coatings

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Review

Influence of Aesthetic Archwire Coatings on Bacterial Adhesion

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Abstract: Bacterial biofilm plays a key role in the development of complications in orthodontic treatment in the form of caries or periodontal disease. The coating of orthodontic archwires can affect their mechanical properties and their bactericidal properties. In connection with the growing interest in aesthetic archwires, it was examined whether aesthetic archwire coatings contribute to the reduction of bacterial adhesion. Based on the available literature, a review was conducted on the basis of the risk of bias (RoB) assessment and GRADE (Grading of Recommendations, Assessment, Development and Evaluations) analysis. The study took into account the results of research on different aesthetic archwire coatings. The analysis shows that there is a lack of homogeneity in the research results. The data on the different aesthetic coatings are inconclusive. On the basis of the data collected, it is impossible to determine whether aesthetic coatings reduce bacterial adhesion. Further studies, standardised in terms of research methods and statistical analysis, are needed to definitively establish whether aesthetic coatings influence bacterial adhesion.

Keywords: aesthetic archwires; coated archwires; biofilm; coating; bacterial adhesion; biofilm adhesion

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1. Introduction

Nowadays, patients are increasingly focusing on the aesthetic aspects of orthodontic treatment. Not only is the final aesthetic effect of the treatment important to them, but also the appearance during the treatment process itself. This trend is particularly noticeable among adult patients. New types of braces such as lingual braces or aligners have been developed to meet the aesthetic requirements of patients [1]. Instead of standard, metal, unaesthetic brackets and archwires, patients can also choose tooth-colored braces, which are much less visible during everyday use. The aesthetics of brackets can be improved by manufacturing them from materials, such as ceramic or plastic. In turn, the aesthetic color of the archwires can be achieved by coating them with teflon, rhodium, epoxy resin, as well as the combination of silver and biopolymers and 24K gold [2]. The reasons why patients decide for aesthetic archwires are varied. Most patients choose them to make archwires less visible and obtain color similar to the tooth enamel. Although 24K gold coated archwires are not less visible than standard metal archwires, some patients choose them because of aesthetic aspects, namely their attractive color and fashion reasons.

During treatment with fixed braces, it is difficult to maintain hygiene. The bracket with the inserted archwire provides a medium for adhesion of dental plaque. Increased bacterial titer may be the cause of complications in orthodontic treatment, such as enamel demineralization or carious lesions [3]. These compilations may have a negative impact on aesthetics and cause significant periodontal complications. Bacteria can also affect the characteristics of orthodontic materials. Research by Gopalakrishnan et al. [4] shows that certain bacteria can induce metal corrosion, which can cause damage to the archwire surface. Attempts to reduce the risk of caries by covering the archwires with various coatings have been carried out for years [5]. Currently, studies are being conducted on different coating materials for archwires and brackets designed to reduce the growth of

bacteria. The study by Zakaria et al. [6] reveals that the coating of archwires with titanium dioxide (TiO_2) has strong antimicrobial and anticorrosive effects. The antimicrobial effect of nanosilver coatings is also well studied, indicating they may reduce the adhesion of dental plaque [7].

Despite growing interest in aesthetic archwires, there are still few available articles that examine the effect of aesthetic archwire coatings on biofilm accumulation. The available literature was reviewed to investigate whether aesthetic archwire coatings reduce bacterial adhesion.

2. Methods

The systematic review of the literature was conducted in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines.

3. Database Search

An advanced search of databases, such as PubMed, Cochrane Reviews, Web of Science, and Ovid Medline, was performed to develop a database of articles for review. The research considered articles published from 15 March 1992 to 15 March 2022. The following keyword combinations were used to obtain relevant articles:

- "aesthetic coated archwire & biofilm adhesion"
- "aesthetic orthodontic wire & biofilm adhesion"
- "aesthetic coated archwire & bacterial adhesion"
- "aesthetic orthodontic wire & bacterial adhesion"
- "orthodontic coatings & biofilm adhesion"
- "orthodontic coatings & bacterial adhesion"

After the duplicates were eliminated (13,272 duplicates), a detailed analysis of the collected articles was performed. The following criteria were applied:

Inclusion criteria:

- In vivo and in vitro studies;
- Studies concerning aesthetic archwire coatings;
- Studies concerning the influence of aesthetic coatings on bacterial adhesion;
- Studies in English;
- Full-text articles published from 15 March 1992 to 15 March 2022.

