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Bacterial Adhesion on Lithium Disilicate Ceramics: Systematic Review

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Abstract

Introduction: All-ceramic systems are constantly being revised and updated to incorporate new ceramic materials. Most of the evidence for the clinical use of new ceramic materials comes from information on mechanical properties and chemical composition. However, information on bacterial adhesion to these new materials is scarce. The aim of this study is to provide a better overview of the importance of bacterial adhesion on lithium disilicate ceramics compared to other dental ceramics. **Material and method:** PubMed, Google scholar, Science direct databases were searched between October 2021 and October 2022 and updated in March 2023. Criteria included: Studies (in situ or *in vivo* biofilm) that evaluated bacterial adhesion to dental ceramics, (including lithium disilicate ceramics). **Results:** A total of 701 studies were identified in the initial survey. After reading the titles and abstracts, we were left with a total of 117 articles. We excluded 54 articles that did not comply with the inclusion criteria. We then excluded 49 articles after full-text evaluation of 63 articles, and finally retained those relevant to our systematic review (14 articles). **Conclusion:** Our systematic review reports that lithium disilicate exhibits higher bacterial adhesion than zirconia, but it is difficult to make definite conclusions based on the results reported. Material composition can influence initial bacterial adhesion; in this respect, further studies are needed to clarify whether there is a correlation between bacterial adhesion and the glass content of ceramics.

Subject Areas

Dentistry

Keywords

Biofilm, Bacterial Adhesion, Dental Ceramics, Lithium Disilicate

1. Introduction

The oral cavity is a unique environment for the formation of complex biofilms, in order to survive within the oral cavity, bacteria need to adhere either to the soft or hard tissues in order to resist shear forces. In addition to the hard tissues of the teeth, the oral cavity also contains commonly used dental restorative materials with hard surfaces to which bacteria can adhere, such as ceramic.

Over the last ten years, scientific research into dental ceramics has focused on zirconia and lithium disilicate. Ceramic systems are therefore subject to constant revision and updating to incorporate new ceramic materials.

Most of the evidence for the clinical use of new ceramic materials comes from information on mechanical properties and chemical composition. However, information on bacterial adhesion to these new materials is scarce.

Several studies [1] [2] [3] have investigated bacterial adhesion on ceramics compared to other dental materials, such as gold alloy, titanium, amalgam and composite. Almost all these studies revealed lower bacterial adhesion on ceramics than other materials. Although ceramics, which are becoming increasingly important in restorative and prosthetic dentistry, generally show lower bacterial accumulation than other dental materials, there is still a lack of knowledge concerning bacterial adhesion on different types of ceramics.

Practitioners need to pay attention to the type of ceramic materials chosen, as they can promote bacterial adhesion in different ways. This is crucial when treating patients with a high risk of caries, inadequate oral hygiene, periodontal disease or systemic health problems that compromise immune function.

The aim of this qualitative systematic review is to provide a better overview of the importance of bacterial adhesion on lithium disilicate ceramics compared to other dental ceramics.

2. Material and Methods

2.1. Study Design

A structured qualitative systematic review following the PRISMA (Preferred Reporting Item for Systematic Review and Meta-Analyses) recommendations and the PRISMA checklist [4] [5].

2.2. Eligibility Criteria

We have tried to answer the following question: does bacterial adhesion on lithium disilicate ceramics differ from that on other dental ceramics, and what factors influence bacterial adhesion?

The population, intervention, comparison, outcomes, and study designs for this systematic review are defined in **Table 1**.

Studies (in situ or *in vivo* biofilm) that evaluated bacterial adhesion to dental ceramics, (including lithium disilicate ceramics). Articles published between 2009 and 2022.

Table 1. PICOS.

Participants	Lithium disilicate
Intervention	Without intervention
Comparaisons	Comparisons of bacterial adhesion between lithium disilicate and other types of ceramics
Outcomes	Bacterial adhesion (Increase/decrease)
Study designs	*In vitro* studies, biofilm in situ or *in vivo*

Exclusion criteria: literature reviews, Systematic reviews; articles published before 2009. Studies not dealing with lithium disilicate ceramics were excluded. Studies not meeting the objectives of our work based on abstract reading and critical reading of the full text were also excluded.

