L, Malic S, Butcher M, Ramage G, Verran J. The denture microbiome in health and disease: an exploration of a unique community. Lett Appl Microbiol. 2022 Aug;75(2):195-209. Doi: 10.1111/lam.13751. Epub 2022 Jun 9. PMID: 35634756; PMCID: PMC9546486.
4. Santacroce L, Passarelli PC, Azzolino D, Bottalico L, Charitos IA, Cazzolla AP, Colella M, Topi S, Godoy FG, D'Addona A. Oral microbiota in human health and disease: A perspective. Exp Biol Med (Maywood). 2023 Aug;248(15):1288-1301. Doi:

10.1177/15353702231187645. Epub 2023 Sep 9. PMID: 37688509; PMCID: PMC10625343.

5. Ionescu RN, Totan AR, Imre MM, Țâncu AMC, Pantea M, Butucescu M, Farcașiu AT. Prosthetic Materials Used for Implant-Supported Restorations and Their Biochemical Oral Interactions: A Narrative Review. Materials (Basel). 2022 Jan 28;15(3):1016. Doi: 10.3390/ma15031016. PMID: 35160962; PMCID: PMC8839238.
6. Shi B, Wu T, McLean J, Edlund A, Young Y, He X, Lv H, Zhou X, Shi W, Li H, Lux R. The Denture-Associated Oral Microbiome in Health and Stomatitis. mSphere. 2016 Dec 28;1(6):e00215-16. Doi: 10.1128/mSphere.00215-16. PMID: 28066812; PMCID: PMC5196032.
7. Shahi, M., & Ebrahimi, A. (2024). Periodontal disease in children and its association with cardiovascular diseases. African Journal of Biological Sciences, 6(14), 2306-2320.
8. Jaeggi M, Gyr S, Astasov-Frauenhoffer M, Zitzmann NU, Fischer J, Rohr N. Influence of different zirconia surface treatments on biofilm formation in vitro and in situ. Clin Oral Implants Res. 2022 Apr;33(4):424-432. Doi: 10.1111/clr.13902. Epub 2022 Feb 13. PMID: 35137461; PMCID: PMC9304171.
9. Daubert D, Pozhitkov A, McLean J, Kotsakis G. Titanium as a modifier of the peri-implant microbiome structure. Clin Implant Dent Relat Res. 2018 Dec;20(6):945-953. Doi: 10.1111/cid.12676. Epub 2018 Sep 25. PMID: 30255621; PMCID: PMC6283679.
10. Ebrahimi, A., Esmailpoor, M. S., Moghadamnia, N., Naeimi, M., Basiri, S., Habibi, N., Ganjehei, F. A., Rafiei Tekieh, S. A., Shahbandi, H., Farzadtabari, E., Nokhbehzaeim, E., Mohammadian Semnani, P., Abbasi, N., Alinejad, K., Alaei, D., Shahvali, M., Arab, A., & Manhaji, A. (2024). The effects of periodontal diseases on mental health and their association. Journal of Advanced Pharmacy Education & Research.
11. Roshan, M. D., Esmailpoor, M. S., Koeini, M., Torabi, E., & Ebrahimi, A. (2024). Association between gastrointestinal microbiome and anxiety: A systematic review. African Journal of Biological Sciences, 6(14), 13166-13178.
12. Amiri, Z., Naeimi, M., Yaghoubi, B., Rahbaryfar, S., Tabas, N. E., Ebrahimi, A., Mohammadamin Semnani, P., Farzadtabar, E., Nokhbehzaemi, E., Rahmanzadeh, A. A., Habibi, N., Abbasii, N., Ahmadreza, S., Moghaddamia, N., & Modarresi, A. (2023). Advancement of dental restoration technique and reviewing the related benefits to periodontium, dental implant treatments, bone grafts and orthodontic treatments. Clinical Cancer Investigation Journal, (ISSN: 2278-0513), 1-14.
13. Sedghi L, DiMassa V, Harrington A, Lynch SV, Kapila YL. The oral microbiome: Role of key organisms and complex networks in oral health

and disease. Periodontol 2000. 2021 Oct;87(1):107-131. doi: 10.1111/prd.12393. PMID: 34463991; PMCID: PMC8457218.

