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Review article

Artificial teeth obtained by additive manufacturing: Wear resistance aspects. A systematic review of in vitro studies

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A R T I C L E I N F O

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A B S T R A C T

Wear resistance is one of the properties that must be considered for maintaining the long-term functionality of artificial teeth in dental prostheses. This property can be altered by the method of tooth fabrication, the material, the chewing force, and the relationship to the antagonist tooth. This systematic review evaluated the wear resistance of artificial teeth obtained by the additive manufacturing method and aims to answer the question, "Do artificial teeth for dental prostheses obtained by additive manufacturing show wear resistance similar to prefabricated ones?" The Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) Checklist guidelines were followed with a customized search in Scopus, PubMed/Medline, Embase, Science Direct, and Google Scholar databases on August 30, 2023. The inclusion criteria were artificial teeth for dental prostheses in acrylic resin by additive manufacturing and comparing the wear resistance with conventional prefabricated teeth, in vitro and English studies, without time restriction. And excluded if 1) do not make artificial teeth by additive manufacturing or that were metal or ceramic teeth; 2) clinical trials, animal studies, review articles, case reports, letters to the editor, short communication, book chapters; 3) another language that is not English. The selection was in two steps, reading the titles and abstracts, followed by reading the selected studies in full. The risk of bias analysis was performed with the adaptation of the quasi-experimental studies tool by Joanna Briggs Institute. Four hundred and twelve articles were found in the databases, after the selection steps and application of eligibility criteria, 6 articles were included for qualitative data analysis and presented low risk of bias. For teeth obtained by additive manufacturing, 2 studies reported lower wear resistance, 2 studies had higher resistance, and 2 similar compared to prefabricated ones. Additive manufactured teeth compared to prefabricated teeth show influences on wear resistance due to differences in material composition, relationship to the antagonist's tooth, applied force, chewing cycles, and processing methods.

1. Introduction

For longevity of complete dentures, the properties of the artificial acrylic resin teeth should be evaluated with regard to adhesion to the denture base, level of brittleness, and possibility of possibility of wear [1–4]. Changes in properties, such as wear resistance, promote modifications in the vertical dimension of occlusion (VDO), reduced masticatory efficiency, impaired intermaxillary

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relationship, and altered muscle function which can lead to temporomandibular dysfunction (TMD), changes in aesthetics, discomfort, risk of fracture and need for prosthesis replacement. Wear is a property that should be evaluated with caution, it can be caused by inadequate brushing, excessive force when chewing, bruxism and clenching, consumption of acidic foods and drinks, improper use of dentures, the length of time they have been in use and the type of material used to make them [1–5].

The polymer composition and structure can be modified with the addition of nanofiller, and incorporation of copolymers to change the wear resistance rate [3,4,6] which depends on the size and type of filler to promote cross-linking between polymer layers, but there is still no ideal protocol to promote improved strength [3].

In addition to the composition, the literature, and the industry present proposals for changes in the obtaining technique that can change the deposition of materials such as additive manufacturing. Advantages to the production of teeth as accuracy and precision, material savings, obtaining objects with complex geometries, cost-effectiveness, and data storage. This method acts by the construction of objects layer by layer, with light-cured acrylic resins by methods such as stereolithography (SLA) and digital light processing (DLP). Prefabricated teeth are manufactured using compression filling and injection molding techniques. They have greater dimensional stability, resistance to bonding to the denture base, and physical, chemical, and mechanical properties compatible with clinical use [7–16].

The composition and method of fabrication have the potential to improve the wear resistance of artificial teeth. However, clinical conditions such as chewing force and frequency, individual diet, material type, antagonist relationship, and parafunctional habits influence the overall properties of artificial teeth. This change causes gradual material removal and occurs through a combination of abrasion, fatigue, friction, and erosion [1,2,4,6,8,9,17]. In addition to wear, teeth produced by additive manufacturing can suffer from color changes due to contact with dyes in liquids, foods, and oral hygiene products, affecting aesthetics. Surface polishing can minimize stain absorption and maintain aesthetics [18].