2.3. Information Sources and Search Strategy

Individual search strategies were developed for each of the following electronic databases: SCOPUS, PubMed/Medline, Google Scholar, and Science direct. These databases were last consulted on: 24/03/2023.

Key words: Based on the PICO sections (Table 1), we first identified the main concepts of our thesis topic: Concept 1: bacterial adhesion, concept 2: dental ceramics. In a second step, we found the keywords via these concepts: biofilm, bacterial adhesion, dental ceramics, lithium disilicate.

2.4. Study Selection and Data Extraction

The first search was performed by a single author (R.S) who was responsible for eliminating several articles according to the inclusion criteria already specified, then the selection of studies and quality assessment were carried out independently by two readers (S.M; R.S) so as to reduce the risk of excluding relevant studies, minimize the risk of error of judgment and subjectivity, and ensure reproducibility of results. In the event of a difference of opinion, the articles concerned were discussed between the two readers in order to reach a consensus.

2.5. Risk of Bias

The quality and risk for bias of the included studies were assessed by the quasi-experimental studies appraisal tool by the Joanna Briggs Institute that had been adapted for another systematic review of *in vitro* studies [6]. This step enabled the final selection of potentially eligible articles. This risk-of-bias assessment stage enabled the final selection of potentially eligible articles.

3. Results

3.1. Study Selection Process and Flow Chart

Figure 1 shows an overview of the study selection procedure. A total of 701 studies were identified in the initial survey. After reading the titles and abstracts, we

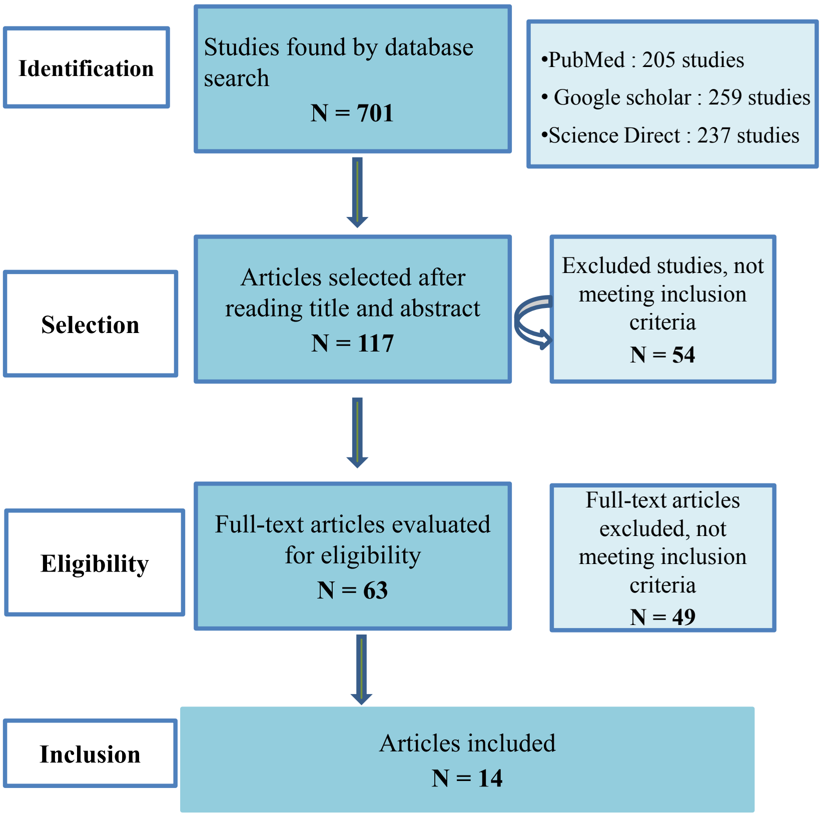

Figure 1. Flow chart illustrating the study selection process.

were left with a total of 117 articles. We excluded 54 articles that did not comply with the inclusion criteria. We then excluded 49 articles after full-text evaluation of 63 articles, and finally retained those relevant to our systematic review (14 articles).