Exclusion criteria:

- Case reports;
- Case series;
- Review articles;
- Studies in a language other than English;
- Studies on animals;
- Studies on patients with systemic disease;
- Studies on patients with periodontal disease.

The records obtained were checked for articles that overlapped with the topic of this review. No similar literature reviews were found. Full-text articles found using the electronic browser were analyzed and manually rated as relevant, taking into account inclusion and exclusion criteria. All articles were then analyzed to ensure that they were consistent with the topic of this review. The authors included articles that addressed the influence of aesthetic archwire coatings on bacterial biofilm adhesion. In vivo and in vitro studies were included in the research. In terms of in vivo studies, only controlled clinical trials and randomized controlled trials were included (Figure 1).

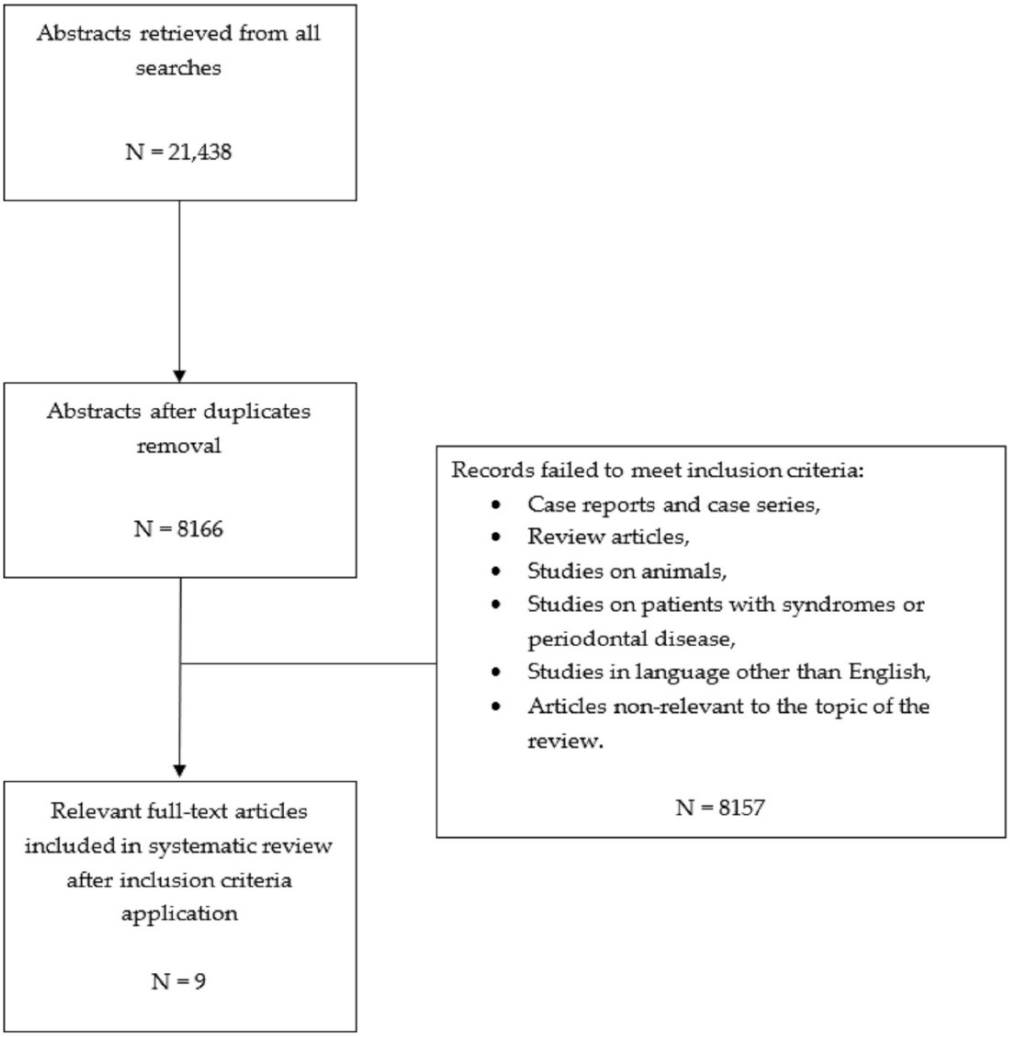

Figure 1. The PRISMA flow chart.