To study the behavior of artificial teeth obtained by different methods. In vitro tests are used from the parameters: force, horizontal movement, number of chewing cycles, and temperature since there are limitations to conducting clinical trials due to the diversity of individual factors of each patient that must be considered [6,7,11]. The two-body wear test simulates the contact direction between the upper and lower teeth during chewing, dynamic occlusal movements, and parafunctional habits. Whereas the three-body wear test simulates the chewing process with the presence of food by inserting abrasive particles [1,14].

As presented, wear resistance is also related to other properties, such as hardness, and to patient individuality, such as masticatory efficiency. This property indicates the type of material, materials with lower mechanical strength, which may be indicated for patients who exert less masticatory force and prosthetic devices. Users of implant-retained dentures have greater masticatory efficiency than those with mucosa-retained dentures [1,2,11,19,20].

In the field of the study of polymers obtained through additive manufacturing in dentistry, there is relative progress regarding the manufacture of bases for complete prostheses [21–23]. However, there is a lack of studies evaluating the behavior of 3D printed teeth and the changes they may cause in patients [11,14,24–26], this paper proposes to answer the following question "Do artificial teeth for dental prostheses obtained by additive manufacturing exhibit wear resistance similar to prefabricated ones?" This study has the null hypothesis that the manufacturing method does not change the wear resistance property of artificial teeth for dental prostheses.

1.1. Material and methods

2.1. Protocol.

For the development of this work, the standards of the Preferred Reporting Items for Systematic reviews and Meta-Analyses Checklist (PRISMA) were followed, registered in the OpenScience Framework (osf.io/24xh7). The study design (PICOS) framework applied was P = artificial teeth for dental prostheses; I = additive manufacturing; C = prefabricated prosthetic teeth; O = wear resistance; and S = experimental in vitro studies, and aims to answer the research question: "Do artificial teeth for dental prostheses obtained by additive manufacturing present wear resistance similar to prefabricated ones? ".

1.2. Search strategy

The search strategy ("denture teeth" OR "artificial teeth" OR "prothesis tooth") AND ("additive manufacturing" OR "3D printing") AND ("wear resistance") was used in the SCOPUS, PubMed/Medline, EMBASE, Science Direct, and Google Scholar databases on August 30, 2023. For each database, the custom search strategy was applied (Table 1).

1.3. Selection process

The selection of articles was carried out in two phases: the first by two authors (I.F and J.V.C.N) with the reading of the titles and abstracts of the studies found. In phase 2, the selected studies were read in full and the eligibility criteria were applied. A consensus meeting was held with a third reviewer (A.C.R) to resolve disagreements. The data extracted from the included papers were tabulated in a Table.

1.4. Eligibility criteria

Studies that made artificial teeth for dental prostheses in acrylic resin by additive manufacturing and compare the wear resistance with conventional prefabricated teeth, in vitro and English studies, without time restriction, were included. And excluded if.

Table 1
Database search strategy.

Database	Search	Found
EMBASE August 30 th, 2023	('denture teeth' OR 'artificial teeth'/exp OR 'artificial teeth' OR 'prothesis tooth') AND ('additive manufacturing'/exp OR 'additive manufacturing' OR '3d printing'/exp OR '3d printing') AND ('wear resistance'/exp OR 'wear resistance')	**12**
PubMed August 30 th, 2023	("denture teeth" OR "artificial teeth" OR "prothesis tooth") AND ("additive manufacturing" OR "3D printing") AND ("wear resistance")	**5**
Scopus August 30 th, 2023	(TITLE-ABS-KEY (("additive manufacturing" OR "3D printing") AND ("acrylic resin" OR pmma) AND "wear resistance")) AND (((("additive manufacturing" OR "3D printing") AND ("acrylic resin" OR pmma) AND "wear resistance" AND ("dentute teeth" OR "artificial teeth" OR "prothesis tooth"))) AND (("additive manufacturing" OR "3D printing") AND "wear resistance" AND ("dentute teeth" OR "artificial teeth" OR "prothesis tooth"))) AND (("denture teeth" OR "artificial teeth" OR "prothesis AND tooth") AND ("additive manufacturing" OR "3D printing") AND ("wear resistance"))	**5**
Science Direct August 30 th, 2023	("denture teeth" OR "artificial teeth" OR "prothesis tooth") AND ("additive manufacturing" OR "3D printing") AND ("wear resistance")	**53**
Google Scholar August 30 th, 2023	("denture teeth" OR "artificial teeth" OR "prothesis tooth") AND ("additive manufacturing" OR "3D printing") AND ("wear resistance")	**337**