3.2. Risk of Bias

The results of the quality evaluation of the studies are summarized in **Table 2**. The risk of bias was evaluated with the use of an adapted quasi-experimental studies appraisal tool by the Joanna Briggs Institute. Of the 14 studies included in this systematic review, most had a low risk of bias, with the exception of questions 5 and 8. Most answers to question 5 (Were there multiple measurements of the outcome both pre and post the intervention/exposure?) were uncertain, we can explain this by the fact that we chose studies without intervention on the ceramics used. Regarding question 8 (Were outcomes measured in a reliable way?), most answers were uncertain, because most studies did not provide information on the number of assessors, assessor training, intra-assessor reliability and inter-assessor reliability within the study, this criteria presents a high risk of bias. Five studies [7] [8] [9] [10] [11] are no control groups.

3.3. Analysis of Selected Articles

After reading the full text of the articles, we tried to extract the results of most

Table 2. Study analysis with adapted the quasi-experimental studies appraisal tool by the Joanna Briggs Institute.

Studies	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9
Hahnel *et al.* 2009	Yes	Yes	Yes	Yes	Unclear	Yes	Yes	Unclear	Yes
Bremer *et al.* 2011	Yes	Yes	Yes	No	Unclear	Yes	Yes	Unclear	Yes
V. O. Diane *et al.* 2015	Yes	Yes	Yes	No	Unclear	Yes	Yes	Yes	Yes
Haritha *et al.* 2015	Yes	Yes	Yes	Yes	Yes	Yes	Unclear	Unlcear	Yes
Hussein *et al.* 2016	Yes	Yes	Yes	No	No	Yes	Yes	Unclear	Yes
L. Viitaniemi *et al.* 2017	Yes	Yes	Yes	Yes	Unclear	Yes	Yes	Unclear	Yes
Dal Piva *et al.* 2018	Yes	Yes	Yes	No	Unclear	Yes	Yes	Unclear	Yes
Jalalian *et al.* 2018	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Unclear	Yes
Dobrzynski *et al.* 2019	Yes	Yes	Yes	No	Unclear	Yes	Yes	Unclear	Yes
Poole *et al.* 2020	Yes	Yes	Yes	Yes	Unclear	Yes	Yes	Unclear	Yes
Matalon et coll 2020	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Shibasaki *et al.* 2020	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Unclear	Yes
Mohamed Mahmoud *et al.* 2020	Yes	Yes	Yes	Yes	Unclear	Yes	Yes	Yes	Yes
Engel *et al.* 2020	Yes	Yes	Yes	Yes	No	Yes	Yes	Unclear	Yes

interest to our study, the results of the articles are summarized in Table 3 and Table 4, those tables includes 11 *in vitro* studies and 3 *in vivo* studies, the table provides several information about the studies namely: Name of authors, purpose of the study, ceramics used, control group, tests used, types of bacteria, results and conclusions.

4. Discussion

4.1. Bacterial Adhesion: Lithium Disilicate vs Other Ceramics

Material composition and surface properties can influence initial bacterial adhesion and compromise dental and periodontal health [12].

According to the study conducted by Diane T. Vo *et al.* [13], lithium disilicate ceramics (Press and CAD) showed no significant differences in bacterial adhesion, but these ceramics were significantly lower than the samples (ZirPress/Ceram), which were significantly lower than the samples (Ceram Glaze), the authors linked these differences to manufacturing factors, Indeed, the glaze application has the roughest surface finish due to the absence of post-fabrication polishing, and the ZirPress samples have been modified by a technique involving the addition of a fluorapatite glazing ceramic, which may explain the non-uniform surface characteristics and the introduction of an additional surface. The manufacturing technique therefore influences the surface properties of lithium disilicate as well as bacterial adhesion.

However, a study conducted by Contreras LPC *et al.* concluded that ceramic manufacturing technique does not influence surface properties such as surface free energy [14].

Table 3. Characteristics of selected studies (*in vitro* studies).

