Materials Sealing Preventing Biofilm Formation in Implant/Abutment Joints: Which Is the Most Effective? A Systematic Review and Meta-Analysis

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The purpose of this systematic review was to evaluate the literature available for materials exhibiting the best efficacy in preventing biofilm formation in the interior of implants. We searched PubMed/MEDLINE, Scopus, and Cochrane databases. This review is registered with the PROSPERO database and followed the suitability of the PRISMA protocol. The initial search resulted in 326 articles from the databases. After they were read, 8 articles remained, and the inclusion and exclusion criteria were applied. Six of these 8 articles were classified as in vitro and 2 were classified as in situ. The regions of the implants evaluated ranged from the interface of the pieces to the occlusal upper access of the abutment. The implant connections evaluated the Morse taper, external connection, and internal connection. Meta-analysis of the quantitative data was performed at a significance level of .05. Cotton exhibited poor control of infiltration, even in combination with other materials. Isolated gutta-percha (GP) and polytetrafluoroethylene (PTFE) tape with composite resin (CR) or GP performed better as physical barriers. The best results for chemical barriers were observed by the application of 1% chlorhexidine gluconate (CG) gel, thymol varnish, and the deposition of Ag films onto the surface. The applied meta-analysis did not show a significant difference in comparison between the different types of implant connections ($P > .05$). The application of CG and thymol varnish antimicrobials was effective in preventing biofilm formation and easy clinical execution; these could be used in combination with CR, GP, and PTFE.

Key Words: implant-abutment interface, biofilms, bacterial leakage

INTRODUCTION

The oral rehabilitation of edentulous and partially edentulous patients using osseointegrative implants has been revolutionary in dental treatment. Additionally, implant-supported prostheses are promising as they provide new opportunities for oral rehabilitation. However, despite the relatively high survival rates with titanium implants, 2-piece dental implant systems may present biological or technical complications.[1–3]

In vivo and in vitro studies have demonstrated the presence of viable bacteria inside implants, including the infiltration of fluids and microorganisms into all internal spaces through the microgap formed between the implant and the prosthetic abutment, which can be a source of contamination for peri-implant tissues.[4,5] The biofilm formed by the microorganisms on the external surface can be eliminated by the body's defense mechanism; however, the internal colonization of the implants on the interface between the pieces can persist, which generates a malodorous, unpleasant taste in the oral cavity, as well as infections and tissue damage to the periodontal tissue.[6]

To control such infiltrations in these regions, the application of chlorhexidine varnish and silicon sealant at the cervical implant portion[7] is suggested; however, this was not effective for more than 35 days, demonstrating that they are unable to seal the abutment-implant interface.

Other studies proved the existence of this bacterial leakage along the access hole of the abutment.[8–10] For this reason, different materials have been heavily studied in an attempt to seal the screw access channel and protect the abutment screw during the provisional time or in the definitive restoration. For this reason, materials such as gutta-percha (GP),[4,11,12] GapSeal gel,[13] and polytetrafluoroethylene (PTFE)-based materials[14] have been used in protecting the abutment screw head and

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promoting the sealing of the region. However, despite these materials presenting favorable results, they do not present durability, as they work against bacterial infiltration for only short periods. Thus, there is no evident consensus in the literature regarding the most efficient material for sealing against the infiltration of the abutment-implant region and preventing biofilm formation.

The fact is that, in screw restorations, the hollow spaces resulting from the implant-abutment joints may act as channels and reservoirs, harboring and favoring the colonization of microbial species present in the oral biofilm. Literature studies have also shown that the internal colonization of the implant after the osseointegration period is related to various implant systems, independent of the type of the connecting platform. The biofilm formed at this interface causes injury to the peri-implant bone tissue.[15,16]

Currently, due the variety of possible sites of microbial infiltration in the implant-abutment joint and different materials used, there is no consensus or defined protocols for this objective for the use of materials sealing to prevent the formation of biofilm formation in implant/abutment joints. In this way, the purpose of this systematic review is to determine the most efficient material for preventing biofilm formation at the implant abutment interface.

Materials and Methods

Registration

This systematic review was registered in the international prospective register of systematic reviews (PROSPERO: CRD42019125816).