1) do not make artificial teeth by additive manufacturing or that were metal or ceramic teeth;
2) clinical trials, animal studies, observational studies, review articles, case reports, letters to the editor, short communication, patent, conferences, book chapters, editorials;
3) another language that is not English.

1.5. Risk of bias analysis

The quasi-experimental studies (non-randomized experimental studies) of the Joanna Briggs Institute (JBI) were adapted to assess the risk of bias. To rate the methodological quality of the studies, each question was scored with a "low", "high" and "unclear" risk of bias. The analysis was performed in RevMan 5.3 software (The Nordic Cochrane Center).

2. Results

Four hundred and twelve articles were found in the databases, and 35 of them were excluded for duplication. After the first phase of selection and application of eligibility criteria, 10 studies were selected for the second phase, and of these, 6 articles [14,15,24–27] were included for qualitative data analysis. The flowchart in Fig. 1 shows the article selection process.

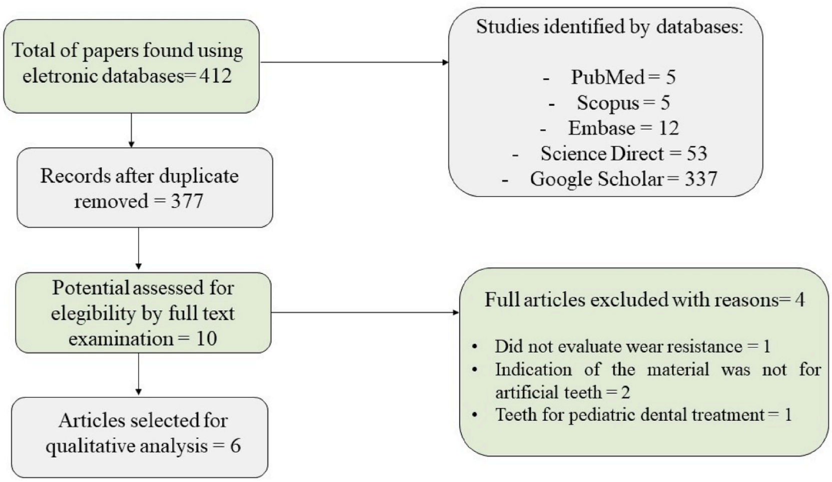

Fig. 1. Flow diagram of the selection process of articles.

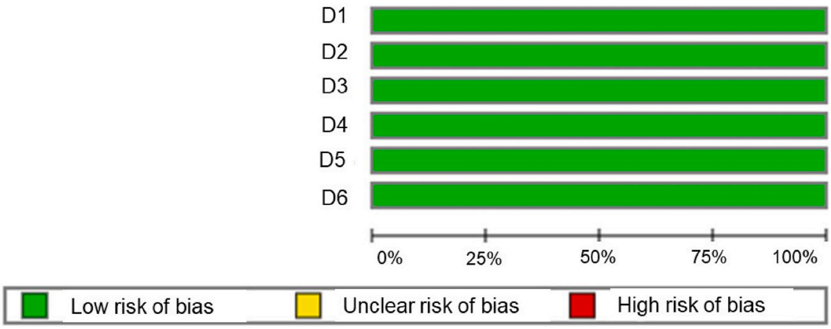

Fig. 2. Risk of bias graph of included studies
Legend: D1- Is it clear in the study what is the 'cause' and what is the 'effect' (i.e. there is no confusion about which variable comes first)?; D2- Were the specimens included in any comparisons similar?; D3- Were the specimens included in any comparisons receiving similar treatment/care, other than the exposure or intervention of interest?; D4- Was there a control group?; D5- Were the outcomes of specimens included in any comparisons measured in the same way?; D6- Was appropriate statistical analysis used.?.