14. Moreno CM, Boeree E, Freitas CMT, Weber KS. Immunomodulatory role of oral microbiota in inflammatory diseases and allergic conditions. Front Allergy. 2023 Feb 17;4:1067483. Doi: 10.3389/falgy.2023.1067483. PMID: 36873050; PMCID: PMC9981797.
15. Hao Y, Huang X, Zhou X, Li M, Ren B, Peng X, Cheng L. Influence of Dental Prosthesis and Restorative Materials Interface on Oral Biofilms. Int J Mol Sci. 2018 Oct 14;19(10):3157. Doi: 10.3390/ijms19103157. PMID: 30322190; PMCID: PMC6213966.
16. Srimaneepong V, Heboyan A, Zafar MS, Khurshid Z, Marya A, Fernandes GVO, Rokaya D. Fixed Prosthetic Restorations and Periodontal Health: A Narrative Review. J Funct Biomater. 2022 Feb 1;13(1):15. Doi: 10.3390/jfb13010015. PMID: 35225978; PMCID: PMC8883934.
17. Dragomir LP, Nicolae FM, Gheorghe DN, Popescu DM, Dragomir IM, Boldeanu L, Boldeanu VM, Popescu MR. The Influence of Fixed Dental Prostheses on the Expression of Inflammatory Markers and Periodontal Status-Narrative Review. Medicina (Kaunas). 2023 May 13;59(5):941. Doi: 10.3390/medicina59050941. PMID: 37241173; PMCID: PMC10221924.
18. Duong HY, Roccuzzo A, Stähli A, Salvi GE, Lang NP, Sculean A. Oral health-related quality of life of patients rehabilitated with fixed and removable implant-supported dental prostheses. Periodontol 2000. 2022 Feb;88(1):201-237. Doi: 10.1111/prd.12419. PMID: 35103325; PMCID: PMC9304161.
19. Deo PN, Deshmukh R. Oral microbiome: Unveiling the fundamentals. J Oral Maxillofac Pathol. 2019 Jan-Apr;23(1):122-128. Doi: 10.4103/jomfp.JOMFP_304_18. PMID: 31110428; PMCID: PMC6503789.
20. Giordano-Kelhoffer B, Lorca C, March Llanes J, Rábano A, Del Ser T, Serra A, Gallart-Palau X. Oral Microbiota, Its Equilibrium and Implications in the Pathophysiology of Human Diseases: A Systematic Review. Biomedicines. 2022 Jul 27;10(8):1803. Doi: 10.3390/biomedicines10081803. PMID: 36009350; PMCID: PMC9405223.
21. Singh PV, Reche A, Paul P, Agarwal S. Zirconia Facts and Perspectives for Biomaterials in Dental Implantology. Cureus. 2023 Oct 11;15(10):e46828. Doi: 10.7759/cureus.46828. PMID: 37954766; PMCID: PMC10636592.
22. Sterzenbach T, Helbig R, Hannig C, Hannig M. Bioadhesion in the oral cavity and approaches for biofilm management by surface modifications. Clin Oral Investig. 2020 Dec;24(12):4237-4260. Doi: 10.1007/s00784-020-03646-1. Epub 2020 Oct 27. PMID: 33111157; PMCID: PMC7666681.