Search strategy

We conducted an electronic search of PubMed/MEDLINE, Scopus, and the Cochrane Library for articles published before February 2019. All studies identified by the inclusion criteria were analyzed, and the authors were contacted to identify possible additional information. The search was performed using the following search terms: "("dental implants"[MeSH Terms] OR ("dental"[All Fields] AND "implants"[All Fields]) OR "dental implants"[All Fields]) AND microleakage[All Fields] OR leakage[All Fields] AND ("dental implants"[MeSH Terms] OR ("dental"[All Fields] AND "implants"[All Fields]) OR "dental implants"[All Fields])." Both manual and electronic searches were performed to select the relevant articles.

Selected studies and eligibility criteria

Initially, we selected the studies by analyzing the title and abstract. The selected studies were further analyzed and included in the sample. Therefore, population, intervention, comparison, and outcome (PICO), as recommended by the PRISMA statement,[17–20] were used as the questioning criteria to establish an objective clinical questionnaire and appropriate inclusion criteria. In addition, we followed systematic reviews carried out for in vitro and animal studies, as well as the process of registration in the PROSPERO database.

PICO Questions

Population: Experiments that involved the study of the materials used to prevent infiltration inside the implants.

Intervention/exposure: Implants with the materials to prevent infiltration inside the implants.

Comparison: Implants without the materials to prevent infiltration in implant/abutment joints or different types of dental implants and connections.

Outcome: Possible differences (clinical significance) between the use and nonuse of a material and between the different materials.

The studies selected for this analysis met the criteria established by the PICO index, defining the following question: "Is there an efficient method to minimize the infiltration of microorganisms in the implant-abutment interface?"

The studies included methods that used materials to prevent infiltration inside the implants. The implant specimens with and without the tested materials were compared for the following outcomes: rate of microorganism infiltration inside the implants when the material is used (primary outcome), the most efficient method against infiltration, and the method that is closest to clinical situations (secondary outcome).

The inclusion criteria included studies published in English, in vitro studies, controlled and randomized studies, and/or prospective clinical trials with more than 10 patients. The exclusion criteria included studies unrelated to offset configurations, duplicated studies, studies not published in English, theoretical studies, animal studies, clinical studies with less than 10 patients, and studies that did not test any materials for preventing bacterial leakage.

Data collection process

The search for the studies was independently performed by two previously calibrated reviewers (C.A.S. and M.B.B.T.) and by a third reviewer (G.A.C.M.). The κ coefficient value was calculated to determine the interreader agreement in the study, evaluate the titles and abstracts selected, and obtain a test of agreement (twice) for the databases MEDLINE/PubMed ($\kappa = 0.48$; 0.71; 1) and Cochrane ($\kappa = 1$; 1). A consensus meeting was scheduled for the Medline/PubMed database articles in which all discrepancies were analyzed and resolved by the third reviewer (G.A.C.M.). All titles and abstracts of papers that were assessed as eligible were separated and thoroughly analyzed. The manual search of the journals was performed by two reviewers working independently of each another (C.A.S and M.B.B.T.).

Meta-analysis

Summary Measures and Synthesis of Results

The quantitative data collected from the event rate (rate of contamination in the implant and prosthesis platform region) and the total number of implants analyzed were tabulated for the analysis of odds ratio (OR) with a corresponding 95% confidence interval (CI).[21] The meta-analysis was conducted using the Comprehensive Meta-Analysis Software version 3.0 (Biostat, Englewood, NJ).[22] The number of implants analyzed was the statistical unit. The I^2 statistic was used to describe the

TABLE 1

Articles excluded and the justifications for exclusion

Studies Excluded	Justifications for Exclusion
Okuyama et al[30]	The study did not evaluate microbiological infiltration. It evaluated the infiltration of aqueous solution of 0.5% basic fuchsine dye.
Pan et al[31]	The study did not evaluate microbiological infiltration. It evaluated the infiltration of aqueous solution of 0.5% basic fuchsine dye.
Park et al[22]	The study did not evaluate microbiological infiltration. It evaluated the infiltration of aqueous solution of 0.5% basic fuchsine dye.

percentage of total variation across studies due to heterogeneity. I^2 values higher than 75 (range, 0–100) were considered to indicate significant heterogeneity.[21,23–27]

RESULTS

A search of the databases retrieved 326 references, including 135 from PubMed/Medline, 186 from Scopus, and 5 from the Cochrane Library. Eleven studies remained after applying the inclusion/exclusion criteria to the titles and abstracts. After reading the full articles, 3 studies were excluded because they did not meet the inclusion criteria (Table 1). Finally, 8 studies were selected for qualitative and quantitative analyses (Table 2).