After applying the JBI quasi-experimental studies tool, the studies included in this systematic [14,15,24–27] were found to have a low risk of bias for all questions addressed. The results can be seen in Fig. 2, which shows a low risk of bias for all the questions evaluated in the 6 included studies, indicated by the green color. Fig. 3 shows the classification of each study in terms of risk of bias for each question, colored green, which indicates a low risk of bias.

The data extracted from the studies are detailed in Table 2.

Artificial denture teeth were obtained by additive manufacturing (3DT) by Stereolithography (SLA) method in 5 studies [14,15,24–27], 1 study evaluated the digital light processing (DLP) method [15], and 1 study did not indicate which technique was employed [26]. The light-curing acrylic resin is the material used for the printed teeth. and these were compared to prefabricated (PT) polymethylmethacrylate (PMMA) teeth of different commercial brands available on the market which have modifications to their composition with the addition of fillers and reinforcing structures to increase the material's properties [14,15,24–27].

The two-body wear test [14,15,24–27], and the three-body wear test [14,26], which added a slurry of abrasive PMMA particles to simulate chewing with the presence of food, a condition that more closely simulates the clinical reality of teeth when functioning in the oral cavity. After the cycles of the wear test were detached, the teeth were scanned for the evaluation of loss in volume [15,24,26,27], heights [25,26], and depth [14]. Grymak et al. [27] performed the test in the presence of artificial saliva at a temperature of 20–37 °C because dry tests cause less wear than those in the presence of water or saliva, as occurs in the oral cavity [27].

In the comparison of 3DT and PT, Cha et al. [24] and Gad et al. [25] showed lower wear resistance for 3DT, and Saadi et al. [26] when comparing PMMA PT with 3DT and composite resin PT showed that the composite resin PT has better wear resistance. Grymak et al. [27] observed a lower rate of vertical loss for 3DT compared to prefabricated with PMMA and modified PMMA and also observed lower surface alterations [27]. Pham et al. [14] reported better strength for 3DT with lower depth compared to PT in the three-body wear test. Gad et al. [15] reported that teeth produced by additive manufacturing showed similar results to prefabricated teeth in terms of volume loss due to wear.

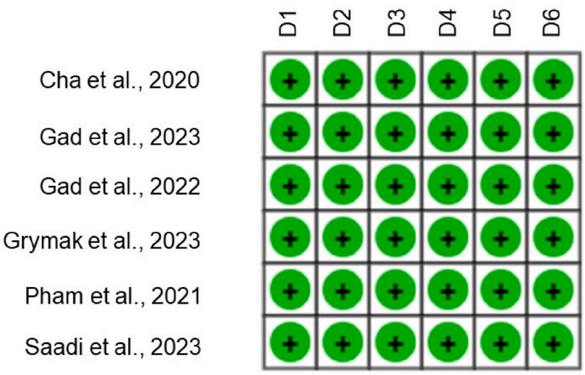

Fig. 3. Risk of bias graph of each included studies.
Legend: D1- Is it clear in the study what is the 'cause' and what is the 'effect' (i.e. there is no confusion about which variable comes first)?; D2- Were the specimens included in any comparisons similar?; D3- Were the specimens included in any comparisons receiving similar treatment/care, other than the exposure or intervention of interest?; D4- Was there a control group?; D5- Were the outcomes of specimens included in any comparisons measured in the same way?; D6- Was appropriate statistical analysis used.?.

Table 2
Data extraction of the studies included in the systematic review.