Author	Objectives	Ceramics	Control group	Tests	Type of bacteria	Results and conclusions
Hahnel *et al.*	To investigate the surface properties of dental ceramic materials belonging to different ceramic classes, and to correlate the findings to the initial adherence of three oral streptococcal strains.	Glass ceramic Lithium disilicate glass ceramic Glass-infiltrated alumina–zirconia ceramic Partially stabilized zirconia ceramic Hipped zirconia ceramic	Glass plates	-Surface roughness -Surface free energy -Bacterial adhesion	-Streptococcus gordonii -Streptococcus oralis -Streptococcus sanguinis	-**Ra:** The lithium disilicate glass ceramic showed the highest values for surface roughness -**B.A:** The control material showed higher values for streptococcal adhesion than all ceramic materials. After protein coating, only slight and random differences in streptococcal adhesion were found between the various ceramic materials **Conclusion:** Dental ceramic materials show differences in terms of Ra, and initial streptococcal adhesion; however, correlations between surface properties and streptococcal adhesion were poor
Diane T. Vo, DDS *et al.*	to investigate how biofilm accumulation is affected by surface quality of differently prepared lithium disilicate all-ceramic materials. A correlation between surface roughness and bacterial adherence was also evaluated.	IPS e.max Press IPS e.max CAD IPS e.max ZirPress/Ceram IPS e.max Press with IPS e.max Ceram Glaze Spray	Without control group	-Surface roughness -Bacterial adhesion	Streptococcus mutans	-**Ra:** Ceram Glaze > ZirPress > Press = CAD -**B.A:** Ceram Glaze > ZirPress > Press = CAD **Conclusion:** The surface roughness of differently prepared lithium disilicate ceramic restorations is closely related to the adherence of S mutans
Ghanta, Haritha *et al.*	To compare the adhesion of Streptococcus gordonii to enamel and other dental materials with and without surface wear.	Lithium disilicate (IPS e.max), Zirconia (Z, Y-TZP)	Enamel	Bacterial adhesion	Streptococcus gordonii	-A.B: The highest bacterial attachment was found at worn enamel surfaces. Among the materials, Zirconia showed the lowest bacterial attachment regardless of wear **Conclusion:** Bacterial adherence was material dependent and worn surfaces increased bacterial adherence
L Viitaniemi *et al.*	Monolithic zirconia and glass ceramics are increasingly used in implant crowns. Limited data is available on bacterial adhesion and early biofilm formation on these materials.	Lithium disilicate glass-ceramics Fully stabilized zirconia Partially stabilized zirconia	Without control group	Bacterial adhesion	-S. mutans	**Conclusion:** LDS has lower S. mutans adhesion than other materials examined in this study, but the difference was not reflected in early biofilm formation
AMO Dal Piva *et al.*	To evaluate the influence of two finishing techniques (polishing or glazing) on the surface properties of two monolithic ceramics, as well as on bacterial adhesion.	-Zirconia -Silicate de lithium renforcé à la zircone (Vita suprinity)	Without control group	-Surface roughness -Surface free energy -Bacterial adhesion	-Streptococcus mutans -Streptococcus sanguinis -Candida albicans	-**Ra:** Glazed zirconia has the highest S.R. **Conclusion:** Glazed surfaces present higher surface roughness than polished surfaces. Glazed surfaces present higher surface roughness and tend to accumulate more bacteria