Characteristics of the studies

Two of the 8 studies were classified as in situ, because the microorganisms evaluated were isolated from the saliva collected from patients' mouths[14]; the others were in vitro studies. All studies were published between 2006 and 2017 (Table 2).

A total of 697 implants were analyzed. The lowest number of implants used in these studies was 12,[28] whereas the highest was 180 (mean, 87.12 implants).[29] Two studies evaluated more than one brand of implants.[7,30] Two studies evaluated just one type of connection[14,31]: the Morse taper connection (MT), with both antirotational geometry and the MT conventional system, but without comparative groups. The other studies evaluated more than one type of connection by comparing internal (MT and internal hexagon [IH]) and external connections (external hexagon [EH]). The mean for the torque values was 22 N/cm, irrespective of the connection type. The smallest connection platform was 2.2 mm (MT)[32] and the largest was 4.0 mm, irrespective of the type of connection.[29]

Different brands of implants/abutments were analyzed, and the evaluated region in the studies varied between the abutment-implant interface and the occlusal screw accesses of the prosthetic abutment.

TABLE 2

General data of the studies*

Author/Year	Publishing Journal	Type of Studies	Implant System	Connections Systems (n)	Platform Size	Torque (N/cm)
Cardoso et al[18]	*Journal of Periodontology*	In vitro	Conexão	EH: 90 and IH: 90	4.0 × 13 mm	20
Cavalcanti et al[21]	*Clinical Implant Dentistry and Related Research*	In vitro	Sin	EH: 60 and MT: 60	HE: 2.7 × 6.5 mm, CM: 2.2 × 7.66 mm	ND
Duarte et al[9]	*Journal of Periodontology*	In vitro	Conexão Implants System (Master Screw-MT), Emfils (Colosso-EH), Neodent (Titamax-MT), Serson Implant (EX-MT) e Titanium Fix	EH: 12 and IH: 12	ND	20
Nascimento et al[13]	*Clinical Oral Implants Research*	In situ	Sin	MT + abutment (ant rotational interface geometry) (n = 60)	3.8 × 10 mm	Implants: 20; crowns: 10
Nayak et al[12]	*Journal of Oral Implantology*	In vitro	Adin	ND	ND	20
Podhorsky et al[19]	*The International Journal of Oral & Maxillofacial Implants*	In vitro	Dentsplay Implants (Xive S Plus) e Bego Implants (Bego Semados RI)	Xive S Plus: 80 and Bego Semados RI: 80	3.75 × 13 mm (Bego implants), 3.8 × 13 mm (Dentsplay implants)	Bego: 30, Dentsplay: 24
Proff et al[17]	*Folia Morphologica*	In vitro	Straumann	ND	3.3 × 5.5 mm	20
Alshehri et al[20]	*Implant Dentistry*	In situ	Sin	MT (n = 60)	3.8 × 10 mm	20

*EH indicates external hexagon; MT, Morse taper; IH, internal hexagon.

TABLE 3

Secondary outcome data of the studies*

Author/Year	Number of Implants	Region of Evaluation	Number of Groups (n)	Microorganisms
Cardoso et al[18]	180	Interface of the abutment-implant	6 (30)	*Enterococcus faecalis* (ATCC 29212)
Cavalcanti et al[21]	120	Occlusal screw accesses of the abutment	8 (15)	*Escherichia coli* (ATCC 25922)
Duarte et al[9]	60	Interface of the abutment-implant	10 (6)	*Enterococcus faecalis* (ATCC 29212)
Nascimento et al[13]	60	Occlusal screw accesses of the abutment	5 (12)	Nonstimulated saliva + supragingival biofilm (from superior and inferior molars) (*Porphyromonas gingivalis s, Tannerella forsythia, Treponema denticola, Candida* ssp)
Nayak et al[12]	45	Interface of the abutment-implant	3 (15)	*Enterococcus*
Podhorsky et al[19]	160	Occlusal screw accesses of the abutment	16 (10)	*Escherichia coli*
Proff et al[17]	12	Interface of the abutment-implant	2 (6)	*Porphyromonas gingivalis* (DSM 20709)
Alshehri et al[20]	60	Occlusal screw accesses of the abutment	3 (20)	Nonstimulated saliva + supragingival biofilm (from superior and inferior molars) *A. actinomycetemcomitans, Porphyromonas gingivalis, Tannerella forsythia, Treponema denticola, Candida albicans*