Author, year	Material and composition	Printer, printing parameters	Samples and standardization	Control group	Antagonist Teeth	Wear resistance	Results
Cha et al., 2020[24]	DENTCA 3D-printing denture tooth resin composed of methacrylate-based photo-polymerized resin.	Stereolithography (SLA) 3D-printer (Zenith D; Zenith). Layer thickness of 50 μm.	Specimens with dimensions of 15 × 10 × 10 mm. Cleaning with isopropanol and post-polymerization for 40 min. Immersion in glycerin.	Six commercial brands of prefabricated teeth.	Zr and CoCr crown.	Two-body wear test, 49 N vertical movement 5 mm and horizontal movement 2 mm. 30.000 cycles (1.5 months) cycles, thermocycling 5–55 °C.	The volume wear of 3DT was higher compared to commercial PTs when the antagonist was Zr and Co–Cr SEM with Zr antagonist showed a smooth surface and no cracks, and Co–Cr showed thin cracks.
Gad et al., 2023[15]	NextDent C&B MFH, composed of 7,7,9(or 7,9,9)-trimethyl-4,13-dioxo-3, 14-dioxa-5,12diazahexadecane-1,16- diyl bismethacrylate. Asiga Denta TOOTH is composed of 7,7,9(or 7,9,9) trimethyl-4,13-dioxo3, 14-dioxa-5,12diazahexadecane-1. Denture teeth resin is composed of Bisphenol A dimethacrylate, urethane dimethacrylate, methacrylate monomer, and photoinitiator.	Stereolithography (SLA) and digital light processing (DLP). Printing angle: 0-degree Layer thickness: 50 μm.	Representative denture teeth with a polished, flat surface. Cleaning with 99 % isopropyl alcohol and post-polymerization with immersion in glycerin in an oven.	Prefabricated mandibular molar tooth.	The study did not specify which antagonist tooth was analyzed.	Two-body wear test, 71 N with 2 mm vertical and 0.2 mm lateral movement and 1,70,000 cycles (1 year). Evaluated by Test Scan" and SEM.	The greatest volume loss was observed in the teeth fabricated with NextDent commercial resin, while the lowest loss was observed with FromLabs. When analyzing the SEM, lines of cracks and grooves were observed in the worn areas, with greater evidence of microholes and voids in the NextDent group. The Formlabs, on the other hand, showed serrated lines with a smooth background in the wear area.
Gad et al., 2022[25]	Methacrylate-based photopolymerized resin. The authors do not provide information on composition.	3D printer (NextDent 5100, 3D Systems Corporation) with printing orientation of 90° and 50 μm layer thickness.	Representative denture teeth specimens. Cleaning with 99 % isopropyl alcohol and post-polymerization for 30 min at 60 °C. Stored in distilled water at 37 °C for 48 h.	Prefabricated teeth of auto-polymerized acrylic resin.	Tooth enamel and Al2O3 metal crowns.	Two-body wear test, 71 N with 2 mm vertical and 0.2 mm lateral movement and 60.000 cycles (3 months) Thermocycling 5-55 °C with 10.000 cycles.	3DT showed lower wear resistance than PT for Al_2O_3 antagonists and natural teeth. Natural teeth caused higher wear on 3DT than the metal.
Grymak et al., 2023[27]	Asiga dentaTooth 3D resin, composed of Bismethacrylate, Tetrahydrofurfuryl methacrylate, and Diphenyl phosphine oxide (10–25 % each). Next Dent C&B MFH composed by Micro-Filled Hybrid: Methacrylic oligomer (>60 %).	3D printer (Asiga Max UV, Australia), with a build thickness layer of 50 μm with a 0° build angle.	Block-shaped samples 10 × 10 × 4mm. Serial polishing with 1200, 2400, and 4000 grit silicon carbide paper.	Prefabricated teeth of PMMA, CAD-milled PMMA.	Six mm diameter stainless steel ball.	Two-body wear test was carried out using a universal testing machine with a load of 49 N, a frequency of 1 Hz, and a distance of 2 mm 250 m represented 12 months, 500 m 24 months, and 1000 m 48 months. The test was carried out in the presence of artificial saliva at a temperature of 30–37 °C. Vertical loss was calculated and MEV.	In terms of vertical loss, the 3DT groups showed less wear than the PMMA and modified PMMA prefabricated and CAD-milled teeth at all months evaluated. By SEM, the stainless steel antagonist showed no wear and the 3DT and CAD-milled teeth showed no significant wear with only a few scratches and microcracks. The prefabricated teeth showed a worn surface with some significant chipping or deformation.