Finally, nine full-text articles were included in the analysis.

4. Quality Assessment—Risk of Bias (RoB)

Based on the recommendations in the review by Ma et al. [8] a RoB assessment was performed. All included articles were divided into two groups: in vivo study group and in vitro study group. Two tools were used for assessing the quality of in vivo articles: the JBI critical appraisal tool: checklist for randomized clinical trials [9] (used for randomized clinical trials) and the ROBINS-I tool [10] (used for non-randomized controlled clinical trials).

Due to the lack of available and clearly specified guidelines for the quality assessment of in vitro studies, the authors developed their own quality assessment tool, based on the QA tool used in the review by Dutra et al. [11]. The following aspects were considered in the evaluation of the RoB for in vitro studies: sample size, sample randomization, control group (uncoated archwires), blinding of the outcome assessor, sample sterilization before use, results measured in a reliable way and appropriate statistical analysis. In the case when a specific parameter was detected in the analysed article, it received a "1" (yes) for the tested parameter. In cases when information could not be found or the parameter was not present in the article, the article received a "0" (no) for the tested parameter. The total score was then counted for each study. The following rules were established to determine the quality of a given article: 0–2 points classified as high RoB; 3–4 points as moderate RoB; 5–7 points as low RoB.

5. Results

After the articles were initially selected, nine articles were recovered that matched the established criteria. During the analysis of the collected material, two articles on aesthetic archwires were rejected [12,13], because their authors did not provide precise information about the material with which the orthodontic archwires were coated in their study. Finally, in this review, seven articles were included: three in vivo studies (including two randomized clinical trials [14,15] and one controlled clinical trial [16]) and four in vitro studies [17–20].

5.1. Risk of Bias (RoB) Assessment

The results of the RoB assessment according to the JBI critical appraisal tool: checklist for randomized clinical trials shows Table 1. In terms of in vivo studies, the review authors assessed that the articles by Costa Lima et al. [14] and Hasipek et al. [15] had similar risks of bias. The most important difference was found in blinding. The trial described in the study by Hasipek et al. was single-blinded, while the trials conducted in the study by Costa Lima et al. were double-blinded. However, the authors of both articles did not use appropriate statistical analysis, and finding answers to some of the questions in the test was problematic. This was the reason the RoB of those articles was assessed as moderate. The third in vivo study (by Raji et al.) [16] had the worst RoB score. Due to serious RoB to confounding, the article received an overall serious RoB (Table 2).

Table 1. The quality analysis of randomized clinical trials using the JBI critical appraisal tool: checklist for randomized clinical trials.

	-	Costa Lima et al.	Hasipek et al.
1.	Was true randomization used to assign participants to treatment groups?	Yes	Yes
2.	Was the allocation to groups concealed?	Yes	Yes
3.	Were treatment groups similar at baseline?	Yes	Yes
4.	Were participants blind to treatment assignment?	Yes	Yes
5.	Were those delivering treatment blind to treatment assignment?	Yes	No
6.	Were outcome assessors blind to treatment assignment?	Unclear	Unclear
7.	Were treatment groups treated identically other than the intervention of interest?	Yes	Yes
8.	Was the follow-up complete and, if not, were the differences between groups in terms of their follow-up adequately described and analysed?	Yes	Yes
9.	Were the participants analysed in the groups to which they were randomly assigned?	Yes	Yes
10.	Were outcomes measured in the same way for the treatment groups?	Yes	Yes
11.	Were the results measured in a reliable way?	Yes	Yes
12.	Was appropriate statistical analysis used?	No	No
13.	Was the trial design appropriate for the topic and were any deviations from the standard RCT design accounted for in the conduct and analysis?	Unclear	Unclear
	Possible answers: Yes/No/Unclear/Not applicable		