*BHI indicates brain heart infusion; PCR, polymerase chain reaction; qRT-PCR, quantitative reverse transcription-PCR.

Evaluation method for the microbial infiltration

In general, the studies evaluated the infiltration of anaerobic and aerobic facultative bacteria in variable quantities (Table 3). Two studies evaluated the infiltration of one species of fungus (*Candida albicans*).[14,31] The bacteria *Porphyromonas gingivalis* was the only microorganism that was evaluated in more than two studies.[14,28,31]

The most common nutrient medium used in the studies was brain-heart infusion (BHI) broth, which was used to cultivate the microorganisms in variable quantities. Only 1 study used thioglycolate bouillon with hemin-menadione solution as the broth for cultivation.[28] The in situ studies used human saliva as the cultivation medium. The mean incubation period (follow-up) was 15.4 days.[14,31]

Four studies evaluated the microorganism infiltration via the turbidity of the medium, without counting the number and species of infiltrated microorganisms (Table 3). The other 4 studies applied DNA methods to identify and quantify microbial species that penetrated the screw-retained implant prostheses.[13,14,30,31] Only 1 study[30] used thermocycling in distilled water prior to microbiological incubation.

Materials tested and bacterial leakage

Sealing these regions from infiltration was achieved via chemical procedures and disinfectants and/or physical barriers as described in Table 4. The chemical procedures included the deposition of a diamond-like carbon (DLC) film, DLC with embedded silver nanoparticle (Ag-DLC) film, chlorhexidine, and GapSeal, and the physical barriers tested were a silicon material, composite resin, cotton pellet, GP, PTFE tape, light-polymerized provisional composite, O-ring, Berutemp 500 T2/Kiero Seal, and vinyl polysiloxane (VP). Nascimento et al[14] evaluated the combination of more than 1 physical barrier. Three studies compared the chemical and physical methods for sealing.[7,13,32]

A brief summary of the bacterial leakage and the capacity of the material seals is provided in Table 4.

Quantitative analysis

Three studies considered 162 internal/Morse connection implants and 162 external connection implants. The CI was 0.08–33.4. The overall pooled OR was 1.64 (random: 1.64–0.08–33.4, $P = .748$). Therefore, no significant difference for microbiological leakage was identified for the different connections ($P = .748$), as shown in the Figure.

DISCUSSION

The primary objective of this study was to identify the most effective material against bacterial infiltration inside the dental implants and prosthetic components. To our knowledge, this is

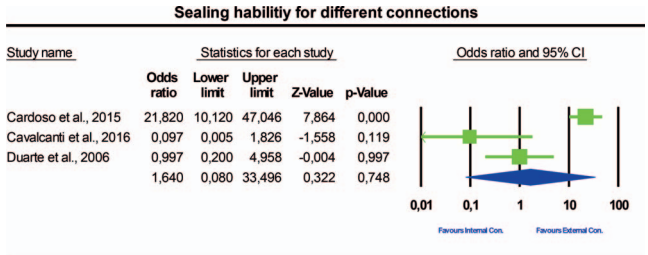

FIGURE Forest plot for sealing ability for different connections. *CI indicates confidence interval.