Continued

Ezzatollah Jalalian *et al.*	To compare adhesion of streptococcus mutans to zirconia, IPS Empress II, noble alloy, and base-metal.	-Zirconia -Lithium disilicate	Enamel	-Surface roughness -Bacterial adhesion	-S. mutans	**-Ra:** There was no significant difference among study groups regarding their surface roughness **-B.A:** The lowest adhesion value was obtained in zirconia group **Conclusion:** Zirconia showed the lowest bacterial adhesion in comparison to other restorative materials. Therefore, the findings of the present study highlight the fact that restorative ceramics, including zirconia is a better choice in patients with poor oral hygiene and those susceptible to periodontal disease
Maciej Dobrzynski *et al.*	to compare adhesion as well as development of the biofilm by chosen oral microorganisms on the ceramics materials in regard to their roughness.	-Lithium disilicate -Hybrid ceramic -Leucite glass ceramics Leucite-reinforced glass	Without control group	-Contact angle -Bacterial adhesion	-C. albicans, -S. mutans, -L. rhamnosus,	**-B.A:** *S. mutans: la céramique hybride: The highest adhesion in S. mutans was noted in polished Vita Enamic and polished IPS Empress groups. Both S. mutans and L. rhamnosus did not adhere to the sintered IPS e.max. **Conclusion:** Streptococcus mutans demonstrated by far the best adhesion to the tested materials in comparison with Candida albicans and Lacto-bacillus rhamnosus. The sintered materials such as IPS e.max polished showed the best "anti-adhesive properties" in relation to Streptococcus mutans and bacilli
Stephanie Francoi poole *et al.*	to evaluate the influence of distinct surface treatments on ceramic surface roughness and biofilm formation of oral bacteria (*Prevotella intermedia*).	-leucite-based glass ceramic, -lithium disilicate-based glass ceramic, -glass ceramic based on zirconia-reinforced lithium silicate, -monolithic zirconia.	Polished ceramics with silicon carbide paper	-Surface roughness -Bacterial adhesion	Prevotella intermedia	**-B.A:** Bacterial growth and adhesion were similar in the lithium disilicate, zirconia-reinforced lithium silicate and leucite glass-ceramic groups. The zirconia group showed higher susceptibility to bacterial adhesion for all types of surface treatment **Conclusion:** Based on our results, it may be suggested that vitreous materials (leucite-based glass ceramic, lithium disilicate-based glass ceramic, glass ceramic based on zirconia-reinforced lithium silicate) had a smoother surface when compared with that of zirconia. Furthermore, grinding with diamond burs led to greater roughness on the ceramic surfaces, and the rugosity of the ceramic material surfaces seemed to favor susceptibility for adhesion of P. intermedia
Shlomo matalon *et al.*	to compare bacterial adhesion to zirconia versus lithium disilicate crowns after artificial aging.	-Zirconia -Lithium disilicate	Cr-Co base metal	-Surface roughness -Bacterial adhesion	-Streptococcus sanguinis	**-R.S:** Statistical analysis showed significant differences ($p = 0.02$) in surface roughness between the Cr-Co base metal, zirconia and lithium disilicate before and after aging. Lithium disilicate had the highest surface roughness values **-A.B:** After aging and bacterial adherence, the zirconia discs had the smoothest surface, with similar bacterial accumulation as lithium disilicate; suggesting that lithium disilicate may be less sensitive to bacterial adhesion than zirconia

Continued

Patricia Akemi Nishitani Shibasaki *et al.*	To evaluate the performance of three types of ceramic subjected to polishing, glazing or no surface treatment after aging.	-Zirconia -Lithium disilicate	Ceramics without any treatment	-Surface roughness -Contact angle -Bacterial adhesion	-Streptococcus mutans -Candida albicans	**-Ra:** Polishing has a lower RS than glazing, and zirconia has a higher Ra than IPS e.max CAD. Surfaces without polishing showed a higher S.R. than the polished group, a higher contact angle and significant morphological changes, irrespective of the glass-ceramic **-B.A:** Regardless of material type, there was higher biofilm formation on unpolished surfaces compared with polished or glazed ceramics In general, zirconia and lithium disilicate showed the same bacterial adhesion results
Mohamed Mahmoud Abdalla *et al.*	To test the hypothesis that surface roughening and polishing of ceramics have no effect on their surface roughness and biofilm adhesion.	-Feldspathic ceramic -Lithium disilicate -zirconia reinforced lithium silicate Vita Suprinity	Ceramics as prepared	-Surface roughness -Bacterial adhesion	-Streptococcus mutans	**-Ra:** Irrespective to the ceramic type, the roughened samples showed significant higher mean surface roughness values compared to the as prepared and polished samples The as prepared ceramics groups had the lowest mean surface roughness values. Regarding the ceramic types, only the as prepared samples of feldspathic ceramic showed statistically significant higher mean surface roughness values than lithium disilciate and zirconia reinforced lithium silicate **-B.A:** Regardless the ceramic type, the roughened ceramic blocks recorded significantly higher mean percentages of live bacteria than the as prepared and polished blocks. zirconia reinforced lithium silicate Vita Suprinity showed significantly lower percentage of live bacteria than feldspathic ceraic and IPS e.max **Conclusion:** Roughened ceramic surfaces contributed to biofilm adhesion regardless of the ceramic type. Despite polishing, the surfaces still facilitated biofilm development. Thus, care should be taken while adjusting such ceramics in order to minimize the risk of bacterial adhesion and recurrent caries. The results of this study highlight that polished zirconia reinforced lithium disilicate surfaces had the lowest bacterial adhesion among the evaluated ceramics followed by lithium disilicate glass

Ra: Surface roughness; B.A: Bacterial adhesion.