The in vitro study was assessed using a customized RoB assessment tool. The results of that analysis are shown in Table 3. In the case of studies by Oliveira et al. [17] and Asiry et al. [18], the study group was small and this affected the assessment of the sample size parameter. The statistical analysis in the studies by Kim et al. [19] and Asiry et al. [18] was not complete, and the authors did not provide exact *p*-values. These factors resulted in higher RoB for these articles. The studies by Oliveira et al., Asiry et al., and Kim et al. were rated as moderate RoB articles. Al-Sheakli et al.'s study [20] was rated as the best

in vitro study; it was also the only article with low RoB. However, none of those articles included sample randomization and there was no information regarding blinding of the outcome assessor.

Table 2. The quality analysis of controlled clinical trials using ROBINS-I tool.

	-	Raji et al.
1.	Bias due to confounding	Serious
2.	Bias in the selection of participants into the study	Low
3.	Bias in the classification of interventions	Moderate
4.	Bias due to deviations from intended interventions	Low
5.	Bias due to missing data	No info
6.	Bias in the measurement of outcomes	Moderate
7.	Bias in the selection of the reported result	Moderate
	Overall bias	**Serious**

Table 3. The quality analysis of in vitro studies using an individual RoB quality assessment tool created by authors of the systematic review.

	-	Kim et al.	Oliveira et al.	Asiry et al.	Al-Sheakli et al.
1.	Sample size/quantity (more than 8 samples of each wire)	1	0	0	1
2.	Sample randomization	0	0	0	0
3.	Control group (uncoated wire)	1	1	1	1
4.	Blinding of the outcome assessor	0	0	0	0
5.	Sample sterilization before use	1	1	1	1
6.	Results measured in a reliable way	1	1	1	1
7.	Appropriate statistical analysis	0	1	0	1
	Overall risk of bias (RoB)	**Moderate**	**Moderate**	**Moderate**	**Low**

5.2. The GRADE Analysis

After the RoB results were obtained, the authors performed the GRADE analysis separately for both in vivo and in vitro studies. The results of the GRADE analysis are shown in the following tables (Tables 4 and 5).

Table 4. The GRADE analysis for in vivo studies.

Title of the Publication, Authors	Study Design	Risk of Bias (RoB)	Inconsistency	Indirectness	Imprecision	Comments	Certainty
"Comparative analysis of microorganism adhesion on coated, partially coated, and uncoated orthodontic archwires: A prospective clinical study" Costa Lima et al., 2019	In vivo study (randomized clinical trial)	Serious	Serious **	Not serious	Not serious		Low ⊕⊕◯◯
"An Examination of Bacterial Colonisation on Nickel-Titanium Arch-wires with Different Surface Properties" Hasipek et al., 2019	In vivo study (randomized clinical trial)	Serious	Serious **	Not serious	Not serious		Low ⊕⊕◯◯

Table 4. *Cont.*

Title of the Publication, Authors	Study Design	Risk of Bias (RoB)	Inconsistency	Indirectness	Imprecision	Comments	Certainty
"Bacterial colonisation on coated and uncoated orthodontic wires: A prospective clinical trial" Raji et al., 2014	In vivo study (controlled clinical trial)	Very serious	Serious **	Not serious	Not serious		Very low ⊕◯◯◯

** A discussion of the results for *inconsistency* is shown in Limitations of the Study in the Discussion section.

Table 5. The GRADE analysis for in vitro studies.