23. Yang J, Liu C, Sun H, Liu Y, Liu Z, Zhang D, Zhao G, Wang Q, Yang D. The progress in titanium alloys used as biomedical implants: From the view of reactive oxygen species. Front Bioeng Biotechnol. 2022 Dec 19;10:1092916. Doi: 10.3389/fbioe.2022.1092916. PMID: 36601391; PMCID: PMC9806234.
24. Gaur S, Agnihotri R, Albin S. Bio-Tribocorrosion of Titanium Dental Implants and Its Toxicological Implications: A Scoping Review. ScientificWorldJournal. 2022 Oct 21;2022:4498613. Doi: 10.1155/2022/4498613. PMID: 36312451; PMCID: PMC9616655.
25. Shi HY, Pang R, Yang J, Fan D, Cai H, Jiang HB, Han J, Lee ES, Sun Y. Overview of Several Typical Ceramic Materials for Restorative Dentistry. Biomed Res Int. 2022 Jul 18;2022:8451445. Doi: 10.1155/2022/8451445. PMID: 35898679; PMCID: PMC9314004.
26. Al-Janabi AAHS. A Positive or Negative Connection of Diabetes Mellitus to the Oral Microbiota. Eurasian J Med. 2023 Feb;55(1):83-89. Doi: 10.5152/eurasianjmed.2023.21164. PMID: 36861873; PMCID: PMC10081019.
27. Nair VV, Karibasappa GN, Dodamani A, Prashanth VK. Microbial contamination of removable dental prosthesis at different interval of usage: An in vitro study. J Indian Prosthodont Soc. 2016 Oct-Dec;16(4):346-351. Doi: 10.4103/0972-4052.176536. PMID: 27746598; PMCID: PMC5062147.
28. D'Ambrosio F, Santella B, Di Palo MP, Giordano F, Lo Giudice R. Characterization of the Oral Microbiome in Wearers of Fixed and Removable Implant or Non-Implant-Supported Prostheses in Healthy and Pathological Oral Conditions: A Narrative Review. Microorganisms. 2023 Apr 16;11(4):1041. Doi: 10.3390/microorganisms11041041. PMID: 37110463; PMCID: PMC10145620.
29. Jaeggi M, Gyr S, Astasov-Frauenhoffer M, Zitzmann NU, Fischer J, Rohr N. Influence of different zirconia surface treatments on biofilm formation in vitro and in situ. Clin Oral Implants Res. 2022 Apr;33(4):424-432. Doi: 10.1111/clr.13902. Epub 2022 Feb 13. PMID: 35137461; PMCID: PMC9304171.
30. Kligman S, Ren Z, Chung CH, Perillo MA, Chang YC, Koo H, Zheng Z, Li C. The Impact of Dental Implant Surface Modifications on Osseointegration and Biofilm Formation. J Clin Med. 2021 Apr 12;10(8):1641. doi: 10.3390/jcm10081641. PMID: 33921531; PMCID: PMC8070594.
31. Chen L, Tong Z, Luo H, Qu Y, Gu X, Si M. Titanium particles in peri-implantitis: distribution, pathogenesis and prospects. Int J Oral Sci. 2023 Nov 23;15(1):49. Doi: 10.1038/s41368-023-00256-x. PMID: 37996420; PMCID: PMC10667540.

32. Lemos JA, Palmer SR, Zeng L, Wen ZT, Kajfasz JK, Freires IA, Abranches J, Brady LJ. The Biology of Streptococcus mutans. Microbiol Spectr. 2019 Jan;7(1):10.1128/microbiolspec.GPP3-0051-2018. Doi: 10.1128/microbiolspec.GPP3-0051-2018. PMID: 30657107; PMCID: PMC6615571.
33. Contuzzi N, Casalino G, Boccaccio A, Ballini A, Charitos IA, Bottalico L, Santacroce L. Metals Biotribology and Oral Microbiota Biocorrosion Mechanisms. J Funct Biomater. 2022 Dec 23;14(1):14. Doi: 10.3390/jfb14010014. PMID: 36662061; PMCID: PMC9863779.
34. Jung S, Moser MM, Kleinheinz J, Happe A. Biocompatibility of Lithium Disilicate and Zirconium Oxide Ceramics with Different Surface Topographies for Dental Implant Abutments. Int J Mol Sci. 2021 Jul 19;22(14):7700. Doi: 10.3390/ijms22147700. PMID: 34299319; PMCID: PMC8306444.
35. Zhao A, Sun J, Liu Y. Understanding bacterial biofilms: From definition to treatment strategies. Front Cell Infect Microbiol. 2023 Apr 6;13:1137947. doi: 10.3389/fcimb.2023.1137947. PMID: 37091673; PMCID: PMC10117668.
36. Chiou LL, Panariello BHD, Hamada Y, Gregory RL, Blanchard S, Duarte S. Comparison of In Vitro Biofilm Formation on Titanium and Zirconia Implants. Biomed Res Int. 2023 Apr 15;2023:8728499. Doi: 10.1155/2023/8728499. PMID: 37096222; PMCID: PMC10122594.
37. Barranca-Enríquez A, Romo-González T. Your health is in your mouth: A comprehensive view to promote general wellness. Front Oral Health. 2022 Sep 14;3:971223. doi: 10.3389/froh.2022.971223. PMID: 36186536; PMCID: PMC9515542.
38. Hoque ME, Showva NN, Ahmed M, Rashid AB, Sadique SE, El-Bialy T, Xu H. Titanium and titanium alloys in dentistry: current trends, recent developments, and future prospects. Heliyon. 2022 Oct 28;8(11):e11300. Doi: 10.1016/j.heliyon.2022.e11300. Retraction in: Heliyon. 2024 May 27;10(11):e31978. Doi: 10.1016/j.heliyon.2024.e31978. PMID: 36387463; PMCID: PMC9640965.
39. Pokrowiecki R, Mielczarek A, Zaręba T, Tyski S. Oral microbiome and peri-implant diseases: where are we now? Ther Clin Risk Manag. 2017 Nov 29;13:1529-1542. Doi: 10.2147/TCRM.S139795. PMID: 29238198; PMCID: PMC5716316.
40. Kim KT, Eo MY, Nguyen TTH, Kim SM. General review of titanium toxicity. Int J Implant Dent. 2019 Mar 11;5(1):10. Doi: 10.1186/s40729-019-0162-x. PMID: 30854575; PMCID: PMC6409289.