Stephanie Francoi poole *et al.* [15], showed that bacterial growth and adhesion were similar in the lithium disilicate and zirconia-reinforced lithium disilicate glass-ceramic groups, however, the monolithic zirconia group revealed a greater susceptibility to bacterial adhesion, This can be explained by the composition of zirconia, which differs from lithium disilicate-based glass-ceramics: zirconia is a glass-free ceramic, a polycrystalline ceramic with a higher percentage of crystalline content and larger crystal size than lithium disilicate-based glass-ceramics. These hypotheses are the same in other published studies [16] [17].

Table 4. Characteristics of selected studies (*in vivo* studies).

Author	Objectives	Ceramics	Control group	Tests	Type of bacteria	Results and conclusions
Bremer et coll	To investigate oral biofilm formation on different dental ceramics *in vivo*.	-veneering glass ceramic -lithium disilicate, -Zirconia (Y-TZP), -Zirconia Y-TZP (HIP) -Zirconia Y-TZP HIP with 25 % alumina.	Without control group	Bacterial adhesion	*in vivo*	**-A.B:** Significant differences in bacterial surface coating and biofilm thickness were found between the different ceramic materials. The lowest surface coating and biofilm thickness were determined on the HIP Y-TZP ceramic; the highest mean values were identified with the lithium disilicate glass-ceramic. **Conclusion:** Biofilm formation on different types of dental ceramics differs significantly; in particular, zirconia shows low plaque accumulation.
Abbas I Hussein et coll	To compare bacterial adhesion between zirconia and lithium disilicate.	-Zirconia -Lithium disilicate	Gold	Bacterial adhesion	*in vivo*	The median number of Streptococcus Sanguineous colonies on zirconia crowns was significantly lower than the other two medians (gold and lithium disilicate).
Alexander-Simon Engel et coll	To compare biofilm adhesion and formation on different dental restorative materials with those on human enamel to detect differences in bacterial composition, growth rate, and morphology of the formed oral biofilms, all *in vivo*.	-Lithium disilicate -Zirconia -Hybrid ceramic	Enamel	-Surface roughness -Bacterial adhesion	*in vivo*	**-A.B:** The results indicate that within 72 hours, mature oral biofilms had formed on enamel, IPS e-max and Vita Enamic, whereas on Lava Plus zirconia, a thin, immature biofilm had formed. **Conclusion:** It can be concluded that material roughness affects biofilm formation on dental surfaces and restoratives, but other factors, such as surface charge, surface energy and material composition, may also have an influence.

Ra: Surface roughness; B.A: Bacterial adhesion.

Maciej Dobrzynski *et al.* have reported that initial bacterial adhesion can be influenced by material composition, and that lithium disilicate glass-ceramics have good anti-adhesive properties [18]. Nevertheless, L. Viitaniemi *et al.* showed that lithium disilicate exhibited lower bacterial adhesion than the other materials examined in their study.

Shlomo *et al.* [19] concluded from their results that lithium disilicate may be less susceptible to bacterial adhesion than zirconia.

In contrast, 5 studies [20] [21] [22] [23] [24] have shown that lithium disilicate ceramics exhibit higher bacterial adhesion than zirconia. The glass content has been suggested as a factor responsible for differences in bacterial adhesion, the results of one study [25] reinforcing this hypothesis since it showed that feldspathic ceramics, containing more glass than lithium disilicate exhibited higher bacterial adhesion than lithium disilicate and in another study [26] the control material (glass plate) showed higher values for bacterial adhesion than all ceramic materials.

However, no conclusions can be drawn since in previous studies [15] [18], zirconia showed higher bacterial adhesion even though it has no glassy phases. In this respect, further studies are needed to determine whether there is a correlation between bacterial adhesion and the glass content of the ceramic.

Comparison of the studies was difficult for several reasons: firstly, the techniques used to assess bacterial adhesion and the surface roughness of the materials studied are different; secondly, we only included three *in vivo* studies, as *in vitro* measurements are not always capable of simulating the complex conditions present in the oral environment.