(*continued on next page*)

Table 2 (*continued*)

Author, year	Material and composition	Printer, printing parameters	Samples and standardization	Control group	Antagonist Teeth	Wear resistance	Results
Pham et al., 2021[14]	Methacrylate-based photopolymerized resin. The authors do not provide information on composition.	SLA printer (Form 2; Formlabs, Somerville, MA), with 50 μm layer thickness.	Representative maxillary first molar. Cleaning with isopropyl alcohol and post-cured according to the manufacturer's instructions.	PMMA artificial teeth.	Monolithic zirconia crown.	Three-body wear test, 36–40 N, 200.000 cycles, 50.000 cycles of which in deionized water and 15 g of abrasive slurry.	The 3DTs showed the lowest wear depth and exhibited the highest wear resistance compared to the PT groups.
Saadi et al., 2023[26]	Methacrylate-based photopolymerized resin. Composition PMMA with auxiliary matters.	The study did not mention the printing technique or parameters used.	The cusps of each specimen were wet sanded with 600–800 grit sandpaper to a total depth of 0.5 mm.	Prefabricated resin teeth from 2 commercial brands and a group with modified resin.	The study did not mention which antagonist was used.	Three-body wear test, 50 N, horizontal movement 2 mm, 750.000 cycles (5 years).	The highest vertical loss was for conventional resin PT, followed by 3DT, with the lowest vertical loss for modified resin PT. The highest volume loss was observed for 3DT, followed by conventional PT resin, and the lowest wear per volume for modified PT resin.

3DT: 3-D teeth; PT: Prefabricated teeth; SLA-stereolithography Zr: Zircônia; Co–Cr: Cobalto-cromo; SEM: scanning electron microscopy; Al_2O_3: óxido de alumínio; PMMA: polymethylmethacrylate; **CAD: Computer-aided design; DLP: digital light processing.**

Gad et al. [25] and Cha et al. [24] show a relationship between wear resistance with the type of antagonist used, this is an important assessment because denture wearers typically have a variety of teeth, including metal restorations, ceramics, and natural teeth, which can change the occlusion and wear pattern of the artificial tooth in the denture. Natural tooth promoted greater wear to 3DT than Al_2O_3 metal [25]. By scanning electron microscopy (SEM) it was observed that 3DT when in contact with zirconia antagonists presented a smoother surface, while with Co–Cr antagonists the surface presented cracks [21].

The heterogeneity of the studies did not allow meta-analysis to be performed.

3. Discussion

Artificial teeth for complete dentures determine the durability and functionality of the prosthetic device specifically in elderly patients with functional loss, muscle changes, and difficulty with hygiene and chewing [14,15,17–24]] Changing the way of processing, such as additive manufacturing, can highlight favorable properties and in this study, wear resistance that affects the function, aesthetics, shape, and durability of the prosthetic device was chosen. To evaluate the current state of knowledge of this property available in the literature, a systematic review was developed with the question "Do artificial teeth for dental prostheses obtained by additive manufacturing have wear resistance similar to prefabricated ones?" Therefore, this study outlines the authors' main findings, which confirm the null hypothesis that the technique has no effect on the wear resistance of artificial teeth used in dentures.

Cha et al. [24], Gad et al. [25], Pham et al. [14], Saadi et al. [26], Grymak et al. [27], and Gad et al. [15] compared 3DT and PT and evidenced that the factors that lead to diversity in the behavior between these two types of teeth are: type, material composition, relationship with the antagonist, processing form and the methodology employed for analysis, in this case, the type of test, applied force and a number of masticatory cycles, influenced the performance of teeth [[14,15,17–24]].