Table 3

Extended

Nutrient Medium	Quantity of Microorganism Used	Incubation Period	Method of Analysis
BHI broth	1 μL (10^6 UFC/mL)	5 days at 37°C, 5% CO_2	Nutrient medium turbidity
BHI broth	ND	14 days at 37°C	Nutrient medium turbidity
BHI broth	4 mL BHI + 100 μL *Enterococcus faecalis* (4×10^9 UFC/mL)	7, 14, 21, 35, 49, and 63 days at 37°C	Nutrient medium turbidity
Human saliva	150 μL saliva	7 days	DNA checkboard (PCR)
BHI broth	ND	5 days at 37°C	Colonies formed unities
ND	DO 600 nm = 1.0	7 days at 37°C and 5% CO_2	qRT-PCR
Thioglycolate boullion with haemin-menadione solution and Schardler agar	ND	72 hours and 4 days	Nutrient medium turbidity
Human saliva	5 mL human saliva with biofilm collected from the first molar of the maxilla and mandibula	7 days	DNA checkboard (PCR)

the first systematic review and meta-analysis aimed at identifying the scientific basis to answer this question. The investigation showed that it was not possible to identify an effective material in the literature. In most studies, the results for the test group materials were close to those of the control groups, in which no materials were used.

However, the null hypothesis was partially rejected because, in comparison of the test groups, Nascimento et al[14] showed that materials such as cotton pellets presented unfavorable results for use as sealants. In combination with other materials, they exhibited better performance. For example, cotton pellets with a light-polymerized provisional composite (mean ± SD: 17.45 ± 1.67) demonstrated poor results in comparison with the other groups of the study. Even though the authors presented more favorable results for GP (mean ± SD: 6.40 ± 1.42), these results were not sufficient for GP to be considered as a good material to seal the implant/abutment region.

These results for cotton pellets are in accordance with those observed in the literature.[33] In an in vitro study by Park et al,[33] which evaluated the infiltration of basic fuchsin into the prosthetic abutments connected to the implants, cotton occupied all the internal space and absorbed the leaked and penetrated fluids, which implied that the amount of microleakage depended solely on the sealing ability of the material combined with cotton. This is similar to the clinical conditions, where cotton absorbs bacterial fluids. This observation may be associated with malodor and bad taste in the mouth. Therefore, these materials should be carefully used as an access filling for implant abutment, even under the cemented crown.

It is also possible to infer, based on the study by Nascimento et al,[14] that the combination of PTFE tape with a light-polymerized provisional composite (mean ± SD: 6.02 ± 1.48) shows similar results compared with the combination of cotton pellet and GP. Thus, it is evident that the use of a light-polymerized provisional composite is insufficient to contain the microbial infiltration when combined with other materials.

Studies investigated by this review demonstrated controversial results for GP. Cavalcanti et al[32] affirmed that GP condensed into the abutment channel was the most efficient sealing material to prevent bacterial microleakage compared with PTFE tape plugging (EH + PTFE = 100% of bacterial leakage; EH + PFET = 90.9%; MT + GP = 30%; EH + GP = 30%; EH, no seal = 100%; MT, no seal = 92.85%). However, removal of GP from the abutment screw access became more difficult over time after cooling down, and it could only be removed as several pieces, often leaving residue within the screw head. However, the results obtained by Nascimento et al[14] showed that PTFE and GP afforded the lowest total microbial counts (3.41 ± 0.38). These results agree with those described by Proff et al,[28] who concluded that there was no evidence to prove that GP should not be considered as a material of choice or as the gold standard as a sealing material. Therefore, the use of GP for sealing the interface is entirely dependent on the choice and experience of the operator.

Cavalcanti et al[32] confirmed that the number of infiltrating microorganisms when PTFE was used was equivalent to that for the groups with no sealing, independent of the implant system evaluated (PTFE groups: EH, all samples contaminated; MT, 90.9%; no seal groups: EH, all sets contaminated; MT, 92.85%). However, the use of PTFE with other materials can be efficient[34] because PTFE with composite resin (mean ± SD: 2.81 ± 0.38) and with GP (mean ± SD: 3.41 ± 0.38) afforded favorable and interesting results in combination with light-polymerized provisional composite (6.02 ± 1.48).