4.2. Bacterial Adhesion and Surface Roughness

A rougher surface and complicated topography present a greater affinity for bacterial adhesion than smoother surfaces, and therefore greater difficulty in completely removing biofilm by mechanical brushing [27]. Surface roughness seems to affect only the number of bacteria in the biofilm, not the species; a rough surface increases the surface area available for colonization compared with a smooth surface [28]. In addition, the crevices created by roughness provide shelter for bacteria, giving them time to secure their attachment to the film.

In our study, 9 studies investigated the association between surface roughness and bacterial adhesion, with six studies [12] [13] [15] [24] [29] showing that surface roughness favors bacterial adhesion. In a literature review by Bollen [30], a maximum surface roughness of Ra = 0.2 μm was suggested as a threshold value for bacterial retention; below this value, no further reduction was observed, while above this value, biofilm accumulation increases with roughness. A systematic review by Wim Teughels *et al.* concluded that an increase in surface roughness above the Ra threshold of 0.2 μm facilitates biofilm formation on restorative materials 29.

Other studies reported that surfaces with a roughness threshold above 0.2 μm showed no difference in biofilm formation [31] [32]. Meier *et al.* found that a five-fold increase in roughness did not result in a greater number of adherent bacteria [33], in our work, three studies [19] [23] [26] among the included studies showed that there is no correlation between surface roughness and bacterial adhesion.

4.3. Influence of Polishing Techniques on Bacterial Adhesion

It has been noted that the ceramic finishing procedure (polishing and/or glazing) can lead to changes in free energy, with the same material exhibiting changes in surface free energy depending on the finishing and polishing procedures applied [14] [34]. Indeed, the microbiota present in the oral environment has a high free energy and adheres preferentially to high free energy substrates.

Several studies [15] [18] [25] [29] have investigated the influence of polishing techniques on bacterial adhesion. AMO Dal Piva *et al.* [12], showed in their study that glazed surfaces have greater surface roughness and tend to accumulate more biofilm. This agrees with the results of another study by Scotti R *et al.* [35]. Another study showed that the presence of glaze on the surface does not prevent the formation of dental biofilm.

Maciej Dobrzynski *et al.* [18], showed in their study that differences in the adhesion of micro-organisms to the surface of polished and unpolished ceramics were statistically significant, with unpolished surfaces being more susceptible to adhesion by micro-organisms. This is consistent with the results of several studies [36] [37]. Stephanie *et al.* [15] also reported that grinding with diamond burs resulted in greater roughness on ceramic surfaces, and the surface roughness of ceramic materials appeared to favor susceptibility to P. intermedia adhesion.

Consequently, grinding with diamond burs is not recommended, to minimize the risk of bacterial adhesion [25].

In one of the studies selected for our systematic review, Patrcia *et al.* [29] concluded that surface treatment influences bacterial adhesion, in fact, the unpolished surface showed the highest bacterial adhesion among the groups studied, they also concluded that mechanical polishing achieved a lower surface roughness than glazing as well as minimal morphological changes to the ceramic.

4.4. Different Types of Bacteria

Within our systematic review, the three *in vivo* studies [24] [25] [29] used a polymicrobial biofilm to assess microbial adhesion to ceramics, after the formation of the acquired exogenous film (AEP), pioneer colonizing microorganisms adhere to this film, creating a basic or immature biofilm, and vary according to the environment and materials to which they adhere. After the pioneer colonizers, the secondary colonizers follow, composed of various species depending on the bacterial composition of the environment; these species can be used to predict the bacterial composition of the mature biofilm. The mature stage of oral biofilm generally occurs after 3 to 5 days [24].

Pioneer colonizers of oral biofilms have been identified as Streptococcus sanguinis, S. oralis, S. gordonii, S. mitis, S. mutans, S. sobrinus, Actinomyces naeslundii and Capnocytophaga ochracea [15].

The *in vivo* studies selected in our work used Streptococcus mutans [12] [13] [18] [23] [25] [29] [38], Streptococcus sanguinis [12] [19] [22] [26], Streptococcus gordonii [21] [26], Streptococcus oralis [26], Candida albicans [12] [18] [29] and Prevotella intermedia [15] as pioneering colonizers.

Streptococcus sanguinis is considered the initial colonizer, while S.mutans is considered the colonizer associated with the development of carious lesions, also facilitating the adhesion of more complex pathogenic bacteria. C. albicans is considered a colonizer associated with caries, periodontal disease and candidiasis [19].