41. Sharma S, Mohler J, Mahajan SD, Schwartz SA, Bruggemann L, Aalinkeel R. Microbial Biofilm: A Review on Formation, Infection, Antibiotic Resistance, Control Measures, and Innovative Treatment. Microorganisms. 2023 Jun 19;11(6):1614. Doi: 10.3390/microorganisms11061614. PMID: 37375116; PMCID: PMC10305407.
42. Tu Y, Ren H, He Y, Ying J, Chen Y. Interaction between microorganisms and dental material surfaces: general concepts and research progress. J Oral Microbiol. 2023 Apr 5;15(1):2196897. Doi: 10.1080/20002297.2023.2196897. PMID: 37035450; PMCID: PMC10078137.
43. Mazurkiewicz D, Pustułka M, Ambrozik-Haba J, Bienkiewicz M. Dietary Habits and Oral Hygiene as Determinants of the Incidence and Intensity of Dental Caries-A Pilot Study. Nutrients. 2023 Nov 19;15(22):4833. Doi: 10.3390/nu15224833. PMID: 38004227; PMCID: PMC10674309.
44. Prakash J, Shenoy M, Alhasmi A, Al Saleh AA, C SG, Shivakumar S. Biocompatibility of 3D-Printed Dental Resins: A Systematic Review. Cureus. 2024 Jan 5;16(1):e51721. Doi: 10.7759/cureus.51721. PMID: 38318586; PMCID: PMC10839546.
45. Luo TL, Vanek ME, Gonzalez-Cabezas C, Marrs CF, Foxman B, Rickard AH. In vitro model systems for exploring oral biofilms: From single-species populations to complex multi-species communities. J Appl Microbiol. 2022 Feb;132(2):855-871. doi: 10.1111/jam.15200. Epub 2021 Sep 2. PMID: 34216534; PMCID: PMC10505481.
46. Zaura E, Pappalardo VY, Buijs MJ, Volgenant CMC, Brandt BW. Optimizing the quality of clinical studies on oral microbiome: A practical guide for planning, performing, and reporting. Periodontol 2000. 2021 Feb;85(1):210-236. doi: 10.1111/prd.12359. Epub 2020 Nov 23. PMID: 33226702; PMCID: PMC7756869.
47. Omerovic E, Petrie M, Redfors B, Fremes S, Murphy G, Marquis-Gravel G, Lansky A, Velazquez E, Perera D, Reid C, Smith J, van der Meer P, Lipsic E, Juni P, McMurray J, Bauersachs J, Køber L, Rouleau JL, Doenst T. Pragmatic randomized controlled trials: strengthening the concept through a robust international collaborative network: PRIME-9-Pragmatic Research and Innovation through Multinational Experimentation. Trials. 2024 Jan 23;25(1):80. doi: 10.1186/s13063-024-07935-y. PMID: 38263138; PMCID: PMC10807265.
48. Liu L, Wang H, Chen X, Zhang Y, Zhang H, Xie P. Gut microbiota and its metabolites in depression: from pathogenesis to treatment. EBioMedicine. 2023 Apr;90:104527.

Doi: 10.1016/j.ebiom.2023.104527. Epub 2023 Mar 22. PMID: 36963238; PMCID: PMC10051028.

49. Li Y, Zhu M, Liu Y, Luo B, Cui J, Huang L, Chen K, Liu Y. The oral microbiota and cardiometabolic health: A comprehensive review and emerging insights. Front Immunol. 2022 Nov 18;13:1010368. Doi: 10.3389/fimmu.2022.1010368. PMID: 36466857; PMCID: PMC9716288.
50. Kakka A, Gavriil D, Whitworth J. Treatment of cracked teeth: A comprehensive narrative review. Clin Exp Dent Res. 2022 Oct;8(5):1218-1248. Doi: 10.1002/cre2.617. Epub 2022 Jul 9. PMID: 35809233; PMCID: PMC9562569.