In terms of the use of chemical composite to decrease the microbial infiltration, Nayak et al[13] confirmed that by using GapSeal (an antibacterial sealing gel), leakage could be reduced

TABLE 4

Primary outcome of the studies*

Author/Year	Sealing Materials Evaluated	Bacterial Leakage From the Connection	Bacterial Leakage From the Material Sealing	Outcome
Cardoso et al[18]	Deposition of a DLC film or Ag-DLC film	EH: 16.09% and IH: 80.71%	EH: 21.43%; EHC: 20.00%; EHAg: 6.90%; IH: 82.14%; IHC: 85.71%; IHAg: 74.07%	The deposition of DLC films in the presence of Ag, despite not presenting a significant difference, positively inhibits infiltration.
Cavalcanti et al[21]	GP and PTFE tape	EH: 100% and MT: 92.85%	HE + PFET = 100%; HE + PFET = 90.9%; CM + GP = 30%; HE + GP = 30%; HE no seal = 100%; CM no seal = 92.85%	GP was more effective than PTFE and no sealing material. The use of PTFE was equivalent to the use of no materials. The GP group with implants MT presented greater microbial infiltration values.
Duarte et al[9]	Chlorhexidine gluconate 1% varnish and thymol (Cervitec, Vivadent-Ivoclar) and silicon material (Dow Silastic, Dow Chemical)	EH: 53.5% and MT: 53.42%	7 days: 3 implants (Conexão, Emfils, Serson Implants groups); 14 days: all implants; 21 days: none; 35 days-silicon groups: EH: 1 implant and MT: none; 35 days-varnish groups: EH: 1 implant; 49 days-silicon groups: EH: 1 implant and MT: 1 implant; 49 days-varnish group: EH: none and MT: 1 implant; 63 days-silicon groups: EH: 1 implant and MT: 2 implants; 63 days-varnish group: EH: 1 implant and MT: 2 implants; Colosso group presented lowest sealing capacity and titanium fix group the highest sealing capacity	The materials evaluated were not able to control the infiltration after a period of 63 days. It was observed infiltration at a period of 14 and 35 days for control groups and experimental groups, respectively. The materials presented similar sealing capacity, and the contamination occurred independently of the connection type.
Nascimento et al[13]	PTFE tape + composite resin (Filtek Z250, 3M ESPE); PTFE + GP sticks (Dentsplay Maillefer); PTFE + light-polymerized provisional composite (Bioplic-Biodinâmic LTDA); cotton pellet + GP; cotton pellet + light-polymerized provisional composite	MT	Cotton pellet + light-polymerized provisional composite group (17.45 ± 1.67) presented the higher microbial counts. PTFE + light-polymerized provisional composite group (6.02 ± 1.48) and cotton pellet + GP group (6.40 ± 1.42) presented higher counts compared with groups 1 (2.81 ± 0.38) and 2 (3.41 ± 0.38)	The quantity of microorganisms was moderated for all groups. The lower counts were found for PTFE tape associated with composite resin or GP. The group cotton + light-polymerized provisional composite showed greater infiltration values.
Nayak et al[12]	O-ring (ORMCO) and GapSeal (Hagerwerken)	ND	UFC: O-ring: 0–183 (SD: 63.62); GapSeal: 0–9 (SD: 3.46)	It was not possible to seal the region of the evaluated materials. However, the best results were obtained by the gel.
Podhorsky et al[19]	Two sealants: Berutemp 500 T2/Kiero Seal (Berutemp 500 T2 [Carl-Bechem] grease; and Kiero Seal [Kuss Dental], PVS) and one disinfectant: chlorhexamed gel 1% of chlorhexidine digluconate (GlaxoSmithKline)	Xive S Plus connection: lower colonization and homogenous results even after mechanical cycling compared with Bego Semados RI	Xive S Plus + chlorhexidine: lower average and better dispersion of values	Independent of the material and connection, there was not efficacy for infiltration.

Table 4

Continued

Author/Year	Sealing Materials Evaluated	Bacterial Leakage From the Connection	Bacterial Leakage From the Material Sealing	Outcome
Proff et al[17]	GP	ND	72 hours: control group: very strong growth GP group: 3 implants; 4 days: control group: 3 implants; GP group: 3 implants	The gutta-percha was inefficient in sealing *Porphyromonas gingivalis*.
Alshehri et al[20]	GP, PTFE tape, VP	MT	No significant statistical difference was observed in relation to the prevalence of the investigated species; *Tannerella forsythia,* presented the highest number of cultures and *Candida albicans* the lowest number	Independent of the material, there was not an efficacy relation with the sealing against the infiltration. He choice of the material is directly linked to the operator experience.