Streptococcus mutans is the most widespread bacteria in the oral environment. It is the most adhesive of all bacteria, irrespective of ceramic type and finishing method [12] [18].

With regard to P.intermedia, Stephanie *et al.* [15] concluded in their study that grinding with diamond burs results in high roughness on ceramic surfaces, and the roughness of ceramic material surfaces seems to favor the susceptibility to adhesion of P. intermedia, Gram-negative bacteria predominantly have a higher surface energy, between 35 and 65 mN/m, while most Gram-positive bacteria have lower values, between 0 and 25 mN/m [39]. The closer the surface free energy of the material and microorganism, the greater the probability of adhesion [40].

Some studies show that certain bacterial species interact preferentially with certain materials, depending on differences in the physico-chemical properties of the surface [18] [41]. Moreover, bacterial adhesion to a given substrate depends on both the hydrophobicity of the surface and the hydrophobicity of the bacteria. Thus, hydrophobic bacteria such as S. mutans, S. oralis and S. sanguinis adhere more readily to hydrophobic surfaces, while hydrophilic bacteria such as S. mitis adhere more readily to hydrophilic surfaces [42].

4.5. Future Prospects: Strategies for Interrupting Biofilm Formation

A number of approaches are being studied to interrupt biofilm formation or prevent its spread. Some strategies are based on materials engineering, where anti-adhesive surfaces are created or antibacterial additives are incorporated into substrates. Other research focuses on ways of acting directly on bacteria, either by inhibiting the quorum sensing system, preventing extracellular matrix formation and, among other things, inhibiting secondary messenger signaling pathways.

With regard to the material's topography, it was seen thath characteristics concerning the size, shape and distribution of roughness patterns affect both attachment and biofilm formation of different bacterial strains on various substrates. Bacterial adhesion decreases as the size of the topographic pattern get smaller, and in this sense, topographies on a micron-scale mainly affect bacterial attachment, while topographies on a nanoscale can have bactericidal effects [43].

With regard to the incorporation of antimicrobial agents into biomaterials, particularly in dentistry, various nanoparticles and agents have been incorporated to prevent biofilm formation without altering physicochemical and mechanical properties [44], such as silver-vanadate (AgVO3), which is an antimicrobial that has the advantage of being stable and not forming agglomerations. It inhibited the growth of Candida albicans, Streptococcus mutans, Staphylococcus aureus and Pseudomonas aeruginosa.

Although there are many antibacterial agents applied to reduce biofilm formation, the current context still shows species resistant to antimicrobial therapies, so more studies are needed to control or reduce pathogenic biofilms by seeking new products and techniques. In this respect, the efforts of materials engineering are essential [43].

5. Conclusions

Our systematic review reports that lithium disilicate exhibits higher bacterial adhesion than zirconia, but it is difficult to make definite conclusions based on the results reported. Despite the limitations of our study, we can conclude the following:

- Material composition can influence initial bacterial adhesion; in this respect, further studies are needed to clarify whether there is a correlation between bacterial adhesion and the glass content of ceramics.
- Surface roughness is a factor promoting bacterial adhesion.
- Grinding of ceramics generates higher surface roughness and thus higher bacterial adhesion. For this reason, grinding is not recommended in order to minimize the risk of bacterial adhesion. In the case of indirect prosthetic restorations in lithium disilicate, for example, where occlusal retouching only applies after bonding, polishing with polishing sets specific to this ceramic is obligatory.
- The ceramic finishing procedure influences bacterial adhesion through changes in surface free energy and surface roughness. Glazed surfaces tend to accumulate more biofilm, in contrary to mechanical polishing which achieves lower roughness and minimal morphological changes in the ceramic, and therefore low bacterial adhesion.
- Streptococcus mutans is the most predominant bacteria in the oral cavity. Streptococcus mutans is the most prevalent bacteria in the oral cavity, with the highest adhesion for all ceramic types and finishing methods.
- Understanding the mechanism of bacterial adhesion to the various materials used in oral rehabilitation may open up new avenues of research aimed at modifying the surfaces and constituents of dental materials, based on knowledge of the bacteria's mechanisms of action.

Conflicts of Interest

The authors declare no conflicts of interest.

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