Title of the Publication, Authors	Study Design	Risk of Bias (RoB)	Inconsistency	Indirectness	Imprecision	Comments	Certainty
"Comparative short-term in vitro analysis of mutans streptococci adhesion on esthetic, nickel-titanium, and stainless-steel arch wires" Kim et al., 2013	In vitro study	Serious	Serious **	Serious *	Not serious		Low ⊕⊕◯◯
"In vitro Streptococcus mutans adhesion and biofilm formation on different esthetic orthodontic archwires." Oliveira et al., 2021	In vitro study	Serious	Very serious **	Serious *	Serious	Small study group; significant inconsistency of results with other available studies	Very low ⊕◯◯◯
"Influence of epoxy, polytetrafluoroethylene (PTFE) and rhodium surface coatings on surface roughness, nano-mechanical properties and biofilm adhesion of nickel titanium (Ni-Ti) archwires" Asiry et al., 2018	In vitro study	Serious	Very serious **	Serious *	Serious	Small study group; significant inconsistency of results with other available studies	Very low ⊕◯◯◯
"Quantitative assessment of Mutans Streptococci adhesion to coated and uncoated orthodontic archwires (in vitro study)" Al-Sheakli et al., 2014	In vitro study	Not serious	Serious **	Serious *	Not serious		Low ⊕⊕◯◯

* For all in vitro studies, indirectness was identified as "serious" because bacterial growth on orthodontic archwires under laboratory conditions and the oral environment can differ significantly. ** A discussion of the results for *inconsistency* is shown in Limitations of the Study in the Discussion section.

5.3. Discussion of Outcomes

Of all the articles, the epoxy resin coating was the most studied aesthetic coating. In the majority of articles, the authors most commonly examined the coatings of nickel-titanium (NiTi) archwires compared to those of stainless steel archwires.

5.3.1. Epoxy Resin Coating

The majority of authors investigated the influence of the epoxy resin coating on bacterial adhesion. This coating was tested using both in vivo studies by Hasipek et al. [15] and Raji et al. [16] and in vitro studies by Oliveira et al. [17], Asiry et al. [18], Kim et al. [19] and Al-Sheakli et al. [20]. These studies were classified by the authors as studies with low or very low certainty.

The findings for this coating are inconclusive. According to Raji et al. [16], Kim et al. [19], and Al-Sheakli et al. [20], the coating of NiTi archwires with epoxy resin resulted in reduced bacterial adhesion. Due to the serious RoB, the in vivo study by Raji et al. was classified as a study with very low certainty. Other in vitro studies had a slightly better certainty score—they received a low certainty score.

However, the studies by Hasipek et al. [15] (low certainty) and Asiry et al. [18] (very low certainty) indicate the opposite relationship. In their studies, bacterial adhesion was increased on epoxy resin-coated archwires compared to uncoated archwires.

However, the study by Oliveira et al. [17] revealed no statistically significant differences in terms of the number of bacteria on epoxy resin-coated and uncoated archwires.

Only the study by Al-Sheakli et al. [20] addressed the coating of stainless steel archwires with epoxy resin. That study found greater bacterial adhesion on epoxy resin-coated archwires compared to uncoated steel archwires. Interestingly, the same author proved that coating NiTi archwires with epoxy resin results in reduced bacterial adhesion.

In conclusion, the results reported in the available literature are of low scientific value and do not allow conclusions to be drawn regarding the effect of epoxy resin coating of orthodontic wires on the degree of bacterial biofilm development.

5.3.2. Rhodium Coating

In vivo studies by Costa Lima et al. [14] and in vitro studies by Oliveira et al. [17], Asiry et al. [18] and Kim et al. [19] addressed the rhodium coating of orthodontic archwires. Those studies were performed only on aesthetic NiTi archwires.

As is the case for epoxy resin coating, the results proved to be inconclusive. A randomized clinical trial by Costa Lima et al. [14] indicates that rhodium coating increases bacterial adhesion. That study had a slightly higher degree of certainty (low certainty) compared to other articles that examined rhodium-coated archwires (very low certainty).

Oliveira et al. [17] and Asiry et al. [18] found no statistically significant differences in terms of bacterial adhesion on rhodium-coated and uncoated archwires.

Kim et al. [19] instead reported reduced bacterial adhesion on rhodium-coated archwires compared to uncoated archwires.

In conclusion, the results reported in the available literature are of low scientific value and do not allow conclusions to be drawn regarding the effect of rhodium coating of orthodontic archwires on the degree of bacterial biofilm development.