*DLC indicates diamond-like carbon; EH, external hexagon; IH, internal hexagon; Ag, silver; GP, gutta-percha; PTFE, polytetrafluoroethylene; MT, Morse taper; PVS, polyvinylsiloxane.

to a negligible amount because the viscosity of the gel allowed it to flow easily throughout the interface, leading to a better seal. This result is consistent with other studies,[7,30,35] which stated that the use of antimicrobial materials made with chlorhexidine gluconate (CHX) show significant decrease in bacterial counts owing to the low viscosity of the gel. Duarte et al[7] showed that combining CHX with thymol varnish could reduce the number of microorganisms in the oral cavity for a 45- to 63-day period, with 40% of interfaces still intact. Thus, we conclude that the application of sealing material before abutment connection can control the peri-implant bacterial population, and in a clinical situation, the use of this material in a 2-stage implant system installation can be very effective.

Coating of diamond-like carbon films with silver (Ag) nanoparticles can reduce the implant–abutment bacterial leakage, with very promising results.[7] The bacterial leakage in EH systems containing silver was reduced to 6.90%, compared with the control group (21.43%); in an IH system, it was reduced to 74.07% compared with the control group (82.14%). Silver influenced microbial decontamination positively; hence, despite the results not meeting the expectations of the authors, increasing the amount of Ag nanoparticles should further reduce the number of microorganisms.

In this systematic review, no significant difference for microbiological leakage was observed for the different connections (Figure; OR, 1.64; random, 1.64–0.08–33.4; $P = .748$). Despite some studies showing lower levels of leakage with conical implants,[36] bacterial leakage has been observed in all types of implant connections.[37] Because of the large differences in the methodologies used, the frequency of leakage varied between the in vitro studies and the many methodologic variables in these studies make comparison very difficult. On the basis of literature[29] reports, several factors can influence bacterial leakage, such as the technique used (direct or indirect), size of the microorganisms, follow-up time, loading of samples, sample size, repeated use of samples, and quantity of inoculated bacteria.[29,38] More studies need to be carried out in this area, including a standardization of methodologies and areas analyzed.

Another important factor that makes it difficult to define an ideal material for sealing the abutment-implant interface is the variation between different brands and types of connections evaluated, whose factors can interfere at indispensable points for the formation of biofilm, such as the type of alloys, wettability, surface energy of the prosthetic components of the alloy,[39–41] implant and abutment design, torque, size of the infiltration region,[32] and irregularities on the surface during the manufacturing process.[42]

However, this systematic review/meta-analysis shows that, although the manufacturers use of commercial chemical methods for coating films deposited onto the surface of the abutment and the implant connection platform exhibit more interesting results than the physical methods, the use of chemical methods is clinically impracticable. Materials such as GP and PTFE in combination with other materials presented interesting results; however, these materials deteriorate over time, making it necessary to change the applied materials. Thus, considering that antimicrobial agents such as CHX have limited time of action, rendering the reapplication of the material important, increased use of such methods are indicated because the results show that they can be more effective against microbial leakage.

Therefore, taking into consideration the difficulties encountered in this review, more studies regarding the materials that can control the microbial infiltration, mainly clinical studies to guide and establish a protocol with respect to clinical approaches, are necessary.

Conclusion

The use of commercial film coatings is efficient, and the use of CHX and varnish applications in implants is effective against biofilms in clinical studies. The use of GP and PTFE in combination with GP, PTFE, and CR, or a combination of these physical barriers with chemicals such as CHX or thymol varnish,

is the best option to prevent biofilm formation inside the implants.

Abbreviations

BHI: brain heart infusion
DLC: diamond-like carbon
CHX: chlorhexidine gluconate
CI: confidence interval
CR: composite resin
DLC: diamond-like carbon
EH: external hexagon
GP: gutta-percha
IH: internal hexagon
MT: Morse taper
OR: odds ratio
PICO: population, intervention, comparison and outcome
PTFE: polytetrafluoroethylene
VP: vinyl polysiloxane

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