Regarding the type of material, PMMA was used for PTs and light-cured resin for 3DTs which have different chemical compositions [[14,15,17–24]], which may explain the difference in performance between PTs and 3DTs. An important study that was not included in this systematic review but does address the mechanical properties of manufactured, milled, and heat-curing acrylic resins was the study by Prpi ć et al. [21] which showed that regardless of the manufacturing method, the properties are not only related to the polymerization techniques but with distinct chemical composition because the printing resin has relatively low double bond conversion compared to traditional acrylic resins [21]. More specific results could be found when one has possession of the chemical composition of these materials and evaluations such as chemical and physical degradation can better explain these differences, the composition of the resins used in the studies is shown in Table 2. However, the composition is not shown in all cases as the commercial brands do not provide the formulation of the commercial product.

Another factor that may explain the difference in results is that prefabricated teeth are processed under high pressure, with different polymerization methods and the addition of different layers of material with reinforcing structures that improve strength. Teeth made by additive manufacturing have difficulty in adhering to the layers, which is inherent to the manufacturing process and alters their mechanical performance due to the low degree of transformation and poor adhesion between the layers [14,15,25].

Currently, 3DT are obtained by the SLA method and consist of a single material with a homogeneous structure, which conferred, in the study by Pham et al. [14] wear resistance from 2 to 3.5 x higher for 3DT compared to PT [14], which are made up of layers of distinct compositions, with the incorporation of fillers and the application of glaze in order to improve mechanical properties, such as wear resistance [1,6,24,25,28], however, despite acting as reinforcement, the type, volume, size and distribution of fillers can interfere with the results [2,26]. Pham et al. [14] observed that double cross-linked and high cross-linked PMMA showed 1.5x higher wear resistance than conventional PMMA. Abbasi et al. [1] reported that removing the glaze layer from the artificial teeth reduced wear resistance by promoting decreased cross-links, the glaze layer improves wear resistance by binding to the monomers on the surface of the specimen and acting as a reinforcing structure, and also by the presence of EGDMA added to the cervical, where the content of this polymer in the enamel can be around 30 %, explaining the whole phenomenon [1,14,29,30]. In printed teeth, this glaze layer can be produced by a light-curing coating, such as that studied by Nam et al., who found an increase in the hardness, flexural strength, and wear resistance of teeth obtained by additive manufacturing that contained a glaze layer with silicon dioxide (SiO_2), which acted as a reinforcing nanofiller and protected the crown surface [30].

Gad et al.[15] compared teeth produced by SLA and DLP and found that the SLA technique produced higher wear resistance results. This is because, although both techniques are photo polymerization techniques, they differ in the specific additive manufacturing process and the post-treatment applied, which directly affect the properties [15,31–33]. In the SLA process, photo polymerization occurs through selective solidification of the material, and the curing process increases the stiffness of the material [31–33]. In the DLP process, solidification is performed using a digital light projector that shines on the entire layer at once, which can reduce the degree of conversion of the material and consequently lower the mechanical performance [31,33].

Also in regard to wear, the consideration of hardness relates to the ability to withstand masticatory forces and reduce wear by friction and abrasion. Although resin has a lower hardness than ceramic, it is less damaging to the antagonist and does not promote clicking sounds [20,34]. Suwannaroop et al. [6] reported that material hardness was not related to PT wear. Muhammad et al. [34] found that the lack of differences between the different types of PT analyzed was due to compositional techniques (type and amount of filler) and manufacturing, such as curing methods and surface treatments.

Fracture toughness may have a relationship with wear resistance and Gad et al. [25] observed that 3DT shows higher fracture toughness compared to PT, this is because the ester-based 3D resin composition and the 90° printing angle favor the direction of the loads perpendicular to the printing layers [25], whereas Chung et al. [35] observed differences in the fracture pattern in 3DT, but the similarity in the toughness results, explained by its chemical composition [35].