5.3.3. Teflon Coating

The influence of teflon coating was addressed in an in vivo study by Costa Lima et al. [14] and in vitro studies by Oliveira et al. [17], Asiry et al. [18], and Al-Sheakli et al. [20].

Costa Lima et al. [14] and Al-Sheakli et al. [20] found that coating NiTi archwires with teflon reduces bacterial adhesion. The certainty in those studies was rated low. In terms of steel archwires, similar observations were reported by Al-Sheakli et al. In this case, teflon-coated archwires also reduced the number of bacteria.

Oliveira et al. [17] found instead no statistically significant differences in terms of bacterial adhesion on teflon-coated and uncoated archwires.

On the other hand, a study by Asiry et al. [18] revealed that teflon coating increased the number of bacteria on orthodontic archwires. However, the studies by Oliveira et al. and Asiry et al. had very low certainty, which is an inferior result compared to the articles discussed above.

In conclusion, the results reported in the available literature are of low scientific value and do not allow conclusions to be drawn regarding the effect of teflon coating of orthodontic wires on the degree of bacterial biofilm development.

5.3.4. Biopolymer and Silver Coating

The biopolymer and silver coating was investigated in only two articles [17,19]. The article by Kim et al. [19] had low certainty, while that by Oliveira et al. [17] had very low certainty. Kim et al. found a positive effect of the coating on bacterial adhesion, while Oliveira et al. reported no statistically significant differences between coated and uncoated archwires.

In conclusion, the available literature on this subject consists of only two articles with low scientific value and inconsistent results. The influence of this type of coating

on orthodontic wires certainly requires further research to provide the results of original, better designed studies.

5.3.5. 24K Gold Coating

The 24K gold coating was studied only in the article by Kim et al. [19]. The certainty in that study was rated low. Kim et al. found that the 24K gold coating may reduce the number of bacteria on the orthodontic archwires.

The influence of this type of coating of orthodontic wires certainly requires further research to provide the results of more well-designed original studies.

6. Discussion

Various types of coating are currently being investigated to improve the properties of materials used in medicine and dentistry. The authors of this review focused on aesthetic archwire coatings, which are increasingly used in orthodontics. Although each of the analyzed coatings changes the visual properties of the archwires, a study by Batista shows that the most attractive are rhodium coated archwires [21].

The authors decided to investigate the effect of aesthetic coatings on the number of bacteria deposited on orthodontic archwires due to the fact that their increased number during orthodontic treatment contributes to the occurrence of complications, including caries and periodontal disease. Complications related to enamel decalcification and periodontal diseases undoubtedly worsen the aesthetics of a smile during and after orthodontic treatment. Research shows that increased bacterial counts can also affect the properties of orthodontic archwires [22]. It was found that high bacterial titers contribute to corrosion of orthodontic archwires, especially steel ones. This may result in the release of metal elements into the oral environment, which have allergic and toxic effects. A high degree of corrosion may also affect the mechanical properties of orthodontic archwires, contributing to the cracking of orthodontic wires [4].The analysis of the collected material reveals that the quality of evidence in the analyzed articles is low or very low. The results of the studies included in this review are mostly more or less inconsistent. Some authors found a positive effect of aesthetic coatings on reducing bacterial adhesion; however, other authors came to the opposite conclusion. The most likely positive effect of coatings on bacterial reduction was demonstrated by teflon coating. However, not all studies regarding this coating found such a relationship.

The issue of bacterial growth on different archwire coatings and the factors influencing this development is still not fully understood. Some research suggests that increased adhesion of bacteria to coated archwires may be associated with increased surface roughness. However, the results of these studies are inconclusive. Some studies show a positive correlation between surface roughness and bacterial adhesion [13,19], but other studies do not confirm this correlation [14]. However, coatings may increase the roughness of the archwire, especially epoxy resin coatings [18,19]. Roughness may potentially affect the mechanics of orthodontics treatment, mainly via sliding of the wire.