Regarding the antagonist, the diversity of materials that rehabilitate the dental arches influences the wear resistance, in this case, zirconia showed less influence on the initial wear of 3DT compared to Co–Cr and this fact was attributed to lower surface roughness [24]. Gad et al. [25] reported that natural teeth as antagonists showed greater wear to 3DT compared to Al2O3, this was because the premolar used presented a sharp cusp, while Al_2O_3 blunt tip [25]. Assessing the wear of the antagonist is important since rehabilitated patients usually have dental restorations made of different dental materials with specific characteristics in terms of hardness and resistance, which can interfere not only with the wear of the artificial teeth of the prosthesis but also with the antagonist, so care must be taken when deciding on the type, material and way of processing the teeth [15,36].

As for the type of test, the two-body wear test simulates the circular chewing motion, whereas the three-body wear test adds particles that simulate food, being the one that most closely resembles the oral cavity [23,27,28]. The data are analyzed by height and volume wear by 2D and 3D methods, the latter being more indicated for not promoting changes in the surface of the specimen, presenting greater accuracy and speed as optical microscopy, 3D scanners, and SEM [25,37,38]. For Saadi et al. [26] 3D is preferable for presenting data that allows more precise analysis. Profilometry is the gold standard method for assessing volume loss due to wear. It measures changes in the height of a surface in relation to a reference line, while the three-dimensional scanning method is able to create 3D digital models of surfaces before and after wear, allowing comparative analysis of topographical changes [15,39].

The fact that the processing method builds objects layer by layer [9,40], one must consider the adhesion between them that, depending on the method, can be weak or strong, which interferes with the mechanical, physical, and chemical performance of the material. Cha et al. [24] and Gad et al. [25] who observed lower wear resistance for 3DT compared to PT, and it is suggested that this result is due to the weak adhesion between the layers [24,25]. Another factor that can affect the properties is the printing parameters, which can include layer thickness, printing angle, laser intensity, and printing speed [41]. The thickness of the layers directly affects the accuracy and precision of the printed parts, because the thinner the layers, the greater the number of layers required to obtain the final part, and consequently the longer the printing time and the probability of variation in properties [41,42]. For the base of printed prostheses, layer thicknesses of 100 μm showed better accuracy and precision, but mechanical performance was not evaluated [42]. For the studies included in this systematic review [14,15,24–27], the reported layer thickness was 50 μm.

Improving and intervening in the factors that influence the wear resistance of artificial teeth for dental prostheses leads to increased longevity to treatment, and ensures facial aesthetics, functionality, maintenance of speech, VDO, and patient and professional satisfaction [14,15,24–27]. The teeth cited in the studies described here are not yet suitable for clinical requirements and 3D printing methods. The number of advantages brought by printing technology brings a great economic impact of time to contemporary societies in various fields, thus for dentistry, the deep knowledge of materials behavior and its improvement is an area of study that deserves investigation and investment. The evaluation of different printing methods, the variation of parameters, the application of glazes or coatings, as well as the use of resins modified with nanofillers are proposals for future studies. The aim of these investigations is to determine the ideal set of factors that not only promote wear resistance, but also improve the aesthetics, hardness, and roughness of artificial teeth for 3D-printed dental prostheses. The intention is to establish additive manufacturing as an effective, safe, and rapidly applicable technique in oral rehabilitation treatments.

4. Conclusion

It can be concluded that teeth obtained by additive manufacturing, compared to prefabricated teeth, show influences on wear resistance due to the diversity of material composition, relationship with the antagonist's tooth, applied force, chewing cycles, and processing methods. 3D printing, by building teeth layer by layer, promotes poor adhesion between them, which suggests the low resistance of teeth obtained by this technique. Such points that interfere with the behavior of the material should be investigated by researchers and research centers.

Data availability statement

This is a systematic review, so the data were detailed in the manuscript.

CRediT authorship contribution statement

Izabela Ferreira: Writing – review & editing, Writing – original draft, Visualization, Software, Resources, Project administration, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **João Vicente Calazans Neto:** Methodology, Investigation, Formal analysis, Data curation. **Andréa Cândido dos Reis:** Writing – review & editing, Writing – original draft, Visualization, Validation, Supervision, Software, Resources, Project administration, Methodology, Investigation, Formal analysis, Data curation, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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