Researches show there are also other factors that affect the bacterial adhesion, such as surface free energy and physicochemical properties of different archwire coatings [23–25]. The issue of bacterial adhesion to coated archwires is complex and requires further research to determine the factors influencing the growth of bacteria. This knowledge could be used to find a coating that is both aesthetic and antimicrobial. The authors of this review attempted to compare the results of the analysis with other articles. However, they could not find any reviews or meta-analyses on the above topic.

As one of the best ways to analyze the collected results is to perform a meta-analysis, the authors of this review also attempted to do so. Unfortunately, the articles included in this review are too different. The existing differences in the methodology of individual studies and the lack of a uniform, properly conducted, and complete statistical analysis in the articles made it impossible to perform a meta-analysis, and hence the authors decided

to conduct a literature review. This, however, allows to make a first, general conclusion, i.e., there is definitely a need for more, well-planned material research on this topic.

Despite the lack of some evidence for the antimicrobial effect of aesthetic coatings, the authors would like to draw attention to an interesting study regarding nanosilver coating and titanium dioxide (TiO_2) coating. Coating orthodontic archwires with these materials, although it does not improve aesthetic properties of the archwires, has proven antimicrobial effect, which may have a potential to reduce bacterial adhesion [26]. These data are very promising and with more detailed research, these orthodontic archwires could be put into greater use. This could significantly reduce the incidence of complications of orthodontic treatment.

According to the study by Elayyan et al. [27], aesthetic coatings may also affect the mechanical properties of orthodontic archwires. Teflon coating or epoxy resin coating may influence, among other things, the surface roughness of orthodontic archwires [18]. Coating the metal surface of the orthodontic archwire with epoxy resin increases its corrosion resistance by limiting the access of bacteria to its inner surface [28].

New research is being conducted on newer and newer technologies to improve both the mechanical properties of orthodontic archwires and their aesthetics. It should be noted that aligners are becoming more common on the market. In addition to their excellent aesthetic properties, aligners can greatly simplify the treatment procedure, as braces are not needed. Unfortunately, these materials are made of plastic, which could adversely affect the environment if they become more common. New alternatives to these materials are currently being investigated, including natural polymers, which, in addition to their good aesthetic properties, could provide a more eco-friendly alternative to artificial materials [29].

Limitations of the Study

Unfortunately, most of the articles analysed in the review had some limitations. These limitations included both how the research was conducted and how the results were analyzed.

- Only one study addressed the influence of aesthetic steel archwire coatings. Other studies focused on the aesthetic coatings of NiTi archwires [20].
- The articles lacked a homogeneous research method. Differences included how the study material was obtained, how long patients used orthodontic archwires in the in vivo study, and how the incubation period was for bacteria collected from the orthodontic archwires studied.
- The authors of the analyzed studies used different methods to analyze the results. In addition, some of the analyzes lacked *p*-values, making it impossible for the review authors to perform a meta-analysis.
- In the GRADE analysis, due to the lack of available other reviews and meta-analyses concerning the hypothesis under investigation, the authors had to develop a way to assess *inconsistency* by themselves. This method was based on a comparison of the results of studies concerning a given coating among the articles included in the review. If the result of an analysed article was confirmed in other articles, then the article received an *inconsistency* score of "not serious" The greater the inconsistency of results in analysed articles, the worse the *incosistency* score for a given article ("serious" or "very serious"). When a study tested several types of coatings and *inconsistency* scores for each type were different (e.g., "serious" for epoxy resin coating and "very serious" for rhodium coating), then the final score for that article was considered the worse *inconsistency* score.
- Due to different scoring gradations in the RoB assesment (grades: low, moderate, serious) and the GRADE analysis (grades: not serious, serious, very serious), the following modifications were adopted: low RoB, not serious RoB in the GRADE analysis; moderate RoB, serious RoB in the GRADE analysis; serious RoB, very serious RoB in the GRADE analysis.

7. Conclusions

The studies included in the review did not provide a clear answer to the question of whether aesthetic archwire coatings reduce bacterial adhesion. Further research is necessary, properly designed and standardized in terms of research methods. The review authors note the importance of a detailed statistical analysis of future studies to enable a meta-analysis. Only studies that are more standardised in terms of research methods will definitively allow to assess the influence of aesthetic archwire coatings on bacterial adhesion.

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